JPRS-EST-90-018
26 SEPTEMBER 1990

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JPRS Report

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TWENTY-SECOND INTERNATIONAL SYMPOSIUM ON AUTOMOTIVE TECHNOLOGY AND AUTOMATION

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36980031 Florence TWENTY-SECOND INTERNATIONAL SYMPOSIUM ON AUTOMOTIVE TECHNOLOGY AND AUTOMATION in English 14-18 May 90 pp i-xxii; 1-1486 (Vols I and II)

[Selections from the Twenty-Second International Symposium on Automotive Technology and Automation, held in Florence, Italy, 14-18 May 90, sponsored by the Italian Committee for Research and Development of Nuclear and Alternative Energies(ENEA)]

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THE PENETRATION OF ELECTRONICS INTO COMMERCIAL VEHICLE TECHNOLOGY - ECONOMY, SAFETY AND ENVIRONMENTAL COMPATIBILITY

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1 INTRODUCTION

Basically, electronics in commercial vehicles should be regarded as an aid in realizing the general objectives of vehicle development, safety optimisation, environmental compatibility and economy.

Other technical aids, whether they be pneumatic or hydraulic, on the one hand represent a potential which has a firm place in automotive engineering, yet, on the other hand, are approaching a state of technological saturation to the extent that the majority of functions in commercial vehicles which have a practical sense, have already been installed. Substituting mechanical systems with electronic components, in the absence of any discernible improvement in function, is not equatable with technical progress.

Continous development of existing and fundamental new developments of electronic components for the road vehicle sector do, however, open up new potentials in the development of mechanical systems. The importance of electronics in road vehicles is in its capability of capturing information from the mechanical environment through the use of sensors, processing, storing and transforming it into control commands for mechanical elements. Consequently, there is a functional split in the duties which were assigned to the mechanical components and to the higher-level electronic control. The mechanical elements perform the basic functions while the electronics intervene as the controlling element wherever information has to be assigned to superior electronic controls, and when the manner and the speed at which such information is captured necessitates the use of electronics as both the driver and also mechanical systems would be incapable of accomplishing this task.

Use of electronics reliefs the stress on the driver, releasing mental capacities to better allow him to concentrate on the traffic scene around him. Use of electronics in commercial vehicles represents a consequent continuation of a path of development which has been pursued hitherto and which is practically concluded, namely relieving the driver of manual operation requiring physical effort.

In addition to the guiding principles outlined, development of commercial vehicle electronics has to take account of the particular requirements of the operator in respect of reliability, service life and ease of maintenance in rugged day-to-day operations. Through the requirements profile, the operator also has a decisive influence on the range of applications for electronics in commercial vehicles of the present day as well as in vehicles of the next generation.

In the European commercial vehicle industry, as well as in Japan and the USA investigations are being conducted regarding the application of electronics in all the important design groups and units [1, 2]:

- Drivetrain comprising engine, clutch, transmission, axle/wheel drives, wheels and tyres.

- Braking system comprising service, parking and emergency braking system. This also includes brake force sensors, control equipment, power supply, actuators and wheel brakes.

- Steering system including steering wheel and linkage, steering gear and power supply.

- Running Gear comprising wheel suspension and the required force transmission between tyre and road, including axle kinematics and spring/damper characteristics.

- Cab or appropriate bodies with instrument panel, information systems, controls, ergonomically refined seat adjustments, air conditioning and anti-theft systems.

The improvement of safety, environmental compatibility and operating economy achieved from using electronic systems in commercial vehicles is essentially determined by the particular application spectrum (Fig. 1). When a manufacturer decides to offer a system as optional equipment or as a standard feature in a particular model, he bases his decision on operator acceptance and on the type of service the vehicle will principally be performing. Based on this, it is quite logical that Mercedes-Benz offers the ABS/ASR safety system in heavy trucks and touring coaches and the electronic-pneumatic shift EPS in long-haul trucks as standard equipment, to cite two examples.

Besides these two systems, a multitude of other electronic systems have encountered application in commercial vehicles. A few of these systems will be described more explicitly on the following text.

2 DRIVETRAIN ELECTRONICS

2.1 Electronic Diesel Control EDR

Development of electronic diesel control EDR [3] is aimed at injecting into the engine the optimum quantity of fuel at any engine speed and under any operating conditions (Fig. 2). On the one hand, the electronic control unit processes the commands dictated by accelerator pedal travel, the kickdown switch or the engine braking switch. On the other hand, signals are conveyed to the control unit relating to the engine speed, charge air temperature, charge air pressure, fuel temperature, vehicle speed and the position of the control rack. The limit values for the exhaust gas composition, the mechanical and thermal engine stresses and also the drivetrain design are stored in the control unit for calculating the optimum injection quantity. The measured values are compared with the values stored and the injection quantity is adjusted if a variation exists. This is performed by means of an electro-hydraulic positioner which operates the injection pump rack.

The electronic control unit adapts the injection quantity to match any variation in atmospheric pressure and ambient temperature. As a result, full engine output can be activated, for example, when negotiating a mountain pass. The quantity of fuel injected is automatically reduced if the smoke limit is reached or if there is a rise in the outside temperature. Use of the electronic diesel control EDR makes it possible to meet a large number of, in some cases contradictory, demands relating, for example, to adherence to exhaust emission levels, improved fuel consumption and limits to the mechanical stresses of engine and drivetrain.

2.2 Electronic power shift EPS

Achieving good fuel consumption figures combined with high average speeds is only possible if multi-step spur gear transmissions are used. The electronic-pneumatic shift EPS (Fig. 3) significantly reduces the stress on the driver through the minimization of frequent gearshift efforts [4].

The mechanical gearshift linkages are replaced on the EPS by electrical connections. The gearshifts are performed pneumatically by solenoid valves and servo cylinders. The driver initiates the gearshift command by moving the gearshift lever. This command is passed to the electronic control unit, which carries out a plausibility check. The gear engaged is signalled to the driver by an optical display on the instrument panel.

The safeguard circuit of the EPS electronics monitors the peripheral components, such as sensors, control elements and control valves, and the function of the central electronics as well. Multiplex data transfer is used as standard, i. e. several signals are transmitted serially over one electrical link.

On the one hand, therefore, EPS takes the strain off the driver when it comes to changing gears, making it a much simpler matter to handle the truck; on the other hand, gearshifts are performed assuredly and more quickly at the optimum points in terms of vehicle dynamics.

2.3 Electronically controlled automatic transmission

Fully automatic, electronically controlled powershift transmissions (Fig. 4) are ideal for specific operating conditions, as, for instance, on city buses where gearshifts have to be performed frequently with the minimum possible interruption to the power flow [5].

The task which the electronics have to perform in this case consists in optimally controlling the gearshift points and in correctly selecting the shift sequence. If necessary, the electronics will interrupt the power transmission in the drive line. Moreover, the retarder with constant torque control and the torque converter lock-up clutch are controlled independently from the gear selected. The electronics of the microprocessor control process the parameters of engine load, engine speed, road speed, retarder operation and interventions on the part of the driver. For reasons of redundancy, the electronic technology is designed as a "2-processor concept" and offers the necessary operating reliability.

The benefits provided by the electronic transmission are ideal, variable gearshift points, easily changeable gearshift programs and comfortable, jerk-free shifting transitions. Elimination of clutch and gearshift operations greatly relieves driver stress. Acceleration with no interruption to power flow represents a considerable improvement in comfort and safety for the passengers.

2.4 Traction control ASR

The traction control ASR (Fig. 5) improves directional stability and relieves the strain on the driver when it comes to moving off on low adhesion or split adhesion road surfaces [6]. The background to this control concept is the physical correlation between slip and circumferential and lateral forces on the wheel.

ASR detects the wheel slip by comparing the state of motion of the driven and the non-driven wheels. The control logic discriminates between two cases depending on the number of wheels slipping.

If only one wheel tends to slip, e. g. on a split adhesion road surface, the wheel brake of the wheel affected is activated (differential braking control). The traction of the other driving wheel is improved by the differential lock effect. Engine output is reduced simultaneously from a certain slip threshold. If both wheels tend to slip, e. g. on a homogeneously low adhesion road surface, engine output is reduced by the control intervening in the throttle linkage in order to restore the optimum slip state (engine control).

2.5 Future Drivetrain Electronic Systems

Relieving the stress on the driver through the use of electronic systems represents a plus in terms of safety and comfort of road vehicles. The dependence on reliable operation of the electronic components is all the greater the more tasks are shifted from the driver to electronic systems. Particular significance is therefore attached to assessing the safety and reliability of a new system prior to its introduction.

Besides the failsafe capability of digital electronics, a system also depends on the service conditions, on the engineering design, the quality of the microelectronics and on the software. The multitude of the causes of failures mentioned illustrates the reasons for the cautious step-by-step approach to the use of electronics in commercial vehicles and buses with their extremely rugged operating environment.

The electronic drive line control EAS is based on the electronic-pneumatic shift EPS. This system links not only the transmission but also the engine and clutch through sensors and control elements to the electronic control unit (Fig. 6). The instrumentation on the dashboard includes not only the usual tachograph and tachometer but also the gear display. The controls which are available for controlling the speed of the vehicle are only the accelerator and the brake pedal.

Gearshifts with EAS can be initiated fully automatically by electronic control or manually by the driver operating a lever. In the manual mode the driver uses the shift lever to select the gear in which he wishes to move off. The driver then need only operate the accelerator pedal to control the actual moving-off operation. The driver can initiate upshifts and downshifts in the same way as with the EPS by moving the selector lever forward or back. As there is no clutch pedal, the actual gearshift is performed immediately after the selector lever is moved. The electronics ensure that the clutch is engaged smoothly and without any jerking motions on every uphill gradient, independent of vehicle load. The electronic control unit maintains engine speed at the lowest possible level and automatically adapts to the operating conditions prevailing at the moment. This in turn reduces the noise emission and avoids unnecessary wear to the clutch lining.

In the fully automatic mode, the EAS controls not only the gearshift sequence but also determines the moment at which the individual gearshift operations are performed. In this mode, the electronics take into consideration not only vehicle speed but a variety of other influencing parameters such as input torque, road gradient and vehicle weight. These variables are measured by intelligently evaluating the longitudinal movement of the vehicle as recorded by the EAS computer. During the automatic mode, the driver can intervene at any time. Consequently, the decision as to whether a gearshift is performed or not remains entirely the driver's.

The actual in-phase control operations performed at the clutch and in the transmission give rise to the fastest possible gearshifts. At the same time, the electronics control the speed of the diesel engine to the level matching the gear being engaged after the gearshift. This allows the clutch to be immediately engaged when the gearshift operation is completed without the need to bridge a difference in speed. The results are faster gearshifts and less wear to the clutch lining.

3 ELECTRONICS RELATING TO BRAKING SYSTEM

3.1 Anti-lock system ABS

The traction control ASR together with the anti-lock system ABS forms a safety system which provides defined prevention of wheel spin and wheel lock [6, 7, 8]. Both systems make use of common components for monitoring wheel movements (Fig. 5). The control and safety electronics are accomodated in a common housing.

The operating principle of the ABS, like that of the ASR, is based on sensing the speeds of the individual wheels. By a comparison with the vehicle speed, which is mathematically approximated by a reference speed, commands are generated and passed on to a solenoid control valve which either increases, maintains or reduces the pressure in the relevant brake cylinder until the wheel speed approaches the optimum slip range as determined by the electronics. The yawing moment produced under split adhesion road conditions, is damped by the so-called Modified Individual Control (MIC) at the front axle with the aim of achieving good vehicle controllability. This ABS design assures the shortest possible braking distances while maintaining stability and steerability of any vehicle combinations, no matter the qualification of the driver or the prevailing weather conditions.

3.2 Electronic retarder

In contrast to the anti-lock system, the virtues of which are displayed solely in emergency braking situations, use of a full electronic retarder (Fig. 7) also offers a perceptible reduction in stress for the driver in everyday situations, while at the same time achieving improved operating economy through longer brake life [9].

The deceleration effect of a retarder with fixed vanes and variable oil charge is controlled via the charge. Electronically controlled proportional valves supply the retarder with compressed air which presses oil out of the supply tank into the vane zone of the retarder as a function of the specified deceleration stage. The system components include an electronic control on a microprocessor basis with sensors for retarder speed and coolant temperature, pneumatic valves for oil level control and also the operating section for the braking functions "constant deceleration" and "constant speed". Incorporating the retarder in speed control systems and into the ABS/ASR safety system with the aim of achieving controlled adaptation of retarder torque, reveals a further potential for improvement.

3.3 Electronic-pneumatic braking system EPB

Whereas the anti-lock system, introduced as a standard feature, intervenes in the braking action only in the boundary range, development of the electronic-pneumatic braking system is aimed at improving the characteristics of normal braking operations through the use of an electronic control, notably in respect of optimizing wear and tear to brake pads and linings.

In this system, the compressed air for operating the wheel brakes is modulated by solenoid valves which are actuated directly by the electronics and are assigned to each individual brake cylinder (Fig. 8). This makes it possible to eliminate a number of complex valves, such as service brake valve, parking brake valve, multiple circuit protection valve and a large number of pneumatic lines.

Brake pedal and parking brake actuator are fitted with sensors which pass electrical signals to the electronic control unit in line with their operating position. The electronics control the braking force of each individual wheel through the control valves as a function of these input signals and additional measured variables such as pneumatic pressure, temperature, braking force, vehicle deceleration and vehicle weight.

The electronic-pneumatic braking system achieves a significant improvement in braking stability of solo vehicles and - with adaptation of the braking performance of tractive unit and trailer - notably also of truck/trailer combinations in comparison to conventional systems, by utilizing the available adhesion between tyre and road to an even extent, by exactly distributing the braking forces according to the load and by considerably shorter response times for the entire braking system. In addition to this, the electronic-pneumatic braking system is likely to offer cost benefits in terms of reduced wear and tear to brake pads/linings, elimination of expensive valves and long pneumatic lines and simplified servicing and maintenance resulting from automatic diagnosis.

4 ELECTRONICALLY CONTROLLED POWER-STEERING SYSTEM

Conventional servo-hydraulic steering systems possess transmission characteristics which represent a compromise in respect of the steering wheel forces which are required for the most varied operating conditions. These characteristics are determined by the transmission ratios of the mechanical steering parts and the hydraulic servo components.

In a steering system with ideal transmission characteristics, the servo action and thus the steering force which requires to be applied is controlled as a function of in-vehicle and external conditions.

Low steering forces are desirable to achieve convenient handling for manoeuvring. At high vehicle speeds and where high lateral acceleration exists, by contrast, safety considerations require that the driver has a direct "feel" of the contact between tyres and road and thus of the steering forces acting at the wheels. An additional parameter for influencing steering characteristics of relevance for commercial vehicles is the steering axle load, which fluctuates within a wide range between "laden" and "unladen".

Only through the use of an electronically controlled power-steering system it is possible to satisfy these requirements (Fig. 9). The major part of this is a proportional valve which enables the pressure in the hydraulic reaction circuit of the steering gear to be modulated by an electrical signal. The measured variables which are supplied to the electronic control unit at the input end are vehicle speed, lateral acceleration and front axle load. Vehicle speed and lateral acceleration can be easily ascertained or approximated by measuring the rotational speed of the front wheels [10].

The desired factors of the parameters mentioned having an influence on the correlation between the input forces at the steering wheel and the output forces at the wheels are stored in the electronics in the form of characteristics from which the actuating signal for the proportional valve is determined. The transmission characteristics of the power steering are thus constantly adapted to the changing operating conditions.

5 ACTIVE / SEMI-ACTIVE SUSPENSION

Suspension systems of road vehicles have to optimally perform two tasks. The driver and the load should be decoupled from the interfering influences of the uneven road surface by isolating the oscillations to the maximum possible extent, whereas the wheels of the vehicle should follow the unevennesses of the road surface in such a way that the wheel load remains constant with the result that the lateral and circumferential forces acting on the tyres from the road surface are available at a level as constant as possible.

A conflict of objectives exists between both tasks by reason of physical laws. A compromise therefore has to be accepted for conventional suspension systems in view of the probable use to which the vehicle will be put, with a greater priority being given to driving safety than to the comfort.

It is possible with comparatively simple means (e. g. level-controlled air suspension, stepped spring, grooved damper) to automatically adapt individual components of the suspension system to the load condition of the vehicle. Particular interest exists in the capability of adapting the suspension system to different speeds and to greatly varying road surface characteristics in terms of the effect of road surface excitation on the two coupled oscillating systems consisting of tyre elasticity and axle mass as well as body springs and body mass.

The capability of a suspension system to rapidly adapt to interferences which occur suddenly also, as a rule, leads to an improvement in driving comfort. As an impairment in driving comfort need only be accepted in those instances where it is unavoidable in order to maintain driving safety.

Two possibilities which exist for rapidly intervening in the suspension system are the "fast damper" (semi-active suspension), (Fig. 10), in which the passive characteristics of the dampers are influenced, and the "active suspension" (Fig. 11) in which forces are actively generated in the suspension system and energy is thus supplied. Both systems are based on measuring a number of parameters in the vehicle and on this information being evaluated in a microprocessor in order to control the electronically variable dampers or the hydraulic actuator elements. The actual control function in both systems is performed by fast servo valves, which have to meet high demands.

In the case of the fast damper, it is possible to control not only the damping which impedes motion, but also the inducing of a directional force on the basis of theoretical and empirical formulations for influencing the natural frequency of the axle by countering the motions of the wheels with unequal, directionally dependent damping characteristics. These directional forces can then be employed to influence the relatively slow motions of the body. The stabilising body forces used in this force-inducing damper control are obtained directly from the motion of the wheels.

Optimum characteristics can only be achieved with active suspensions in which energy is supplied into the system. The forces between axle and body, or between wheel and road surface are generated as complex functions of practically random information. In addition to optimum adaptation of the suspension to the prevailing load and driving conditions, separation of motion into dynamic lifting, rolling and pitching control is possible. The active suspension reacts to individual obstacles on the road surface and the over-/understeering characteristics of the vehicle can be dynamically controlled as required. The fast reaction of the servo actuators requires not only an extremely fast servo-valve control but also a matching hydraulic supply which the electronics has to control in such a way that only the power demanded is actually supplied.

Further comprehensive theoretical investigations into the design of the control element are needed in order to be able to exploit the full potential for enhancing comfort and driving safety with an active suspension system. Accurate and reliable sensors for advanced sensing of unevennesses on the road surface will provide the system with the capability not only of reacting but also of acting.

6 FLEXIBLE SERVICE SYSTEM FSS

The primary aim of a diagnosis system for commercial vehicles is to achieve a further improvement in operating economy. Technical development increasingly offers more opportunities for data processing and storage on board of commercial vehicles (Fig. 12). At the same time, as a result of this technical development, complicated control systems are integrated in the vehicle. Some of these are so complex that it is only possible to provide the necessary operational reliability and service life or specific repair facilities if appropriate monitoring equipment has been envisaged right from the design phase.

Use of a diagnosis system can have a direct impact on the operating economy of a commercial vehicle by reducing downtimes to a minimum. This is achieved on the one hand by minimising the time the vehicle spends in the workshop, on the other hand, vehicle monitoring in advance of a workshop diagnosis can limit the number of down-times. A further important factor is that it is then possible to reliably calculate in advance the time when a commercial vehicle will be out of service for maintenance work.

Manufacturing costs can be reduced by eliminating design redundancies, if it is possible to reliably detect in advance damage arising from above-average stresses. Operating costs can be cut if service products such as engine and transmission oil can be used to the point where it is actually exhausted by constantly monitoring its efficiency level.

The aims which have been mentioned can only be achieved with a diagnosis system which provides for continous monitoring. The consequence of this demand is that diagnosis equipment should preferably be on-board. In comparison to an external, workshop-based system, the on-board diagnosis system opens up the additional possibility either of activating emergency running functions or of recommending to the driver suitable rules of conduct simultaneous to the occurrence of the fault. The on-board diagnosis unit is supplemented by stationary test equipment in the workshop, with data being transferred from the vehicle through a special diagnosis interface.

The diagnosis system will be standardised by each electronic unit being provided with a uniformly defined interface. This can perform the function of transferring fault codes to a central display unit provided in the vehicle and also data transfer to external diagnosis equipment, allowing interactive communication to be conducted between the test equipment and the electronics under test and more sophisticated test routines to be initiated.

7 FLEET MANAGEMENT SYSTEM MB-ASSISTENT

The fleet management system MB-Assistent is a modular information and communication system for commercial vehicles which fills the gap between fleet operations centre and vehicle. Essentially, MB- Assistent comprises the on-board components such as computer with portable hand terminal, screen, printer and sensors (Fig. 13).

MB-Assistent is offered in various modular configurations in terms of hardware and software to satisfy different demands, for instance, for local delivery services or for long-haul trucking. Basically, it performs two groups of tasks, which can be considered independently of each other. On the one hand, it is a "transport support system", on the other hand, a "vehicle monitoring system". Two different types of data are recorded depending on the particular tasks:

Commercial data relate to vehicle loads and trip scheduling. Most of these data are produced by the fleet operations centre computer. In some cases, though, these data may also be recorded or altered by manual input. This would be the case, for example, after the issue or return of goods.

Vehicle data document the route followed and the condition of the vehicle. These include measured values such as distance, time, speed of vehicle, engine speed and fuel consumption. These data are recorded by sensors and data cables, which are fixed installations in the vehicle. In addition, it is also possible to record diagnosis information captured by individual electronic on-board sensors. The vehicle data are merely buffered in the on-board computer to be evaluated subsequently in the fleet operations centre computer in respect of vehicle conditions, servicing, running costs and trip optimization.

The MB-Assistent comprises in hardware terms on board the vehicle the computer with screen, printer and portable terminal as well as the sensors. The portable terminal with a large CMOS-RAM memory acts as the data storage medium between on-board and fleet operations centre computers. In the centre, the hardware consists of the computer and only a reader for the disc with an interface to the fleet operations centre computer.

8 OUTLOOK

Envisaged in the long term for commercial vehicles is an integrated electronic system which represents the higher level in a configuration of individual sub-systems. An integrated electronic system of this nature is characterised by largely self-contained electronic functional units which are assigned to individual vehicle components. System analyses can be performed separately for each system as part of a vehicle diagnosis. All the electronic units communicate over a central databus, providing rapid data transfer. The individual electronic modules exchange sensor and actuator signals over the bus. Diagnosis data can also be sent over the databus to a central information module. This not only provides the data for an on-board diagnosis display but also acts as a central interface for transferring diagnosis information to an external tester.

In the ideal of a self-controlling vehicle, the driver need only advise to the electronic control the extent of the desired acceleration or deceleration and practically leave the intelligent sub-systems to execute his command. This enables the entire driver-vehicle-environment system to be optimized by taking into account all the interactions and to free the driver to concentrate on higher-order management control functions.

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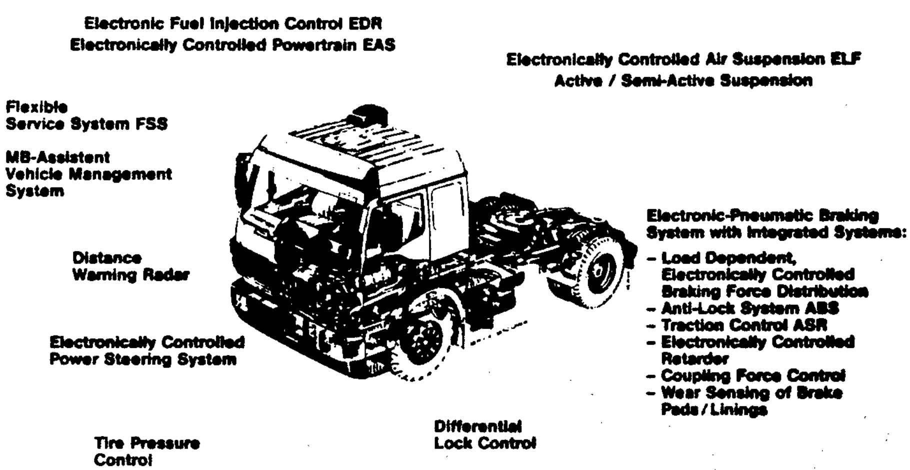
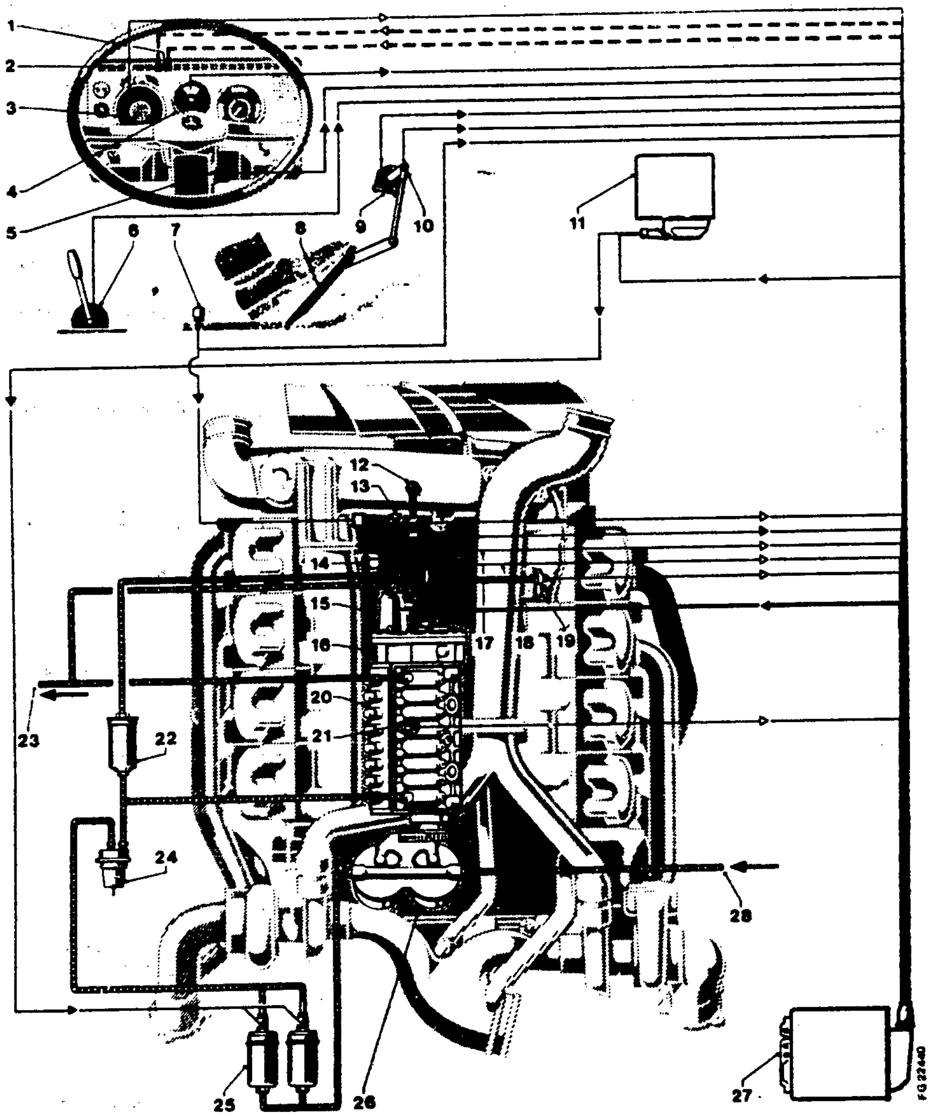


Fig. 1: Electronic applications in commercial vehicles



1. Warning Light
2. Power-On Light
3. Speedometer
4. Tachometer
5. Ignition Key
6. Lever for Manual RPM Adjustment
7. Engine Brake Switch and Engine Cut-Off
8. Accelerator Pedal
9. Set Value Pickup
10. Kick-Down Switch
11. Electronic Control Unit for Fuel Pump
12. Turbo Pressure Pickup
13. Turbo Temperature Pickup
14. Start/Stop Switch (Cab Tilted)
15. Solenoid-Operated Control Valve
16. Injection Controller
17. Rack Control Pickup
18. RPM Pickup
19. Turbo Pressure Pickup
20. Injection Pump
21. Fuel Temperature Pickup
22. Fuel Filter
23. Fuel Return
24. Reservoir
25. Elec. Fuel Pump
26. Fuel Filter
27. Electronic Control Unit
28. Fuel Coming from Fuel Tank

Fuel Feed Line
Fuel Return Line
Metering Unit
Actuator
Measurement
Control

Fig. 2: Electronic fuel injection control for Diesel engines

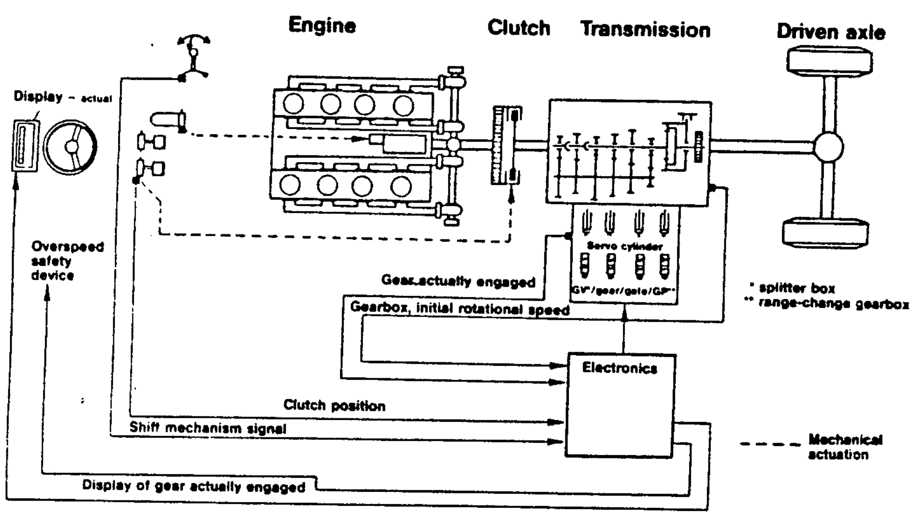


Fig. 3: Electronic-pneumatic power shift EPS

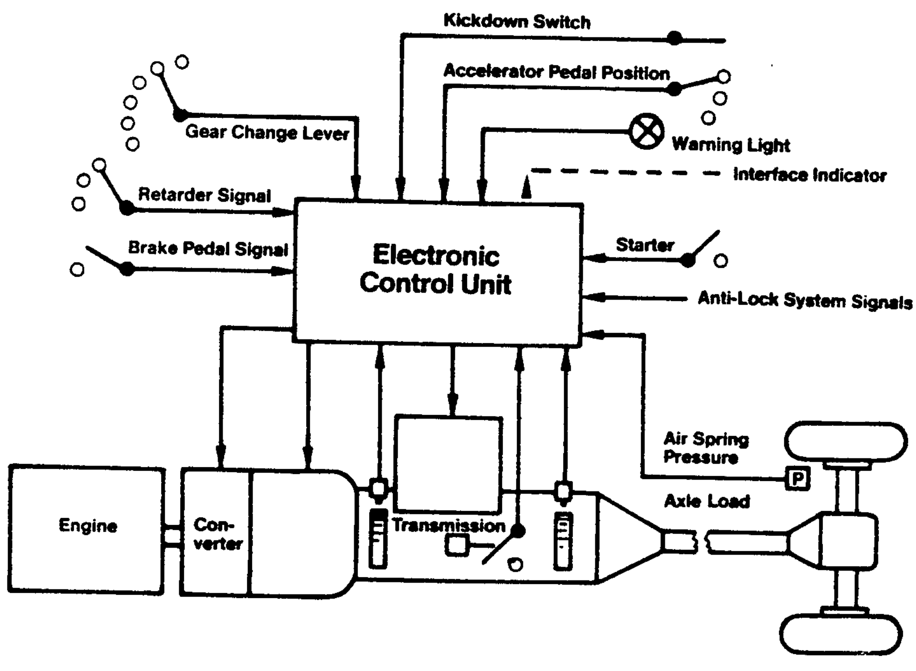
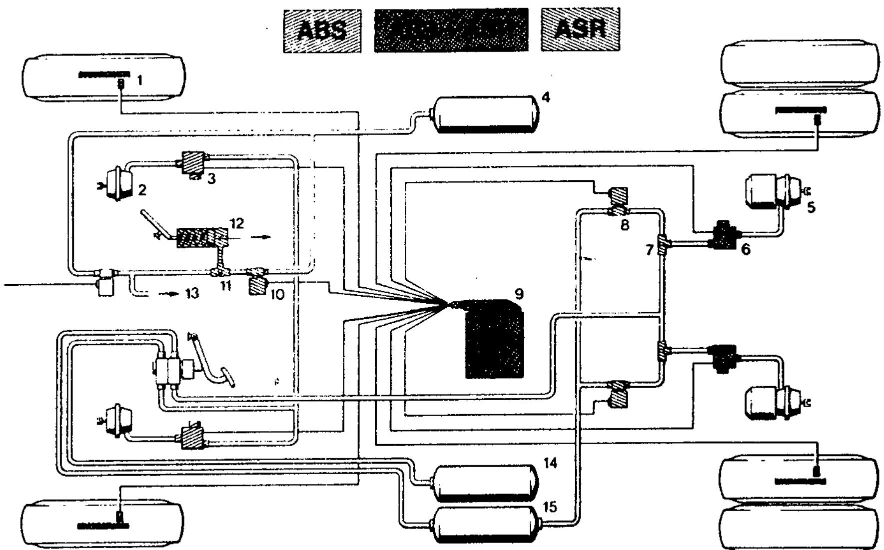


Fig. 4: Electronically controlled automatic transmission



1 sensor and rotor
2 front axle brake cylinder
3 solenoid control valve
4 compressed air reservoir (auxiliary consumers)
5 rear axle brake cylinder
6 solenoid control valve
7 2-way valve
8 3/2-way solenoid valve
9 electronic control unit
10 3/2-way solenoid valve
11 2-way valve
12 engine control cylinder
13 to exhaust brake
14 compressed air reservoir (brake circuit, front axle)
15 compressed air reservoir (brake circuit, rear axle)

Fig. 5: Anti-Lock System ABS and Traction Control ASR of 2-axle-CV

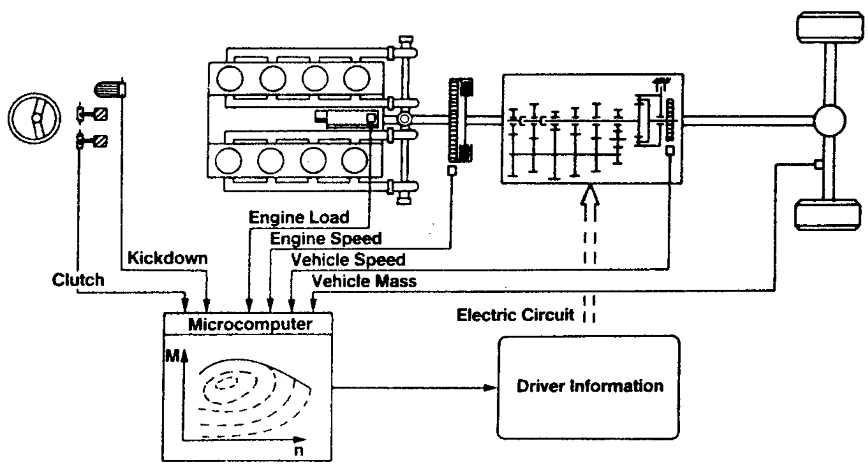


Fig. 6: Electronically controlled powertrain EAS

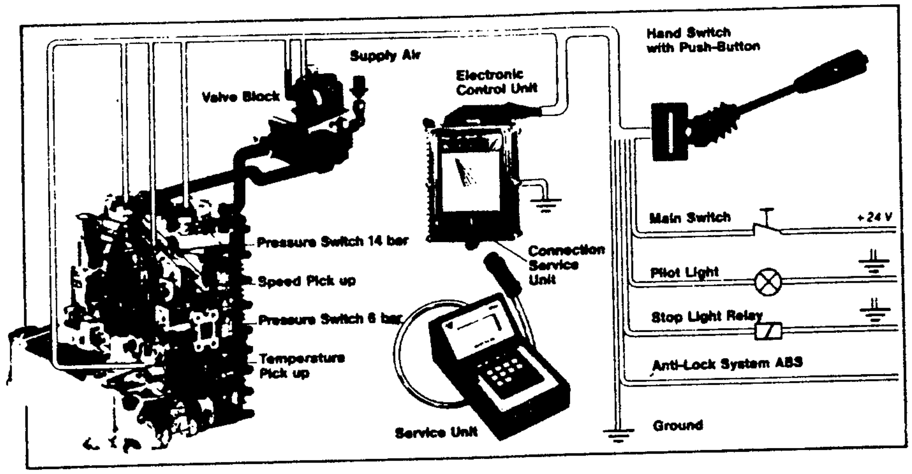
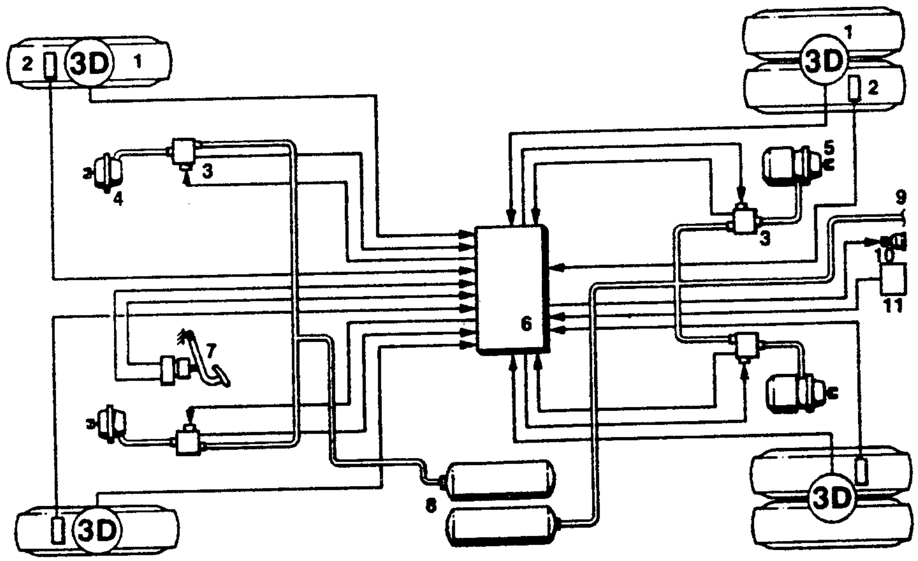


Fig. 7: Components of a fullelectronic retarder



1 3-D-wheel-force sensor
2 pad/lining wear indicator
3 control valve
4 front axle brake cylinder
5 rear axle brake cylinder
6 electronic control unit
7 brake pedal
8 compressed air reservoir
9 supply reservoir hose (trailer)
10 electric control line (trailer)
11 coupling force sensor

Fig. 8: Electronic-Pneumatic Braking System EPB for a 2-axle-CV

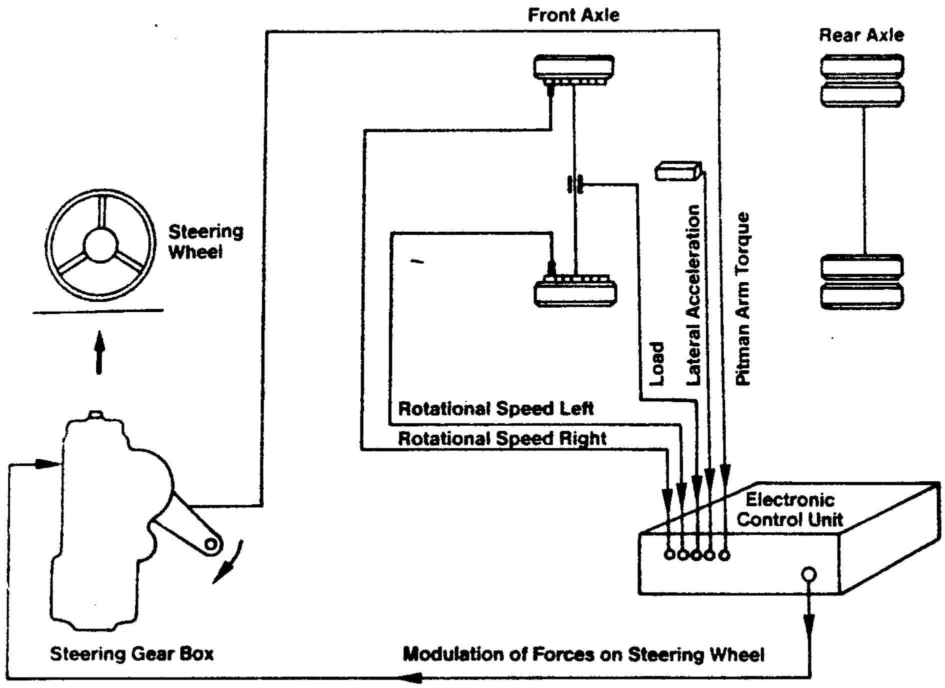


Fig. 9: Electronically controlled powersteering system

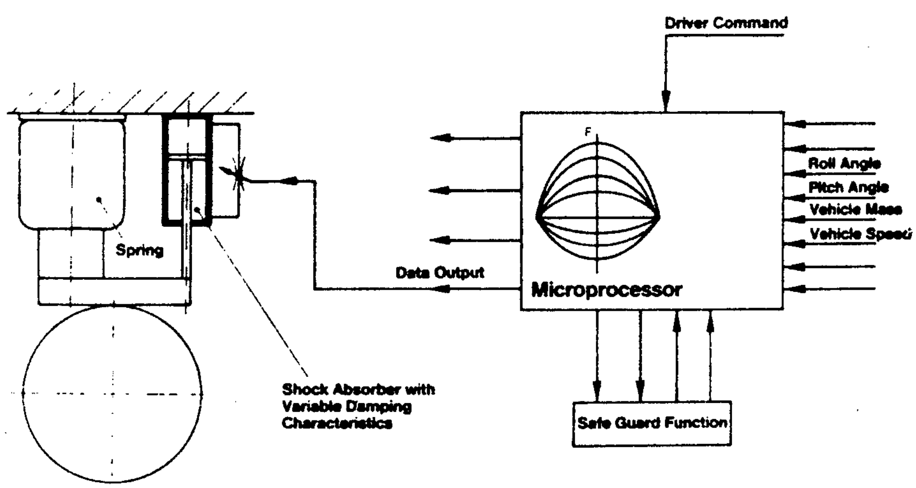


Fig. 10: "Fast damper" controlled by microprocessor

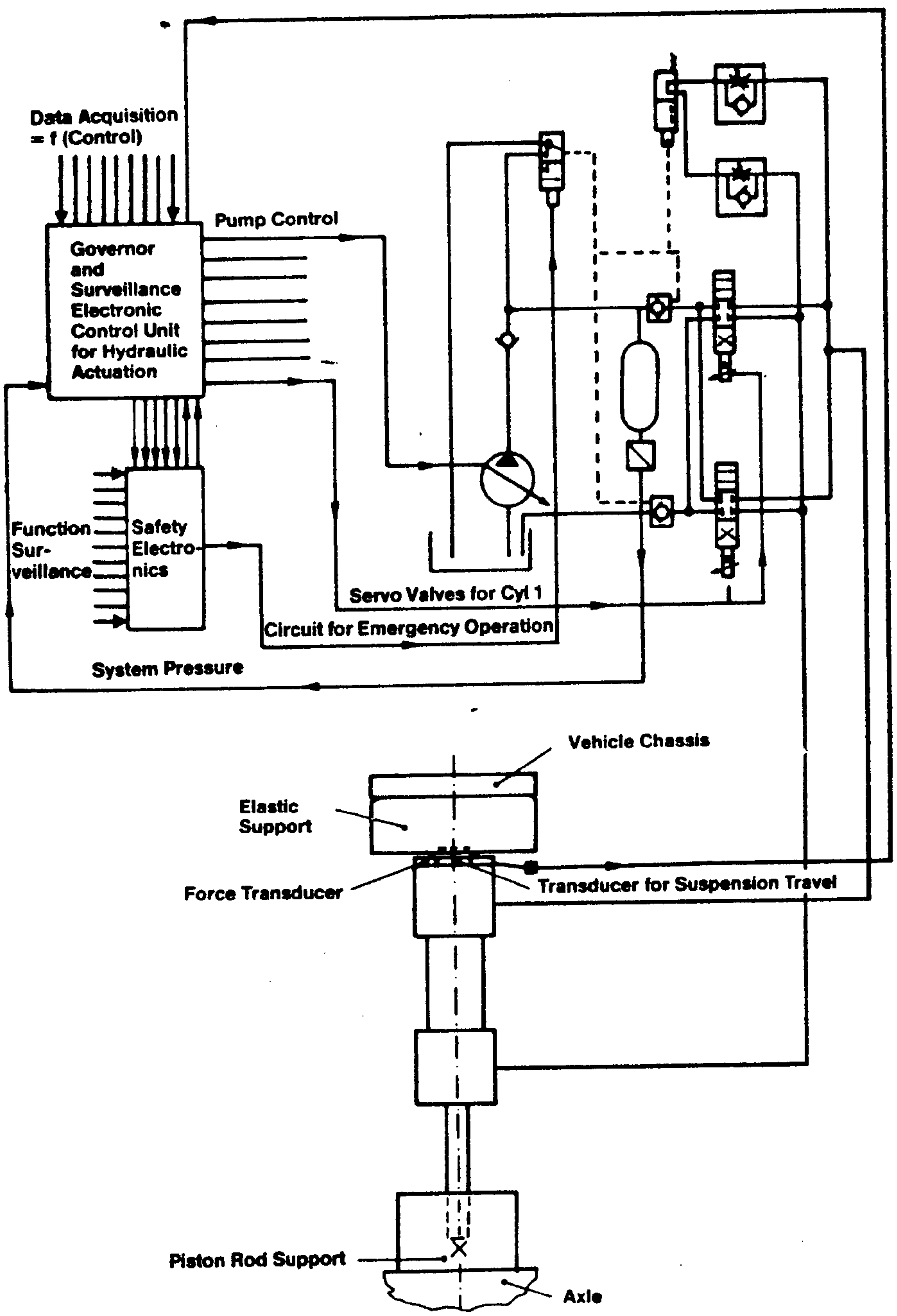


Fig. 11: Micro-processor controlled active suspension

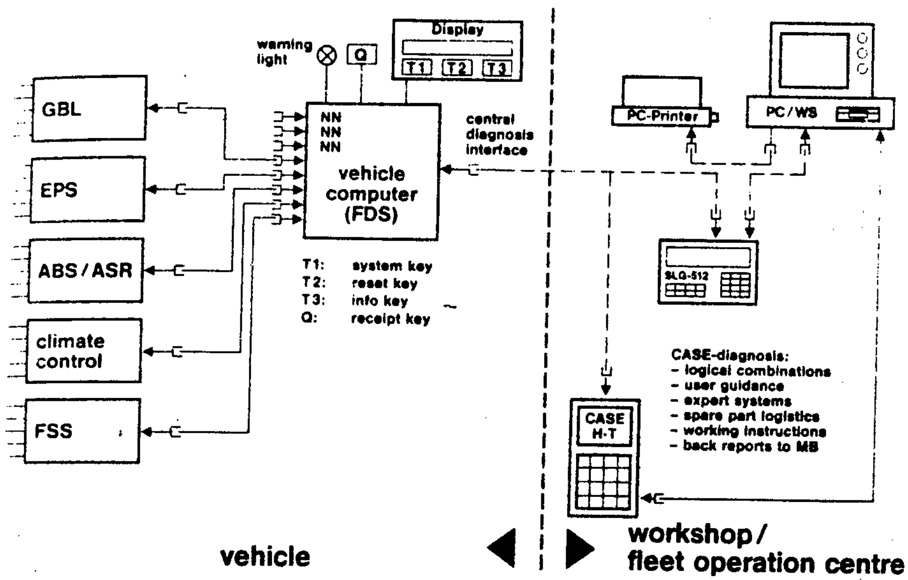


Fig. 12: Flexible Service System FSS

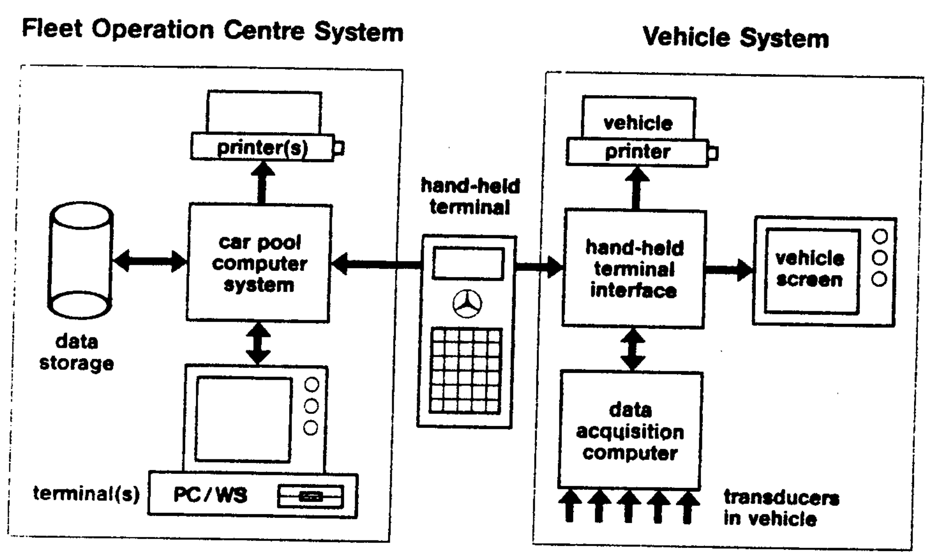


Fig. 13: Components of vehicle management system MB-Assistent

FUTURE TRENDS IN AUTOMOBILE TECHNOLOGY

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The automobile industry is an integrated industry made up of a variety of technologies. Some say it has no technology of its own. This situation makes predicting the future of automobile technology difficult. Predictions may be totally invalidated by advances in peripheral technologies applicable to automobile manufacturing. Nevertheless, I will include in my talk today demands for advances in the peripheral technologies.

There is concensus about what cars in the future should look and act like in general, but each country has its own minor variations to these general desires. I would like all of you to realize that what I am about to say is a Japanese perspective.

1. Environmental and social changes that affect the automobile industry

1-1. Changes in society and people's lives

Society has undergone many changes. As social and economic activities have increased, population centers have moved from city centers to city outskirts. Improvements in earnings and an increase in leisure time has meant changes in lifestyles. Furthermore, personal consumption has brought about a demand for increased quality. We live in an age of materialistic abundance, and their is a growing desire to see how much more mental abundant life can be.

- The relationship between people and automobiles

Changes in society has brought about changes in the relationship between automobiles and people. To begin with, an increase in the opportunities in mobility has meant an increase in the use of automobiles. More than 70% of the households in Japan own cars and 18% own more than one car. The automobile has become an essential part of life, and, more and more closely adheres to peoples' lives as a means of transportation. In other words, as lifestyles and the relationship between automobiles and people change, importance placed on qualitative aspects of using automobiles is becoming rapidly increasing. People now seek to have a feeling of comfort, satisfaction and reassurance by owning, riding in, and driving a car, without, though, underrating the importance of meeing social needs such as energy conservation and reduced pollution, economic needs such as lower prices and lower fuel bills, and need for practical functions such as luggage accomadations and residential suitability. Automobiles help to complete a person's personality. Automobiles are necessary if we want our friends and people of the sub-cultures within which we live to recognize our individuality. Automobiles are an essential element in coordinating our sense of self and lifestyles that fit our interests. People are taking more seriously the importance of owning an automobile, and of an automobile's shape and design. This indicates that more and more the value of owning an automobile is being measured in terms of its usefulness as a means of self expression.

• Changes in living environment and judgment of values

From Things to Services in a World of Individuality and Variety

People's lifestyles and judgment of values have become more varied, and their desires for life are moving from things to the services that surround those things. Spending has increased for culture, education, health, and leasure: things that make life more worth living. Together with a personal independence that includes a desire for the real and for the first-class, a desire has been born to spend for a richer and happier life. Therefore, people now recognize the automobile as an object that increases the quality of life and as an instrument that makes life more enjoyable. The desire for greater comfort and greater usefulness has become even stronger.

Women's Advancements in Society and an Aging Society

Female drivers and elderly drivers have increased. The use of automobiles by housewives whose lifestyles are centered on the home has increased rapidly. Automobiles are being used by housewives in an ever widening range of daily activities such as shopping, community activities, and chauffering people around. Elderly people also use automobiles in a variety of ways in order to give themselves more affluent lives. Their uses include visiting families, leisure, education, and hobbies.

Increased Leisure Time

People's leisure time has increased. Furthermore, we are witnessing the birth of a society that places importance on leisure time. Time is actively being devoted to leisure in a variety of ways: everything from recreation to self improvement and self expression.

Entering the Information Age

We are becoming a society that deals with a great deal of information. The expanding information and communications network, which permeates even our communities and family life, has also meant an increased need for cars to send and receive information. Ultimately cars will become information bases in the form of "mobile livingrooms," "mobile offices," and "mobile stores."

Twenty-four Hour Life Styles

Lifestyles that make full use of the twenty-four-hour day, such as night shifts and flexible-time work schedules stemming from internationalization and the proliferation of information, have led to an increase in night traffic.

1-2. Changes in traffic and transportation

Building expressways and improving their surrounding environments will mean advances in traffic and transportation.

- Establishment of traffic and transporation systems

Construction of a Unified Traffic System

In the future it will be necessary to complete facilities for a unified traffic system that will make possible a variety of choices. Specifically it will be necessary to install equipment that allows the flow of people by public transit system and in private cars to be regulated together efficiently. The same holds true for the flow of objects in traffic.

Establishment of a Traffic Information System

A comprehensive traffic information system will be completed in the future. This will include not only road information but also information on related social facilities such as parking lots, leisure facilities, and recreational facilities. There will also be research to develop traffic control systems designed to take the burden from the driver by safely guiding traffic based on decisions concerning vehicles, road surfaces, weather, and traffic volume.

2. Changes in the Requirements for Automobile Technology

As has been stated above, transportation changes to meet a changing society and changing lifestyles, and this in turn means changes in the requirements for automobile technologies. There are two major viewpoints concerning the way in which the automobile will change in the future. One viewpoint is that the functions and values of the present car will be further improved to cope with such changes as the desire for leisure, women's advancements in society, and an increasingly aging population. The second viewpoint, which seeks more human-like lifestyles, considers the car an essential element in a high-mobility system.

2-1. Topics in Automobile Technology

• The 1990s

The movement for a comfortable environment is growing stronger, and society is maturing and becoming more abundant. To cope with this, even more value must be built into automobiles, and progress is necessary in new fields such as automobile aesthetics and automobile psychology. Furthermore, the automobile is an essential part of the information age. It will be made a necessary element in traffic information systems, and will actively use information transfer technologies.

The movement to improve the environment has expanded to a global scale. We must demand of appropriate technologies responses to such issues as CO_2 emission regulations, a part of global warming policies, and fluorocarbon emission regulations, which aim to prevent destruction of the ozone layer in the stratosphere.

• The Year 2000 and Beyond

As developing countries progress, the world's energy consumption in absolute quantity increases. But we cannot expect a leap to happen in oil production. On the contrary, because we must greatly reduce the consumption of oil to solve the problems of global warming, the existence and maintenance of oil produced energy has become a real issue. Developing highly efficient systems for automobiles is urgently required. These systems would use, for example, ceramic gas turbines, multi-fuel engines that can run on alcohol-based fuels as a way to avoid oil-produced energy, solar batteries, and solar electric automobiles that use superconductivity technologies. Furthermore, automobile traffic can be highly systematized and speed up using a unified traffic system. Technological progress will also occur in the areas of automatic guided control on expressways, and self-running vehicles with a high degree of autonomy.

2-2. Trends in Automobile Technologies

New technologies that will play important roles in the future of automobile manufacturing will be automobile control technologies, communications technologies, new materials, computer technologies, biotechnologies, and technologies for systemization.

- Automobile Control Technologies

Progress in microelectronics technologies will by applied to the engine, drive system, and chasis system in order to develop automobile control. Future developments in integrated control will follow the two paths of greater safety and a higher degree of driving feel. "Easy driving" will eventually lead in the direction of self-drive automobiles with a high degree of safety. Traction control systems have driving support functions that make driving possible for anyone from first time drivers who aren't used to driving to veteran drivers, and these system will move in the direction of more powerful support systems. When these systems link up with communications technology they will move toward an automatic driving system. Individual technologies related to this field include fuzzy controls, photoelectric ICs, VLSI, and intelligent sensors.

- Communications Technology

Communications technology will begin with the perfection of navagation functions. Advancements in this area will come in the form of driving aids, and, ultimately, information manipulation methods that will allow cars to drive themselves. As one part of a traffic control system, this work will help to alleviate traffic jams, reduce fuel consumption, shorten driving time, as well as make efficient links to other expressway systems. In particular advances can be expected in high-density digital optical recording technologies, large-scale memory technologies, and satellite communications technologies.

- New Materials

The use of engineering plastics in automobile parts has been smoothly increasing, and as such can no longer be called new materials. Ceramics are being used as functional material in sensors, and have begun to be used as heat-resistant material in turbo-charger rotors. If, in the future, the performance of ceramics can be increased, then they will be usable in ceramic gas turbines, and we can expect to see a subsequent jump in heat efficiency. Furthermore, if superconductive materials that operate at normal temperature are developed, then they will be applicable to both motor and battery technologies, and the electric car will become usable.

• Computer Technologies

Of the technologies used in manufacturing and marketing automoibles, computer technologies are among the most widely used. Computers are used in development for specification tests, in production for machining and assembly, in sales for handling customer data and taking orders, and in service for making repairs. Supercomputers are used in development for aerodynamic and construction analysis, and, in particular, the newest computer technology is being employed in driving simulator. Not only does the simulator make an extremely effective tool in research and development, it is also effective in revealing human driving actions.

• Biotechnologies

The impact of biotechnologies for automobiles is not yet fully known, but it includes essential technologies that can be used in automobiles such as the obstacle detection of bats, reduced resistance of dolphins, and direction detection of birds. This kind of research also offers revolutionary possibilities in car sensor technologies. Furthermore, biotechnology may play an important role in solving the global warming problem if the mechanism of CO_2 assimilation by plants is revealed, and its rate and quantity artificially boosted.

• Systemization

Automobile technology is a systemized technology that satisfies a large number of requirements to correctly assemble more than 10,000 parts. In order to make the individual existence of today's completed car into a social existence, we must hope for progress in a wide range of systemization technologies that make possible the systematic linking of automobiles to the road infrastructure.

3. The Automobile Society of the 21 Century

People's judgment of values diversify as their wages increase. They value time more as their free time increases. Populations and industries are dispersed. As industries computerize, not only the quantity of roads and public transit systems expands but also qualities such as speed, reliability, safety, and comfort are improved. In the midst of all this, the automobile's uses becomes more varied, and its role in relationship to public transit is more clearly defined. In the 21 century the automoible will be even more recognized as a means of transportation and a living space that are more closely tied to our lives.

3-2. Changes in automobiles and technologies that will form the base for progress

Future conditions for the automobile will include safety, energy conservation, protecting the environment, and harmonizing with social systems. The following is a view of the automobile's future and of the technologies that will form the base for progress in automobile technology. Figure 1 shows the kinds of technology that will arise over time based on each technology's goals, and the kinds of automobiles that will result from this technology. The items of the figure are as follows:

3-1. Automobiles and People: Unification and Diversification

The automobile's role will change: its importance in a faster public transit system as a way to move through major cities will increase. It will become an inner-city transit and an access to expressway systems. The automobile will become more than just a means to get from home to a recreational site: it will become a personal and independent mode of transportation. The functions of these new cars will become more high level. Automobiles will make an appearance that can drive quickly, safely, and comfortably on specially designed roads; order made cars to suit a variety of special uses; leisure cars with increased space; as well as logical and economical commuter cars to provide everyday transportation. Cars abundant with individuality will fill our cities in the future. Furthermore, increases in the number of elderly and female drivers will cause an increase in households with more than one automobile, so the percentage of total transit time taken up by business related trips will decrease, and the percentage for shopping, errands, and leisure will increase.

Safety

- Development of higher-performance tires
- Improvements in full-time four wheel drive technology
- Perfection of four wheel steering systems
- Increased use of antilock brakes
- Increased use of traction control systems
- Improvements in approach sensors (to detect obstacles)
- Development and improvements in active control technologies
- Application of fuzzy control systems
- Development of Ultra Strong Materials
- Development of bio-sensors
- Development of automatic guidance systems

Energy Conservation

- Improving aerodynamic characteristics of automobile bodies
- Lightening autmobile bodies and parts
- Improving the performance of batteries and motors for electric automobiles
- Making ceramic gas turbines practical
- Making solar energy automobiles practical
- Development of energy recycling technologies

Environmental Protection

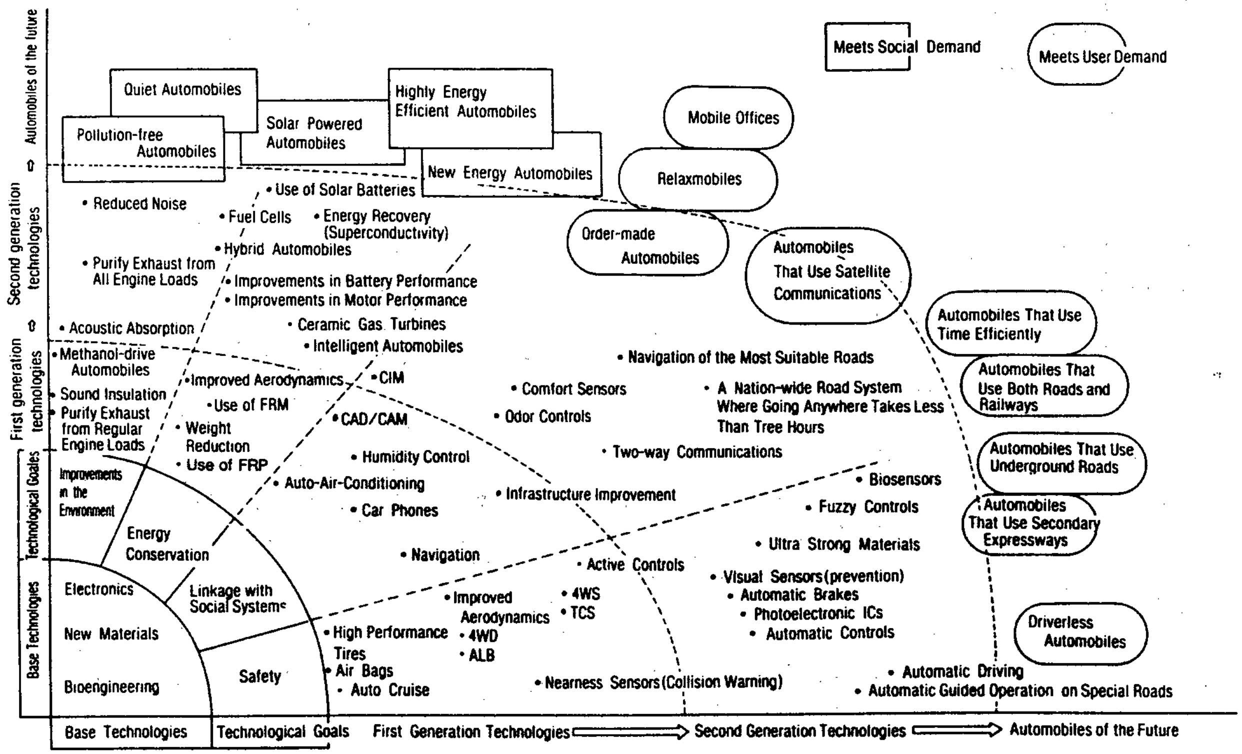
- Improvements in noise dampening and noise absorption technologies
- Improvements in the technologies necessary to purify exhaust not only for regular engine loads but also for entire engine loads
- Development of engines that use alternate energy forms, such as methanol
- Development technologies to make automobile bodies even quieter

Harmoniously Combining with Social Systems

- Expansion and installation of navigation systems
- Perfecting an infrastructure of roads and a transit network
- Developing and increasing the performance of intelligent cars
- Installing systems to allow communications between one automobile and another and between automobiles and roads

Figure 2 takes these points in mind and estimates what kinds of automobiles will be developed and when they will appear.

These two figures describe the future prospects for automobile technology. Changes that will occur in the way people, things, and money are invested for the research, and development of this technology is forecasted in Figure 3. This figure shows changes in the technologies related to automobiles seen from a macroscopic viewpoint. I am interested to hear what those of you present here have to say concerning these points.



K.Goto	**Fig.1 The Automobile's Changing Future through Expanding Technology**	90305

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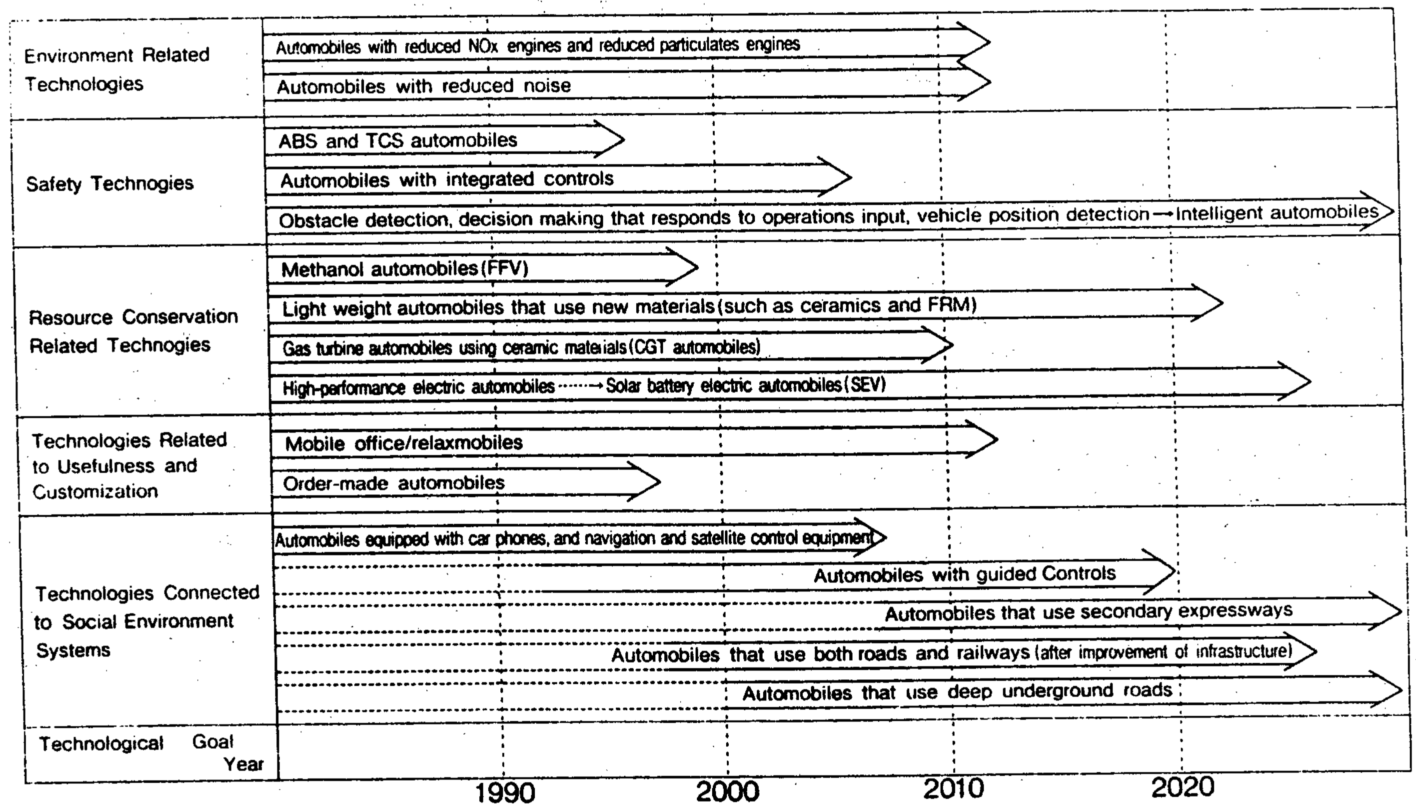
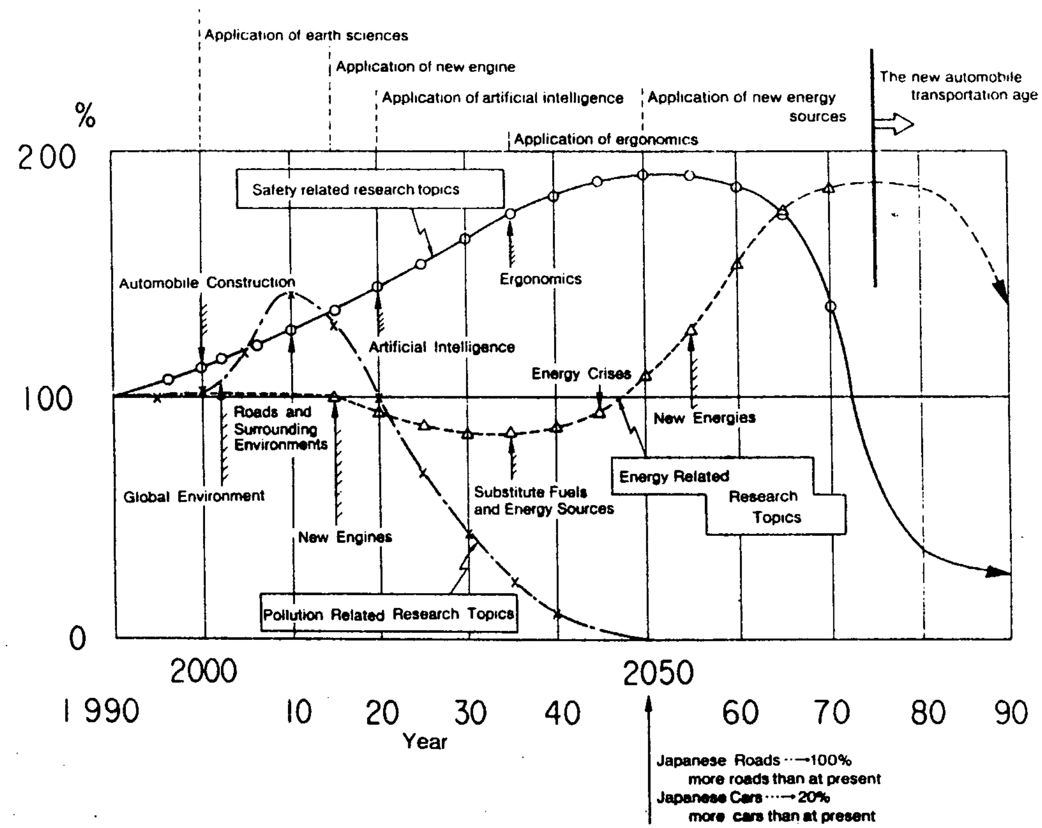


K.Goto	**Fig.2 Automobiles of the Future Based on a Changing Society and Changing Technologies**	90305



K.Goto	**Fig.3 Prospects for Sciences and Technologies Surrounding the Automobile Industry**	90305

NEW ROLES OF AUTOMOTIVE ELECTRONICS

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1. INTRODUCTION

Progresses made in electronics are remarkable in recent years. Semiconductor technology in particular has increased its degree of integration dramatically in only four decades or so, with the capability to integrate several hundred thousands to several millions of semicondoctor elements on a single chip, along with advances made in manufacturing technology. Semiconductor application areas are also expanded to communications, computers, household appliances, controls and all other areas today, owing to excellent characteristics of semiconductors, which are dramatically changing our society.
Automobiles are also undergoing major changes by the application of electronics, which are being employed not only in fundamental technological areas such as "running, turning and stopping" but also in all areas of automobile electronic systems/devices, including those for information, display, comfort and convenience, entertainment, wiring and diagnosis.
The key requirement for future automobiles will be the systematic combination of conventional functions and new functions to be added - that is, the concept of system integration. New roles will be provided with automotive electronics in this direction accordingly.

Changes Made by Introduction of Electronics

TOYOTA's vehicles have also undergone remarkable changes over the past decade by the introduction of electronics. Namely;

* the number of ECUs installed in a single automobile is increased by 5 times compared with a decade ago;
* the number and volume of wire harness are also increased in proportion to the increase in the number of systems-that is, the number of circuits is 3.8 times, the harness length 2.9 times, and the weight 3.3 times greater than those of a decade ago; (Fig.1)
* the use of EFI (Electronic Fuel Injection) is increasing year after year, and 80 % of passenger cars are using EFI today;
* the percentage of ABS (Anti-lock Brake System) installed on vehicles is also increasing every year; and
* the utilization of electronics for an entire vehicle is also showing an even higher increase rate than those of the EFI and ABS.

Necessity of Integration

The increased use of electronics has brought about improvements in functions, comfort, convenience and safety of automobiles. It will be, however, necessary to meet the demand for further expansion of control functions, and to ensure adequate spaces for system control devices while ensuring sufficient spaces for occupants within the limited total space of the automobile. Securing high

reliability against the complexity of the systems and reductions of vehicle weight and cost are also vital. Integration of systems is hence necessary in order to meet all of those diversified requirements.
Basically, automobiles are one of means to transport people and goods safely and quickly to anywhere. Life styles of people are, however, about to change due to the diffusion of information in every key area of socioeconomics - such as individuals, homes, enterprises and regions. Under such circumstances, automobiles are about to enter into an era where the reinforcement of information processing technology is indispensable, in addition to their inherent functions as a transportation medium.
Before going into discussions on integration, automobiles may be considered in terms of "mobile information equipment" with their information processing functions classified into following four categories. (Fig.2)

1) Vehicle Information
2) Man-machine Information
3) External Environmental Information
4) Information for Communication with Outside-the-Vehicle

2. PROCESSING IN VEHICLE INFORMATION

The most crucial and basic control function of automobiles is the optimum control of individual components so that automobiles may run, turn and stop properly. The primary mission of any engine is to control contradictory requirements on exhaust emission control, horsepower and fuel economy with a proper balance among them, and that of a transmission is to transmit the power from the engine to driving wheels in a powerful and efficient manner. Brakes are expected to stop vehicles at any time, while suspensions are to control the riding comfort in the optimum manner. Those control functions are performed by using various physical conditions of individual components and meteorological conditions around automobiles, as input information to allow predicted control and feedback control. The introduction of electronic systems is indispensable to allow such control functions.

"Running" - Engine/Drive control

Lower-than-ever fuel consumption is required of automobiles today as a vital engine characteristic, together with higher performances and lower pollutant/noise emissions, due to social demands for resources conservation and energy saving, as well as higher requirements and the personalization of users' needs for automobiles. Such requirements can be met by more precise control by means of electronics.
A feedback system using a lean mixture sensor and a three-way catalyst in particular has cleared the U.S. 83 emission standard with 10 % improvement in fuel economy, while maintaining a similar power performance to that of conventional engines. This system has been already introduced into the European market.

"Turning" - Chassis Control

Electronic controls are increasingly employed in order to make steering stability and riding comfort compatible at a higher level than ever before. The shock absorber damping force automatic control system also employed in the European market, air suspension spring constant and damping force automatic control system and vehicle speed sensing type four-wheel drive steering system,

in which the capability to make small turns smoothly at low vehicle speeds and the steering stability at high speeds coexist, are some examples of such systems already introduced into production.
The active suspension system introduced into the Japanese market in 1990 has attained a higher level of flat ride comfort by means of following - the oil from the hydraulic pressure generation source is fed into the hydro-pneumatic suspension, then exhausted out of it by means of the hydro-pneumatic pressure, in order to suppress the fluctuation of vehicle posture caused by steering, acceleration/deceleration and inputs from road conditions.

"Stopping" - Brake Control

The ABS with the function to ensure vehicle safety by preventing the wheel lock is currently used in various kinds of vehicles, aimed at providing brakes capable of stopping vehicles under any conditions. Here again the electronic control method is the main stream of ABS, though some of such systems are mechanical type.
Owing to functions of ABS to reduce braking forces on individual wheels and to recover the road gripping force, the optimum brake control may be obtained in some cases despite the antimonic requirements on braking distance and vehicle stability. In order to ensure the optimum control according to various road surface conditions, such as asphalt paved roads, snowy roads and unpaved roads, diversified driving conditions at high speeds and cornering, and different vehicle conditions including those of tires and loaded luggage, it is necessary to change the control method by estimating actual vehicle speeds, road and driving conditions through detailed calculations of wheel rotation speeds and accelerations, and to feed back variations in kinetic conditions of wheels by means of hydraulic control of brakes.
It will not be an over-statement to say that the optimum control can be hardly attained without the electronic control method. Moreover, the weight reduction of components, the installation at any location, and the optimum matching per vehicle type within a short period of time could not have been allowed without the electronic control technology. Furthermore, even the improvement in braking feelings when the ABS is activated may be considered recently, owing to the dramatic improvement made in capabilities of microcomputers.
The introduction of electronics in vehicle control is indispensable to the conformity with environmental requirements, riding comfort, and the improvement in safety. The integration of such control systems should expand their functions furthermore.

Effects of Integration of Vehicle Control Functions

The improvement in vehicle total performance, addition of new functions, simplification of systems, higher efficiency in space utilization, reinforcement of reliability, and reductions of total cost and weight can be attained by the multiplied effect of sharing sensors and actuators among plural systems and the total control of such systems.
The entire control performance is improved by the total control of transmission, traction, brakes and suspensions in addition to the engine control by means of conventional EFI.
The integration of installation techniques allowed by the progresses made in semiconductor integration technologies has contributed to the coexistance of an adequate space for occupants and a sufficient space for system control devices which continued to increase in number year after year, within a limited total space of an automobile. The size and weight of ECU for engine control are almost same as that of older one, despite the fact that its functions are increased by 6 times. (Fig.3)
Higher reliability is attained by the introduction of single chip type

microcomputers and custom LSIs/ICs, since they have reduced the number of elements used in electronic systems and the rate of failures, while they have improved the noise immunity. The percentage of custom design of semiconductors for control purpose is 73 % for microcomputers, 34 % for LSIs/ICs and 26 % for discrete devices, which are rather high percentages. (Fig.4)

Integration of Future Vehilcle Control Systems

The total control of various aspects of engine power is attainable by a single actuator, by using electronic control technology for the engine throttle valve instead of conventional mechanical control method. That is, in addition to the engine power control by the will of driver, the total control of engine power can be done according to signals sent from the cruise control, traction control, transmission control and other control systems. (Fig.5)

Since the engine, transmission, brake, suspension and steering systems of a vehicle are closely correlated, the optimum total control cannot be necessarily obtained by the separate optimum control of each system. A total control system for vehicle is hence considered, aimed at the exertion of the total performance by the multiplied effects of individual systems, which is higher than the mere arithmetic sum of performances of such systems. Namely, the engine throttle, transmission, 4WD, 4WS, active suspension, power steering, brake, traction and cruise control systems are integrated by the communication network and controlled totally. (Fig.6) The greater becomes the volume of information obtained from a number of systems, the more crucial becomes the issue of securing appropriate information to provide the optimum control. In this regard, not only the development of hardwares but also the development of softwares are necessary.

A proper control method capable of optimum control under any given conditions, by applications of advanced control theories, fuzzy control theory and artificial intelligence, is being studied. For the materialization of such a system, it will be necessary to increase the semiconductor memory, and to develop smart sensors and actuators even if we consider hardwares only.

More effective use of space and further weight reduction are possible by the installation of a compact ECU connected directly to the engine and the use of LAN in the vehicle for the wire harness.

Reliability can be upgraded further and the fail safe capability can be reinforced by the simplification of systems and the development of smart sensors and actuators.

As described so far, an intelligent linkage can be established among individual systems by connecting them organically by means of communication network. For example, when a system fails, the on-board diagnostic system senses the failure accurately and sends out a proper information to other systems for the minimization of the effect of the failure, so that some other system carries out the fail-safe function or backs up the failed system in order to satisfy both performance and safety requirements, as in the case of fail-safe function by reducing the engine torque when a brake has failed.

In aircraft, complex system performances and safety are ensured by linking various systems organically or automating them so that the pilot is obliged to carry out only minimum necessary operations with ease. Similar concepts are likely to be introduced into the field of automobiles as well.

3. PROCESSING MAN-MACHINE INFORMATION

Man-machine systems are available to process necessary information for the accurate communication between the driver and the vehicle. In order to allow such communication, a system to transmit the "information from the driver (will of driver)" and another system to process necessary "information from the vehicle" are required, so that the driver may move or stop the vehicle by his or her own judgement.

This two-way information processing operations depend mainly on physical feelings of the driver today. Namely, sensory feelings on sharpness or dullness of steering wheel or brake, accelerations and riding comfort. are the basis of judgement. However, speedometer to indicate the vehicle speed, fuel meter to indicate the remaining amount of fuel, and various tell-tale lights to inform some abnormality of a component, have been made available from some time ago. As for means to communicate the driver's will to the machine, on the other hand, the level of driver's operation force on the steering wheel, brake, transmission system or the difference in operation speed had been used. In future, however, the development of information processing technology is desirable, which is capable of more accurate communication of driver's will by means of electronic signals.

Changes in Form of Information from Vehicle...Transition of Instrument Cluster

The history of automobile displays could be roughly divided into three stages. Namely, the early stage where displays were developed in line with the development of vehicle performance itself - vehicle speeds or engine speeds, the growth stage to improve its legibility, and the development stage of the present where the major emphasis of research is placed on fashion and increase in functions. Digital instrument clusters proved to require shorter read-out time than the analog type by 10 to 20 %, which have been improved for further better legibility. Since instrument panels are located at the most conspicuous location in each vehicle as the man-machine interface, and some fashionable features are required, the integration of instrument cluster is quite useful for the effective utilization of human vision in the limited space. (Fig.7)

A distant display position is effective for obtaining a good readability. This allows a driver less changes of his focus distance when he moves his eyes from the road to instruments on the vehicle. "Dual Vision Meter" equipped on the TOYOTA CROWN normally shows the driver a real image of the speedometer emitted from a VFD (Vacuum Fluorescent Display). By switching over to a virtual image display, a speedometer image is reflected by two mirrors. (Fig.8)

Considering the role of automobile display as an interface between the driver and vehicle, instrument clusters should be always be attractively designed in a fashionable manner. The instrument cluster of the LEXUS LS400, despite the conventional analog type, has most up-to-date technologies. Cold cathode discharge slender tubes are used for the pointers of speedometer, tachometer and gauges. Circuler tubes are designed to fit the dial plate as back illumination, resulting in a readable, legible and fashionable display which has not been found in past.

Measure for Multi-Display

Vehicle speeds, engine speeds, amount of remaining fuel and coolant temperatures used to be typical display items. Later on, conditions of vehicle control systems such as that of suspension control, and such driving aid information as trip computer were added to items to be displayed. More recently, a navigation system to display road maps was developed. (Fig.9)

As contents of display are becoming more various and complex, drivers may not understand displayed details with their own eyes within a limited time frame. It is thus necessary to process and display information in such a manner that they can understand it within a short period of time, as it will be dangerous for them to avert their eyes too long from the onward direction. In other words, only the information necessary for the driver at a given moment should be

clearly displayed. Graphic display is a means to allow such a degree of freedom. CRT (Cathode-Ray Tubes) are currently used, but TFT-LCD (Thin Film Transistor-Liquid Cristal Display) will be used for space and weight reductions.
HUD (Head Up Display) and synthesized voice are also used as information display media with shorter travel of eyes and higher safety. Display methods with gentler appeals to human being by the integration of such systems will be studied in future.

Communicating Driver's Information (Will) to Vehicle

Driver's will can be more accurately communicated by the introduction of electronics in this area which used to be done mainly by mechanical devices. Restrictions by the shape and size of switch are also reduced by the electronics, which has resulted in a higher degree of freedom in layout, while operation ease and feelings are also improved.
Only a few locations are available in vehicles to provide ease of operations to drivers. The operational ease is incorporated in the combination switch used from some time ago. The turn signal switch, head lights switch, wiper control switch and cruise control switch are integrated around the steering column.
As regards the steering pad, it used to be difficult to install many switches around it due to the difficulty in transmitting signals to the rotary unit, despite the convenient location for drivers. It is now, however, possible to install control switches for audio equipment and climate control around the pad, owing to the development of signal multiplexing technology, and the ease in operation is improved accordingly.
In order to allow the operation of more functions, the integration of switches themselves would be effective to provide more functions to a single switch. Recent car audio equipment requires a number of switches to operate the radio, tapes and compact discs, but the method to use a single switch for multifunctions by the selection of a proper mode is also used. (Fig.10) On TOYOTA SOARER, a switch is used on the same flat panel to operate the climate control and audio equipment. The "Multi-Vision" equiped in TOYOTA CROWN is also capable of operating 21 functions by the soft-touch key on the CRT display screen.
The use of "Keyless Entry" in which the ignition key and the wireless door lock/unlock switch are integrated is also spreading.
One of promising means to convey information to vehicles in future is voice recognition. It is already used in some of automobile phones, and it has increased the driving safety without any hindrance to vehicle operations. The voice recognition rate is, however, still low by the currently available technology, and the development of technology to increase the voice recognition rate among many and unspecified persons will be necessary.

Integration of Comfort - Climate Control

The air conditioner and heater are integrated by the climate control for the creation of comfortable vehicle interior. The use of automatic climate control capable of adjusting the vehicle inside temperature to the preset level is expanding. The system using a microcomputer is capable of precise control and creating a comfortable space against changes in environmental conditions. The riding comfort will be increased further by its integration with the humidity control and the air purifier.

Integration of Convenience - Power Equipment

Power assist and remote control systems are used in door windows, rod antennas, outer mirrors and seats, and items to be included in objects of such systems are still increasing. Some vehicles are using a system capable of determining the optimum position of seat and mirror, according to the will of driver, by the operation of a single switch. (Fig.11) Diffusion rates of such driver-assist systems will become higher in coming years.

4. PROCESSING EXTERNAL ENVIRONMENTAL INFORMATION

Systems to process external environmental information are necessary for drivers to drive automobiles safely on roads.
Although such processing operations depend entirely on powers of vision and hearing of drivers today, it cannot be said that such powers are sufficient, considering the differences among individual drivers and their physical limitations. Further studies are expected, as such information processing technology is highly necessary and indispensable to safe vehicle operations, in terms of detecting obstacles lying ahead of the vehicle or close-by objects behind the vehicle, observation of objects in the forward direction during night or in rough weather conditions.

Functions of Driver's Eyes

For example, the presence of obstacle may be detected by means of ultrasonic waves. That is, the distance to an object is determined by the length of time from the moment ultrasonic wave was emitted until the moment it returns to the detector.
The detectable range is limited to several centimeters to several meters, but a system to check on safety in dead angles in the backward direction when backing up the vehicle is already used in practice. There is a method to monitor conditions in dead angles by means of a TV camera, which is used in heavy duty trucks and buses. This may be also used in passenger cars for the safety in rear when backing up the vehicle or when checking on sideward safety at intersections with poor visibility. When the visibility is low during night or in rainy or foggy weather, environments that cannot be observed by naked eyes can be recognized if an infrared ray camera is used.

Intelligent Driver Assist

The most vital factor of external environmental information is the relative distance and the relative speed from the vehicle to an object several meters to 100 meters ahead. If they are known, not only the intelligent cruise control to adjust the relative distance but also the prevention of collision will become possible by alarming the driver of the possibility of collision, or by means of automatic braking. For the determination of the distance to an object, there is a method to use millimeter wave radar and another method to use laser radar. The image processing obtained by a TV camera for the identification of object, as human beings do, is also being studied for the determination of relative distance. It is possible to recognize not only objects but also driving lanes by the image processing, which may allow the automatic steer. Various methods to obtain external environmental information are studied as described so far, and driver assist systems should be materialized in future by the integration of various kinds of information - for example, hazzard warning or automatic speed control, braking and steering.

5. PROCESSING INFORMATION FOR COMMUNICATION WITH OUTSIDE-THE-VEHICLE

Some communication system to communicate with the outside is necessary for automobiles, in order to create proper conditions for occupants, similar to those of daily life, in an independent space of an automobile, by linking the automobile with the infrastructure built into to the information society.

Conventional Communication Technologies

The history of exchange of information between automobiles and society goes back to the old time when radios were installed in automobiles for the first time. Although this was the one-way communication from the external world to the completely closed world of an automobile, the installation of radio must have been an epoch-making incidence. This age of one-way communication lasted for a long period of time, but two-way communication media began to be diffused very slowly but steadily, owing to progresses made in the radio communication technology.

However, these communication systems for automobiles are restricted for the specific use such as police, fire and taxi communications.

Although such systems were technologically similar to those of public communication systems, they were of very closed nature which functioned in respective specialized fields only, without any extensive integration with society in general. So-called CB radio for amateur radio and personal radio communications was available as a public communication medium, but its users were limited to particular users consisted mainly of hobbyists. In case of Japan, the personal radio communication started in 1982 showed a rapid expansion at the initial stage, but it is nearly saturated now with 1.5 million sets of radios. This is partially due to the inconvenience of so-called "press and talk" two-way operation, but mainly due to the absence of network, with the communication range limited to areas where the radiowaves can reach.

Introduction of Automobile Phones - Integration with Society

It was in the 1980s when automobiles were provided with means to communicate "anytime, anywhere and with anyone" when cellular automobile phones were substantially introduced into market. In the former half of the 1980s, the number of such phones in use was not so huge, as countries concerned were in the phase of expanding their service areas. In the latter half, however, a rapid growth was observed. The number of cellular phones in Japan currently amounts to 0.4 million sets or so, but some people predict that the number will reach 4.5 million sets by the year 2000. Since the predicted number of automobiles in use as of the year 2000 is 39 millions, about one vehicle out of nine will have a cellular phone.

Reasons why automobile phones are noticed are that the network is expected to be reinforced as part of social infrastructure, and that it is expected to grow as an extensive social netwotk. Public telephone networks in cable systems are already connected with various types of computers, showing aspects of a huge network.

Incorporation of automobiles into this network as a component of the network will turn their communication systems into those open to society. In other words, it will heighten the degree of integration of automobiles with society. Automobile phones as a means for the substantial integration of automobiles with society are facing a number of problems.

First, there is the problem in allocation of frequencies. Shortage of frequencies has already become obvious in some regions, which is becoming a serious bottleneck against the diffusion of automobile phones. Although

technological efforts are being made to narrow each band width and zone, and to introduce the sector system, it will be inevitable to reach the limit in near future. The key issure, therefore, is to obtain and secure the allocation of necessary frequencies.
The second problem is that present automobile phones are not a perfect system for users. For example, when the vehicle runs into a tunnel, behind tall buildings or an underground parking lot, the communication becomes impossible. Although efforts such as the installation of leaky coaxial cables are being made, the installation is limited to particular regions only.
There are also the problem of radio-interference and the problem of being unable to gain phone connections, as the number of automobile phones is increasing. Hence, some appropriate measures should be taken to prevent serious problems that may occur when the diffusion rate of such phones becomes higher.
Along with the upgrading trend of social systems, applications of information/communication systems are becoming more diversified, and the trend toward digitalization is also becoming more pronounced at the global level. Digital communication networks make us to diversify the information/communication methods such as data communications and image communications in addition to the conventional voice communications. It has also become possible to take necessary steps for ISDN (Integrated Services Digital Network) currently in progress. In the area of automobile communications, size and weight reductions of equipment, reduction of electric power consumption, reduction of cost, improvement of security function and more efficient use of frequencies, are also expected in future owing to the digitalization trend.

Utilization of Satellites - Global Network

Mobile users of communications include ships and aircrafts, and the use of satellite communications is being studied in this area. Also in the area of automobiles, experiment are being carried out to check on the feasibility of the use of satellite commnications. For example, the Japanese ETS-V satellite also has undergone communication verification tests for automobiles. This is worth noticing since it may become one of promising communication media for entire mobile users in future.
The example of another network utilizing satellite communications is shown in the figure attached herewith.(Fig.12) Although communications are not done directly between the satellite and automobiles, this network aims to upgrade the diagnostic function by connecting automobiles to its communication circuits. For example, automobiles in the field may use database at the service center through respective regional dealers which allows instantaneous diagnosis for each automobile concerned, and its diagnostic data are added to its system simultaneously, which in turn will be reflected to diagnosis of other cases.

Expansion of Automobile Traffic Systems

Discussions will be made next on communications between traffic information systems and automobiles. It is a global trend that traffic congestion, safety, environments and aging population are becoming social issues, according to the increased volume of automobile traffic, which call for new countermeasures. Europe, the U.S. and Japan are energitically engaged in research and development of such measures, and their practical applications in future are expected. RDS, LISB and AUTOGUIDE in Europe should be useful as meaningful sources that provide effective traffic information to drivers. Moreover, large scale PROMETHEUS programme and DRIVE research programme are being promoted under the joint cooperation among EC member countries, and their practical applications are also expected.
In the U.S., Pathfinder project and IVHS (Intelligent Vehicle/Highway System), which are information systems for drivers, are being planned.

In Japan, several projects have been also implemented. Recent examples include AMTICS (Advanced Mobile Traffic Information and Communication System)[2] and RACS (Road/Automobile Communication System)[3]. AMTICS provides realtime traffic information collected by Traffic Control Center to the car location function of automobiles through its Teleterminal network. (Fig.13) Types of information are as follows. Its dynamic information includes traffic congestion, temporary traffic information (road repairs, accidents, road surface conditions), emergency information, weather information and parking lot information. The static information is stored in its CD-ROM, which includes road network data, general traffic regulation (speed limit, one-way traffic), and locations of parking lots. This system is being promoted under the guidance of National Police Agency, and most of the Japanese car manufacturers and electronics manufacturers participated in the development activities. Since April, 1987, the experimental system has been constructed, and a larger scale experiment is planned for "International Flower and Greenery Exposition" to be held in Osaka in April, 1990.

The RACS is a system developed and promoted under the initiative of the Ministry of Construction since 1986, aimed at providing high level road traffic information and meeting new information needs. This system consists of the communication equipment (beacon) embedded along roads, on-vehicle equipment and central processing system located at the control center.(Fig.14) Functions of this system are the navigation, information service and individual communications. The navigation function estimates the present location of each vehicle by means of the on-vehicle sensor and the digital road map, in order to guide the driver to the destination.

The beacon provides necessary information to each vehicle for the correction of location. The information service function sends out road traffic information and parking lot guide through the beacon. The individual communication function connects the beacon and each vehicle to provide message communication and traffic control information services, and collects road traffic information. This system was experimented in Tokyo in November, 1989. Studies on the practical application are being done at present.

6. CONCLUDING REMARKS

Discussions have been made so far on the issue of integration in attempt to find its future outlook, with due remarks on the past history in retrospect, in relation to four aspects of information processing -- namely, vehicles themselves, man-machine, external environments and communications with the outside the vehicle. Requirements for automobiles will become more stringent and diversified in coming years. Not only higner safety, lower pollution, better fuel economy, higher speed and reliability, but also the realization of more comfortable and convenient automotive society will be required. In order for automobiles to make proper advancements in line with social changes, the integration in each area of four types of information is indispensable, and electronics holds a vital key to the success.

Automotive electronics has been making advances by incorporating such related technologies as semiconductor technologies into it. This tendency will remain unchanged in years to come. Of various technologies expected to make contributions to the enhancement of integration, those on elements such as semiconductors, electronic systems/devices, sensors and actuators, and those on softwares, such as control theory and artificial intelligence, hold particular significances for the enhancement of vehicle information.

As for the man-machine information, display devices, means to express information, synthesized voice and voice recognition technologies are vital to humanize the interface with drivers. Technologies on external environmental

information are areas to be explored in future, but those on vision are particularly important. Regarding the information to communicate with outside-the-vehicle, networking technology for the entire system and database for traffic related information are vital.
Automotive electronics has been in its growing phase up to the end of the 1980s, and electronics itself has been in the "objective phase". The 1990s will be the maturing phase, and we will have "the age of means" in coming years. In other words, emphasis will be shifted from "something to show off" to "something hidden", and from "functions first" to "ease in operation". Technologically, emphasis will be shifted from "single system" to "integrated systems". The more complex becomes integration, the more important becomes the total reliability. The concept of "fault tolerant" will be necessary so that the entire system will not be paralysed even if some part of the system fails. In order to construct a truly desirable automotive society, a number of issues will have to be dealt with for automobiles. Cooperation among all automobile manufacturers in the world and exchange of frank opinions among experts of respective fields are vital in this regard. That is, I strongly feel the necessity of a proper network among us engineers, and the integration of the entire automotive industry. In this sense, this international conference holds high significances, and I hope that new international projects be born out of this meeting.

ACKNOWLEDGEMENT

I like to express my sincere appreciation to Mr. Y. Nishikawa and Mr. Y. Kato of Toyota Motor Corporation and all others concerned who have given cooperation for the preparation of this paper.

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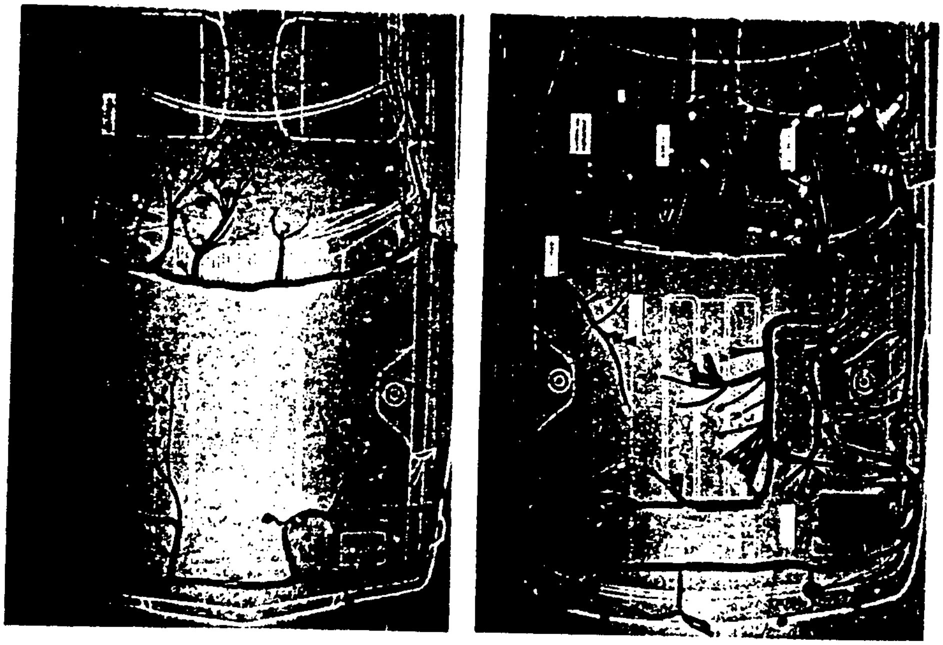

1980 1990

Fig. 1 Wire Harness (TOYOTA CROWN)

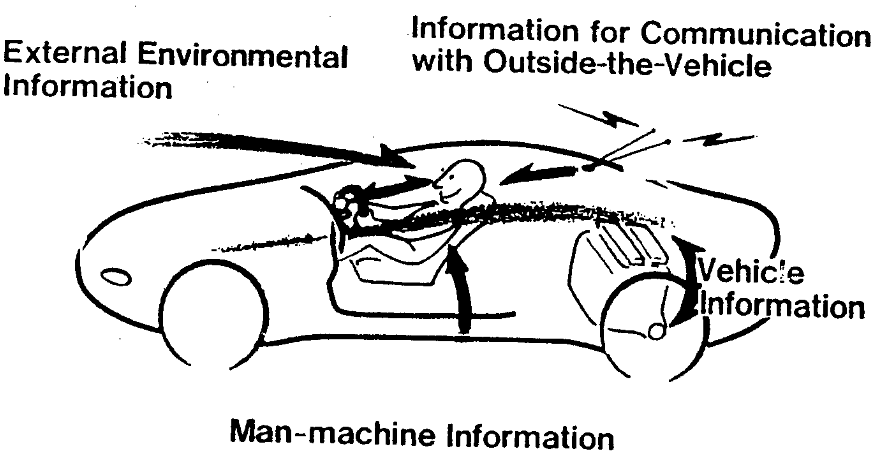

Fig. 2 Automobile Information Processing

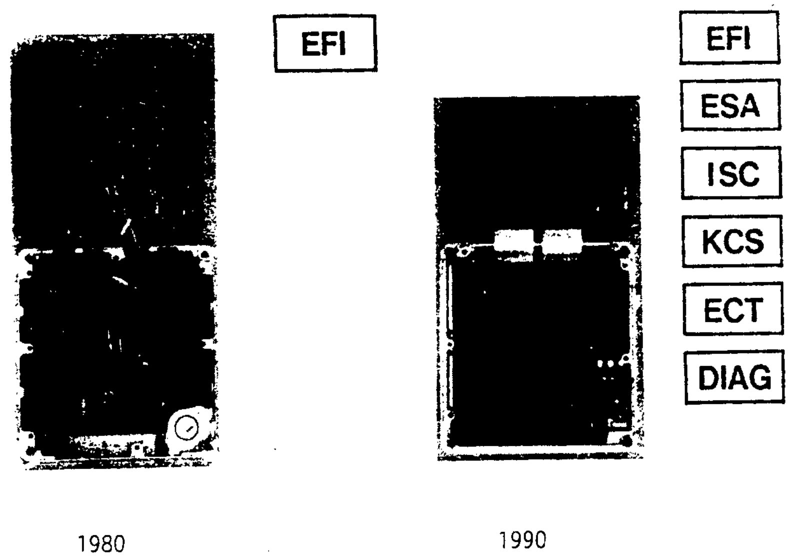

Fig. 3 Functions of Engine Control System

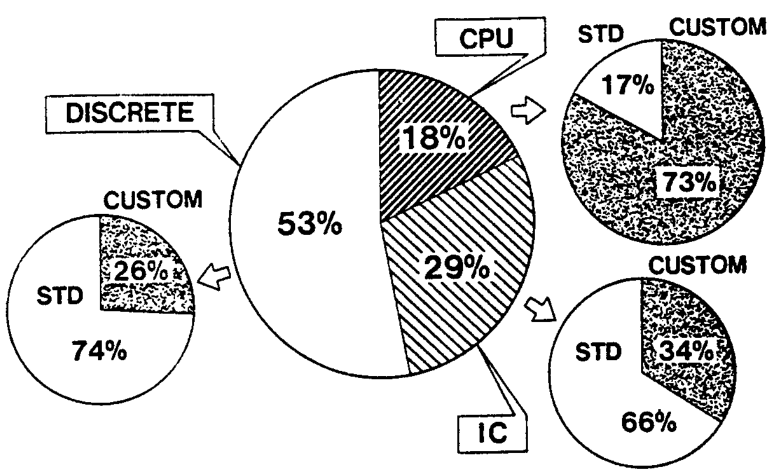

Fig. 4 Semiconductors Used in Automobiles

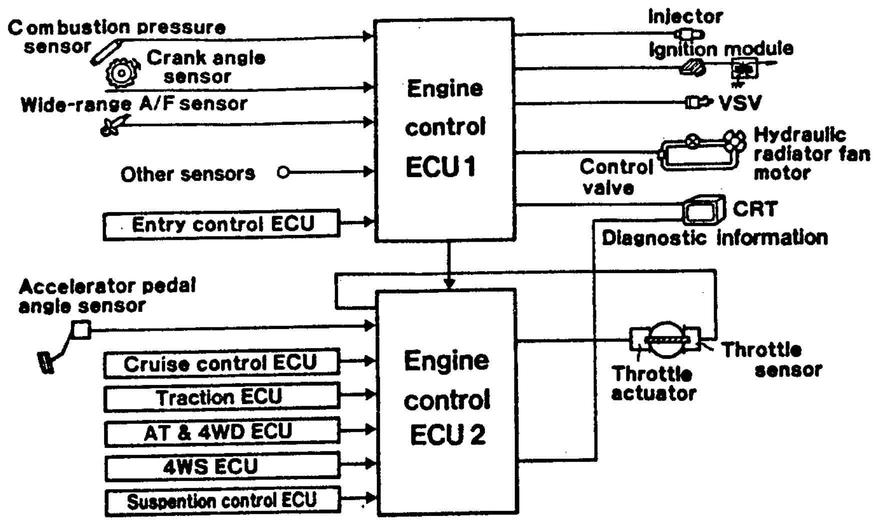

Fig. 5 Engine Throttle Control System

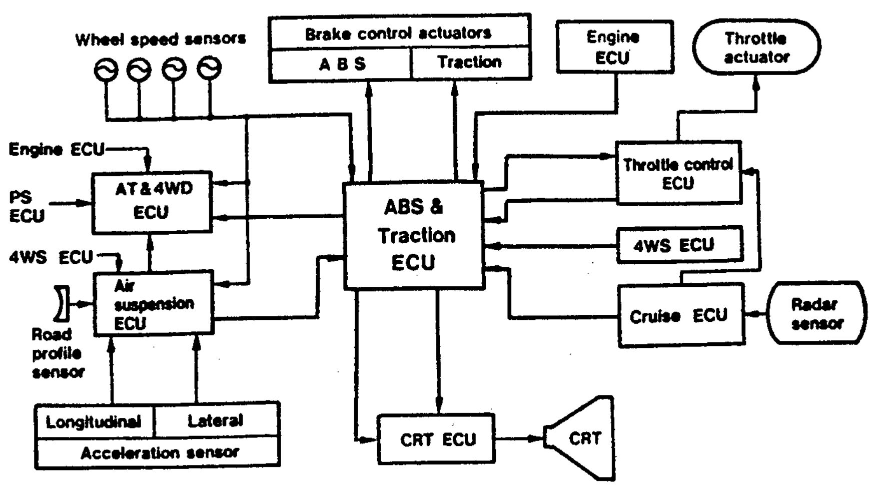

Fig. 6 Integrated Vehicle Management System

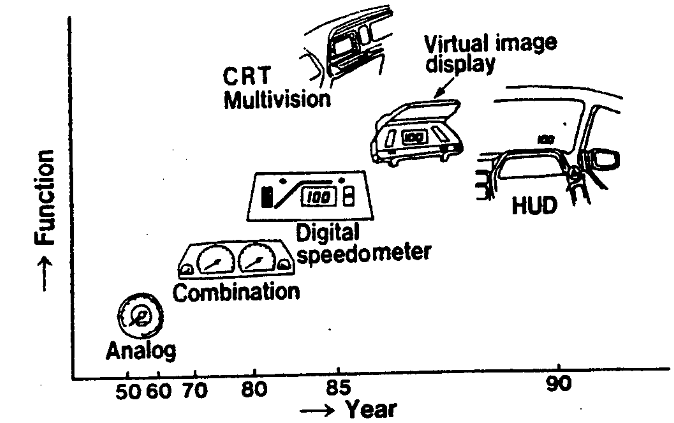

Fig. 7 Transition of Instrument Cluster

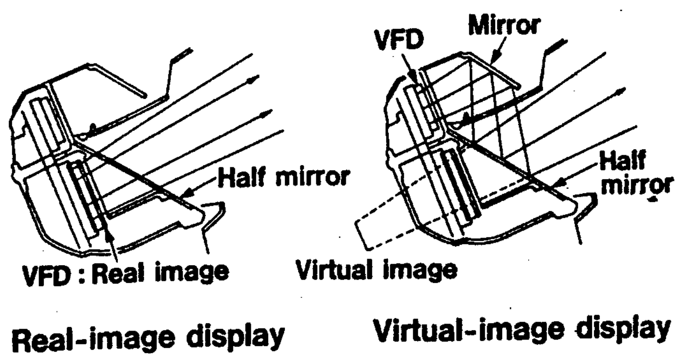

Fig. 8 Dual Vision Meter (TOYOTA CROWN)

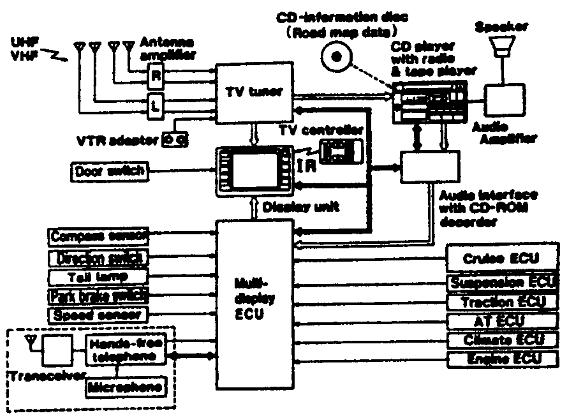

Fig. 9 TOYOTA Electro Multivision

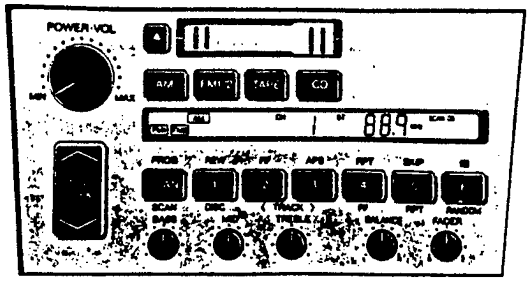

Fig. 10 Audio Panel (LEXUS LS400)

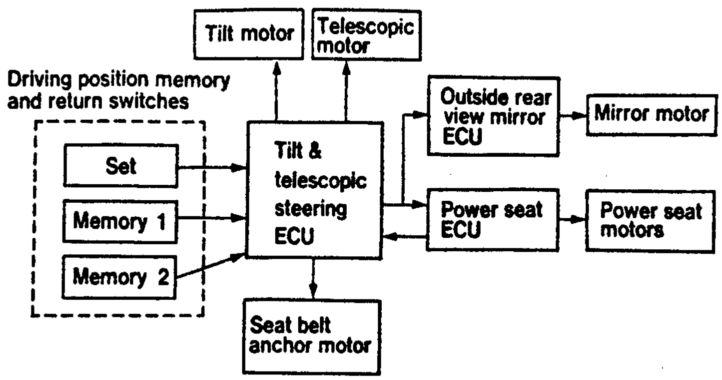

Fig. 11 Automatic Adjusting System

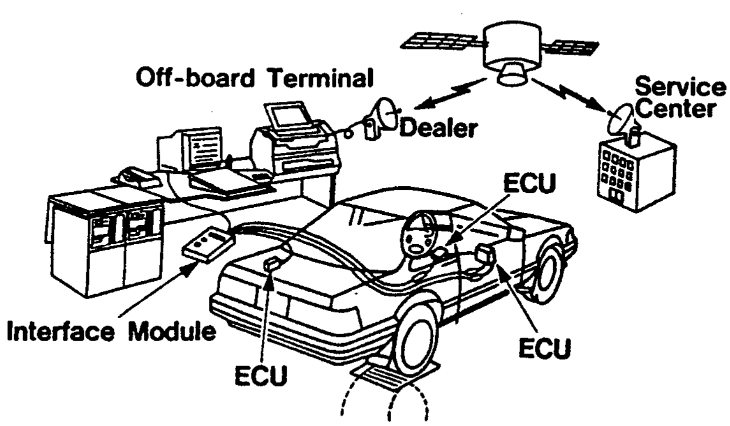

Fig. 12 Network of Diagnostic System

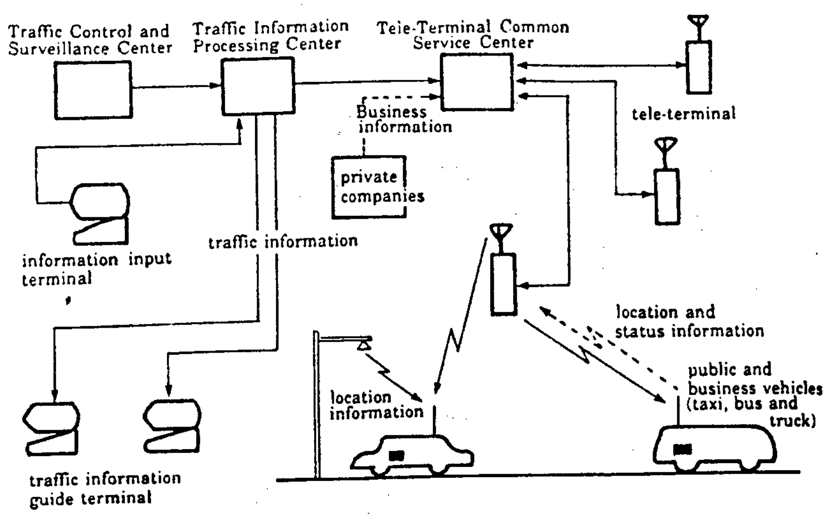

Fig. 13 AMTICS

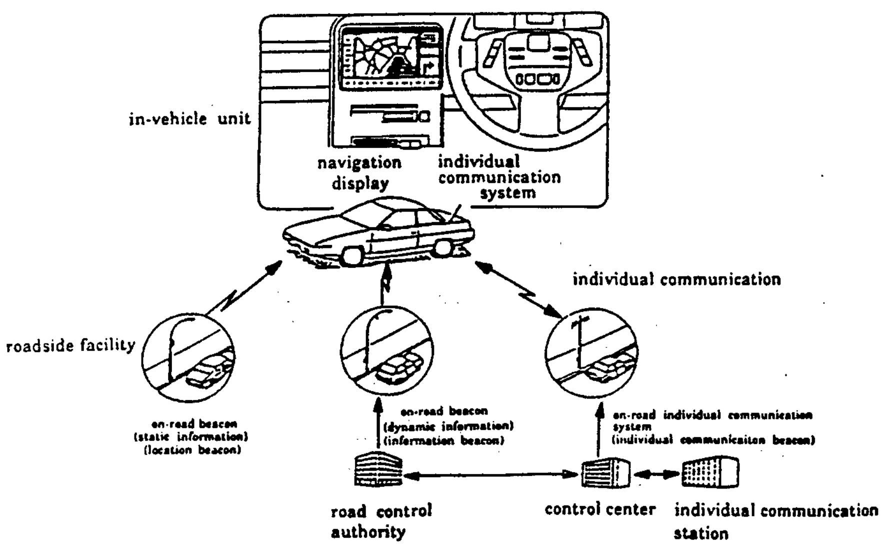

Fig. 14 RACS

AUTOGUIDE: POLICY AND PRACTICE IN GREAT BRITAIN

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ABSTRACT

Autoguide is an in-vehicle, electronic route guidance system that will respond to traffic conditions. It will give drivers recommended routes to their destination using information transmitted to the car by roadside beacons linked to a central control. Autoguide advice is based on information derived from other equipped vehicles about changing traffic conditions. The system will respond in real time to changes in network conditions. The paper describes the British Government's approach to devising a commercial regime licensed by the Secretary of State for Transport. It contains a brief account of the issues that emerged during the passage through Parliament of enabling legislation under the 1989 Road Traffic (Driver Licensing and Information Systems) Act, and the assessment arrangements devised with the police and local highway authorities. Preparations for a large scale Autoguide pilot scheme in the London area are now under way. The paper covers financial, monitoring and licensing issues relating to Autoguide and to other systems where the licensing provisions of the 1989 Act apply.

Context

1. The British Government's policies for surface transport include the following main objectives:

(a) To increase consumer choice and efficiency and to reduce real unit costs. Major emphasis is placed on policies which increase competition and decrease the role of the public sector.

(b) To improve road safety of both highways and vehicles. A target of one-third casualty reduction by the year 2000.

(c) To conserve the environment. This involves seeking a reasonable balance between the demands for movement and the costs of protecting or enhancing the amenity of localities affected by motor vehicles.

2. Policies are based as far as possible on free market competition between modes of transport and the progressive reduction of subsidies. Major capital investment in road and rail infrastructure and in rail-road stock is judged using cost benefit criteria.

3. Traffic growth in Britain in recent years due to economic expansion has led to higher longer term forecasts of national growth in vehicle use. Details of an expanded trunk road and motorway programme were published in February 1990. Car ownership in Great Britain measured per head of population is lower than in many Western European countries but is growing steadily. Much of this growth is from multi car households. This, together with the size and density of most British urban areas, contributes to congestion and requires a range of policies designed to make best use of existing roads. As part of longer term thinking the British Government is encouraging the private sector development of electronic forms of driver information and route guidance. The first beacon based systems for which licences are being negotiated are Autoguide for London and TRAFFICmaster for the motorways.

4. The British Government is working closely with the Federal German and French governments in producing technical standards to allow compatible technical development of infra-red based systems for route guidance. Several other European Countries have also declared an interest in seeing standards that will enable vehicles to cross national borders and pick up guidance information using their own equipment. British made Rover cars and vans have visited Berlin, the location of the LISB experiment, and operated fully satisfactorily - and with guidance instructions in English.

5. Research under way or planned under the PROMETHEUS and DRIVE programmes is relevant to the Government's objectives in these areas. <u>Close co-operation is being fostered with both EC and ECMT programmes in the field of road transport informatics.</u>

<u>Traffic in London</u>

6. The London area is the largest urban area in Europe. London itself has a resident population of over 7 million and is the focus of a metropolitan area of over $12^1/_2$ million. Transport and traffic demands in London and the South East have led to several studies being commissioned into the enhancement of road and rail transportation systems. The Channel Tunnel will create fresh demands. London's Docklands are being re-developed through a Government sponsored development corporation. The scale of employment and residential building there is bigger than any similar area in Europe, and is having a significant effect in changing the transport geography of London. Massive infrastructure investment is envisaged including new rail links, but all proposals for new road and rail links are controversial particularly where they would involve the destruction of houses. This means that major activity must be concentrated on making better use of existing infrastructure.

7. Over one million people commute to and from central London each day. About a seventh of them use cars. Car commuting to central London has been in decline in recent years. Elsewhere it has been increasing. There are about 30 major business and retail centres in the London area. Nearly half of outer London residents travel to work by car. This is likely to rise with increasing car ownership and greater diversity of job location. London attracts large numbers of visitors from all over the world and is a thriving cultural centre. Motor vehicle traffic has increased by about 40% since 1970 in London as a whole. The evidence is that journey patterns are diversifying. <u>This suggests the need for better systems of route guidance and driver information so as to avoid wasted journeys</u>.

<u>Local and Central Government</u>

8. The Greater London Council was abolished in 1986. Local Government in London is now divided between 33 local Councils, each of which is a highway authority in its own right. Outside London there are a further 39 County Councils in England and a further 36 Metropolitan Districts each of which act as highway authority. The Secretary of State for Transport is the highway authority for some 340km of the major, or "trunk", roads in London and for trunk roads and motorways throughout the country. The remaining roads in London are the responsibility of the 33 local authorities. Of these, some 530km are "designated" as part of a strategic network of roads. Recently the Government has announced a strengthening of this road network with a proposal for 480km of 'red route' clearways with enhanced penalties, and enforcement. The division of responsibilities between 33 highway authorities has created some important considerations for the Government in devising legislation and practice that can enable Autoguide to be developed across London.

9. Traffic control systems based on real time data rather than fixed time sequences are now available and large parts of London are now covered by the British developed SCOOT system. It is likely that the SCOOT system will be extended to all London's 1300 intersections currently on computer control. A large number of the remainder could be on MOVA. In the longer term route guidance and traffic flow information derived from systems such as Autoguide should play an increasing part alongside improvements in parking control and 'red routes' in improving traffic flow.

10. Enhanced UTC systems make much better use of road networks but they do not offer route information or guidance. Poor routeing in Britain has been estimated as about 6% of all vehicle mileage. Combined with UTC improvements average journey times of vehicles equipped with Autoguide in the London area could be reduced by as much as around 10% according to TRRL estimates.

AUTOGUIDE

(a) The approach so far

11. In 1986 the British Government published a discussion document called "Autoguide - A Better Way to Go?" which outlined work at the TRRL on interactive route guidance. This proposed the idea of a national Autoguide system, with London as the natural starting point. It suggested that the next steps would be an on-street demonstration project and further discussions with industry, local authorities, the police and those working on similar projects overseas.

12. By April 1987, a large number of responses had been received. Reaction was very supportive. There were many constructive suggestions. From this process it was established that the on-street demonstration project should go ahead; that infra-red should be the communication medium between road and vehicles; that international standards should be developed; and that facilities for fleet location should be included.

13. The British Government believes firmly that, as with many civilian projects involving development of new technology, any route guidance system should be promoted by the private sector. This will ensure that it meets a real need among motorists and provides value for money. The commercial test of whether a route guidance system is worthwhile or not will be the number of people who subscribe to it. It also has to be established that the system does not have any harmful effects on safety or traffic management.

14. As a first step an on-street demonstration project covering part of central and West London began in 1988 with 5 beacons -2 near Heathrow airport and 3 in Central London. The demonstration was maintained by the Department of Transport and was originally sponsored by the motoring organisations, equipment suppliers, transportation engineering consultants, London Buses, British motor manufacturers and the Department of Trade and Industry through a technology support scheme. It was carried out in co-operation with the organisation involved in the LISB trials in Berlin. Over 1000 people drove the specially equipped Rover cars. The Automobile Association and Royal Automobile Club had additional vehicles of their own for demonstration purposes. The demonstration is to be continued by GEC, the prospective licensees of the pilot scheme which is likely to commence shortly.

(b) Legislation

15. Under British law it is not possible for the Government and public bodies such as local authorities to engage in activities unless they are specifically empowered to do so. Before the Government could undertake a licensing function for route guidance systems it was necessary to seek powers from Parliament.

16. In November 1988 a Bill was introduced into Parliament enabling the licensing of a variety of types of driver information systems. The Bill completed its passage through Parliament in July 1989 and became the Road Traffic (Driver Licensing and Information Systems) Act 1989. The first type of route guidance scheme to be licensed will be a pilot Autoguide project for part of the London area. A further driver information system confined to the motorway network is under consideration (see paras 29-32).

17. Different licences, possibly to a variety of different operators, could be granted in different regions of Great Britain. Legislation for systems using road-side beacons is needed to provide powers for licensed operators to install the necessary infrastructure on the highway. Statutory undertakers (such as the electricity or water utilities) have similar powers to carry out public street works.

18. Legislation has also been needed to safeguard issues of wider public interest. Of major concern to Parliament was the question of which roads might an Autoguide operator be able to direct through traffic. A balance needs to be struck between a flexible and commercial route guidance system and the desirability of preventing Autoguide traffic being directed onto roads which are unsuitable. Arrangements will be made through individual licences, to ensure that any route guidance system is operated safely and responsibly. An assessment group (APAG) has been established with the Police and Associations representing the highway authorities to examine the experience gained during the pilot scheme. At the conclusion of the pilot scheme there is a requirement to report experience to Parliament prior to issuing a commercial licence.

Privacy

19. An issue of particular concern to Parliament was the privacy of individuals. Though it can be possible using the data collected by route guidance equipment to track the movements of individual vehicles the intention is to distinguish carefully between kinds of service in terms of identifying vehicles. Amendments were made to the Bill during its passage through both Houses of Parliament to limit the use which can be made of data on vehicle movements.

Licensing Powers

20. Although the enabling legislation was of necessity fairly wide in scope, a decision had to be made as to how far the Secretary of State's new licensing functions should extend. The principal aims of the 1989 Act were (a) to enable the control of driver information systems which might otherwise produce undesirable road safety or traffic management effects and (b) to facilitate the installation of systems which require streetworks for the installation of system apparatus. In bringing the Act into force, the licensing requirements of the Act cover dynamic route guidance systems and any system which requires the installation of infrastructure in the highway, even though it may not give route guidance. Autonomous navigation and route guidance systems will not require a licence from the Secretary of State before they can be operated in Britain.

Financial Provisions

21. There are no financial provisions in the legislation to enable public investment in driver information systems either at pilot stage or in the lead up to a commercial system. The intention is that all investment in infrastructure for a fully commercial system will depend on private finance being made available. Operators will have to assess the market so as to judge the financial return. The Government sees its role as being one of licensing in the interests of safety, traffic management and the public interest. This will include conducting research into the performance of a pilot scheme. The legislation also makes provision for the sale of information on vehicle movement patterns to the Government as well as for licence fees to be levied on operators.

Guidelines

22. During the passage of the Bill the Secretary of State issued Guidelines which set out the way in which he saw an Autoguide system being put into practice, commencing with a pilot scheme for the London area. The Guidelines sought from system promoters their general proposals on issues such as:

- commercial factors, including the financial structure, in car unit costs, subscription methods, retailing methods and general business planning

- quality of service, including beacon density in a pilot scheme

- level of terminal guidance and type of in-vehicle units proposed (the demonstration equipment suffered from control pad problems. It was generally agreed to be too complex and not user friendly)

- operating the system: links with the police, urban traffic control and motorway control centres, motoring organisations and local highway authorities

- ancillary services such as fleet location and message display

- competition in the manufacture and retailing of in-vehicle units

- compatibility: permitting the use of in-vehicle units in other operator areas and countries.

Pilot Scheme

23. Two sets of proposals were received by the Department's April 1989 closing date:

- **ASL**
  A joint venture company formed by Plessey, the Automobile Association, Siemens, Wootton Jeffreys and Barclays Bank.

- **GEC MARCONI**
  A bid by GEC Marconi originally involving the Royal Automobile Club, W.S.Atkins and Partners and Logica.

24. After careful consideration, the Secretary of State decided that the proposals from GEC-Marconi would best meet his objectives for the introduction of the system. Accordingly, negotiations between the Department and GEC on the terms of a licence under the 1989 Act were commenced with a view to agreeing in early 1990 a licence to install and operate an Autoguide pilot scheme in the London area.

25. A programme of research is being commissioned to assess the impacts of a pilot scheme in London. This work will include a projection of the influence of a mature Autoguide system on equipped vehicles, un-equipped vehicles and the consequences for existing arrangements for traffic management in urban areas. It is hoped that relevant results can be exchanged with those carrying out similar studies in Berlin and anywhere else that comparable systems are established.

26. The initial proposal is that there should be a substantial pilot project involving around 300 roadside beacons on London's primary road network within and including the M25 orbital motorway, and around 1000 vehicles of various uses and types.

Purpose of Licence

27. A major purpose of the licence is to set out clearly the respective powers, responsibilities and objectives of the Secretary of State and GEC-Marconi. As the licence is for a pilot scheme it will contain a number of novel features not all of which would be expected in a licence to operate a full commercial scheme.

28. As Autoguide is a private sector venture the licence will need to strike a balance between safeguarding the public interest in respect of road safety and environmental concerns and providing GEC-Marconi with sufficient flexibility to develop a commercially viable system. The framework of the licence will need to ensure Autoguide will not be detrimental to road safety or the environment and at the same time that it would not be seen by the public as a traffic management 'tool' with consequent negative effects on its marketability. As yet it is too early to report any progress on the development of the pilot scheme.

TRAFFICmaster (THOMAS)

29. Apart from Autoguide, the operation of one other driver information system is likely to be licensed by the Secretary of State. A UK company, General Logistics, has developed a system for warning drivers of traffic congestion on motorways and is currently proposing to install a pilot system on the M25 London orbital motorway.

30. The THOMAS system (Traffic Hold-up on Motorway Alert System) is a real-time information service designed to provide subscribers with the location and an indication of the severity of traffic congestion on the main motorway network. The promoters plan to seek an agreement with the Secretary of State to extend the system to the complete motorway network.

31. Information on traffic speed and volume in the outside lane will be gathered via infra-red sensors placed on overbridges at intervals along the motorways. This information will be analysed at a control centre and congestion information transmitted via the radio paging network to display units in subscribers vehicles. The display in the vehicle provides a diagram of the relevant motorway network and warns the driver of where congestion is occurring. The display contains a rechargeable power source and can also function outside of the vehicle (eg in the home or office).

32. Unlike Autoguide, this system does not give route guidance, and would not of itself direct traffic on particular routes even when heavy congestion was present ahead. It would simply warn of congestion, in the same way as traffic broadcasts on the radio. The promoters claim more accuracy and 'real time' conditions. The pilot licence is intended to enable the installation of system apparatus on motorway bridges. Arrangements are being made for the Department to monitor the pilot scheme particularly to ensure that the in-vehicle display is not a distraction to drivers, thus securing the safety objectives of the Secretary of State's licensing function.

FUTURE OF SYSTEMS IN EUROPE

33. Route guidance and driver information equipment promise to be some of the more interesting innovations from the point of view of international collaboration. Approaches will vary between countries, particularly over funding and the extent to which the systems are seen as part of an overall approach to traffic management. A basic test they will all have to pass is one of driver acceptance. So far the systems have tended to be technology driven, but as each system comes forward to be sold to car drivers and fleet operators it will have to achieve quite demanding standards in terms of:

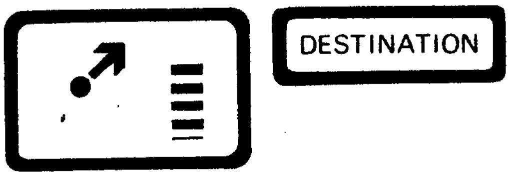
- ease of use
- quality of information provided
- cost - both purchase and subscription
- reliability and ease of maintenance

34. At present there are four basic types of output as illustrated in the diagram. It is too early yet to predict which one of the systems - or combinations of systems - will find the most worthwhile markets. More systems are likely to emerge. Ergonomic and safety studies will help to confirm the most suitable kinds of display. National characteristics may even suggest that there will be different markets in different countries.

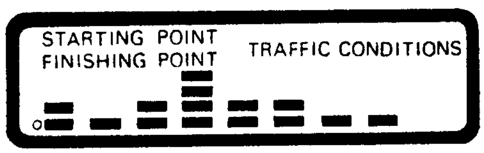
35. So far as the British Government is concerned the key to progress is to seek private sector participation and to encourage innovation and competition, whilst ensuring that standards of safety are not compromised. The contribution that each system can make to the task of improving overall driver information will be kept under close review. Opportunities will be actively sought to collaborate with other European countries in developing systems that can cross the boundaries of geography and of language.

DRIVER INFORMATION DISPLAY SYSTEMS

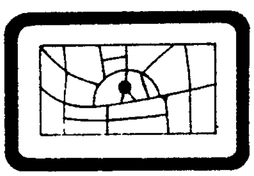
LISB/AUTOGUIDE (D, UK) WITH AUDIO OUTPUT (OPTIONAL) GIVES POSITIVE TURNING DIRECTIONS



INF - FLUX (F) GIVES TRAFFIC DENSITY ALONG CHOSEN ROUTE

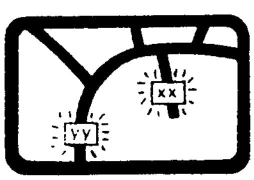


TRAVELPILOT / CARIN / ETAC (D, J, USA)



GIVES VEHICLE POSITION ON SCREEN MAP (WHICH MOVES WITH VEHICLE)

THOMAS (TRAFFICMASTER) (UK)



INDICATES POSITION OF LIKELY HOLDUPS ON MOTORWAY NETWORK. WILL CARRY RADIOPAGER MESSAGES AS OPTION

COMMUNICATION NETWORK OF RACS: BASIC CONCEPT AND EXPERIMENTAL SYSTEM

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Abstract

The purpose of the road/automobile communication system (RACS) is to provide a total communication means between running vehicles and road side beacons. This system will be able to provide the function of navigation, traffic information and individual communication. There are the following three types of roadside beacon stations in RACS:

a) A static information beacon that offers fixed information, such as the position and road signs.

b) A dynamic information beacon that offers changing information, such as concerning traffic conditions.

c) An individual communication beacon capable of two-way communication function.

The static informaiton beacon stands alone, while the later two types of beacons require the networks to transmit information online. This paper describes the study about the network construction of RACS. It first explanes basic concept, hierarchical structure and the functions of a nationwide network for the future.

An experimental system is being built in the Tokyo area to confirm the overall function of RACS. This paper also reports the evaluation of the experiment and technical study for the designing of future RACS network.

Introduction

At present in Japan, mobile communication systems for the moving vehicle are cellular phones and CB systems for business use. Sign posts used for the Automatic Vehicle Monitoring (AVM) system which lets the taxi management center monitor the taxi situation are established in specific areas. However the following problems arise in adapting the existing system to user's needs.

1) A system for mobile communication must include the entire service area in order to provide continuous communications. Therefore, the appropriate traffic information is limited and depends on the situation for each vehicle.

2) For the same reason, the system cannot be used both to assess traffic flow and assist in vehicle navigation.

3) A cellular phone system is the only one that can be used nationwide. However, it is very difficult to offer the expected services using cellular phones that rely on voice communication.

4) To satisfy various needs, it is necessary to use several systems. However, numerous problens exists such as the installation of epuipment in small vehicles, increase in electric power consumption, installation of wireless antenna, etc..

Accordingly, the new system must meet the following requirements.

- Local communication is possible between the road administrator and individual automobiles
- Nationwide application is possible
- The various services are offered comprehensively

Construction of the system

The purpose of the information system between the road and vehicles is to offer various communication services by creating a circuit between the communication facility established on the road (hereinafter referred to as the "roadside beacon station") and a device installed in vehicles (hereinafter referred to as the "mobile staion").

The overall construction image of this system is shown in the Figure 1.

Radio zone structure

This system is characterized by its minimum radio zone structure placed intermittently. Its outline is shown in Figure 2. We call this is as the intermittent minimum radio zone structure. A high-speed digital transmission path is

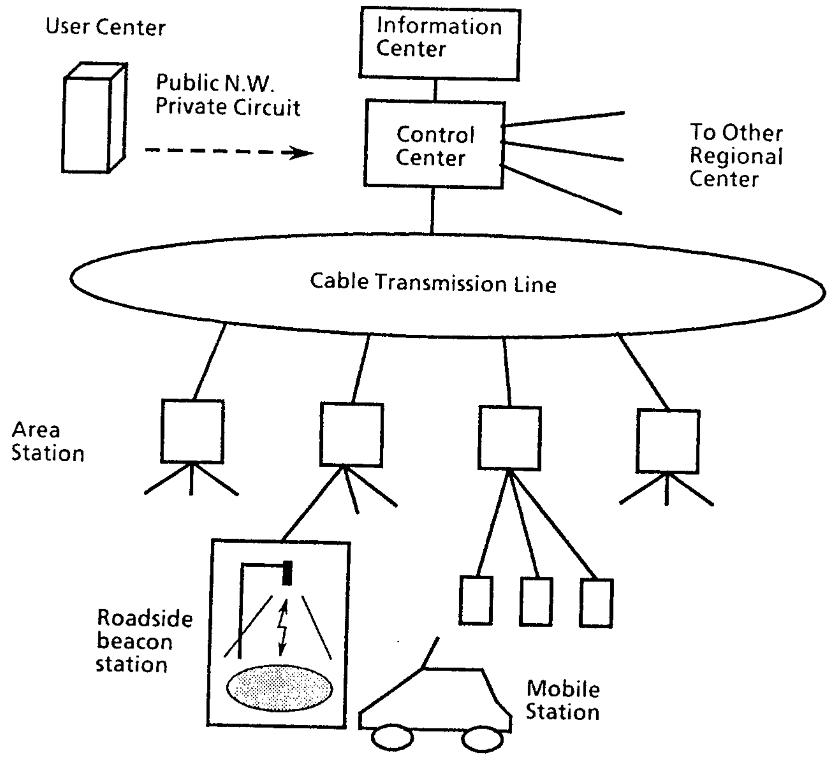


Fig. 1 Total Construction Image of RACS

established in a short time when vehicles pass by the zone and information is being transmitted.

Radio transmission protocol

To transmit high-speed digital data information, it is neccessary to secure a high quality radio transmission path by constructing a minimum radio zone. A transmission speed of 512 kbps by semi-micro wave (2 GHz band) is used in the experiment example.

The transmission format in the individual communication beacon is shown in Figure 3. The length of frame is about 0.7 to 0.8 seconds. This enables vehicles running at the speed of 100 km/h in a zone diameter of 60 m to receive at least two frames.
The information contents of each frame are as follows:

1) Open communication period (from the beacon station to the mobile station)
A synchronizing signal, location siganl and beacon code are transmitted to vehicles. Such attributes of the beacon station as its type are identified using the beacon code.

2) Automobile registration and request period (from the mobile station to the beacon station)
This is a section to register the individual vehicle identification (ID) code. When each vehicle wants to communicate in the zone, it transmits the communication request signal in addition to its ID code.

3) Broadcast period (from the beacon station to the mobile station)
This section offers dynamic navigation signal of traffic, etc. to vehicles. Also the section transmits the acknowledge (ACK) signal, existence of individual communication and the allocations of time slots to the vehicles from which the automoble registration period received the ID code correctly.

4) Individual communication period (from the beacon station to the mobile station or vice versa)

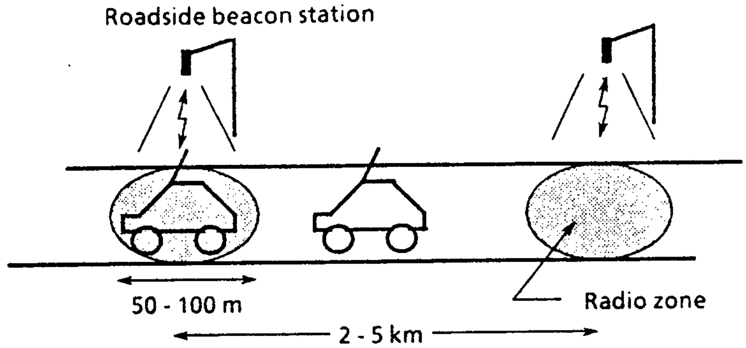


Fig.2 Outline of the Minimum Radio zone Structure

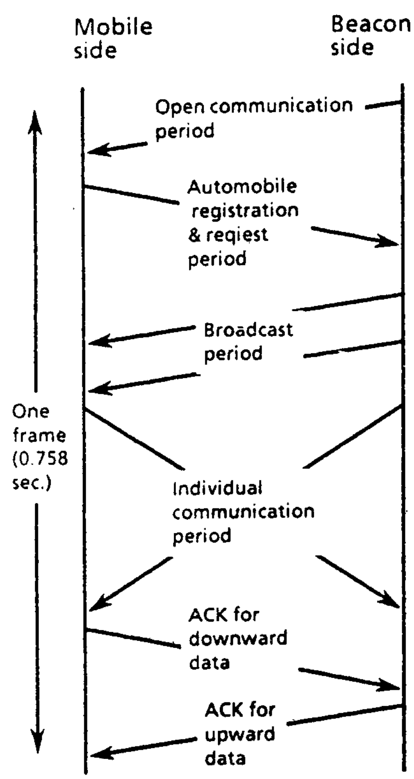


Fig. 3 Transmission frame format

This section transmits and receives data to or from each vehicle using the time slot designated by the 3rd period. Data varies from a short message of 100 bytes to a long message of 25 kbytes (image information, etc.). These data will be transmitted by a packet of 140 bytes units.

5) Close communication period

a) Downward ACK (from the mobile station to the beacon station)

ACK will be returned when correct data is received from the beacon. NAK will be returned when abnormal data is received from the beacon.

b) Upward ACK (from the beacon station to the mobile station)

The beacon station transmits the reception result (ACK/NAK) to the vehicle station.

<u>Communication network</u>

A communication network is needed to transmit road traffic information or offer AVI(Automatic Vehicle Identification) function, AVM(Automatic Vehicle Monitoring) function and individual communication to the beacon stations along the road. Specifically, the communication network has a hierarchial structure that can be developed nationwide by connecting the beacon stations with the upper stations using wire transmission paths such as optical fiber cables laid in the road.

Figure 4 shows the basic concept of the communication.network for actual using stage. The network is divided into two by basic functions. Area stations control the multiple beacon stations and concentrate transmission lines. On the other hand, upper regional stations and the control center stations are the data communicaion network. The functions of each station are as follows.

1) Roadside beacon statiun

This station constitutes the minimum radio zone.

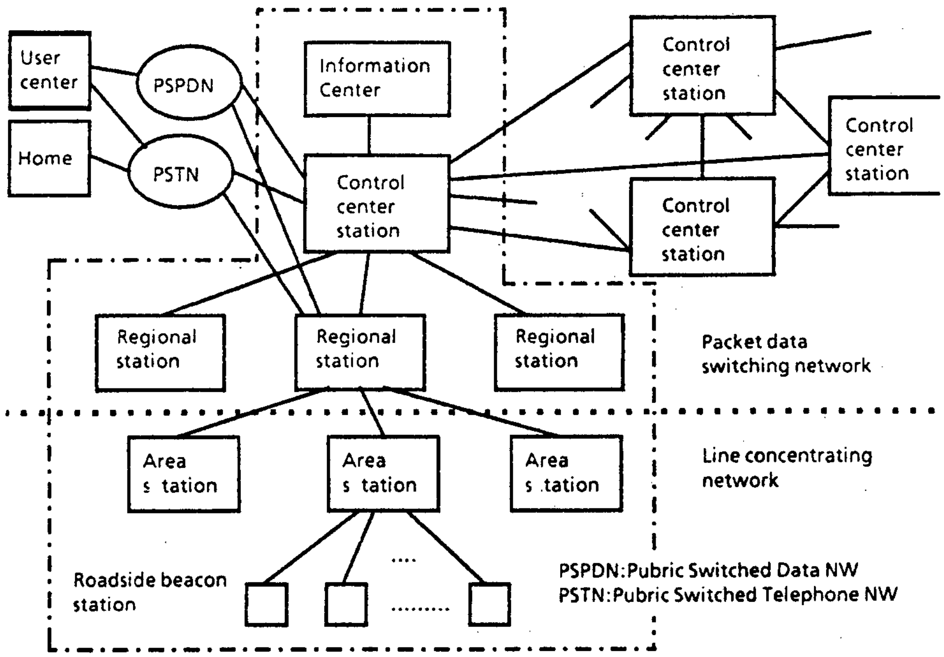


Fig. 4 Basic concept of the communication network

This station identifies the participating vehicles and controls radio communication both ways between the road and vehicles.

2) Area station
This station controls multiple beacon stations. It assesses the running vehicle positon and transmits the information to the upper station by calculating the traffic stream information of the section by the vehicle passing time between the beacon stations.

3) Regional station
This station registers the vehicles of each region. This station connects with the public circuits.

4) Control center station
This station registers the vehicles nationally. It offers data for AVM, etc. by connecting with the transportation management center (user center) of vehicles using the public or private circuits.

5) Information center station
This station provides the road traffic information, processes route guidance information, obtains information about weather, etc. from other organizations and transmit the information to subordinate stations.

Experimental system

At present, under initiative of private companies and the Ministry of Construction, and in collaboration with the Highway Industry Development Oragnization and related road administrators, synthetic experiments are continuing on RACS equipment. An experimental system is being built in the Tokyo area to confirm the overall function of the information system between the road and vehicles. Construction of the experimental system includes the basic functions of the communication network as shown in Figure 5.

1) The roadside beacon stations are established along the express ways.

2) The experimantal system consists of the area station equipment (AS) that receives signals from each beacon station, the packet switching unit (PSU) that switches and connects data, the information processing unit (IPU) that processes data, and the interface unit (IWU) that makes connection with the external circuits in the system center.

3) Communiction terminals for each vehicle, display terminals for AVM, etc. are prepared in the demonstration center.

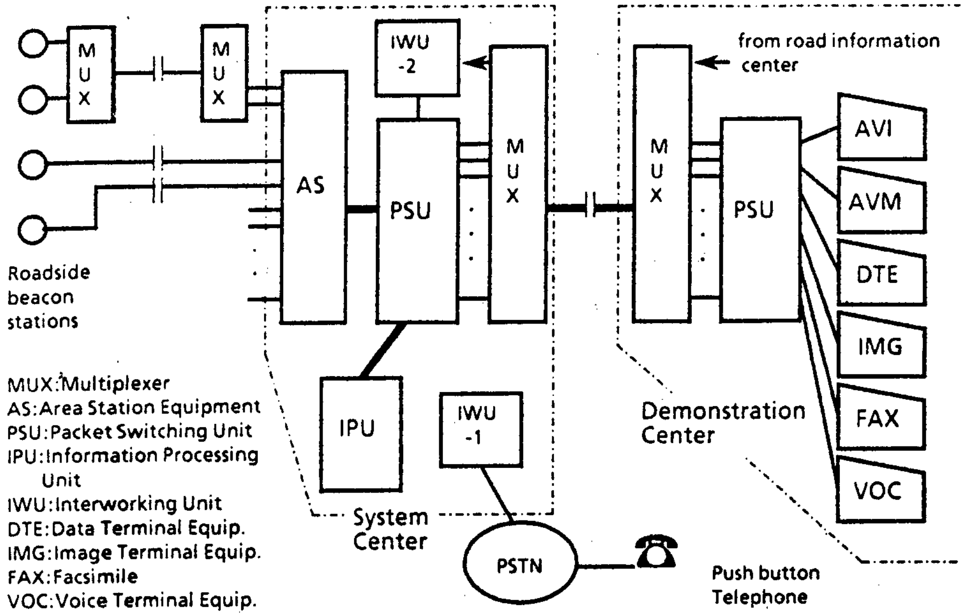


Fig.5 Construction of the experimental system

Evaluation of the experimantal system

Since this system is so flexible, it is possible to construct a stepwise system strucrure and services available. It is necessary to study each step carefully from the first step to the final step of a total communication system.

Since communication traffic in this experiment was small in scale compared to that in actual applications, each component had low capabilities. However, the communication format and function distributions were based on functions needed in practical use. This means that the format and the distribution of functions directly affects the system architecture, but that increased traffic can be handled by changing the scale of the system.

The constitution of the overall experimental system is shown. The main sequences of communication processing used in the experiment are shown in Fig.6—7.

1) Evaluation of the system architecture

The architecture of this system is of nearly same scale as that used in practice. Experimental results showed that for the most part this system can be used in practical applications so long as certain problems are cleared up.

2) Evaluation of the main equipments

An evaluation of the system equipment follows:

a) Beacon stations and mobile stations
Radio transmission method can be used practically, to be carried out instantaneously with the transmission of navigation data and various communications between vehicles and roadside beacon stations.

b) Packet switching unit
This unit is the main equipment consisting the packet communication network. Communication between equipment units can be made regardless of the application. The packet switching unit is for genaral communication use, and its switching ability can be fully adapted to practical application.

c) Information processor
The information processor manages identificaion code and vehicle position data, and processed the communication information. A genaral-use computer is used. In this experiment, the transaction could be processed by a comparatively small computer. In practical stage, it is necessary to use several computers or to use bigger computers depending on the required transaction capacity.

d) Equipment for area stations
Equipment for area stations convert the

communication protocol LAPB from roadside beacon stations to packet communication format, CCITT X.25. This equipment also dispatch the simultaneous information to the beacon stations. This experiment showed that the memory capacity for communicaiton processing was short in some cases. For practical use, configuration needs to be changed partially.

3) Evaluation of the transmission line

In this experiment, existing cables and multiple transmission lines were used, and the rate of transmission was equal to 9,600 bps. Since the quantity of traffic was comparatively small, it was able to transmit the information in various combination. For practical use, a higher rate (ex. 48kbps - 384kbps) transmission line is needed so as not to delay transmissions because of insufficient transmission line capacity. Capacity depends on the number of roadside beacon stations and the amount of traffic.

4) Evaluation of maintenability

At the experimental scale, equipments were installed closely, maintainability was out of the question. In practice, it must be possible to use remote centralized control. The great distance between individual roadside stations makes it absolutery necessary to study the question of maintenance, to achieve effective remote control including remote accident monitoring and remote program loading.

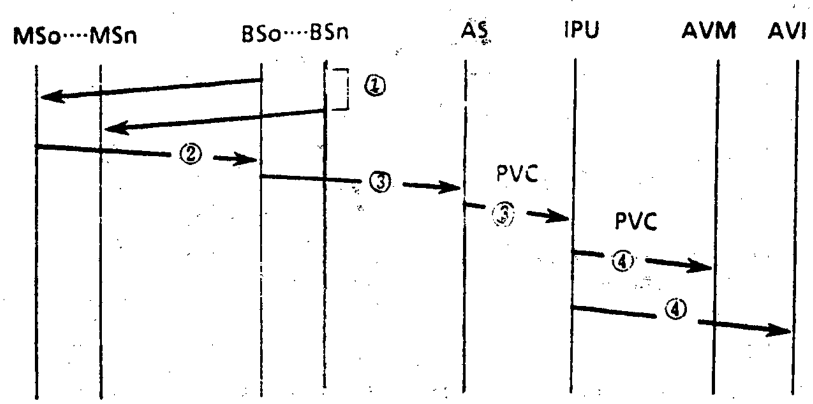
Conclusion

Public Works Research Institute of the Ministry of Construction has been promoting the development of RACS as a joint study project with 25 private companies since 1986. In 1989, a comprehensive experiment of whole RACS system was tested. We consider the technical research phase is almost finised at present. To achieve the actual system construction, operations of the system and related legal subjects must be studied, in addition to the technical evaluation.

RACS wil permit an abundance of information to be sent to cars from road administration sites. Consequently, studying this system is considered an important step for developing the technology that will lead to our dream for the future automated driving.

Acknowledgement

The authors wish to thank the persons concerned RACS research activities for the cooperation.



①:Open communication period
②:Automobile registration period
③:Automobile registration data
④:Data for AVM/AVI
PVC:Permanent verchal call

Fig.6 Example of transmission Sequences (vehicle position detection)

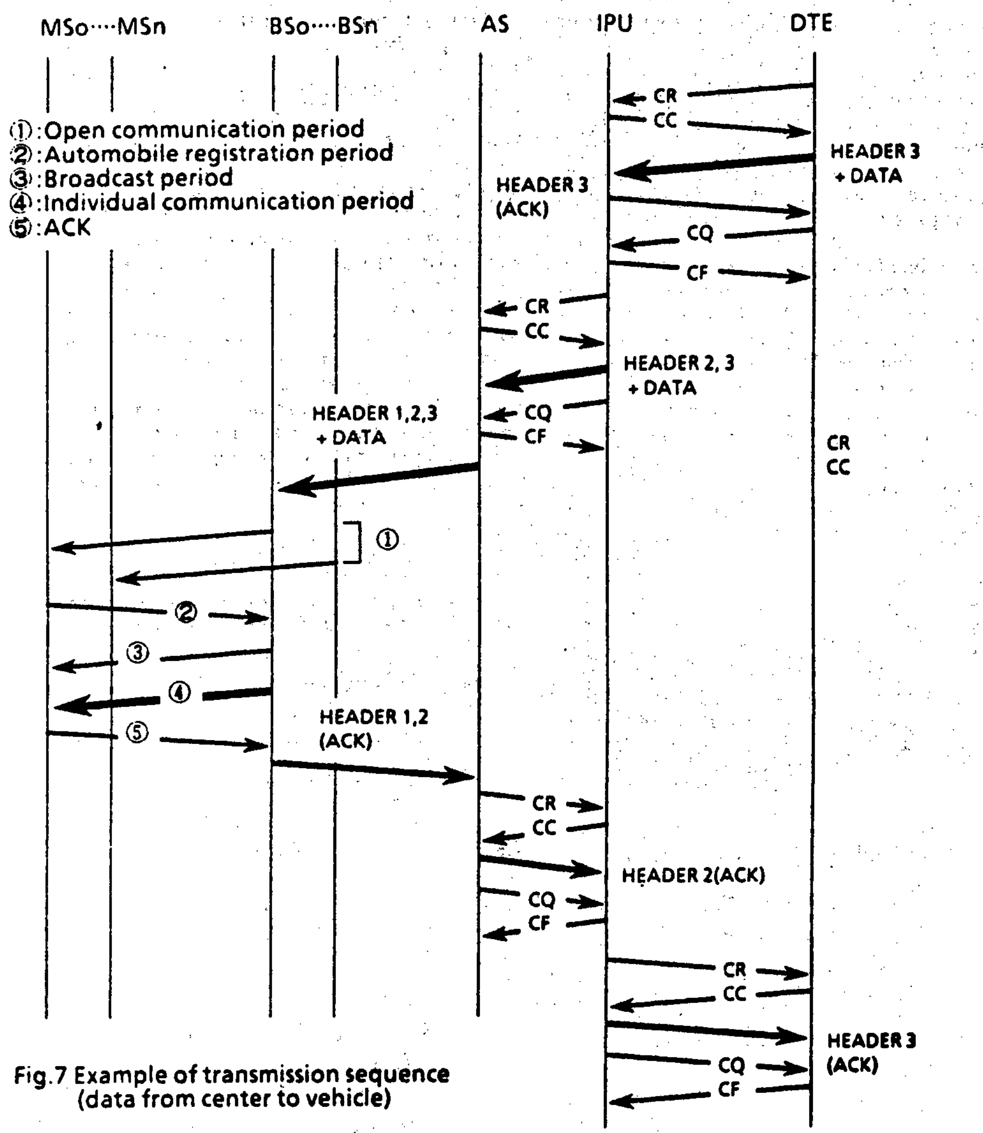


Fig.7 Example of transmission sequence (data from center to vehicle)

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AN INTER-VEHICLE COMMUNICATION TECHNOLOGY AND ITS APPLICATIONS

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ABSTRACT

An inter-vehicle Communication technology will contribute to improve the safety and the efficiency of automobiles' trips by exchanging data on driving operations, locations and traffic incidents etc. between autombiles directly through digital communication links.
Using this technology, it is possible to realize such systems which provides the information of the traffic jams or accidents ahead.
The idea of this technology was introduced in order to complement the function of spot communication media between vehicles and roadside, and has been studied for several years in the Association of Electronic Technology for Automobile Traffic and Driving(JSK).

INTRODUCTION

An inter-vehicle communication system which forms direct digital packet radio data links and exchange information between automobiles without drivers' operation will play an important role in a road traffic system in the near future. So far, a couple of spot digital communication systems between a roadside communication site and an automobile have been developed.

These systems porvide much many important information both for drivers and road traffic managers. However these systems require a large scale infrastructure. And because of the physical location of discrete roadside communication sites, there will be a possibility of information delay. In the worst case, if an accident occurs between two sites and the involved automobile can not move, this information can not be transferred to the ground system. An inter-vehicle communication system will not only complement these shortcomings but also provide many attractive functions by itself. Such as emergency report, warnings of the abnormal driving situation, driving operation information excahnge and exchange of other information without a ground system. These functions can be exploited by personal radio systems and automobile or portable telephone system to some extent. But what we need is a fully automated inter-vehicle communication system. This inter-vehicle communication system is quite different from the existing communication system and requires technological developments. Especially formation of links is very important. This paper describes both application aspects and technological aspects.

1. CATEGORY OF APPLICATION

Application of an inter-vehicle communication can be divided into following fields according to data contents.
(a) message exchange, correspondence
(b) urgent signal or warning for safety
(c) driving control or support

The application systems of inter-vehicle communication are listed in table 1.

Table 1 APPLICATION SYSTEMS OF AUTOMOBILE-AUTOMOBILE COMMUNICATION TECHNOLOGY

Function field	Transmission information type	Information flow pattern	Application system [(*) corresponds to the information flow pattern]
Information exchange / transmission	Road traffic information	Same direction (1) ←V←V←V←V←V · · · (R ↑ to third V) (2) V→V→V→V→V · · · (third V ↓ (R)) (3) R→V→V, V, : Opposite direction (4) R→V→v, v, : (5) V→v, v, : (6) V→v→r, v; V ↓ R	① Information transmission system for following automobiles (2) ② Moving information board system (4,5) ③ Transportable road side equipment system (3) ④ Moving information collection / transmission system (6) ⑤ Traffic information transmission system (4,5) ⑥ Traffic information service system linked with the bus operation control system (4,5,6) ⑦ Inquiry response system (8) ⑧ Hello for request and caution system (7) ⑨ Calling type Automobile-Automobile communication system (7) ⑩ Automobile-Automobile coummunication system linked HAR system (9) ⑪ Control station distribution type MCA system (1) ⑫ Relay type personal radio system (1) ⑬ Illegal parking warning system (3)
	Automobile operation control information	The whole vicinity	⑭ Automobile operation control system (reverse of 2, 3)
Safe driving / emergency information transmission	Emergency information	(7) V→v, v (8) V→V, v→V, v (↓ (R)) (9) V→R→V, r	⑮ Abnormal driving condition detection system by police cars (7) ⑯ Abnormal condition notification system (7) ⑰ Emergency notification system (8) ⑱ Emergency automobile approaching notification system (7)
	Location /speed / direction information		⑲ Head-on collision avoidance system (7)
Automobile control /driving assistance	Automobile control information	Same lane V→V→V→V · · ·	⑳ Automatic driving system for following ㉑ Static route guidance system

V, R : In-vehicle unit and roadside equipment in the same direction
v, r : In-vehicle unit and roadside equipment in the opposite direction

They contain many kinds of chaining schemes of data transmission, and some cases require to be combined with vehicle/road communication links.
The type of inter-vehicle communication used in these schemes varies on direction of data link (one way/two way etc.), range and direction of transmission and so on.

1 − 1 Message exchange, correspondence

① transmission of traffic information
New concept of information service system can be proposed using the inter-vehicle communication technology. That is the traffic information network in which vehicles or drivers exchange traffic information collected in the vehicle (or by drivers) directly between vehicles cruising same or opposite direction. The functions which figure out the traffic situation from their driving record or detect the abnormal condition such as skid, sudden decceleration will make this network very attractive.
The new type of traffic information service by specific types of vehicles such as buses, taxis and trucks can be implemented using inter-vehicle communication.

② conversation between vehicles
Inter-vehicle communication technology can be used for the message exchange between vehicles in their vicinities. Although the message length is limited due to the characteristic of inter-vehicle communication, this medium would be adequate to transmit following messages.

- Caution for "cargo crumbling", "incomplete door closure", "unnecessary lights".
- Confirmation for "pass please", "go ahead", etc.
- Intention to start communication with a specific driver.

③ miscellaneous
The applications of inter-vehicle communication can be extended to the communication between vehicles and the drivers who are apart from their vehicles, for example the theft warning transmission to the drivers.

1 − 2 Urgent signal or warning transmission for safety

① Emergency call, rescue call
This is similar to 1 − 1 functionally. In the case of the vehicle failure or accident, inter-vehicle communication can be used to inform these situation and ask for rescue to the other vehicles.
Police cars or ambulances can inform their direction of approaching or ask to clear the way to the other ordinary cars.

② collision avoidance
By transmitting the vehicles location and speed etc., a kind of cooperative radar system can be formed. This function would be utilized for collision avoidance at intersections.

1 − 3 Driving control and support

The headways of vehicles which are cruising as a group would possibly be reduced by exchanging the data upon driving operation. Thus the capacity of roads will be utilized effectively.
This kind of systems require the reliable inter-vehicle communication media which has adequate transmission rate and automatic driving control technologies.
This system can be used to pilot or guide a driver who is not used to an area.

2. DIGITAL LINK FORMATION AND CHAINING

2 − 1 Categories of digital communication link

Our goal is to establish an inter-vehicle autonomous digital mobile radio packet communication network system. There could be many levels of requirements for the system. First of all, the system configuration will be under constant change from time to time because of vehicles' motion. This will make the system very complicated and difficult to build, but on the other hand very interesting and challenging too. It is useful to categorize the system requirements from physical aspect and data linkage aspect.

From physical aspect, the system will be categorized into a short range type (including beam type) and a middle range type. The basic difference of these two is that there will be virtually only one communication target in the former one and many in the latter one. We do not consider long range type because it is not recommendable from the view point of finite frequency resource utilization.

From data linkage aspect, the system will be categorized into a broadcasting type (one way type), a responding type (two way type) and a constant report repetition type (all to all). In many application, not only the linkage between a transmitter and receiver (first order linkage) but also chaining of this linkage (relay type) will be required. Analysis of the first order linkage formation and linkage chaining process of moving vehicles are very important.

2 — 2 First order linkage formation

There will be a broadcasting type (one way type) and a responding type (two way type) for the first order linkage set up as mentioned above.

2 — 2 — 1 Broadcasting type (one way type)

In this type the transmitter does not specify the receiver and does not care for the result of transmission, i.e. whether the package is received or not, and simply transmit information to the unspecified receivers. For the short range type, the receiver will be one or very limited. For the middle range type, many receivers will exist. However even the short range type, by the vehicle motion, it will work as broadcasting to some extent.

2 — 2 — 2 Responding type (two way type)

This type is basically one to one and requires linkage formation confirmation. For the linkage formation, next procedures will be required.
(i) search for the party that satisfies the condition.
(ii) proceed or continue communication with the specific party.

Those procedure can be used in any combination according to the application. For the search procedure, examples of some possible conditions are as follows.
(a) vehicle identification code (police car, public service car etc.)
(b) physical direction and range of communication
(c) communication media (mobile phone, personal radio etc.)
(d) existence of the specific data
(e) receiving driver's intention (accept the call or not)

In this type, especially for middle range type, the protocol should provide a scheme to solve the transmission contention problem. Also when applied for multicast, acknowledge control procedure is important.

2 — 2 — 3 Constant report repetition type (all to all)

In this type, all vehicles will exchange information each other constantly. This will be required, for example, for a collision avoidance system. For this application, the required data rate could be high and very secure transmission will be required. Therefore, closed area ground supported synchronized time slot allocation system will be needed.

2 — 3 Chaining and technical problem

For the inter-vehicle communication application, information propagation process is essential. Therefore we focused on the protocol and performance of the first order linkage formation and chaining problems.

As for chaining, we consider repeating type and autonomous network formation type. Each corresponds to broadcast type and responding type respectively.

(i) Repeating type
In this type, when a station receives a packet, it will retransmit the packet. For this system, the procedure to avoid the collision of broadcast is essential. Also, packets could increase and fill up the whole system. To prevent the infinite broadcast repetition, broadcast should be terminated. This can be achieved by limiting repetition by a predetermined number. This type seems to be very promising.

(ii) Autonomous network formation type
In this type, chaining will be guided by searching certain information or station identification. Once the chaining has been completed, this information will be chained back to the original station. For this back chaining, there could be two procedures.
(a) same procedure as forward chaining i.e. search route independently
(b) trace back the forward route using stored the chaining data

In inter-vehicle communication application, the network configuration could be changed rapidly and type(b) seems to be impractical.

3. FEASIBILITY STUDIES BY EXPERIMENTS AND SIMULATIONS

To send a packet to a station which is out of a single hop communication range, each station should have a relay function. We developed a simple protocol (an extension of AX.25) and analyzed the information propagation performance by both experiments and simulations.

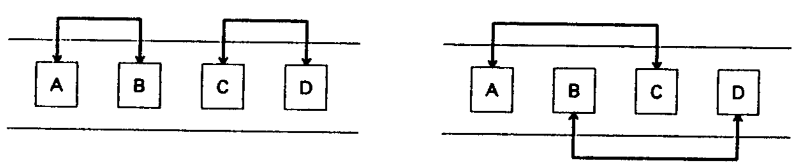
3 − 1 Experiment

3 − 1 − 1 Preliminary experiment
We implemented a radio communication device on a vehicle (we will call this a station) and conducted a couple of experiments while driving on roads.

Basic experiment conditions are

frequency	:	1.2 GHz
modulation	:	FSK-FM
bit rate	:	1,200bps
communication range	:	50∼100m
duplex	:	half duplex
protocol	:	extended AX.25
number of data	:	64 octet/frame

As for a preliminary experiment, we compared effective data throughput between a moving pair and a stationary pair first. It turned out that the throughput is almost the same for both (protocol with acknowledgment). As a multi communication pair situation, we experimented two configurations shown in figure 1. In case of figure 1 (a), the throughput was fairly well. However in case of figure 1 (b), the throughput was impaired substantially.



(a) (b)
Figure 1 Two pairs configuration

3 - 1 - 2 Broadcasting type experiment

In the network we assume,
(a) all station will use single frequency
(b) communication range is limited to proximity
(c) network configuration is changing rapidly
(d) for two stations not in a communication range, station(s) in between act as a repeater

protocol
- physical layer protocol
  access : CSMA 1-persistent
  duplex : half duplex
- link layer protocol: AX.25L2V2 connection less type (use UI frame)
- packet length : real data 64 octet/frame fixed (total 85 octet/frame)
- network layer protocol

For the inter-vehicle network application, the network configuration will change rapidly and conventional link formation will not work well. One way of solving this problem is to use connectless datagram system. We propose an extension of AX.25 protocal for broadcasting routing. In this algorithm, one station which has some message to send will transmit it as a packet. A station that receives this packet will retransmit the same content. By this repetition, the packet will arrive at the destination station at the end. The problem of this algorithm is that once a packet is transmitted, it will increase and fill out the network (Figure 2). Schemes to prevent the increase of packet are as follows.
(i) the destination station will not retransmit the packet.
(ii) limit the number of retransmission (hand over number)
(iii) limit the number of retransmission at the same station (Digi count)

It was experimented using 6 cars (A-F) running in tandem. The head (A) and the tail (F) car send a packet every 30 seconds for 30 minute. Therefore 60 packets were transmitted. Table 2 shows the number of received packets by each station.

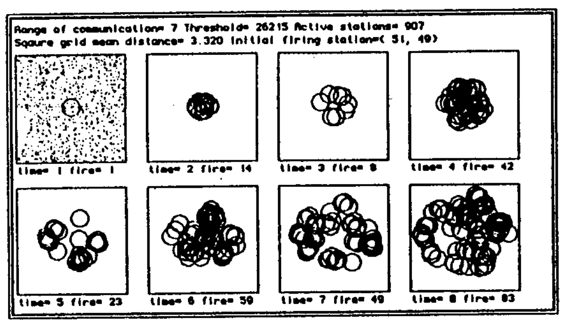


Figure 2 Example of packets propagation

Table 2 Result of the experiment for the broudcast type communication

station	digicount 1		digicount 2	
	station A	station F	station A	station F
A	29	20	28	27
B	52	29	50	45
C	51	28	51	49
D	20	33	38	52
E	12	38	31	52
F	11	18	20	22
average	48%	48%	63%	75%

3 − 2 Simulation

The basic behavior of broadcasting routing algorithm was analyzed by simulation. The purpose of this simulation is to show the effectiveness of broadcasting routing. Two stations are located in a normalized x-y space at (0, 0) and (1, 1). Station at (0, 0) will transmit a package destinating the station at (1, 1). The basic algorithm: when a station receives a packet correctly, it will retransmit the packet. If the station at (1, 1) receives the package, transmission is completed. Stations other than these two are distributed randomly in two dimensional space $-0.2 < x < 1.2$, $-0.2 < y < 1.2$. Transmission success probability from station at (0, 0) to (1, 1) and number of retransmission is measured with varying parameters. For retransmission control, slotted ALOHA and p-persistent are simulated.

• slotted ALOHA

In the slotted ALOHA, when a station receives a packet at time slot(t) it will retransmit the packet at time slot (t+1), the transmitting station will not detect collision. A collision is detected by receiving station as a conjestion, and when collision occurs, that packet will be discarded. Figure 3 shows the communication success probability and number of retransmission.

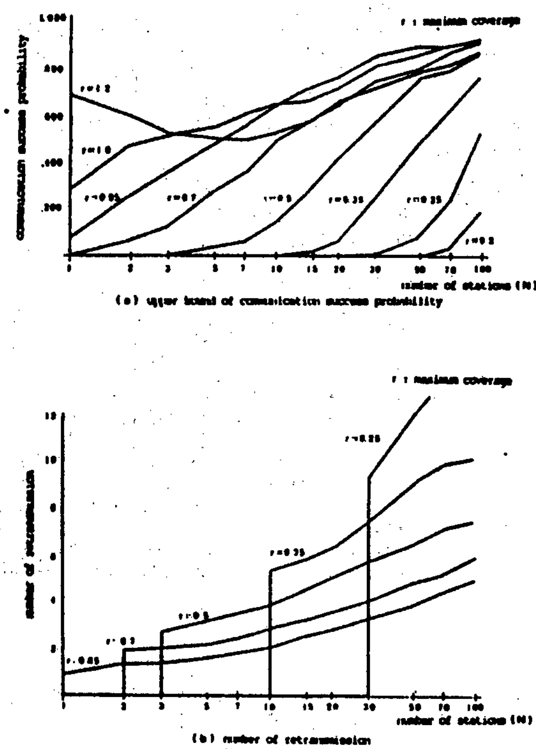


Figure 3 slotted ALOHA model

• p-persistent

In the p-persistent system, when a station receives a packet at time slot(t) it will retransmit the packet at time slot (t + 1) with probability p. Figure 4 shows the communication success probability and number of re-transmission for this algorithm. These results shows the effectiveness of both slotted ALOHA and p-persistent algorithm for broadcasting routing.

CONCLUSION

The required implementation ratio for successful operation depends on each application. However the system basically works on localized link, therefore some application can be established with a limited number of stations.

We suppose that following scinario would be a hopeful penetration process of inter-vehicle communication units. That is the one which is started from formation of information exchanging networks among the specific vehicles such as taxis, trucks or the ones belonging to certain clubs and then proceeds to the stage where the general vehicles take part in these networks.

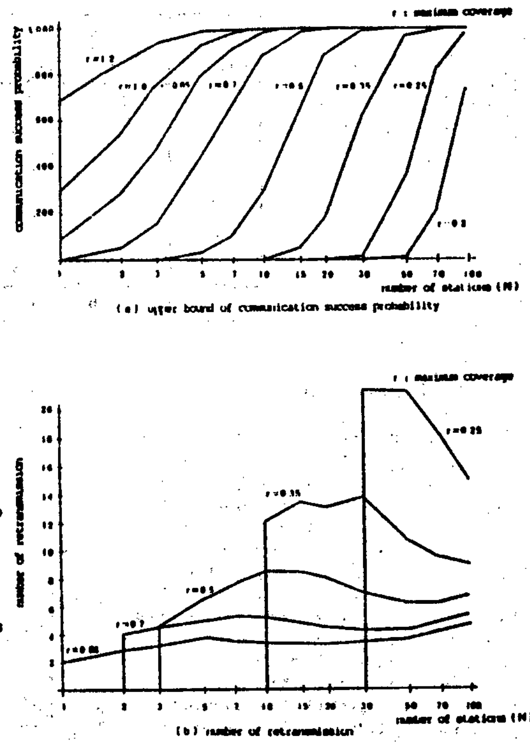


Figure 4 p-persistent

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USE OF TRANSPONDER TECHNOLOGY FOR FACTORY ORGANISATION AND ROAD TRANSPORTATION INFORMATICS

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90092

Introduction

A general problem in computer aided and computer integrated systems is the integration or synchronization of a flow of objects with a flow of informations. The flow of objects is occuring in a wide range of environments: Production cell, factory, transport, traffic, etc and the requirement to monitor and control a flow of objects is well known.

Increasingly transponder technology, as an electronic identification plate or escort memory attached to the object, is being applied to organize and monitor a flow of objects.

The purpose of this paper is to discuss in general terms the use of transponder technology over a wide area of applications covering factory organization and road transportation informatics.

The discussion is based on the experience of transponder technology from the PREMID-activity and on the experience of smart cards and in-vehicle networks from Philips Components.

Factory Organization

In CIM systems and in other computer aided or highly automated production systems, electronic ID-tags, transponder or escort memories are placed on products, components, tools and transport carriers in order to give distributed management systems and flexible distributed manufacturing systems.

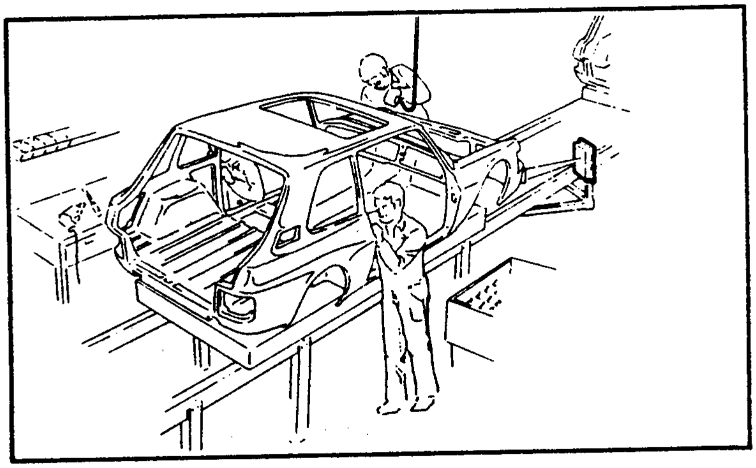
The transponders are used to carry:

Static information on
- Serial number
- Type number
- Initial product specification

Dynamic information on:
- Machine control data
- Routing data
- Process data
- Inspection and quality data
- Data for repair and complementary work
- Trend analysis data
- Liability documentation

The application of transponder technology is deeply involved with the information and network architecture of the factory. At specific points in the flow of objects information is required on the specific object present and this information can be transported with the object via a network with a node at the specific point or by using a combination of both.

Thus transponder technology constitutes a complimentary network with sets of stationary and mobile nodes with the mobile node in the transponder. Such a complimentary network has some unique properties of relieving network and host computer of guaranteeing data for local use and of integrating processes, production cells or different flows of objects without synchronization requirements on time or place.



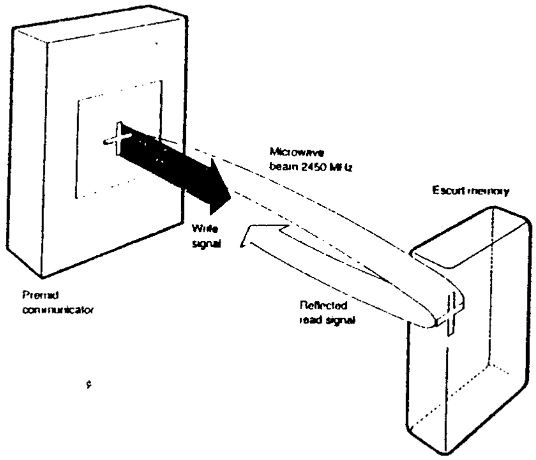
When the transponder is equipped with an external connection such a complimentary network can also be called upon to serve sensors and activators. The benefit of this will become more evident when discussing transport applications.

A discussion topic of long standing in the automotive industry is the use of an electronic ID-tag permanently mounted on the automobile at the start of production and with an after-sales function for service, product life tracking, etc. So far it has not been possible based on available technology to find economic solutions.

Technology

PREMID is offering a concept for product identification based on a two-way microwave link operating at 2.45 GHz.

- o Programmable escort memories with a capacity of 20 - 8 kBytes which can be remotely read and written.
- o Communicators with antenna arrangements for reading and writing at different distances: up to 0.5 m, up to 2 m and up to 5 m.
- o Software that supports a flexible file handling and individualization file formatting as well as error detection and protocol towards host.



New development will within short present enhanced performance in terms of data speed, modularity, etc.

The PREMID technology is well established in the automotive industry serving in different application and production environments in body shop, paint shop and final assembly as well as serving different information and network architectures.

Transport

It has been said that a major part of any industrial activity is the management of transport. Transport is handled by fixed installations like conveyors, roller belts, etc but also by carriers such as: AGV:s, trucks, railroad cars, containers, pellets, etc.

Functions that can be accomplished with the remote programmable ID-system PREMID:

Localization and monitoring of movements
Entrance/Exit control
Routing
Monitoring of cargo and destination
Service and maintenance
Automatic weighing and debiting
Container identification and routing
Hazardous areas and cargo-surveillance

PREMID has been installed in a number of these applications:

Maintenance

The Swedish Railroads have a maintenance program where the dimensions and wear of the wheels of the railroad cars are automatically and regularily checked. It is essential that the automatic checking is automatically coupled to a railroad car identity. Since mid 1985 a pilot system covering 60 cars in both south and north of Sweden has been running. ID-plates (10 decimals) are mounted on the cars and read at the entry and exit of the marshalling yard. During a one year test period no problems have been experienced because of climate conditions (e.g. heavy winter) and an error rate below 3 o/oo has been obtained.

A similar application, wheel checking, has been taken up by the Danish Railroads and implemented on 300 cars on the Copenhagen Underground. ID-plates (4 decimals) are mounted on the cars and read at strategic points. As this is a closed rail system it is planned to use the identification system to monitor the distance travelled by the cars and base a scheduled maintenance on this information.

A similar maintenance application is the detection of hot box (overheating of wheel bearing) on line using infrared detectors. Here it is also essential to couple the automatic checking with a car identity.

In another maintenance application the ID-system is used for creating a data bank on vehicle status, fuel consumption, etc, in order to accomplish a preventive maintenance procedure.

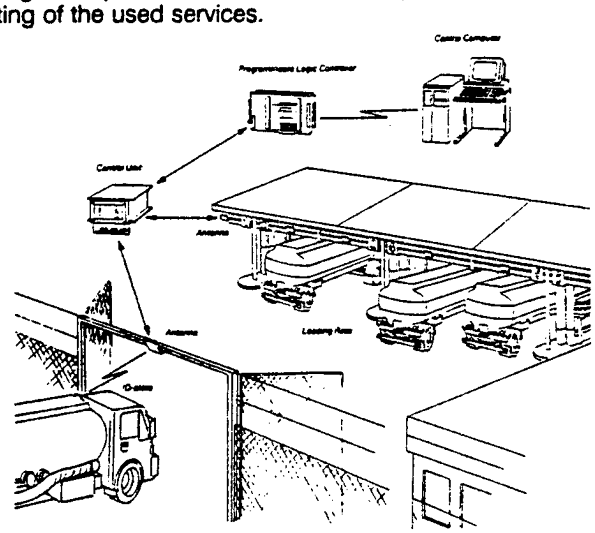
Fleet management

Several organizations within transport and heavy industry have captive fleets of vehicles for dedicated transport tasks. Examples are local bus and transport companies, steel industries, mines etc. The fleet is kept within a defined geographical area and is transporting people or goods between several points within the defined area. To make the fleet efficient it is important that the vehicles have a high degree of availability and are not standing or running idle.

In order to increase the efficiency of the feet the individual vehicles can be identified by PREMID-plates and read and reported to the central computer at strategic points.

One such installation is in a steel industry, SSAB, 150 km south of Stockholm, where the fleet consists of 20 railroad cars and 20 trailers. The vehicles are identified at the entry and exit of factory buildings and loading areas, and a central computer keeps a register of the location and use of the vehicles. It is calculated that the efficiency of the fleet will increase with 10 % which more than pays for the installation.

In several applications fleet management is combined with in-motion weighing and debiting. In addition to fleet management it is possible to arrange automatic loading/unloading in depos for oil, cement, carbage, coal, etc and as a follow up automatic debiting of the used services.



Train movements

For subways and buses on regular routes it is important to know when a specific routenumber is approaching or passing a defined point. Such information can be used for displaying the number of incoming trains at station, for regulating traffic signal, monitoring of the traffic etc.

For a period of one year we are running a test system on S-bahn in Hamburg, Germany. The system covers ten trains running at 80 km/h with 10 decimal ID-plates. So far the system has accumulated 10.000 readings without error and no influence from climatic conditions have been experienced. ID-plates with increased data speed and special antennas giving a larger reading interval are used.

Also for industries with company-managed fleets of rail-road cars similar applications are of interest.

Transponder interface

Characteristic for transport is that the objects in the flow frequently have an intelligence either from the driver or from on board automation. Provided that the transponder has an external interface it is possible to use the transponder as a two-way communication link between the moving object and some en-route point.

Such a transponder interface is designed for connection of displays, tachographs, sensors etc and follows preferably an established network standard.

Toll road applications

Charging toll fees to finance new roads is becoming increasingly common all over the world. The first toll stations were manually operated but coin machines and pay card systems have now been introduced.

The major disadvantage of all these charging systems is that the driver has to stop his vehicle in order to make the transaction. Queues may build up and stopping is an inconvenience to the driver.

As in many other areas advancing technology has provided new opportunities. PREMID offers a complete system which eliminates the need to stop or even to slow down when passing a toll station. The modularity of the system permits its use on differing numbers of lanes in any individual toll station and on any numbers of stations per town or area.

PREMID systems allow rapid two-way communication between vehicle and roadside and can be modified to meet the demanding requirements of future road pricing schemes.

The principal aim is to make traffic flow more efficient and to reduce the damaging effects of traffic on the environment. The users of the roads have to pay for their usage, and the PREMID system is an integral part of road pricing schemes.

In toll road applications a PREMID transponder can have a function starting from a simple license or account number to a sophisticated credit card with a possibility for encrypted financial transactions on the fly.

On the 20th of October 1987 the world's first automatic toll station was officially opened in the city of Ålesund on the west coast of Norway. After only a few months nearly 60 % of all traffic passing the toll station used the "PREMID-lane" instead of either paying by magnetic card or at the manual booth. During rush-hours as many as 80 % of the cars are equipped with a PREMID ID-plate.

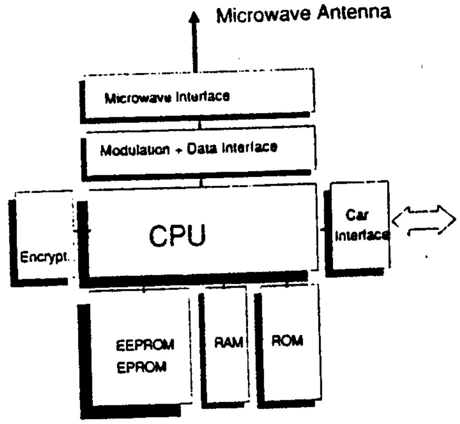
The Ålesund toll station is open 24 hours a day, 365 days a year, and the PREMID system has been operational continuously since the opening. Rough climatical conditions and other factors have not influenced the system in any way. Operators, owners and not least the drivers find the system easy to use and efficient in its operation.

PROMETHEUS and DRIVE programs

Within the European Community two major research programmes, concerned with Road Transport Informatics, are running.

Prometheus, instituted by the European automotive industry, aims at developing in-vehicle electronics for adapting the vehicle to an infra structure for road transport informatics in applications like intelligent cruise central, collision, avoidance, route guidance etc. In a Prometheus project CAROSI PREMID transponders are used as electronic road signs being read by a communicator in the vehicle.

DRIVE is a CEC research programme directed more towards the infra structure for road transport informatics. The DRIVE programme PAMELA is based on PREMID technology developing a two-way microwave link for road pricing, parking and route guidance applications. The aim of the PAMELA project is to develop a secure transaction system to be applied on open muilti-lane motorways with guaranteed anonymity, encryption, transaction register, driver display, etc. The transponder on-board the vehicle has an interface to the in-vehicle network and an interface to a smart card. Results up till now are presented in paper 90026 (22nd ISATA) and cover multi-lane strategies transmission characteristics and basic design of a first demonstrator.



Modular Structure of the Tag

In-vehicle network

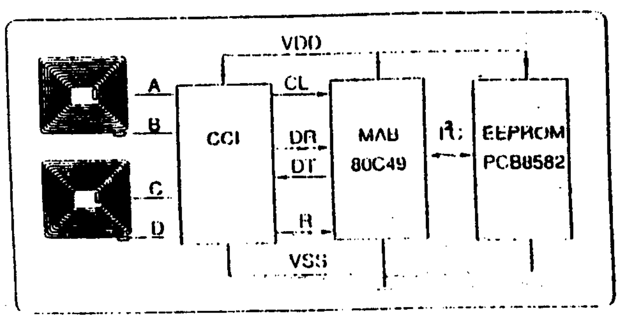
Some different concepts of in-vehicle networks are being promoted for the interconnection of electronic components and subsystems in the vehicle. The medium used by the network can be optical fibres on twisted pair.

The network protocol can follow the I^2C-concept or the CAN-bus which is developed specifically for automotive applications.

Smart card

Plastic credit cards can be foreseen to be replaced by smart cards or chip cards. A smart card can basically be in two versions: A memory smart card or an intelligent smart card.

The smart card is accessed via an eight-pin contact or can be accessed via a contactless inductive interface.



A smart card meets a number of important requirements:

- Division and administration of memory space after application
- Encryption and protection of stored data
- Encryption and decryption
- Compatible with external protocol
- Multi-functionality
- Authentication of user (PIN-code)

Some smart cards also are equipped with an internal network, I^2C.

Future trends

With the described transponder technology we have demonstrated a palet of technology that can be applied over wide applications in factory, organization and road transportation informatics.

It can be assumed that an important future trend will be the possible integration of a number of different functions based on interconnection via the in-vehicle network.

- An electronic ID-tag premanently mounted on the automobile at the start of the production will be economic by being designed for later integration in the in-vehicle network.
- The in-vehicle network will connect different functions such as vehicle diagnostics, road transport informatics services, vehicle control, after-sales data storage, service log book, external communication channels, etc.
- A transponder for communication with external systems will be integrated with the in-vehicle network and will external access to the functions accessable from the in-vehicle network.

HOW CAN THE DYNAMIC ROUTE GUIDANCE SYSTEM ALI-SCOUT HELP TO SOLVE TRAFFIC PROBLEMS AND TO PROMOTE THE ENFORCEMENT OF PUBLIC TRAFFIC POLICY MEASURES?

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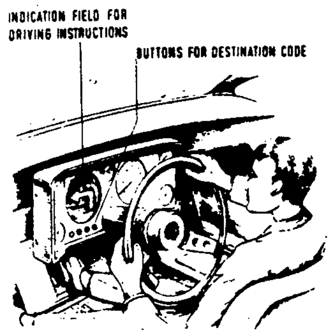
90163

1. What actually is a dynamic route guidance system?

The answer could initially be formulated as follows:



"A system that guides all road users in the best way to their destinations and which at the same time takes the current traffic situation into account"

As it will be seen later, such a system offers more than simply vehicle guidance. But first of all its structure.

Its core is a **control center** with a **powerful computer** in which all permissible traffic routes of the guidance area and their conditions (e.g. one-way streets, number of lanes, roundabouts etc.) are stored and which continuously receives data concerning the current traffic situation from this area.

Classic Map "Electronic" Route Guidance Map

It is thus possible to compute **guidance recommendations as a function of the current traffic situation** and to keep these up-to-date at all times.

Guidance recommendations must then be transmitted to individual road users to guide them **o p t i m a l l y** to the their destinations.

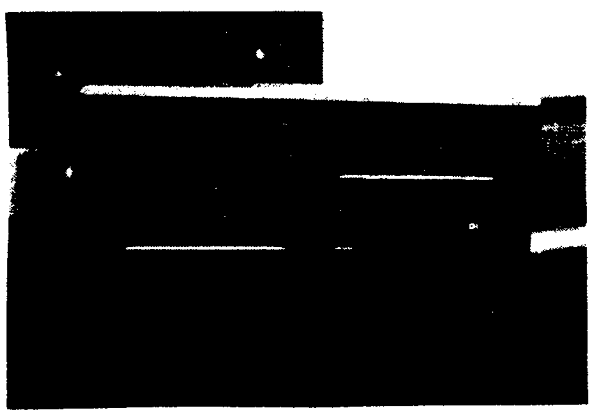
Now, **optimally** can mean:

- over the q u i c k e s t route, i.e. generally the shortest one. If roads should happen to be jammed, this simply means "taking a detour around the congestion by computer".
- over the c o r r e c t route if, for example, heavy, special or dangerous goods have to be transported and bridge loads and passage heights etc. have to be taken into account
- over the c h e a p e s t route, for instance if toll motorways, tunnels and bridges (particularly in the USA) can be avoided.

We also need a reliable **data transmission system** that is capable of transmitting 50 kByte/s reliably from the central computer to the individual vehicles and, as will be seen later, transmits data also in the reverse direction, i.e. from the vehicle to the central computer.

As a third component, **in-vehicle units** are required which must at least execute the following functions

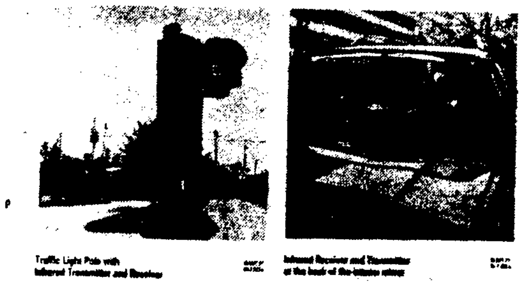
- Receiving/transmitting data
- Processing received data and providing a **simple** and **clear** display of guidance recommendations. Parallel to this, providing an audible announcement of the display's contents.
- Navigation because the vehicle has to know at all times w h e r e it is located and in what direction it is looking.



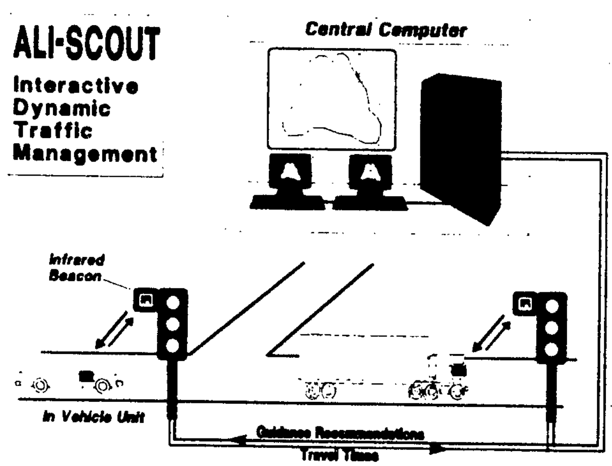
"Please turn right after approx 200 m (= 5 horz. bars)". Distance as the crow flies to your point of destination is 1.18 km. Programmed destination: Airport (Flughafen)
(Picture Bosch)

2. **How is data exchanged between the central computer and vehicle?**

All essential traffic lights in the road network, generally 20-25 %, are assigned a fourth color "infrared" which the in-vehicle unit is capable of "seeing" and recognizing. It is an infrared transceiver, an **infrared beacon** which is connected to the central computer by cable.



Its counterpart, an infrared receiver/transmitter is located in the vehicle, behind its interior rear view mirror.



When a vehicle approaches an intersection, infrared contact lasting a few seconds now occurs (as soon as the vehicle has entered the infrared beacon's illumination area) to allow all data to be exchanged several times over. This takes place every time the vehicle passes a beacon and any number of times until it has arrived at its destination.

As already mentioned, reliable data communication between the central computer and vehicle is an indispensable pre-requisite for reliable and sure guidance of vehicles.

Basically, there are various possibilities of communication between a vehicle and a road network's infrastructure, but **infrared technology is far superior** to all other technologies.

3. Where does the central computer now continuously receive data concerning the actual traffic situation from?

Quite simply, from the vehicles themselves! This is because the vehicles function as traffic measurement probes.

By way of the infrared communication link, they continuously report to the central computer about their journey and queueing times in the road sections they have passed through, i.e. from one beacon to the next (see fig. of section 2).

It is important to point out that this is done completely **anonymously without any identification of vehicles.** So, nobody needs to fear that "big brother" might be watching.

4. Dynamic Route Guidance - fiction or reality?

All what has been mentioned above can be found in the dynamic route guidance system **ALI-SCOUT.** Under the name of **LISB**, its basic functions have already been undergoing trials for more than 2 years now in the entire city of **West Berlin.**

250 of the existing 1200 traffic lights of Berlin have received the "fourth colour" i.e. are equipped with infrared beacons and approximately 1500 km of the existing street network are digitized for guidance. 700 in-vehicle-units have been distributed to representative users. Final results of this large scale field trial are scheduled to be available by the end of 1990. The aims of LISB are to obtain sufficient information about:

- technical operability

- acceptance and

- traffic engineering benefit

of a traffic guidance and information system known in Great Britain under the name of AUTOGUIDE. It is interesting to note that AUTOGUIDE will be based on the same technical principles as ALI-SCOUT (LISB).

The LISB trial in Berlin is being sponsored by the German Federal Ministry of Research and Technology and by Berlin's Senate. It is being conducted by the Bosch and Siemens companies and involves decisive cooperation by the Studiengesellschaft Nahverkehr (SNV) and the Technical University of Berlin. The trial is being supported by the motorvehicle manufacturers BMW, Daimler-Benz, Opel and Volkswagen as well as by Mannesmann-Kienzle.

5. What else can we expect from a dynamic route guidance system?

At the beginning, it was mentioned that such a system offers more than "o n l y" optimally guiding individual vehicles to their destination. Systems like **ALI-SCOUT** influence the complete traffic process.

Solely by virtue of the fact that vehicles are guided **in the shortest time**, many of them are diverted around arterials on which traffic becomes dense and where congestions may occur. In many cases, such diversion is capable of preventing congestions from actually occurring, i.e. **the traffic is kept fluid!**

Now, if we also optimize traffic lights' green phases on the basis of guidance recommendations, we have taken a further step towards **making traffic more fluid.**

Who has not already been in a situation, where, having lost one's way, one only encountered people who were also unfamiliar with the place? It couldn't be different according to Murphy's law (anything that can go wrong will go wrong)!

The result certainly was annoyance, stress, lost time, unnecessary fuel consumption and pointless clogging of roads. ALI-SCOUT prevents all that because one is guided directly to its programmed destination.

In the future, ALI-SCOUT will also be able to provide a similar service in assisting drivers to find a parking space. They will be able to avoid stressful roving about in their cars and desperate searching for a free space if they ask the central computer beforehand from their in-vehicle units about what car parks still have free parking spaces. If booked remotely through the existing communication system between the vehicle and central computer, a parking space can even be firmly reserved. Drivers can then relax and have themselves guided to the appropriate car park.

However, if there is no parking space available at all, the driver would be offered the nearest P&R possibility including information about public transport to his point of destination.

Not only individual ALI-SCOUT drivers will therefore benefit from these and further services. The public at large will profit, too.

Guided vehicles will spend less time on roads that are far too clogged anyway, traffic will be more fluid, fuel consumption and consequently the burden on the environment will thus be reduced.

6. What about the possibility that ALI-SCOUT can also promote the enforcement of public traffic policy measures?

In most countries, the infrastructure, i.e. the central computer, the data transmission system and the infrared beacons, will be public property.

If now we take a look at the central computer in its true dimension, we discover a highly intelligent data base with which whole traffic processes can be managed without having to frighten individual road users with prohibitions and restrictions.

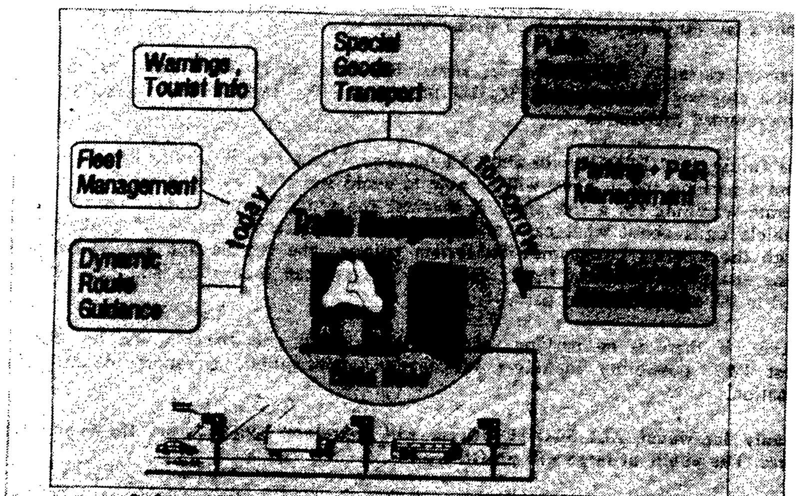
For example, the central computer only needs to be programmed accordingly if it is intended to divert traffic past schools in the mornings and the midday hours. The guidance instructions computed by it will then simply divert drivers around such arterials.

A similar situation is conceivable for hospitals, old folks' homes and residential areas etc. Traffic flows will be displaced depending on requirements.

If public authorities wish to particularly **promote local public transportation**, for instance, and restrict individual traffic to a greater or lesser extent depending on requirements, buses and trams can transmit green phase demands from the in-vehicle units to control traffic lights so as to visibly put individual cars at a relative disadvantage.

Who would not seriously consider then changing over to the much faster local public transport, particularly if public transport vehicles also have special lanes and are punctual?
By means of interactive dialog with the central computer, delayed buses or trams could catch up with their timetables relatively easily by controlling traffic lights variably.

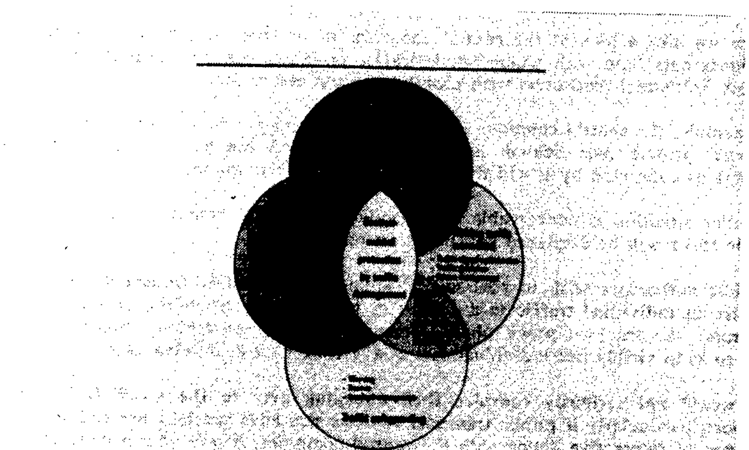
So, as far as **individual road users** are concerned, local public transport can be made attractive enough as an alternative that one will make use of it.



Interactive Dynamic Traffic Management

Unfortunately, such an alternative is not available for **goods delivery traffic**. In this case, we can only come to terms with the increasing flood of road-jamming vans by enabling tours to be planned as a function of the traffic load (currently also being tested in Berlin) or by rationally combining goods for delivery. The **ALI-SCOUT** data base is potentially prepared to meet also these requirements.

Further traffic policy measures which can easierly be enforced with the help of **ALI-SCOUT** freely acceccible data bases are shown in the following picture.


Task of an Interactive Dynamic Traffic Management System

Other selected services which will be standard in ALI-SCOUT of the future, but which are to some extent already being tested today in Berlin, are **automatic transmission of hazard reports concerning black ice, fog or accidents etc., tourist information** at the driver's recall or quite simply "where can I find the next open filling station after 10 pm?".

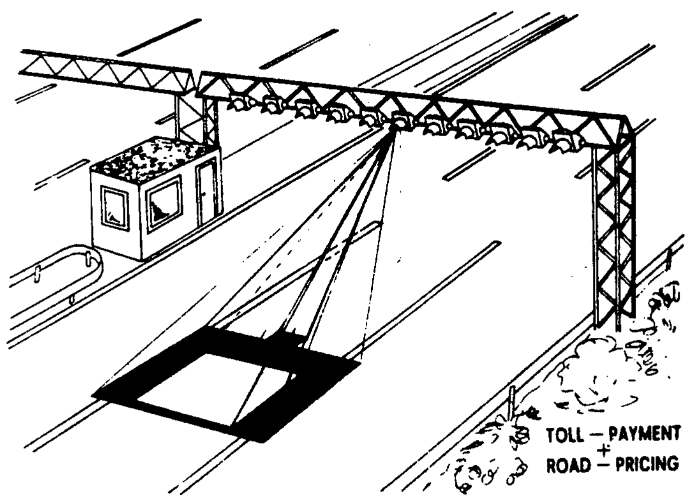
The possibilities of ALI-SCOUT are far greater than only **dynamic vehicle guidance. It is a** genuine system for

Interactive Dynamic Traffic Management

and represents an outstanding instrument for public authorities to enforce their traffic policies "**by offering convincing alternatives and citizen oriented new services**".

7. What about Toll Payment and Road Pricing?

The last point to be briefly mentioned here is the possibility of paying tolls for the use of traffic routes via the infrared connection and **at an unreduced speed. The figure shows the** principle configuration which is actually being tested at speeds of up to 160 km/h.



As soon as a car enters the big area of the a. m. figure "infrared radio contact" is established. Toll payment takes place when the vehicle is within the inner area and final check is performed when leaving again the "contact area". Above mentioned areas are overlapping on the left and right hand side to allow multi-lane operation and not giving any possibility to cars to sneak through without payment.

Today, this technology could help to reduce the endless queues waiting at motorway toll booths, but in the near future it will perhaps be one of the few or even the only technology which will enable the inevitable

r o a d   p r i c i n g

to be handled practically.

TRAFFIC CONTROL USING ARTIFICIAL INTELLIGENCE

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Introduction

Congestion of the urban road network is one of the most important problems facing traffic engineers today. Construction programmes aimed to ease congestion will only accommodate a fraction of extra demand imposed upon the road network. Coupled with the increasing awareness of environmental issues, it has never been more important to find alternatives to highway construction to solve the problem of congestion. It is now imperative to ensure that maximum use is made of the existing highway network.

The implementation of artificial intelligence (AI) based traffic control systems could directly improve transport efficiency through reduced congestion. Environmental pollution effects could be minimized through the adoption of suitable control strategies by the expert system. Greater efficiency resulting from congestion reduction could also lead to improvements in European road safety standards.

This paper has been prepared as a result of work carried out in the DRIVE programme's Artificial Intelligence Based Systems for Traffic Control project. It presents some of the issues that have been raised in this project in the development of an expert system for traffic control. This introduction is followed by a short background section, which reviews the main objectives of the project, presents a discussion of some of the problems encountered in applying artificial intelligence to traffic control, and finally, provides some conclusions and recommendations. The main finding of the project to date is that although expert systems are attractive and potentially powerful, they must not be regarded as a panacea. Careful task analysis and development processes must be incorporated into the construction of an effective expert system in this domain.

The main objective of the Artificial Intelligence Based Systems for Traffic Control project is to delineate techniques for the application of AI to traffic control problems though the development of an expert system. Expert systems for traffic monitoring and control will aim to assist, supplement and perhaps eventually replace police and highway personnel who currently staff motorway and urban traffic control centres. There are several reasons to expect substantial benefits from this approach. Firstly, staffing of control centres is very costly, due to early and late shift working. Some centres are left unstaffed at nights and weekends due to the high cost of labour. Expert systems could relieve pressure on staff at peak periods and take over certain functions entirely at other times.

Another difficulty with conventional traffic centre staffing is boredom. For much of the day, sometimes for whole days at a time, events are very predictable. Operators who are supposed to watch TV monitors have little or nothing to do, and may therefore fail to notice a real incident when it occurs. Although some systems incorporate alarms to draw operators' attention to congestion, alarms become routine and are again ignored. An expert system could take over routine monitoring and make intelligent decisions on when to involve a human operator. Eventually, the system might be allowed to implement its own responses to incidents, without human intervention.

A final limitation of current traffic control centres is the difficulty of attracting skilled staff. Because of the unsocial hours and boredom, it may be impossible to employ highly skilled experts in the field of traffic control. Control strategies are so complex within large metropolitan areas that semi-skilled operator intervention may make matters worse over the network as a whole. Even where highly trained staff are available, it is difficult for them to be sure whether a particular change is an improvement overall. An expert system for traffic control would be better able to take an overall view in real-time than is possible for any human operator. The expert system should be able to identify, with the help of a traffic management system, when the impact of the selected strategy would make recommendable the use of other policies such as rerouting, and which one to use.

The Expert Control System will enhance current traffic control systems in controlling undersaturated networks by building up a knowledge base, learning engineering judgement and monitoring performance of the network. Furthermore, when congestion occurs the Expert Control System will override the usual control procedures to restore normal conditions as efficiently as possible.

The four main areas where significant development has taken place are:

* developing procedures enabling inference to be made about traffic conditions on the basis of incomplete or incorrect data;

* defining the key information required to select or determine an appropriate traffic control strategy;

* designing and building a congestion knowledge base for use by the expert system; and

* designing the appropriate interfaces.

Three major problem areas can be identified in the work that has been carried out on the project to date. These problem areas can be categorised as:

* interfacing;

* knowledge engineering; and

* future evaluation .

Interface Issues

An expert system that is required to make sensible decisions about traffic conditions needs a constant stream of relevant traffic parameters in real time as input. The choice of these parameters, such as traffic flow or occupancy, determine how the interfacing software is designed.

At present there is no software available that is capable of performing the interfacing function between a data manipulation device such as an expert system, and the traffic control system itself. There are several reasons why this sort of generic interface is implausible. Firstly, there are many different manufacturers and designs represented in traffic control systems installed throughout Europe. Within the broad categories of traffic control systems, such as fixed-time and adaptive systems, there are many different variations in the designs. Although efforts are being made to produce standard specifications for traffic control systems there are still wide variations. This means that there are widely differing software demands placed upon potential interfacing programs.

A second problem that often arises relates to the number of traffic sensors that a control system utilises. This figure will vary according to the type of system and the geography of the city in which they are employed. A typical adaptive traffic control system, such as the SCOOT (Split, Cycle and Offset Optimization Technique) system, will employ in the region of 200 to 500 sensors. A fixed-time system, on the other hand, will employ few, if any sensors at all, relying on historical data input instead. The combination of a highly variant total number of sensors and a fixed or continuous time parameter creates formidable problems for the software engineer.

Once the data has been collected from the traffic control system it requires pre-processing or 'cleaning'. Castle Rock Consultants has developed a software package which will clean, manage and manipulate traffic data in order to monitor the state of the road network and identify problems as they occur. By employing suitable indicators, events can be detected which require expert system action.

The data processing, manipulation and cleaning software is required to detect unusual events by comparison with established cycles and trends contained in archived data files within the software. These typical profiles are developed through an analysis of the on-line data. Once the processing is complete, the data are buffered in a format suitable for the knowledge base system to use and for the second level of software concerned with displaying the parameters.

A software functional specification was first developed, detailing the operation of the software and describing the methodologies adopted. A top-down functional systems approach was utilized in this development process. For enhanced system operation and flexibility, the software was designed to potentially operate in a real-time environment on a PC, using the 'C' language.

The software specification detailed the main activities associated with data cleaning that could be utilized by the expert system. The first of these is faulty data identification based on previous trend assessment or network data consistency. The second is data substitution for faulty data using historic averages. The cleaning procedure can be performed automatically, or by request.

To operate the software, the user needs to specify a number of operational parameters which are stored in a configuration file. These are concerned with setting thresholds and whether to clean or substitute the data. For on-line output to the expert system, flags are set if values lie outside the thresholds specified in the configuration file.

The interfacing discussed above is solely concerned with a one-way link from the traffic control system to the expert system. Whilst this link is essential, the existence of a link from the expert system to the traffic control system is significantly dependent upon the role defined for the expert system. An expert system for traffic control can be used in at least two ways; in a controlling capacity or in an advisory capacity. An expert system used in a controlling capacity is fully integrated into the traffic control system and requires a link from the expert system to the traffic control system. This link is used by the expert system to alter system parameters and thus effect change in the traffic network without the intervention of a human controller.

Alternatively, the expert system can be utilised in a more traditional capacity as an advisory tool. In this role the system presents the human controller with a detailed description of the situation plus a recommended course of action and a limited explanatory capability. This does not necessarily require a link back to the traffic control system as any remedial action can be instigated by the traffic engineer.

Knowledge Engineering Issues

Knowledge engineering is possibly the most important aspect of the development of any expert system. The task of the knowledge engineer is to collate all the important knowledge required for successful operation of the system and then to encode it in a knowledge base. The transfer of an expert's knowledge into a form that can be used in an expert system is now widely agreed to be an extremely costly and unreliable process. One of the major reasons why knowledge elicitation (KE) is difficult is that no received wisdom about how to go about the process exists. If knowledge engineers are not able to go to a body of knowledge on how to proceed in elicitation, the process will inevitably be a hit or miss affair that could be very costly in terms of time spent performing the elicitation task.

Experts sometimes find it difficult to explain why they have taken a certain course of action. This is consistent with the finding of previous research which found that automatic processes do not require attention and are unavailable to introspection. It has been claimed that cognitive skills become grouped together and individual steps cannot be identified. In a similar vein, an increase in expertise is correlated with a decrease in the ability to express the knowledge.

If experts are able to express themselves they may give totally misleading reasons for an action. This is an example of cognitive dissonance. An expert may feel uncomfortable when made aware of an action for which there seems no apparent reason and may therefore invent a justification for that action. The whole tradition of behaviourism in psychology does not regard self report as a valid measure of behaviour, recognising the difficulty of getting an objective measure of validity from introspection. These are important reasons why knowledge elicitation is costly in terms of the time taken up in consultation with experts and in knowledge engineering terms to implement what is usually a rich and diverse data source.

Expert knowledge for encoding can be derived from a variety of sources which include:

* literature reviews;

* observation of behaviour;

* various forms of interview with domain experts; and

* formal elicitation techniques.

It is rare that literature is sufficiently concise to provide the type of knowledge required for an expert system. The objective of the knowledge elicitation task is not to discover mature cognitive structures, but is to glean those facts and procedures that have a direct relevance for problem solutions in a particular domain. Literature reviews are of course a good starting point and should not be completely disregarded. Observing the expert carrying out his job is a useful task that can uncover many informal procedures and protocols that could be otherwise missed.

In the development of the expert system, detailed observation of traffic controllers using the SCOOT system was carried out. Observation techniques need to be backed up with the use of interviews, and preferably formal elicitation techniques, both with domain experts. There is strong evidence to suggest that a very structured interview forces the expert to give precise answers and formulations which are of considerable help in the subsequent encoding of the knowledge base.

Structured interviews require the interviewer to limit questions to explicit forms such as "Why did you ......" as opposed to "Tell me everything you know about traffic management". Consultations with experts are costly affairs and it is therefore imperative to ensure that the expert rigidly sticks to relevant information. Much of what a traffic engineer has to do is repetitive and therefore does not make for an interesting interview. However it is vital to glean this routine information and not so important to listen to anecdotes about freak events.

A problem associated with the use of any formal knowledge elicitation method is that there does not exist any formal technique to deal with real-time continuously changing events. This has meant that a combination of the approaches mentioned earlier have been used to develop the knowledge base. For the development of the expert system discussed here, this problem was minimised due to the fact that many of the personnel involved in the system development are themselves experienced domain experts.

A second issue which has arisen in the development of this system and arises generally in the field of expert systems concerns the nature of the expertise that the knowledge engineer encodes. It may seem obvious to state that the success of an expert system is fundamentally dependent upon the capture of true domain expertise in the knowledge base. This is, however, a non-trivial problem and one that has not been adequately covered in the expert system literature. This is especially important in the field of traffic control where many authors recommend the use of expert system technology in traffic control because the problems facing the traffic engineer are complicated and ill-defined, lacking explicit numerical algorithms. It is precisely for this reason that it is essential to identify and consult true domain experts in the development of the knowledge base.

This has serious implications for the choice of methodology in the area of traffic control. The intuitive solution is to consult the personnel responsible for operating urban traffic control centres. These staff have responsibility for changing fixed time plans or overriding the traffic control systems to accommodate flow fluctuations. It is clear that this operator intervention in the traffic control system is not always effected in a principled fashion. As it is imperative that the expert system has expert knowledge, the lack of consistent human intervention strongly implies that experts with a deeper understanding of traffic control systems need to be consulted in system development. This problem has been overcome within the framework of the DRIVE project discussed here by consulting traffic control experts within the consortium.

Future Work

Much of the expert system definition for the Artificial Intelligence Based Systems for Traffic Control project has already been accomplished. The last definition task that needs completing before prototyping can commence is the congestion strategy rule set. This task essentially involves the coding of ready articulated knowledge into the AIDA language rule format. Once completed the expert system prototypes will be developed. These will be evaluated using simulated conditions. As with any software that is potentially safety critical, rapid prototyping is only feasible using simulated conditions. The consortium has direct links into fully-adaptive traffic systems and so can use real data to test the performance of the expert system. This solves what could have been a significant evaluation problem, enabling project results to be given meaningful interpretations.

Conclusions

The results emerging from the development of this expert system are clearly indicating the potential efficacy of using an expert system for traffic control. During the planning and definition phases of this project issues such as interfacing, the nature of expertise and where the expertise is really to be found, have been confronted. This has proved to be a valuable exercise and has helped immeasurably in the development of the system. The clear insights into what is really happening in expert decision making will be transferable to other expert systems developed for traffic control and should serve to make the development of future systems considerably easier.

Artificial intelligence techniques have proved to be useful tools in helping to solve traffic control problems. What has been learnt is that these techniques are only powerful when the problem that needs to be solved is clearly defined. Combining the expert system technology with other technologies such as route guidance and pollution prediction, the system will provide a powerful tool in managing and controlling the road network into the next decade.

THE PROGRESS OF TRAFFIC CONTROL AND SURVEILLANCE TECHNOLOGY IN JAPAN

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90310

The Japan Traffic Management Technology Association of our organization was founded in 1978 with the authorization of National Police Agency of Japan and by the financial support from private companies.

Our main activities are to conduct and promote the research and development of road traffic control technology and system, thereby substantially contribute to the traffic administration of Japan.

Japan Traffic Police performs administrative functions on road traffic control, and main roles are

. establishment of road traffic law and regulation
. traffic safety education
. traffic enforcement
. installation and maintenance of traffic safety facility and control equipment
. collection and provision of traffic information
. issue and control of driver's license
. supervision of driving school

This report describes the recent development of traffic control and surveillance technology which is one of the high-lighted results in our activities.

In the society of motor vehicle, traffic problems are becoming worse in every country as the common social topics.
In our country, big cities are now in serious condition on traffic circumstances due to high density population, continuous rise of land price, difficulty of keeping new traffic road, remarkable increase of transportation demand, etc.
As a typical example which shows the above situations, we explain you two figures on the trend of traffic conditions in Tokyo and average travelling time at national roads as below.

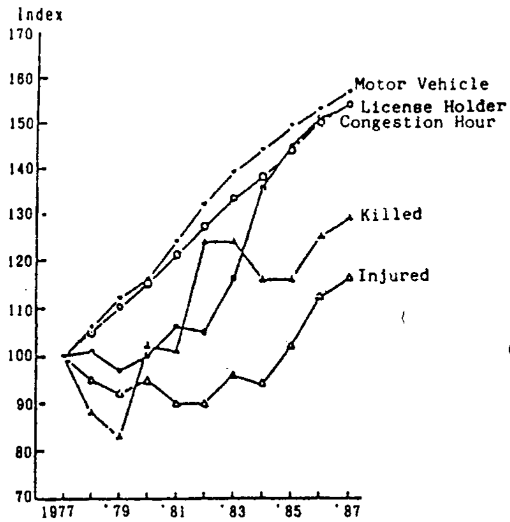

Fig. 1 Traffic circumstances
Tokyo Metropolitan Area
(Police Traffic Annual
Report 1987)

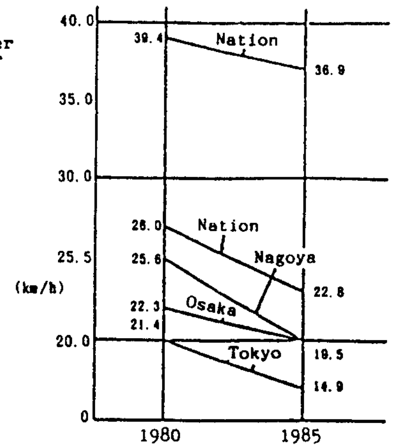

Fig. 2 **Average Travelling Speed (Peak time)**
(Road Traffic Census)

Our country facing to the very severe condition in traffic has established in the 1960's Traffic Control and Surveillance System in major cities and on expressways as a leading method to enhance the efficiency of existing roads.
Since then, various improvements have been made, and this system is now working in 74 major cities and important locations on expressway.
Various sizes of Traffic Control and Surveillance System in cities are managed by police departments.
The oldest center was built more than 20 years ago, and some systems are renovated in order incorporating recently developed electronic technology and concept in new age.
In Japan, the major function of existing system is the traffic signal control, and with the traffic information collected by this system, we make use of traffic regulation activity on site and traffic information supply activity - that means so called the Total System for traffic control. -

So, we would like to introduce the system in Tokyo Metropolitan Police Department.
The Traffic Control and Surveillance System calculates the queue length of cars and the degree of traffic condition basing upon informations on traffic volume and speed collected by vehicle detectors installed at the road side.
It controls traffic signals on line so that the traffic flows in the most appropriate manner.
At the same time, such traffic congestion information collected is displayed on the Traffic Information Display Board in police department (in three kinds of different colors on a schematic road map).

The traffic control officers comprehend a total traffic control and provide informations to radio broadcasts and publics.
Moreover, they supply traffic informations to the vehicle driver through information boards or road-side broadcasting systems.
The basic concept of the Traffic Control and Surveillance System is illustrated in Figure 3.

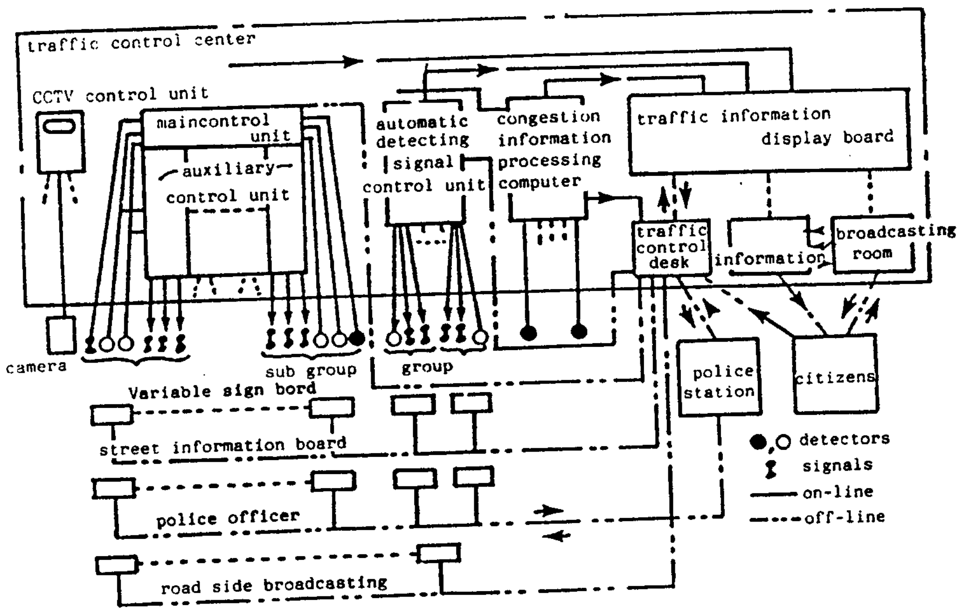

Figure 3 Schematic Diagram of Traffic Control and Surveillance System

The traffic signal at about 12,000 intersections is installed in Tokyo Metropolitan Area, and more than 6,000 are integrated into this system. Informations on accident, road repair and temporary traffic regulation are input to the system manually and are also displayed on the Traffic Information Display Board.

The equipment layout in the center and the system scale are shown in Figure 4 and Table 1.

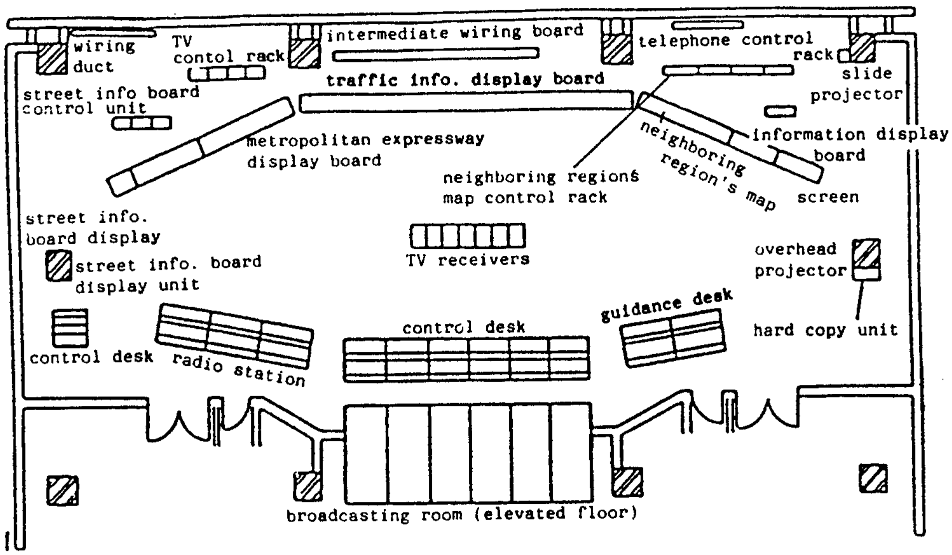

Figure 4: Diagram of Equipment at Tokyo Metropolitan Trafic Control Center

Table 1: Scale of Traffic Control and Surveillance System of Tokyo Metropolitan Police Dept.

component	scale
centralized control signal	6275 (out of 12,660) intersections
vehicle detector	6172
intersection with information on board	461
TV monitoring camera	93
TV receiver	20
mainframe computer	1 unit ACOS 550 x 1
medium size computer	26: NEAC 3200 x 7, Model MS x 19
minicomputer	22: NOVA x 19 etc.
equipment floor space	1380 m^2
No. 1 equipment room	430 m^2
No. 2 equipment room	330 m^2
traffic control and surveillance center	320 m^2 (excluding broadcasting room and office room)
broadcasting room	8 rooms (with 6 occupied)

Today, the renovation for Traffic Control and Surveillance System is being made in Japan nationwide, and the conventional system will undergo a big change in a several years.
In Tokyo, for example, we will construct an integrated intelligent building by 1994 to be the center of brain in police activities as well as traffic controls, and a new Traffic Control and Surveillance Center will be located in this building.
Our association is now developing the new design concept of this system entrusted by the Tokyo Metropolitan Police Department.

Here is the introduction of interesting points in both hardware and software on the basic approach of system design and the induction of newly developed technology.

(1) The current Traffic Control and Surveillance System is basically composed of Signal Control System in the middle.
And the new system, however, sets up the Traffic Information Data Base in the center and surrounds with the Signal Control System, the Information Providing System, the Information Exchange System, the Traffic Flow Simulation System, the Multi-Function Console (which can analyze and evaluate the traffic conditions) and the Large Scale Information Display Board.
Computers of this system will be inter-connected with so called "LAN" and can be operated as the key brain of the traffic management.

(2) For the effective operation of Traffic Information Data Base, we are planning to keep the data processing capacity to be able to respond the increase of vehicle detector.
And at the same time, we introduce Semi-Microwave Sensor which has functions of both location information supply and vehicle detection, Image Processing Sensor and License Plate Reading Device.
Moreover, we will have the information exchange function with traffic control centers of neighboring prefectural police departments and other authorities.

(3) The new Signal Control System adopts the control mode used with the saturated traffic flow rate and the figure of queue length, and aims to enhance the signal control capacity in heavy traffics.

(4) The system has the function to indicate the matters which disturb traffic flow (such as extraordinary traffic conditions in accident or disaster, chronic traffic congestion, traffic becoming congested, illegal parkings), and combines the Digital Map Information Data Base under development.

(5) This system evaluates in advance the efficiency and/or result of various traffic measures by accomplishing the traffic flow simulation function.

(6) This system is also useful to support traffic police activities such as the detection of hell-rider groups or signal violating cars.

(7) The system is going to integrate into systems for other police activites such as drug or criminal investigations for which such police officers must keep in their minds the traffic matters.

(8) The large scale traffic information display board will use LED (Light Emitting Diode), LCD (Liquid Crystal Display) or High-Definision Rear-Projection Display instead of incandescent bulb.

(9) The terminal equipments are able to perform the control function more efficiently by using microcomputers.

With the above idea, we start to work the design for the new system aiming the traffic management technology to the 21st century.

The Traffic Information Providing System called as AMTICS (we present our project in separate session of this ISATA conference) has been also developed by our association and is going to connect with the above Traffic Control and Surveillance System.

By providing the traffic information through the Information Data Base as described above, functions of AMTICS such as vehicle location and real-time traffic information are brought into better scope, and we are able to induce the dynamic route navigation system into AMTICS as our ultimate target.

And it is expected to develop new concepts of the Traffic Management on the optimal distribution in trafic flow.

DEVELOPMENT OF A ROUTE GUIDANCE SYSTEM
(AN ON-BOARD SYSTEM USED IN RACS)

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Abstract

With the aim of studying a new communication system between roads and automobiles, we have been participating in a joint research program(RACS) of the Ministry of Construction, the Highway Industry Development Organization, together with other private enterprises since April, 1986. Our system has the following four functions.

1) Vehicle location using a combination of dead-reckoning, map-matching, and beacon location
2) Maps and other information displayed on a CRT screen
3) Optimum route guidance using traffic information received via roadside beacons which is shown on a head-up display
4) Message communication via two-way beacons

The system description and its evaluation is introduced in this paper.

1. Introduction

The creation of an enjoyable environment for driving naturally requires the construction and maintenance of a network of high-quality roads. At the same time, another important issue is to improve and expand navigation systems and systems for providing road and traffic information. These systems are closely related to the aspects of road and traffic administration and operation and will promote more effective utilization of roads and highways.

In view of this situation, a joint research program concerning a Road Automobile Communication System was launched in April 1986 by the Ministry of Construction's Civil Engineering Research Laboratory and 25 private companies. Throughout this program, Nissan has been involved in research dealing with the on-board equipment, particularly the route guidance system.

This paper presents an on-board route guidance system which was developed for use in a pilot experiment carried out during the third year of the RACS program.

2. Objectives

Nissan has already developed and commercialized a standalone navigation system, called a Multi-AV System, which incorporates map-based navigation functions and audio-visual functions. This system is featured in the 1989 and 1990 Cedric, Gloria and Cima models and about 1,500 units of the system are sold per month.

The route guidance system for the RACS program was conceived of as a future version of the Multi-AV System. It has been developed with various advanced functions in order to fulfill the following development objectives (Fig. 1).

(1) To construct a system capable of receiving traffic and positional information from roadside beacons and of providing two-way individual communications with other terrestrial stations.
(2) To include in the system a head-up display for showing information received from roadside beacons in a safe, easy-to-understand manner without requiring a large shift in the driver's line of vision.
(3) To achieve a route guidance system that would safely and accurately guide people to their destinations, including even those unfamiliar with the freeways of the Greater Tokyo area where the pilot experiment was scheduled to be conducted.
(4) To examine the transmission/reception performance of two-way beacon communications equipment using the quasi-microwave band and to clarify any problems that might occur in using the system in production vehicles.

3. System Functions

3.1 Overview

The system offers five different modes including an audio-visual mode, map mode, information mode, route guidance mode and two-way individual communications mode. The audio-visual, map and information modes are incorporated in the Multi-AV System now offered in certain Nissan models. The route guidance and two-way individual communications modes are functions that have been newly developed and added to the present system.

Fig. 1 Appearance of on-board system

3.2 Audio-visual mode

The audio-visual mode includes four submodes for the radio, TV, CD player and cassette tape deck. The desired submode is selected by pressing the corresponding control switch in the same way as for conventional car audio equipment. In the TV submode, only the audio portion is provided while the vehicle is moving and the video portion is not shown for the sake of safety.

3.3 Map mode

In this mode, the present position of the vehicle and its direction of travel are indicated on a map display shown on a CRT screen. Once the present position has been entered, such as at the time of purchase, it is continually calculated thereafter as the vehicle moves. The vehicle's location can be displayed at any time just by selecting the map mode. When the map control switch is pressed, the screen display immediately changes from any of the other modes to the map mode.

3.4 Information mode

This mode displays the addresses and telephone numbers of golf courses, hotels, department stores, marinas, Japan Automobile Federation (JAF) offices and Nissan dealers. After the information has been retrieved, the location can be displayed on the screen map (except for the JAF offices) and selected as the destination.

3.5 Route guidance mode

The system switches to the route guidance mode when a destination is entered from the map mode menu. In this mode, the information needed to guide the driver to the destination is mainly displayed using the HUD. Maps, the vehicle's present position, selective roads and other supplementary information are shown on the CRT screen. In other words, the driver can reach his destination safely and quickly by following the information shown on the HUD. The route guidance function is achieved by means of the following five capabilities.

3.5.1 Route selection

After a destination is input, the system selects the optimum route there, taking into account traffic congestion along the way based on traffic information received from roadside beacons. The best route is selected using an algorithm for calculating the shortest distance to the destination. To make sure the optimum route is selected, a procedure is provided whereby distances are weighted according to the type of road to be taken and the degree of congestion present. The names of major intersections along the selected route and railway lines to be crossed are displayed on the CRT screen. In addition, the intersections along the way are indicated on the screen map display by means of red circles. (Fig. 4). The direction to the final destination from the present location and the straight-line distance are also indicated on the CRT screen.

3.5.2 Autonomous guidance

This function guides the driver from the present location to the starting-point intersection (the first intersection on the route) and from the last intersection to the final destination. This is accomplished by means of arrow indicators shown on the HUD which point out the direction to the starting-point intersection or to the intended destination. An example of an arrow indicator is shown on the right side of Fig. 5.

3.5.3 Starting-point intersection guidance

When the vehicle approaches within 500 meters of the starting-point intersection, the direction to the intersection, the proper lane to be in and the name of the intersection are shown on the HUD. As illustrated on the left side of Fig. 5, the lane the driver should be in is indicated by hatched markings, which serve to provide lane guidance and also indicate the direction in which the driver should go.

3.5.4 Advance display of upcoming intersection

The next action that the driver should take is displayed in advance when there is a long distance between intersections. The advance notice is shown on the HUD and consists of a simplified display of the intersection shape and the direction to take. While this advance notice is being displayed, the driver can choose any traffic lane and knows ahead of time what action to take at the next intersection (Fig. 6).

3.5.5 Direction indication at intersections

As the vehicle approaches an intersection along the selected route, the shape of the intersection, name, direction to take, lane to be in, distance to the intersection and the relevant roadside information are shown on the HUD (Fig. 7). When there are two adjacent intersections, both can be displayed in one HUD image. In addition, after the vehicle has passed through the first intersection, the HUD image scrolls so that the driver continues to receive accurate information as to whether he should turn left or right and so on. The bar graph (Fig. 7) indicating the approach to the intersection is designed so that another line is added every 50 meters. This distance was chosen in consideration of the resolution of the HUD and the position detection capability of the system.

3.5.6 Lane change indication

A lane change indication is shown on the HUD when the driver should be in a different lane so as to be in the right position to execute the next driving maneuver smoothly. The lane configuration, lane to be in and the approach to the point where the lane change is executed are displayed on the HUD (Fig. 8).

3.6 Individual communications mode

The individual communications mode in RACS supports various forms of communication including short and long text messages, facsimiles, images and voice messages. Since this route guidance system was intended for use in passenger cars, it provides only text messages. While the scope of communication is limited, this mode has been designed so that communication can be accomplished through simple operations without affecting driving safety. Specifically, incoming messages received from roadside beacons are displayed on the CRT screen and the driver can respond by simply pressing the YES or NO switches. Outgoing messages from the vehicle are sent by selecting a predetermined message prepared in advance (Fig. 9).

3.7 Other functions

The system developed for use in the RACS pilot experiment has also been provided with a function for automatic vehicle monitoring and automatic vehicle identification. When a vehicle enters the communication area of a particular roadside beacon, its identification code is sent to the control center and processed automatically for use in the individual communications mode. On the basis of the vehicle identification code and the beacon number, the control center can confirm the vehicle's present location (i.e. which beacon it passed last) and measure the traveling time of particular vehicles between two beacons. That information enables the control center to monitor the flow of traffic.

4. Principle of Position Detection

4.1 Overview

In this system the position of a vehicle is determined using dead-reckoning technology as well as a map-matching technique and a beacon position orientation method. Dead-reckoning is accomplished by means of a geomagnetic sensor and wheel speed sensors, and the map-matching technique includes an automatic error correction capability.

The reading of the geomagnetic sensor is automatically corrected for the magnetization of the vehicle which occurs when it passes through a strong magnetic field, such as that of a railway crossing. In addition, the readings of the wheel speed sensors are also automatically corrected during driving to take into account tire wear.

4.2 Dead-reckoning calculation procedure

The bearing of the vehicle is calculated from the distance traveled, geomagnetism and the differential rotational speed of the tires. The result of the bearing calculation is successively integrated per unit of distance traveled to yield the present position of the vehicle. It should be noted that the absolute bearing is found with the geomagnetic sensor while the distance traveled and changes in bearing, reflecting differences in tire revolutions, are found with the wheel speed sensors.

4.3 Beacon position orientation method

The roadside beacon communications equipment uses the quasi-microwave band and employs an reverse amplitude modulation method for transmitting position orientation signals. This method assures the largest possible communications area and it also supports accurate position detection. With reverse amplitude modulation the modulated data signal is split into two portions, as shown in Fig. 10. Amplitude modulation is superposed on each portion such that their phases are mutually opposite and the signals are transmitted using two antennas. As a result, the modulated data component of the signal transmitted from each antenna is the same, but their amplitude components have opposite phases.

Fig. 2 Map mode screen display

Fig. 3 Selective road screen display

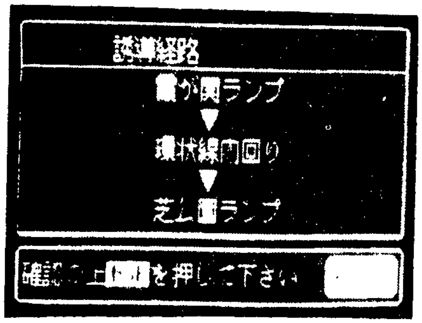

Fig. 4 Selected route screen display

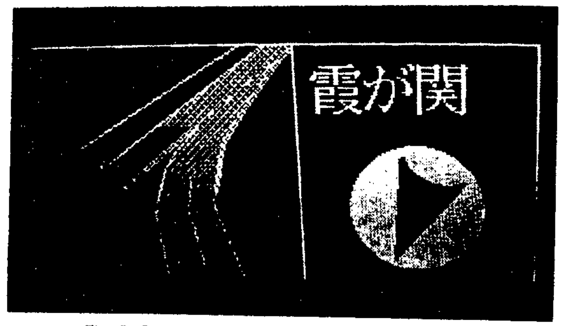

Fig. 5 Guidance to starting-point intersection (HUD)

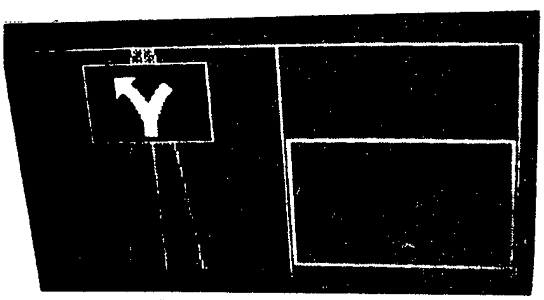

Fig. 6 Advance notice of intersection (HUD)

Fig. 7 Screen display for intersection guidance (HUD)

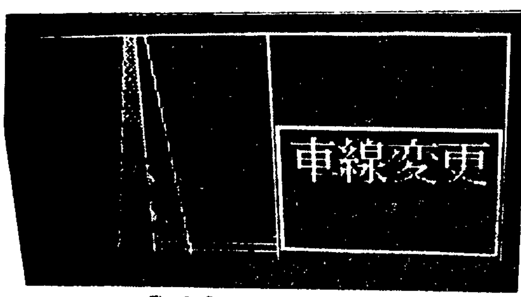

Fig. 8 Screen display for lane change (HUD)

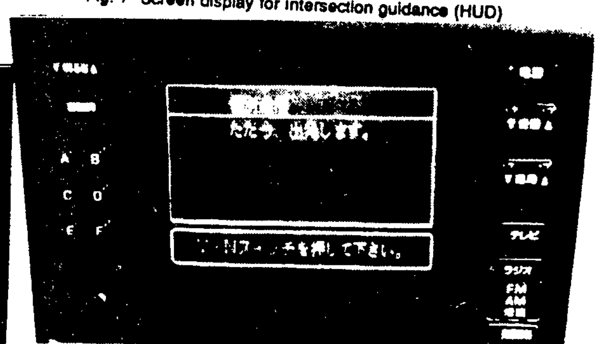

Fig. 9 Individual communications mode

When the signals are received by the on-board beacon communications equipment, the amplitude components are canceled out directly under the beacon antennas. Consequently, that location can be used to detect the position of the roadside beacon. Coordinate data and other positional information are included in the modulated data portion. Based on the timing of position orientation, the position of the vehicle is corrected by replacing the positional data in its navigation control unit with the coordinate data.

The use of this method together with the map-matching technique dramatically improves position detection accuracy.

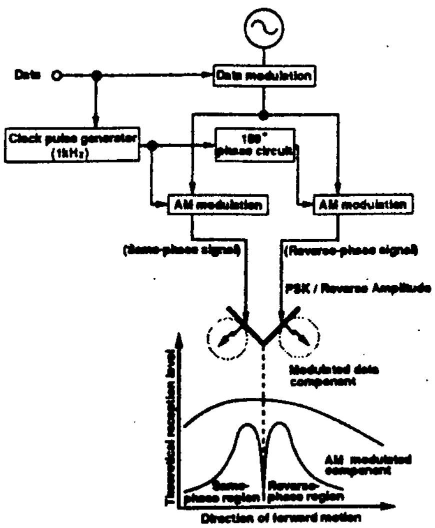

Fig. 10 Beacon position orientation function
(concept of PSK / Reverse Amplitude Modulation scheme)

5. System Configuration

5.1 Outline

The units making up the route guidance system are shown in Fig. 11. Besides the elements of the commercialized Multi-AV System, a head-up display, route guidance control unit and a beacon communications receiver and antenna have been added to form this system. The HUD equipment includes a combiner and a projector for projecting the displayed image onto the lower center of the windshield.

The Multi-AV System comprises the CRT display, control switches, AV control unit, navigation control unit, geomagnetic sensor and wheel speed sensors. The system that is actually offered in production vehicles also includes music enjoyment capabilities in the form of a cassette tape deck and an autochanger CD player with a ten disk magazine.

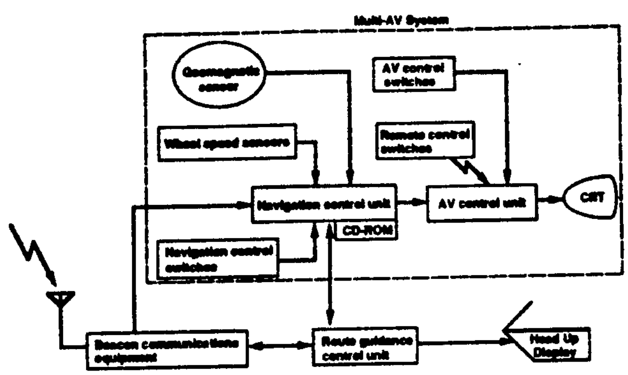

Fig. 11 System configuration

5.2 Head-up display

A monochrome dot-matrix HUD is used which can display any desired image pattern. The device has a resolution of 240 by 120 pixels. It is also equipped with a function that automatically adjusts the display brightness to match the luminous intensity of the surrounding environment.

As indicated in Figs. 12 and 13, the HUD comprises a display unit, a combiner coated on the windshield, a control circuit and a luminous sensor. The display unit consists of a backlight, a diffuser, a liquid crystal display device and a top cover.

(1) Backlight

The backlight consists of three hot-cathode tubes, 10 mm in diameter and 160 mm long. The maximum brightness at the tube surface is 33,500 nit and the tubes emit a green-colored light having a wavelength of 545 nm. The average tube life is 3,000 hours and each tube consumes 0.6 A with a supply voltage of 12 v.

(2) Diffuser

The diffuser is used to direct the light emitted by the backlight uniformly onto the LCD device. The maximum and minimum brightness values of the mirror are 19,050 nit and 31 nit, giving it a light adjustment ratio of 1.6 : 1,000.

(3) Liquid crystal display device

The LCD device is of the negative display type and has a dynamic drive system. It measures 124 x 78 x 5 mm and has a resolution of 240 x 128 pixels. The dot size is 0.4 mm and the dot pitch is 0.45 mm. The contrast ratio between the ON and OFF portions is 20, with the ON portions having a transmissivity of 13.5%. As a result, the maximum and minimum brightness values at the display surface are 2,750 nit and 4 nit. The device operates in a temperature range of - 20°C to 70°C and has sufficient durability to withstand the on-board environment.

(4) Top cover

The top cover is provided to prevent dust and dirt from ingesting the display device. To minimize transmissivity loss, the cover is made of a glass material that allows 98% transmissivity of the 545-nm light emitted by the backlight.

(5) Combiner

The combiner is coated on the lower center of the windshield by means of a deposition technique. It provides reflectivity of over 45% for light having a wavelength of 540~560 nm. Since the HUD display unit does not contain an optical system (Fig. 12), the displayed image is formed in front of the windshield at a point equal to the distance separating the combiner and the display unit.

(6) Control circuit

The control circuit is provided separate from the display unit and comprises an LCD controller, a display RAM, kanji ROM, 8-bit CPU and an A/C converter. It functions to construct the image displayed on the HUD and to adjust the display brightness.

(7) Luminous sensor

The luminous sensor is of the same type used in automatic lighting systems and is located on top of the instrument panel. Based on the sensor output signal, the display brightness is continuously varied to match that of the ambient environment.

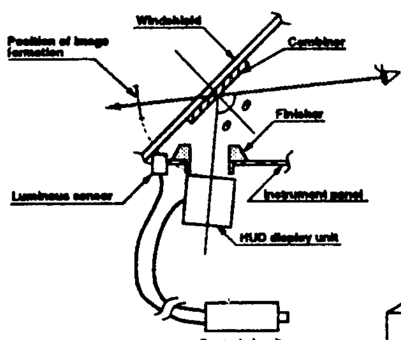

Fig. 12 HUD construction

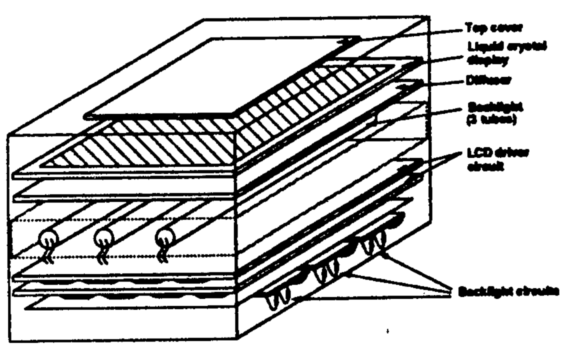

Fig. 13 Construction of HUD display unit

5.3 Route guidance control unit

The control unit is built around a 16-bit personal computer which performs the route selection calculations, route guidance processing and data processing for the received and transmitted beacon communications signals. Data used for route guidance are stored in this control unit and are completely independent of the map data.

Beacon signals received by the vehicle carry traffic information and incoming messages in the individual communications mode, while those transmitted from the vehicle carry outgoing individual communications messages.

5.4 Beacon communications equipment

The configuration of the on-board beacon communications equipment is illustrated in Fig. 14. It includes a duplexer, receiver, data demodulator, position detection/direction discriminator, receiver control circuit, localized oscillator, transmitter, data modulator, transmitter control circuit, CPU, memory unit and interface circuit.

The main specifications of the communications equipment are noted below.

- Transmission frequency:	2.598 GHz
- Reception frequency:	2.538 GHz
- Transmission output:	10 mW
- Reception sensitivity:	-85 dB maximum
- Frequency fluctuation:	±2 ppm
- Transmission speed:	512 kbps
- Occupied bandwidth:	1.7 MHz
- Modulation scheme:	Binary phase shift keying(BPSK)
- Transmission scheme:	Time division multiple access (TDMA)
- Equipment dimensions :	275 x 175 x 105 mm
- Power consumption:	12 W

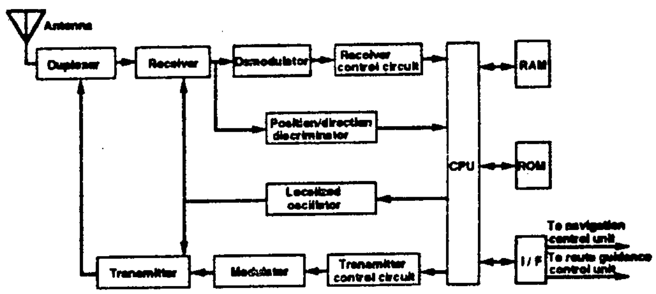

Fig. 14 Configuration of on-board beacon communications system

5.5 On-board antenna

The on-board antenna for beacon communications is a flat antenna with an reverse L-shape. Its dimensions are 100 x 100 x 10 mm. The beam radiation pattern in the vertical direction is designed with a low downward gain so as to avoid fading due to the reflection of waves from the road surface. In the horizontal direction, it is designed to provide the same level of gain in all directions so as to avoid any reduction in available communications area due to a reversal of transmitted signal polarization.

5.6 Navigation system control unit

This unit comprises a display control section, location control section and CD-ROM deck section.

(1) Display control section

This section consists of a 16-bit CPU, graphic display controller, RAM and ROM. It is responsible for controlling the functions explained in section 3 and the CD-ROM deck.

(2) Location control section

This section is made up of a 16-bit CPU, numerical processor, RAM and ROM. It manages the functions explained in section 4.

(3) CD-ROM deck

The CD-ROM deck is a modified version of a standard CD player for music without the loading mechanism. It is built into the drive guide control unit and is used exclusively for storing map data.

The provision of a separate CD autochanger enables the customers to enjoy listening to music while the navigation system is being used to compute the present location of the vehicle.

6. Evaluation Test Results

Test-drives were conducted as part of the pilot experiment open to the public. The participants gave high marks to the concept of a route guidance system employing a head-up display and to the map display quality and position detection accuracy of the navigation system.

The results of the pilot experiment confirmed that the automatic vehicle monitoring and automatic vehicle identification functions pretty much met their performance objectives. In the experiment, these two functions were provided through the reception of positional data, excluding traffic information, navigation information displayed on signboards and position orientation. The following are areas where further research is required.

(1)Position accuracy: It was found that there were some roadside beacons where the position accuracy did not reach the performance objective (i.e accuracy to within roughly 10 meters). This was attributed to the effects of sound isolation walls which caused the radio zone to expand or islands to form separate from the original radio zone.

(2)Communication quality: Errors tended to occur occasionally when several vehicles attempted to communicate at the same time. One basic reason for this is that the system had not been fully tuned yet. It is also thought that in many cases errors can be attributed to the complexity of circuit control. This complexity has resulted from the addition of a vehicle homing function to the beacon communications system in order to support the individual communications mode, whereas the original concept of beacon communications envisages that communication is completed within a single radio zone.

(3)HUD configuration: Some of the participants expressed concern that the driver's forward visibility would be affected by the large size of the HUD image and the fact that the image was formed in the lower center portion of the windshield. Thus the size and position for the formation of the HUD image is one aspect that will require re-examination in the future.

7. Conclusion

The basic technology for the Road Automobile Communication System has been virtually completed through the past four years of joint R&D work. However, both the on-board system and the land-based system will require further study and improvement if RACS is to function as a useful and effective system for society. Specifically, future effort needs to be directed toward the following issues.

(1) On-board system
- Improve vehicle position detection capability and achieve accurate position-finding to within 30 m under any conditions.
- Develop a display device (HUD, etc.) for providing the driver with information safely and investigate what information should be displayed and where.
- Improve the route selection method so that the optimum route can be chosen over a wide area.
- Reduce the cost of the on-board units.

(2) Land-based system
- Clarify and improve the transmission characteristics of quasi-microwave communications in an actual field environment.
- Improve the reliability of the network system for the roadside beacons.
- Establish a method for analyzing traffic flows using roadside beacons.
- Establish a fundamental design for determining the respective roles to be played by RACS and other mobile communications systems including car telephones, pocket pagers and teleterminals.

Acknowledgments

The authors would like to thank the many people who contributed in various ways to the development of this route guidance system.

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MEMS (MODULAR ENGINE MANAGEMENT SYSTEM)

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SYNOPSIS

MEMS is a new generation engine management system for fuel injected engines. The system control unit is modular in construction to cover various combinations of Programmed Ignition, Singlepoint, and Multipoint Fuel Injection. The system was designed and developed at Rover, and is in volume production on the new Rover 214, 414 and Metro GTi, all fitted with the new 'K' series engine, and on Montego.

CONTENTS:

1. Introduction

In 1985 Rover took the decision to design and develop in house its own engine management system for fuel injected engines. The result is MEMS which is a combination of Electronic Fuel Injection and Programmed Ignition in a single underbonnet control unit. The Rover 214 system block diagram is shown in Figure 1.

MEMS is formatted to provide expansion for future engine developments. This paper details the concepts put into the design and briefly describes the results before examining the real benefits to Rover of its unique product.

MEMS ECU's are designed at Rover, in conjunction with Motorola AIEG, the ECU manufacturers. Software is written in house at Rover.

2. Product Philosophy

The following philosophy guided the development of MEMS:-

Product leadtime two years. This led to the decision to take the design of the ECU in house and use an external manufacturer. It is our experience that this methodology optimises leadtimes.

Cost to be lower than equivalent bought out system. Again this led to the decision for in house design especially when coupled with the need for design flexibility.

Quality to be best in class. This was controlled by the design and the choice of supplier.

Product to be supported with advanced tuning aid. This gives online tune changes, tune swapping, high speed data logging and the ability to release a tune directly from the tuning aid. All these features had a significant impact on reducing product leadtimes.

Modular Design. This was to cover a wide range of specifications from base open loop TBi to closed loop sequential MPi with boost control of turbo charging within one basic product.

3. System Hardware

The Modular approach. To cater for various combinations of vehicle requirements, and to achieve the aim of improved quality, with reduced cost the MEMS system hardware was integrated as much as possible: A single base ECU (Electronic Control Unit) design was used with 11 add-on internal modules. Table 1 shows the production options available and those used to date. The only module options that are mutually exclusive are the choices of single, dual, or banked Injection. Within the limits of the matrix there is no need for hardware redesign, or retesting.

One ECU - Underbonnet. Previous EFI systems had two Engine Management ECU's, an Electronic Fuel Injection unit sited in the vehicle compartment, and a Programmed Ignition Control unit underbonnet. MEMS combined these functions into one underbonnet ECU near to the majority of the system components. This improved vehicle assembly and eliminated 25% of the system connections.
To operate underbonnet and keep the internal temperature below component limits of +125° C, low power consumption Field Effect Transistors were used on all outputs.

Designing for manufacture. The previous engine management system with two ECU's had a combined PCB area of 588 sq cm. Such a size would not package in the confined underbonnet area where mounting space is always at a premium. By using surface mounted components and a 4 layer PCB it was possible to reduce the PCB size by 54% to a manageable 272 sq cm. 92% of the ECU's components are automatically surface mounted, only power and some specialist components are not surface mounted. The use of rapid automatically assembled components removes many of the quality issues associated with leaded and hand assembly operations. Manufacturing costs were reduced with simpler parts storage and preparation prior to assembly, and increased ECU throughput.

Designing for testability. Testability was improved in ECU manufacture, vehicle assembly and service by designing into the MEMS ECU a diagnostic link. Serial communication can take place between the ECU's microprocessor and external computer based test equipment without breaking the connection between ECU and vehicle. The need for large ECU test rigs in manufacturing have been eliminated. "Burn in" rigs, previously used for 100% testing are not used in the MEMS manufacturing process. We chose instead to rely on the ECU's design integrity and more stringent functional testing via diagnostics.
Semi-automatic test stations have been added into the vehicle assembly track. When connected to the vehicle's diagnostic connector they identify the ECU and test all system sensors and switches. Any faults are printed out for use in rectification. They are also used to aid system fuel and idle "adjustment" settings.
Test and fault diagnosis in the dealer networks is done with Rover's computer based 'COBEST' and 'Microcheck' Service test equipment. These also access the vehicle system via the diagnostic link. Failed parts returned under warranty must be accompanied by a test report from one of these units. This technique is vital in reducing the number of ECU's wrongly returned as faulty.
The use of a non volatile EEPROM (Electrically Erasable Programmable Read Only Memory) in the MEMS ECU allows system faults, even if intermittent, to be recorded.

ECU Reliability. Two different prediction methods were used on the MEMS design:-

FITs (Failures In Time)
US Military-Handbook-217E

The FIT method. Failures In Time were seen as a more user friendly way of predicting ECU reliability. 1 FIT = 1 failure in 1 billion device hours of operation.
All suppliers were asked to supply a FIT number for each of their components, based on a

predicted lifetime temperature/time profile of:–

40 hours at 125° C, 360 hours at 65° C and 8366 hours at 25° C.

MEMS had 1692 soldered joints. It was interesting to note that different manufacturers gave quite different soldered joint reliability figures. In one case the soldered joint failure rate was 46% higher than for all the components in the design, indicating how important manufacturing processes are in true reliability.

The Overall ECU FIT figure was 8241 FIT.

ECU failure rate per year was calculated as: 8241 x 600 hrs x 100%/(1E+9) = 0.49%

Reliability = 1 - failure rate: ECU Reliability Prediction = 100% - 0.49% = 99.5%

US Military Handbook-217E Adaption Method. MIL-HNBK-217E, although not an exact correlation to field reliability, provides a standard on which to base reliability design reviews. The MEMS study used Parts Stress Analysis.

Results:–

	FAILURES PER MILLION HOURS		
	+25°C	65°C	125°C
Total MEMS ECU	13.2	32.0	838.3
Highest failures:–			
Circuit board	1.5	8.3	169.6
Intel 8096 uP	0.9	4.0	112.7
Drive Circuit Hybrid	1.4	2.5	66.1
Knock Sensor Hybrid	1.1	2.3	63.6

Failure rate over the recommended temperature profile was calculated as;

Failures per million Hrs =(Failures per Million Hrs @ T°C)(Hrs @ T°C)/(Total Hrs)

Failures per million Hrs @
25°C =13.2 x 8366/8766 = 9.6
65°C =32.0 x 360 / 8766 = 1.3
125°C =838.3 x 40 / 8766 = 3.8
====
Total Failures per million Hrs =14.7

Percentage MEMS failure rate per year = 14.7 x (600hrs)(100%)/(1E+6) = 0.88%

Reliability = 1 - failure rate: ECU Reliability Prediction = 100% - 0.88% = 99.12%

Product Proving and Testing. The proving programme employed a comprehensive test matrix to examine the functionality, durability, and reliability of the MEMS system.

Laboratory DV (Design Validation) test matrix on a minimum of 39 'off tooled' production level ECU's covered; Functional, Humidity, Temperature, Dust, UV Light, Thermal Shock, Salt Spray, Contaminants, Mycological, Vibration, Rig Endurance, Stress to Failure, Thermal Cycle, and Electrostatic Discharge Testing.

An environmental test rig C&R (Confidence and Reliability) programme tested over 320 'off tooled' production level ECU's. Each ECU was thermally cycled under simulated vehicle load conditions for 600 hours to achieve at least a 99.5% statistical reliability, to an 80% confidence level.

An on-vehicle test programme, distributed over 25 vehicles, covering High Speed, Urban, Rough Road, and Pave achieved over 500,000 vehicle miles prior to product launch.

Vehicle EMC performance of MEMS was improved beyond the previous minimum pass level of 50v/m by using one of the ECU's four PCB layers as a ground plane.

4. Software Design.

A single chip microprocessor was used to minimise the cost of the ECU by obviating the need for external memory and associated port reconstruction components. An additional benefit of using on chip resources was shorter execution times - another key parameter in an Engine Management Controller.

The software is designed to provide a large number of features:-
These include Steady State and Transient Fuel Control, Ignition Control incorporating individual cylinder Knock avoidance, Idle Speed Control, Faulty Sensor Backup/Limp Home, End-of-Line Test at both the ECU manufacturer and the vehicle line and finally diagnostics for service technicians incorporating intermittent fault logging.

A complex design and a limited resource of 8K of ROM and 232 bytes of RAM, albeit in a 16 bit single chip Intel 8096, provided a very special challenge. It is clear that very tight control of code usage would be required, and to aid this the various features were allotted a proportion of the overall memory allocation. The initial and realised feature breakdown is shown in figure 2. As can be seen Fuel Control is the largest consumer of resource but surprisingly Idle Speed Control came second, taking as long to develop as the Fuel Control. Ignition Control was complex but required less space than the associated Knock Control.

The predicted figures bear comparison but were in error primarily in Ignition, Diagnostics and the Idle Speed Control area. The Tune area was also a minor casualty.

In order to meet the programme timing and the memory limitations the strategies were developed in very close conjunction with the customer. The customer in this case being our own Engines and Emissions departments. Having in house control of the software allowed for very rapid feedback and minimised the number of "official" links in the chain.
Specification development, customer liaison, testing and delivery of code was carried out by the same engineer to ensure very short communication links. This way of operating has stood the test of time and has been developed further on current designs.

Previously software had been designed on stand alone development systems. These projects were characterised by having a single specification for a particular model, or developments where the software was not planned to go into volume production. They were typically the responsibility of one engineer. MEMS was a radical change. MEMS software had to be developed by a team of people and for a mix of specifications over a wide range of models and engine variants. The decision was therefore taken to develop the software using a network of PCs. This enabled a database of software modules to be constructed and allowed all team members access to the latest code. The network approach is still in place today, the major change being that it has expanded from 4 workstations to 20.

A vital part of any engine management programme is the development of the Calibration or Tune. This process can be greatly enhanced by the use of portable computers. A major part of the MEMS development was the design of a tuning aid or PETA (Programmable Engine Tuning Aid). PETA enables the engineer to display and modify any of the tune parameters both on line and off line. There is capability to dynamically switch between tunes while the engine is running. Printouts of maps can be readily obtained, and even the final tune release comes from PETA and is integrated into the final mask in an automated fashion. This reduces the possibility of errors as well as being more efficient. The PETA project was a major development in its own right involving the production of 200K of code. The system is continually being enhanced and is fundamental to the successful development of any vehicle programme.

Control strategies A representation of the relationships between inputs and outputs is shown in Fig 3. The interconnect between the various blocks shows the desirability of having all the control functions handled by one microprocessor. The base designs that are currently in production employ the speed density method of air flow measurement. This places a greater overhead on the system in terms of computing power required but provides significant system cost savings by not requiring a mass air flow meter.

Validation. Software validation is an important part of any design/development process and is required to ensure that critical areas are closely scrutinised.The process employed on the first production MEMS units was that of formal design review including FMEA code walkthrough and peer scrutiny. This method has proved to be satisfactory with regard to the quality of the software produced but was very labour intensive. All future designs will include the above process but will also be presented to a third party validator with static code analysis being a minimum requirement.
Future areas of work include the use of formal methods for specification generation and consideration is also being given to dynamic analysis. The key is to get the design right at the specification phase and to use computers to automate the process of validation.

5. Product Feedback

ECU and system cost. The trade off between cost, quality and increased system functionality is always a popular subject in the Automotive Industry. However, improved functionality and quality do not always mean increased cost. MEMS ECU system costs were reduced by 46% with a combination of design integration and the use of a speed density, instead of the previous mass air flow system strategy.

ECU Reliability. Figure 4. shows the normalised warranty returns against vehicle build month for the MEMS ECU and the control units it replaced. Although it is early to make firm conclusions the initial MEMS ECU warranty results are encouraging. The results indicate the move down the classic 'new product' manufacturing learning curve, and that warranty returns have already been significantly reduced. Comparing the July/August 88 and July 89 returns we have an ECU warranty reduction of 40%.

Conclusions. As a result of the design and development efforts MEMS was launched in April '89 on the 2.0 litre Montego 'O' engine with multipoint fuel injection, in October '89 on the Rover 214, March '90 on Rover 414 and May '90 on the new Metro GTi. The three latter models all use the new Rover 'K16' engine with singlepoint injection. To date over 100,000 units are in customer use throughout the EEC. Figure 5. shows the benefits Rover has gained over the previous system in terms of warranty improvement, cost and ECU packaging size. The normalised figures show gains at 40%, 46% and 54% respectively. As a result of this success MEMS is now being targetted at future Rover products with developments to reduce emissions, minimise fuel consumption and to provide major engine feature enhancements. The experience gained in developing MEMS as a reliable, high quality product at a competitive cost is allowing expansion to greater levels of sophistication, leading to enhanced customer satisfaction with the Rover product.

6. Acknowledgments.

The authors are indebted to the Rover Group for permission to publish, and for the contribution, help and advice received from all our colleagues. A special acknowledgement is due to the engineers in the Emissions, Engine and Engine Management Systems departments for their pioneering and dedicated work developing the MEMS system.
THANK YOU.

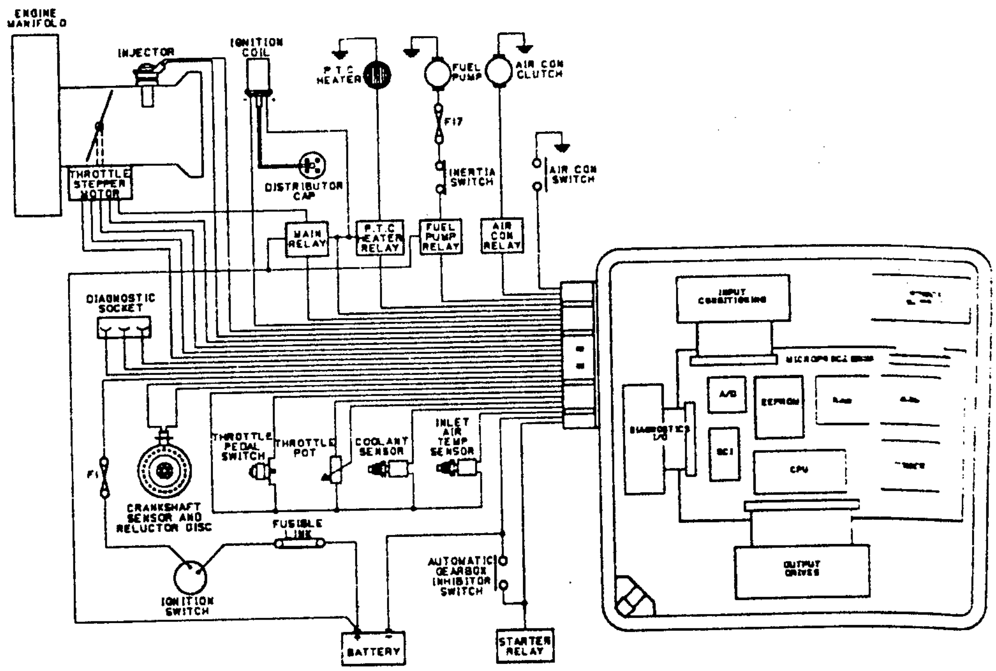

Fig.1 Rover 214 System Diagram

	OPTIONS	MONTEGO 2.0 EFI	MONTEGO 2.0 EFi AUTO.	ROVER 214		
1	BASE PROGRAMMED IGNITION	✓	✓	✓		
2	SINGLE TBi			✓		
3	SECOND TBi					
4	BANKED MPi	✓	✓			
5	AUTOMATIC TRANSMISSION		✓			
6	PULSE AIR					
7	EGR					
8	PURGE					
9	KNOCK	✓	✓			
10	AIR CONDITIONING	✓	✓	✓		
11	OXYGEN SENSOR					
12	SPARE OUTPUTS (4)					

Table 1 MEMS 1.2 Production Options used to Date

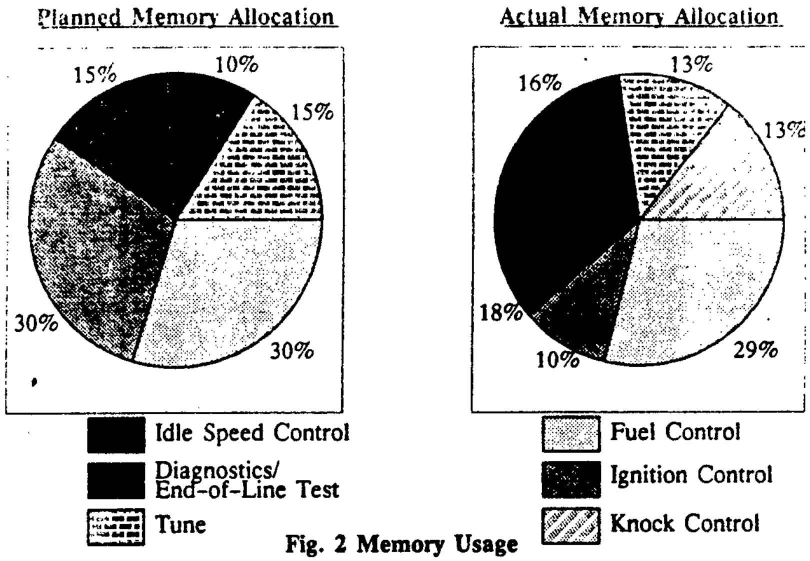

Fig. 2 Memory Usage

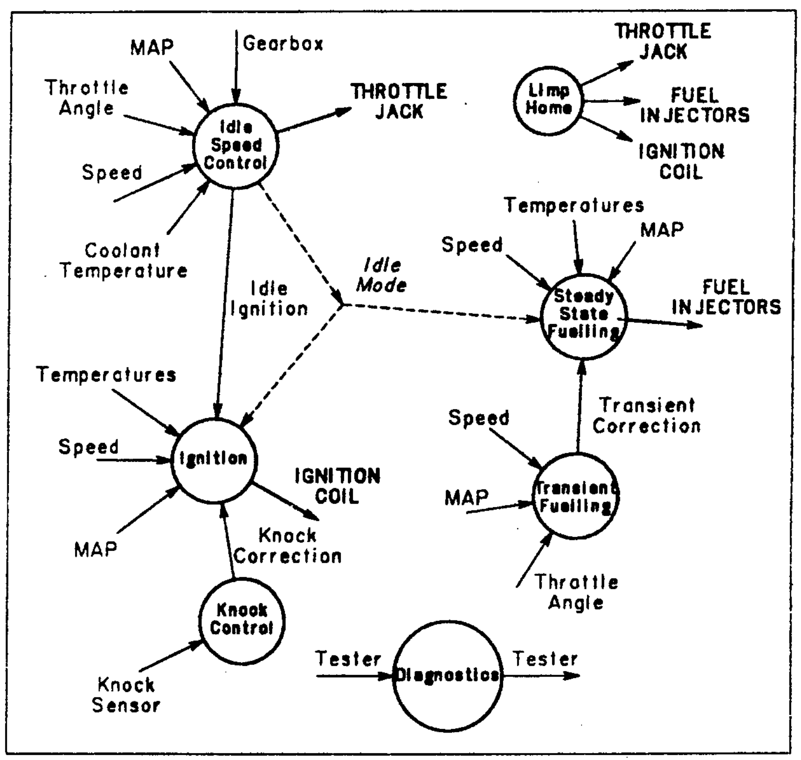

Fig. 3 Data Concept Diagram

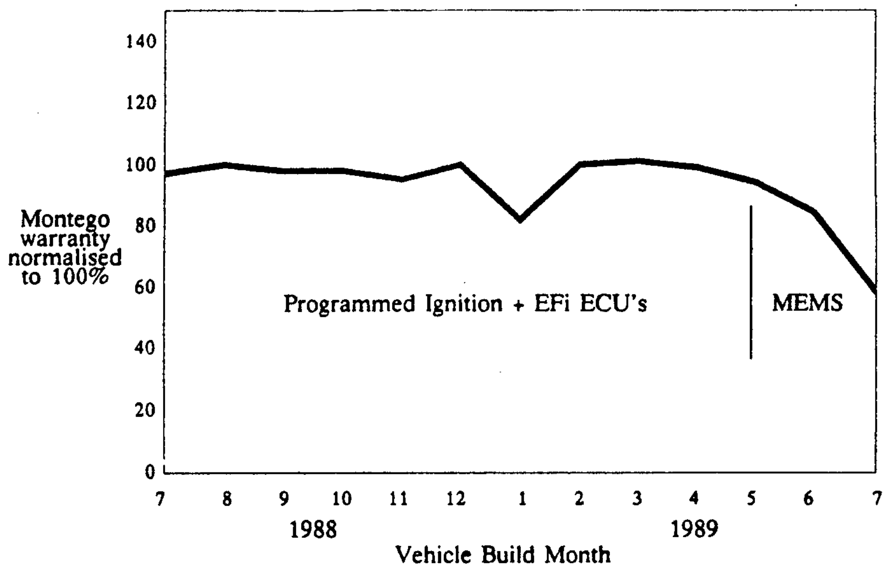

Fig. 4 Normalised Warranty Claims Montego Engine Management ECU's

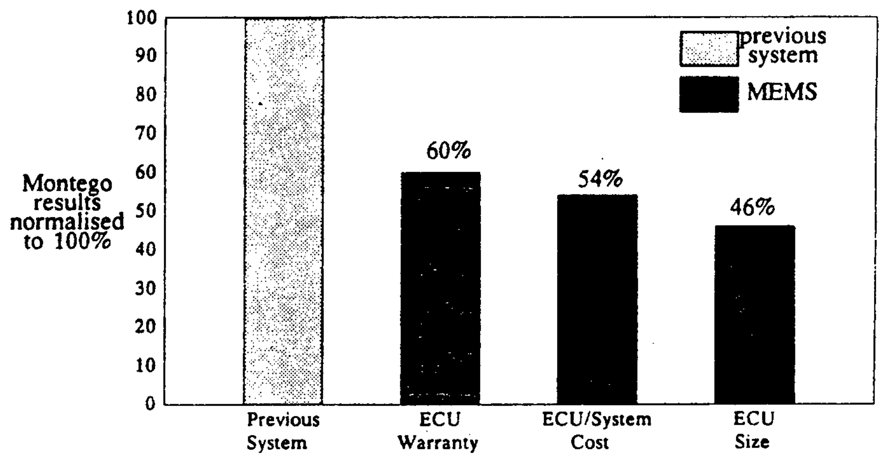

Fig. 5 Histogram of Warranty, Cost and Size Improvements Achieved on Montego with MEMS.

MICROCOMPUTER FOR REALTIME CONTROL - OPTIMUM FOR ANTI-LOCK BRAKING SYSTEM AND TRACTION CONTROL SYSTEM

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1. Abstract

In recent years, the performance of automobiles has drastically improved thanks to rapid advances in electronic control technology in engines, etc. Safety has also become more important than ever as a result of the improvement in driving performance, and the various safety systems below have been developed.

(1) Anti-lock braking system
(2) Air-Bag system
(3) Automatic seat-belt system
(4) Shift lock system

For the anti-lock braking system, with its conventional mechanical control, it was difficult to achieve optimum control in response to change in conditions between wheels and road surface. However, as a result of the rapid development of semiconductor technology, electronic control technology has been introduced into the anti-lock braking system, making it possible to execute complicated and delicate braking control under all types of operating conditions. In recent years, a traction control system to prevent skidding of the drive wheel when stopping on the accelerator pedal has come into practical use.

The key to a successful electronically-controlled anti-lock braking system and traction control system is the performance of the microcomputer, so it has become important to develop microcomputers capable of processing vehicle speed or wheel speed signals quickly and accurately.

In this paper, we discuss how to achieve compound control of the anti-lock braking system and traction control system by using the 16-bit single-chip microcomputer µPD78322, which can accurately process high speed operations and realtime output control.

2. Introduction

The first mechanical type Anti-lock Braking System (ABS), which designed to improve vehicle performance capabilities such as braking distance and maneuverability, as well as ensure vehicle safety by preventing spin or other unwanted behaviors on snow-covered and other slippery roads, has been used since 1969. However, because road conditions change momentarily from a snow-laden road to a dry concrete road and vice versa, the coefficient of friction between the wheels and road surface changes rapidly, so does the slip ratio necessary to obtain optimum braking performance under given road conditions. For this reason, it was very difficult for the mechanical type ABS to obtain optimum control against constant changes in tire-to-road relative conditions. In fact, ABS-mounted vehicles required longer braking distance than other ordinary cars depending on situation, thus its usage conditions were limited.

In the meantime, electronic control technology was introduced into ABS thanks to rapid progress in semiconductor technology ,and it become possible to change the desired slip ratio moment by moment according to changes in road conditions. Thus, electronically controlled ABS provides complex, fine-tuned braking control under any road conditions.

In resent years, moreover, the Traction Control System (TRC), designed to prevent the drive wheels from skidding when the accelerator pedal is pressed on, has been put into practical use as an application of ABS control technology. TRC is basically the same as ABS control. It suppresses the slippage of the driving force by changing the desired slip ratio every moment according to changes in road conditions.

Although the basic technologies for electronically controlled ABS and TRC have already been perfected to a fairly high level owing to electronic control technology, but various problems remain yet to be solved. These include improving system control accuracy, minimizing erroneous operation, reducing dimensions and weight, and reducing cost. Microcomputers are the key to solving these problems. In the following sections of this paper, we outline the functions required for ABS and TRC, and discuss the functions of the microcomputer which are necessary to control both anti-lock braking and traction by using a single control unit in place of two separate units as are used today.

3. Functions Required for ABS and TRC

The most important point in ABS is control the brake actuators so as to optimize the wheel-to-road slip ratio when the brakes are applied by measuring the conditions of each wheel independently. Similarly, the most important point in TRC is control the engine output or the brake actuators of the drive wheels so as to optimize the wheel-to -road slip ratio when the car starts or the speed is accelerated by measuring the conditions of each wheel independently.

The following describes the features of these functions.

(1) Measurement of wheel speed (for ABS/TRC)

The signals from the wheel speed sensors are characteristic in that the signal frequency changes proportionately to the rotation speed of wheels. Therefore, the wheel speed is calculated by measuring these changes in signal frequency. For ABS/TRC, the wheel speed must be measured with high accuracy because the wheel speed is the basis of control.

Today, there are two standard methods of wheel speed measurement; a 3-sensor method which measures the left and right front wheels independently and measures the rear wheels simultaneously and a 4-sensor method which measures all four wheels independently. The 3-sensor method is effective for rear wheel driven vehicles to reduce cost; the 4-sensor method is effective for front wheel driven or four wheel driven vehicles, as well as for TRC, to improve accuracy.

(2) Brake actuator control (for ABS/TRC)

Currently, the solenoid valves (actuators) used to increase or reduce the hydraulic pressure applied to brakes (wheel cylinders) are controlled by turning the electric current ON and OFF to increase, reduce, or retain the pressure.

For ABS, several methods of wheel controls are used, including a 3-channel method which controls the left and right front wheels independently and controls the rear wheels simultaneously, a 2-channel method which controls the left front and right rear wheels simultaneously and controls the right front and left rear wheels simultaneously, and a 4-channel method which controls all four wheels independently. The 2-channel and 3-channel and methods are effective in reducing cost; the 4-channel method is effective in obtaining highly accurate brake control.

For TRC also, there is a quick-responding, torque-reducing method that is effective in drive wheel braking control.

(3) Engine output control (for ABS/TRC)

Broadly classified, there are two methods of engine output control. One method involves controlling the fuel injection rate or ignition timing by sending the appropriate signal to the engine control unit; the other method is used to control the suction air rate by controlling the opening of the throttle valve. In the future, these methods of control may be combined with drive wheel braking control to attain more effective control.

(4) Control of road condition determination (for ABS/TRC)

It is known that when a car is braked or accelerated when running on a bad road (gravel road, etc.), better effects are obtained by braking or accelerating the car with a greater range

of wheel-to-road slip ratio than normal. Therefore, it is important to determine the road conditions by, for example, detecting the tires' oscillation period.
In the case of four wheel driven vehicles, the rotation of each wheel is easily synchronized because each wheel is constrained via the differential gear. Because of this characteristic, when ABS is applied to a four wheel driven vehicle on a low-μ road, if control is done by the wheel speed only, all the four wheels stop in the same way as if the car had halted on a high-μ road. Therefore, although the fact is that the wheels have been locked, the ABS may determine that the car stands still.
To solve this problem, a sensor is installed that detects the acceleration of vehicle speed, and the system determines whether or not the currently braked road is a low-μ road based on the information from this acceleration sensor. If determined to be a low-μ road, the system executes dedicated processing to prevent the wheels from being locked.

(5) Steering angle control (for ABS/TRC)

It is known that when a car is braked or accelerated, better acceleration or braking effects are obtained when the drive wheels slip against the road to some extent than otherwise. However, if the drive wheels' slip ratio becomes large when the car is accelerated or braked while turning to the left or right, its transversal resisting force decreases and, if ABS or TRC is applied with the same target slip ratio as used when driving straight forward or backward, the car may become unable to bear the transversal drag and begin to slip sideways.
Steering angle control has been devised to solve this problem. Using a steering sensor, this system obtains the driver's desired angle of vehicle gyration (angle of steering wheel), determines the target slip ratio of control from the angle of vehicle gyration and current vehicle speed to enable the car to turn smoothly without slipping sideways, and exercises control based on that target slip ratio.

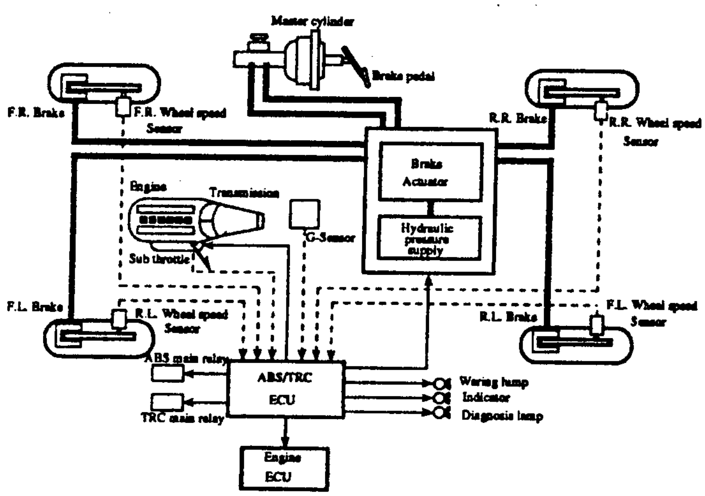

Figure 1 ABS/TRC Simplified Diagram

4. Microcomputer Functions Necessary for ABS/TRC

The following describes the microcomputer functions that are especially important when the above ABS and TRC are performed by using a microcomputer.

4.1 Pulse input processing function

For the measurement of wheel speeds, the basic of ABS/TRC, a function is required that can independently measure signal periods from 4-wheel wheel speed sensors and, in addition, can measure the signals in a wide frequency range with high accuracy.

4.2 Pulse output processing function

When brake control is done by using solenoid valves, a pulse output is required accurate in terms of time.
In addition, a pulse output is also required because stepping motors are normally used to control the throttle valves.

4.3 High-speed calculation function

ABS/TRC control requires a wide range of numerical calculations from wheel speed and virtual vehicle speed to slip ratio and target slip ratio, and these calculations must be done at high speed.

5. Application Examples of ABS/TRC Using the µPD78322

This section describes the application examples of ABS/TRC using the µPD78322, a 16-bit single-chip microcomputer for realtime control use featuring the functions and performance capabilities suited for ABS/TRC.

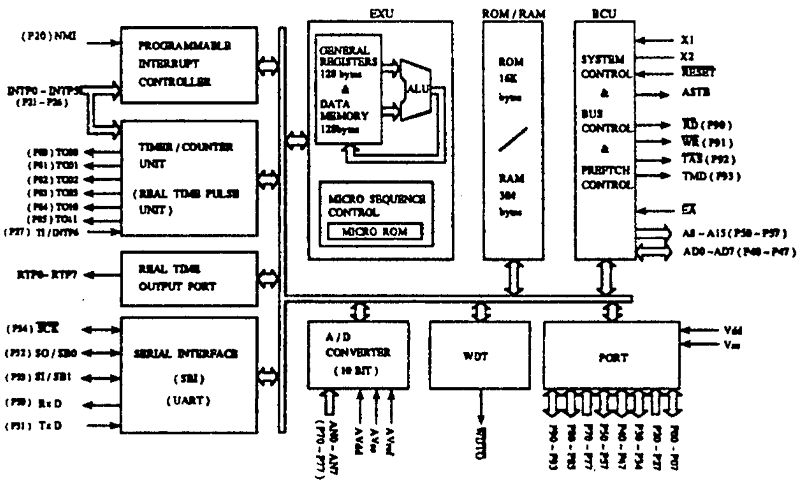

Figure 2 µPD78322 Block Diagram

5.1 Features of the µPD78322

The µPD78322 is a 16/8-bit single-chip microcomputer in the 78K/III series of NEC's original single-chip microcomputers.
The µPD78322 contains 16K bytes of ROM and 640 bytes of RAM, and can directly control the address space up to 64K bytes. In addition, it has a powerful instruction set (110 instructions), and can process calculations at high speed with the minimum instruction cycle of 250 ns (using a 16 MHz crystal oscillator).
The µPD78322 also incorporates versatile hardware features including a multipurpose realtime pulse unit (RPU), 8-channel 10-bit A/D converter, and a watchdog timer. In addition, the µPD78322 has a high-function interrupt controller to provide macro service functions so that it enables direct memory access (including addition/subtraction processing) between the internal peripheral I/Os such as memory, timer, etc.

Features:

- 16-bit CPU (78K/III)
- 110 powerful instructions, including:
  - 16-bit operation instructions
  - Bit manipulation instructions
  - Multiplication instructions (16 bits x 16 bits = 32 bits)
  - Division instructions (32 bits ÷ 16 bits = 32 bits + 16-bit remainder)

String instructions
User stack instructions

- Minimum instruction cycle: 250 ns at 16 MHz
- Memories
  On-chip ROM : 16K bytes, On-chip RAM : 640 bytes, Memory space : 64K bytes
- Multi-purpose pulse input/output unit (Real-time Pulse Unit)
  16-/18-bit free running timer : x1
  16-bit timer/event counter : x1
  16-bit compare register : x6
  18-bit capture register : x4
  18-bit capture/16-bit compare register : x2
  Timer output : x6
- High-precision, 10-bit A/D converter (8 channels)
- Real-time output port: x8
- Serial interface (with baud rate generator) : x2
  Asynchronous serial interface (UART), Serial bus interface (SBI)
- Interrupt controller
  Vector interrupt function, Context switching function, Macro service function
- Watchdog timer
- Standby function (STOP/HALT)
- CMOS technology
- 68-pin PLCC package

5.2 Application examples of ABS/TRC by the μPD78322

Figure 3 shows the block diagram of a ABS/TRC control system using the μPD78322. This application example is designed on condition that four wheel independent braking and engine (throttle valves, fuel injection timing and ignition timing) controlled by measuring the speed of each of the four wheels independently.

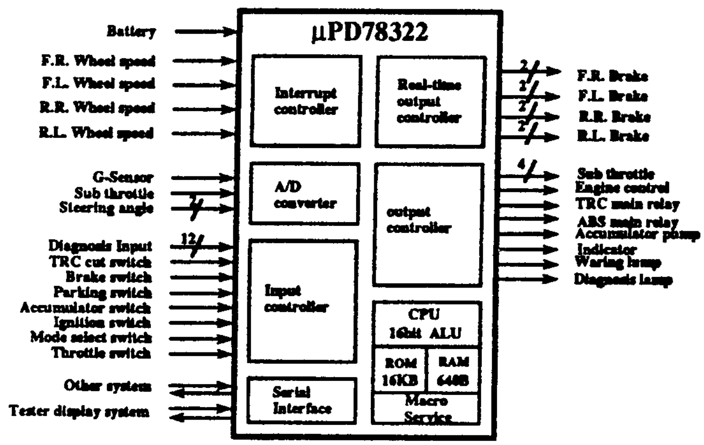

Figure 3 Application examples of ABS/TRC by μPD78322

5.3 Method of measuring wheel speeds

Here, description is made of how the built-in hardware of the μPD78322 is used to measure the wheel speed, the most important element of ABS/TRC.

Note that there are several methods to measure pulses: a frequency measurement method which counts the number of pulses within a certain time, a period measurement method which measures the duration (period) of one pulse, and a method which obtains the average duration of one pulse after measuring pulse periods within a certain time. Here, a method of measuring the average period by counting the number of pulses in 5 ms is used in describing the usage of the μPD78322's built-in hardware

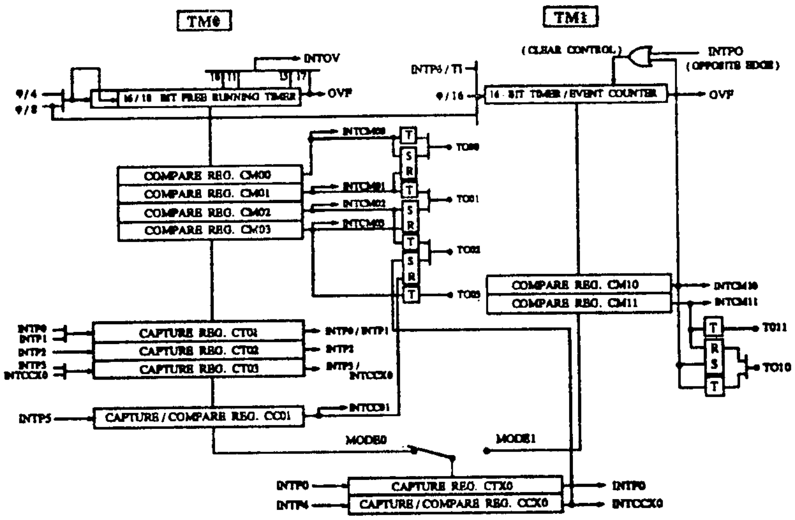

Figure 4 Real-Time Pulse Unit Block Diagram

(1) Usage of the µPD78322's built-in hardware

Figure 5 show the built-in µPD78322 hardware used to measure wheel speeds. The following describes how to measure the speed of the right front wheel. The speeds of the other three wheels are measured in the same way.

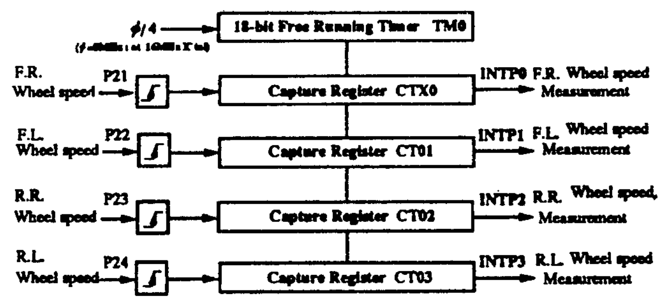

Figure 5 Method of Measuring Wheel Speeds

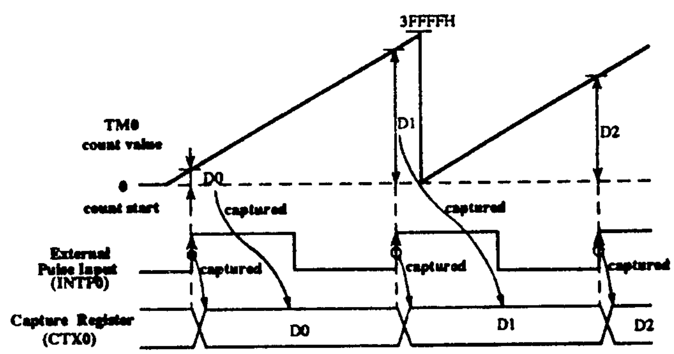

Figure 6 Pulse Measurement Timing

No.1 When a rising-edge signal is input to the input port (P21), the capture register (CT01) stores the value of timer (TM0) at that point in time and, at the same time, generates interrupt request (INTP0).
No.2 The interrupt handler determines whether or not this interrupt occurred within 5 ms after the previous measurement (a), and executes one of the following two tasks depending on the results.
No.3 If less than 5 ms (b), the pulse-count counter is incremented, then processing is terminated.
If more than 5 ms (a), the pulse-count counter is incremented, then the timer value is cleared after being loaded into memory (used when calculating wheel speeds).
No.4 The difference between the current value in the capture register (CT01) and the capture register value stored in memory when an interrupt occurred previously is loaded as period data into memory (used when calculating wheel speeds).
No.5 When the above calculation is completed, the current value in the capture register is stored in memory before processing is terminated.

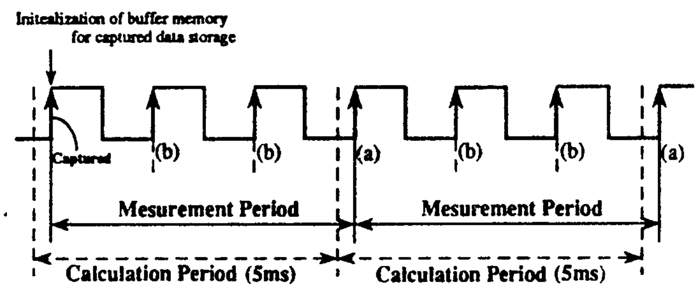

Figure 7 Measurement Period

(2) Accuracy of measurement

When the average period in 5 ms is measured as described above, if the input signal from wheel speed sensors is assumed to be in the range of 16 Hz to 5,200 Hz (62,500 µs to 192 µs), measurement can be made with an error of 0.009 km/h without overflow processing. In addition, based on the measurement data of wheel speeds measured in this way, it is possible to calculate the wheel speeds and virtual vehicle speeds by using multiply/divide instructions (16 bits x 16 bits = 32 bits, 32 bits ÷ 16 bits = 32 bits).

5.4 Method of controlling the brake actuators

Brake actuator control is equally important for ABS/TRC as is the measurement of wheel speeds. If this control is made by using timer interrupt and general-purpose ports, an error of ± 1 to 100 µs may result depending on the priority of processing. For this reason, the following describes the usage of the µPD78322 hardware by assuming the use of a realtime output port which is free of interrupt- related overhead and capable of highly accurate pulse output.

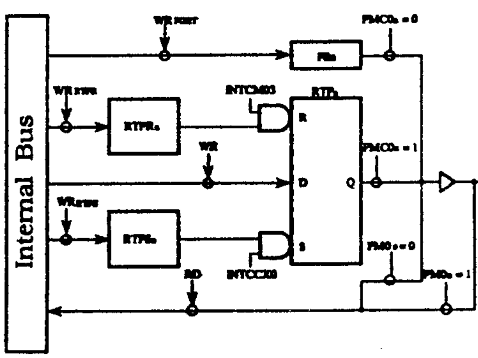

Figure 8 Block Diagram of the Realtime Output Port

(1) Usage of the μPD78322's built-in hardware

No.1 The rising-edge timing of the output pulse to control each brake actuator is set to the realtime output port set register (RTPS).

No.2 The falling-edge timing of the output pulse to control each brake actuator is set to the realtime output port reset register (RTPR).

No.3 When an interrupt occurs in INTCM03 and simultaneously when processing is started, the set values of RTPR and RTPS are output from the realtime output port.

No.4 The timing values for the next output pulses to control the brake actuators are set to CM03 and CCX0, then processing is terminated.

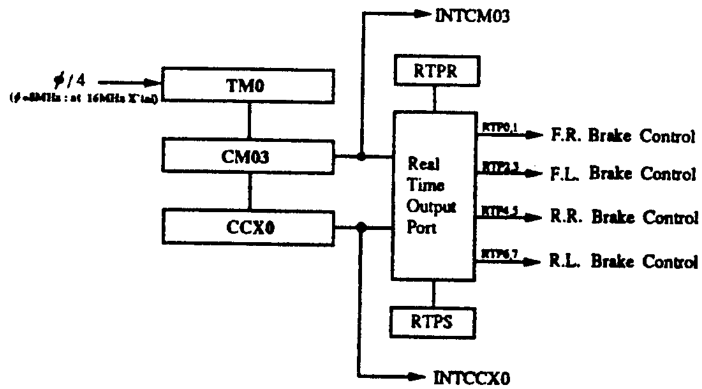

Figure 9 Brake Actuator Control

(2) Accuracy of control

When the brake solenoid valves are controlled by using a realtime output port as described above, it is possible to control the 5 to 95% duty outputs (in 1% increments) within an error of ±0.5 μs.

6. Conclusion

In this paper, we have examined the required functions of ABS/TRC and discussed how a microcomputer can effectively be used for this purpose by using the μPD78322 as an example.

The important thing with ABS/TRC is how to detect the slippage of each wheel accurately and reduce the braking distance or improve acceleration performance while maintaining vehicle stability and maneuverability under varying road surface and traveling conditions. To accomplish this objective, it is important how accurately the ABS/TRC can measure the periods of wheel speeds and how fast they can calculate the results of measurement. As indicated in this paper, the μPD78322 can not only accurately measure the speed of each of the four wheels by using its hardware resources, it can also calculate wheel speeds and other control parameters at high speed by using its 16-bit multiply/divide instructions.

Thus, not only does the μPD78322 improve the control accuracy of ABS/TRC, it can also minimize overhead in software development, reduce the dimensions and weight of the control unit through simplified peripheral hardware configurations, and cut the cost. All told, the μPD78322 can be thought of as the most suitable microcomputer for ABS/TRC.

In this paper, we introduced the μPD78322 16-bit single-chip microcomputer as an ideal candidate for ABS/TRC now under development. In the future, we plan to examine microcomputers suitable for the next-generation ABS/TRC which would provide even more sophisticated control functions.

CHIP IN GLASS TECHNOLOGY FOR AUTOMOTIVE FIP

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1 ABSTRACT

The fluorescent Indicator Panel(FIP) is currently the main electronic display for automotive dashboard systems.Starting from the simple seven segment clock FIP,more complex FIPs are widely installed in automotive electronic systems, such as digital speedo-meter,fuel-temp guage,tachometer,digital tuing radio and climate-control system.

The chip in glass(CIG) technology contributes to realize,easily assembled and cost effective systems. Due to these features,CIG technology has started creating new era for automotive display systems.

2 CIG TECHNOLOGY

2.1.CIG STRUCTURE

The FIP has a triode structure,containing three fundamental electrodes,cathode, grid(s) and anodes. The cathode is an oxide coated tungsten wire with a diameter of about 10 um. When the appropriate voltage is applied,the filament heats up to about 600 C and emits electrons. The grid is a metal mesh formed by chemical etching.The grid material is generally iron-nickel alloy.

Grid potential controls the flows of electrons emitted by the cathode.

The anode is a graphite electrode covered with phosphors using thick-film technology.

The light output color is defined by the phosphor materials.

The basic structure of the CIG FIP is shown in Fig.1 and the cross section of the IC mounting area is indicated in Fig.2.

The main objectives of this technology are to reduce the number of pins on the display and realize a compact, light weight display system with high reliability at a reasonable cost.

The IC is mounted inside of the FIP vacuum envelope.

The IC mounting location is selected under the filament end-cooling zone.

Therefore CIG FIP does not need to enlarge the total package size. Also the newly designed IC for CIG has a rectangular shape to keep the package size the same as a conventional FIP.

The IC chip is mounted on the glass substrate with a thermosetting resin base adhesive materials. The IC chips are electrically connected to the aluminum bonding pads on the glass substrate using an aluminum wire bonder. Aluminum is selected as the wiring material to avoid gold-silicon alloying during high temperature FIP sealing processes.

The bonding wire strength is tested with the pull test method specified in MIL-STD 883B with an expected 4g value. Fig.3 shows the distribution data to certify that the wire has enough strength. Most of the broken points are at the neck of the bonded wire and the middle of the loop. This also indicates the bonding is sufficiently strong. The die attachment strength data is shown in Fig4. The test is applied to a finished CIG FIP. The IC chip is 3.45mmX3.45mm in size and the strength is measured with push-pull gauge. The adhesive material breakage is observed for all measured samples, indicating sufficient strength.

Also CIG FIP has various advantages, from a reliability standpoint.

First is the humidity resistance improvement. This is due to the IC being mounted inside the FIP vacuum envelope and sealed perfectly.

A second advantage is the elimination of problems originated from a molded package, such as open circuit, short circuit in the boundary area between the IC chip and molding plastic.

Third is the decrease of solderconnections. The number of leads of a CIG FIP has less than that of conventional FIP and the failure rate due to soldering decreases accordingly.

2.2 CIG DESIGN CONSIDERATION

The IC chip to be used for CIG FIP must withstand the high temperature environment of the FIP sealing processes.

The special IC manufacturing process is applied to the IC chip.

And the connection pad area is designed to match with the aluminum wire wedge bonding method. Also the IC pad layout is well designed to fit CIG FIP usage. for example to be located under the filament cooling zone,and to be cascadable. The shape of the IC chip is designed to match with CIG FIP,and is rectanguler rather than the square shape of common IC chips.

The available LSI characteristics are indicated in Table 1.

As for automotive display,the battery direct-drive one is preferred and the uPD16351 is used as the CIG FIP driver.The uPD16351 has 33 output drivers to drive the FIP segments. For more than a 33 segment FIP, two or more uPD16351 are cascaded.

3 EXAMPLES

Fig.5 shows the example of 98 segments CIG FIP with six(6) 20 bit driver chips. Unless the CIG technology is applied, a larger package must be used to allow room for the output leads.The latest driver chip uPD16351 can decrease the number of chips to be used for this case down to three(3).

Various custom design CIG FIPs are developed with up to three uPD16351 chips. For non automotive standard products, 5X7 or 5X12 dot matrix CIG FIP modules have been developed and currently mass produced. The module size is remarkably reduce down to 40% of th non CIG one.

The next step for CIG is graphic FIPs which are under development. Fig.6 shows 180X64 graphic FIP,conventional version(top) and CIG version(bottom).

Two IC chips for grid drive and three anode driver IC are installed in both ends of the CIG FIP.

The conventional FIP has 286 leads and a package size of 160(L)X60(W).

On the other hand,the number of leads is reduces down to 35 and package size of

173(L)X57(W) in the case of CIG vergion.

4 CONCLUSION

An integrated high performance system is required for automotive to fit within limited spaces. The Chip-In-Glass Fluorescent Indicator Panel helps these system to be designed as cost-effective, compact, highly reliable ones. Audio system, air-conditioning system, fuel management system find great advantages in CIG FIP. The CIG FIP will be widely used in near future.

The full graphic CIG FIP is under development to meet with future software oriented display system requirements.

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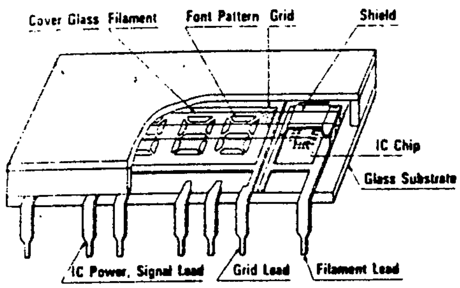

Figure 1.

Chip-In-Glass FIP Structure

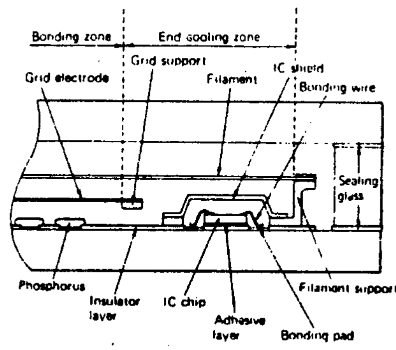

Figure 2.

CIG Cross Section of IC Mounting Area

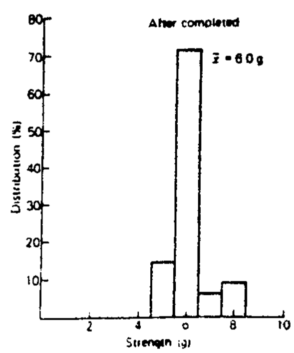

Figure 3.

Bonding Wire Strengh Distribution

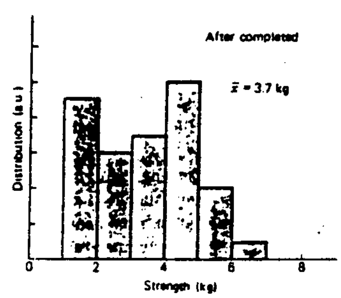

Figure 4.

Die Attachment Strength Distribution

(30um diameter Al wire in finished CIG FIP)

Table 1. Available LSIs for CIG FIP

Item	D16351	D6340	D16304	D16306
Function	S/R. latch and driver	S/R. latch and driver	S/R. latch and driver	S/R. latch and driver
Number of output drivers	33	20 (5 × 4)	40	64
Output driver	Open-drain Minimum breakdown voltage is 40 V dc.	Push-pull	Push-pull	Push-pull
Maximum supply voltage (V)	20	80	200	80
Main use	Segment type (static drive)	Dot character and graphic	Dot character and graphic	Dot character and graphic

Figure 5. Automotive CIG FIP

Figure 6. Conventional Graphic FIP(top) and CIG Graphic FIP.

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DEVELOPMENT OF FLAT TYPE ACTUATOR FOR AIR SUSPENSION CONTROL

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1. Preface

In recent years, the request has been increased more and more for amenity and driving comfortableness of vehicles and the electronically-controlled air suspension has generally been installed on high-class motorcars. Though the air suspension improves driving comfortableness because it has a small spring constant, it is needed to secure the vehicle controllability by changing over the air spring constant and shock-absorber damping force according to necessity because the air suspension decreases the roll·dive stiffness. The actuator for changeover has used a geared DC motor and encoder, or solenoid so far. The author et al, however, newly developed the disk-rotor-type stepping motor to meet the requirements of thin type, high torque, and quick responsibility for vehicles and mass-produced it as the actuator for LEXUS LS-400.

2. Requested specification

The following shows the specification requested from suspension design div.. Both the spring constant and damping orce are synchronously changed over in three steps. Especially, as shown in Fig. 1, it was requested to

Output Shaft	2 Shaft (Synchronized)
Position	3 Position (60°Step)
Height	Below 40mm (-30%)

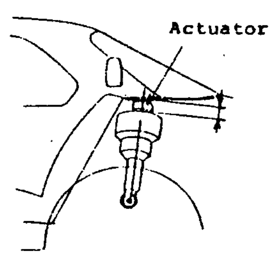


Fig. 1

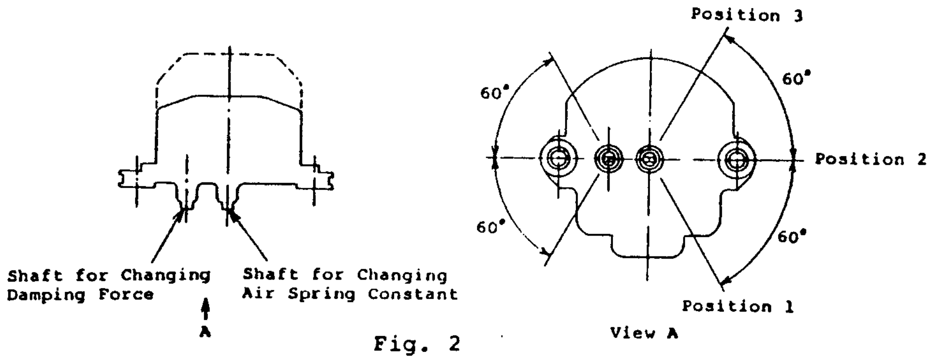


Fig. 2

decrease the gap between the air suspension unit and rear tray trim by 30% or more in the vertical direction compared with the existing value.

3. Decision of structure

They studied the following plans by making each prototype in order to meet the requirements of thin type and driving torque. (See Fig. 3.)
However, they had the policy to use no sliding contant point and fix the coil section in view of reliability. They decided to push development according to the disk rotor type of the plan "C" among three plans because the type allows a large effective diameter of rotor and improves the space efficiency of the coil winding section.

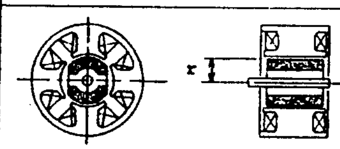
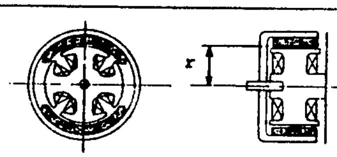
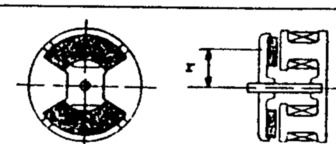
	Type	Pictorial	Coil Space	Rotor Radius	Torque
A	PM Stepping Motor Type		△	△	△
B	Outer Rotor Type		×	◎	△
C	Disk Rotor Type		◎	○	○

Fig.3

4. Securing of torque characteristics

The torque characteristics of this actuator include the driving torque to change over positions (in electrification) and the detent torque to maintain positions(out of electrification). Figure 4 shows the relation between the electrification mode and each position and Figure 5 shows the target of each torque .

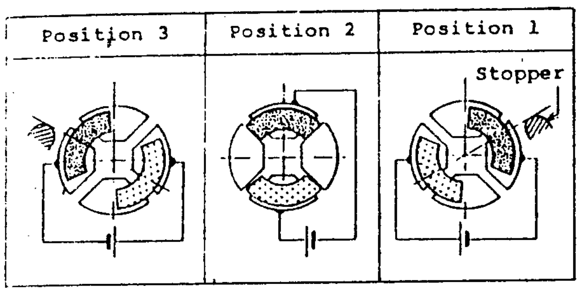


Fig.4

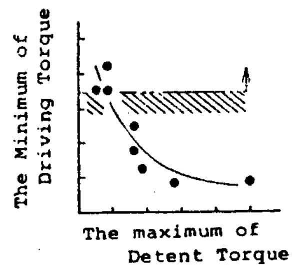


Fig.6

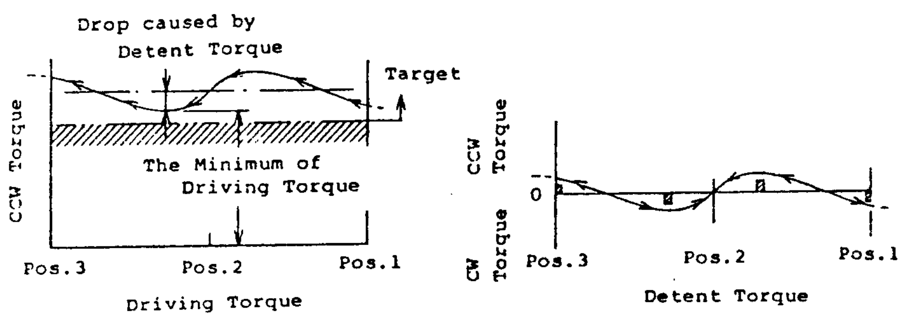


Fig.5

The driving torque is expressed as the sum of " electrification torque " and "detent torque" . To assure the minimum of the driving torque, it is an important subject to decrease the detent torque(Fig.6.) The following is the consideration for factors to determine the detent torque.

$$TD = \frac{\Delta \Phi}{\Delta \theta} = \frac{k}{\Delta R} \cdot \frac{1}{\Delta \theta}$$

TD : Detent Torque
Φ : Magnetism
θ : Rotor Angle
R : Magnetic Resistance

The magnetic resistance is determined by formula below

R = L1(air gap) μoA1(the stator/magnet overlapped area) ………… ①

+ L2/μ1A2 + L3/μ1A3 + L4/μ1A4 + L5/μ1A5 …… ②

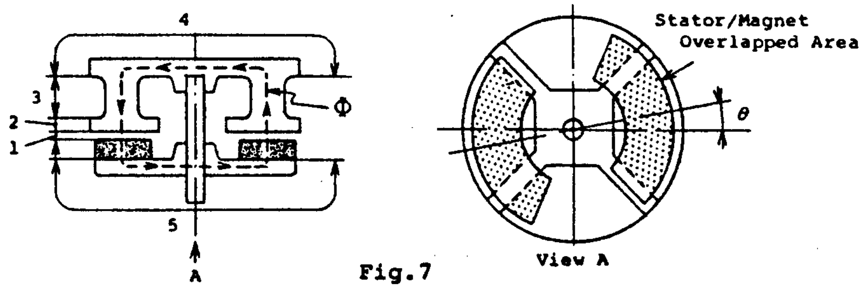


Fig.7

Where, Li : Length in the direction of flux, Ai : Flux flowing area

μo : magnetic permeability in air

$\mu 1$: magnetic permeability in iron

The about term ① changes according to rotation of the rotor. Figures 8 and 9 shows the result of the test using three types of rotors.

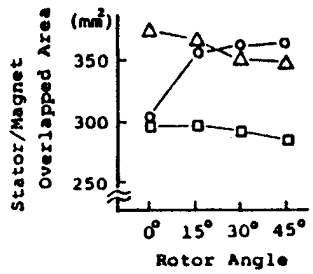


Fig.8

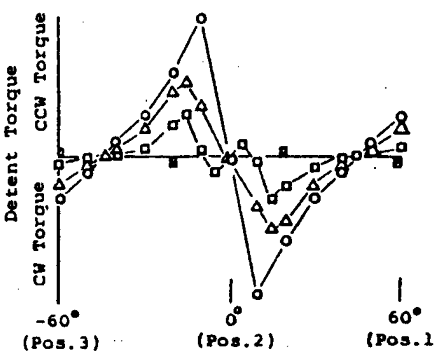


Fig.9

From the test, the following results are obtained. To decrease the detent torque.

(1) It is needed to decrease the change rate of the stator/magnet overlapped area according to rotation of the rotor. (See Fig. 10.)

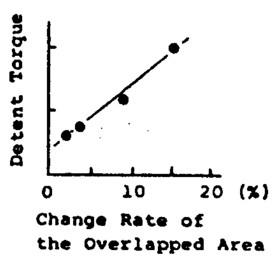


Fig.10

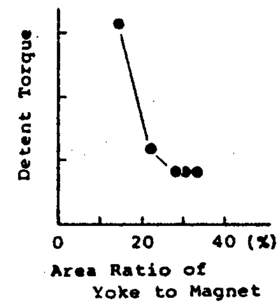


Fig.11

(2) It is effective to set the areas A2, A3, and A4 to the value in which magnetism is not saturated. (See Fig. 11.)

If the magnet is made of Sm2Co17 and the yoke is made of S10, the magnetism is saturated at the area ratio of 0.3 or less.

Control of detent-torque stabilizing point.

From Fig. 9, it is found that 45° is the stabilizing point other than the stop position. However, the problem can be solved by:

(1) Optimizing the flute spacing angle of the stator. (Fig. 12)

(2) Continuously changing the torque curve by installing short bridges at the tip of the stator. (Fig. 13)

The results are shown in Fig. 14.

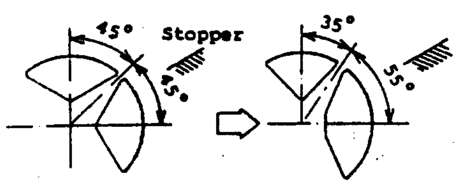


Fig.12

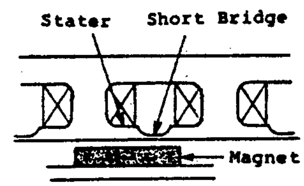


Fig.13

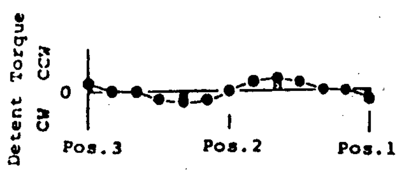


Fig.14

5. Decrease of changeover noise

Because the vehicle equipped with the air suspension has a low room noise level, changeover noise should be decreased. The source of changeover noise includes the hammering noise due to backlash of each part at start of driving and the impact noise produced when the rotor collides with the stopper. As the result of examination, it is found that the hammering noise due to backlash can be almost ignored but the impact noise due to stopper should be decreased for vehicles. The impact when the rotor stops is determined by the formula below.

$$F = \frac{MV}{T}$$

M: Inertia mass of rotor
V: Velocity at collision
T: Collision time

Therefore, they took actions to increase time and decrease velocity. Especially, to increase time (or to increase stroke), it was difficult to simultaneously meet the durability.

5-1 Increase of collision time.

They evaluated stoppers consisting of a coil spring and deformed rubber. As a result, they adopted the case " D " instead of adopting the stopper with a large stroke because it is inferior in durability though effective for decrease of changeover noise.

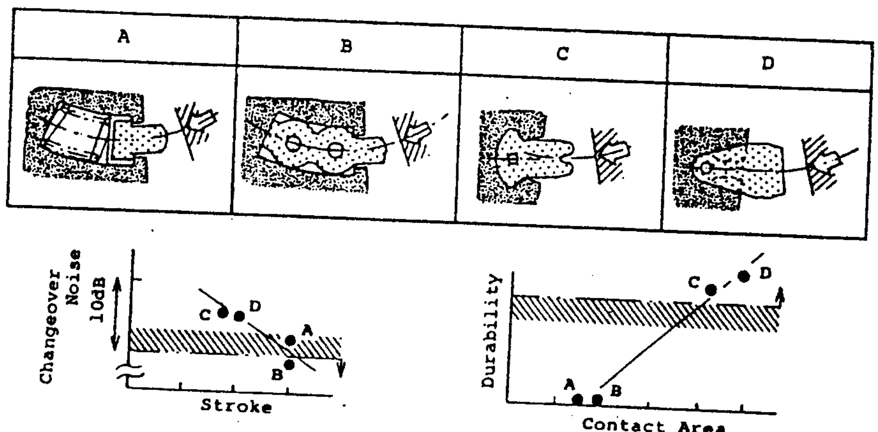
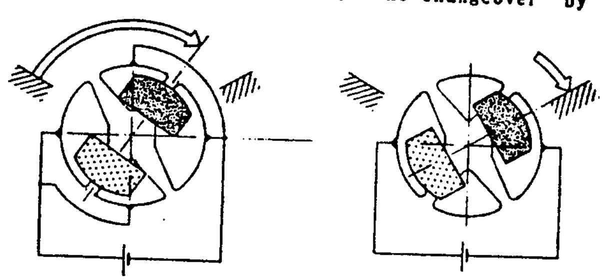


Fig.15

5-2 Decrease of collision velocity.

They performed the two-stage electrification test consisting of the first electrification to provide the stabilizing point before the stopper and the second electrification to securely make changeover by pressing the



First Electrification Second Electrification

Fig.16

rotor to collide with the stopper. Concretely, the first electrification is the method to stop the rotor by electrifying all poles of the stator to set the stabilizing point at the middle of the normal stabilizing point. However, they did not adopt the method because no remarkable effect was obtained and a complex electric circuit was needed.

5-3 Addition of mount insulator.

As the result of setting a resin tube to the joint with the shock adsorber in additioa to the insulator to mount the actuator, transmissibility of noise is decreased and the changeover noise in vehicles is decreased.

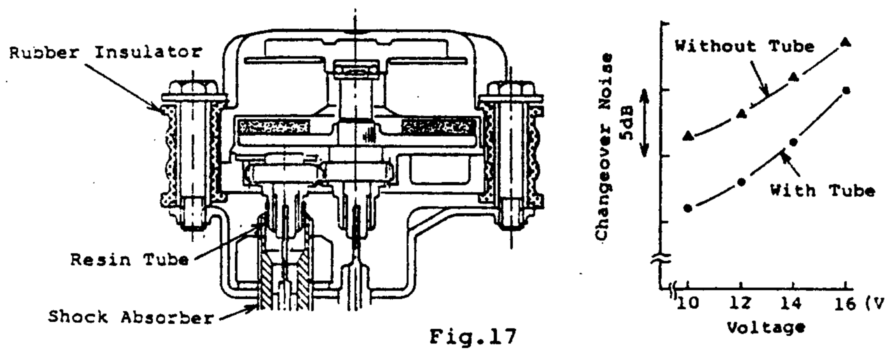


Fig.17

The changeover noise can also be decreased by changing the hardness of the insulation rubber installed between the air suspensioa unit and body. However, because the vehicle controllability also changes, it is needed to chose the area to meet the both requirements.

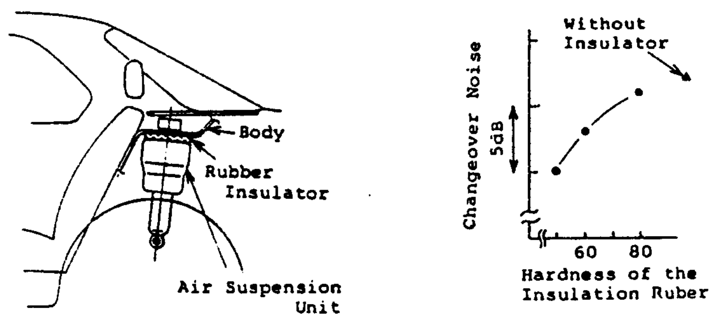


Fig.18

6. Improvement of productivity

To improve the reliability and productivity, wires between coils use Print -Wired-Board and are molded by resin together with the lead resistor which is installed to detect disconnection. The lead resistor is installed at the position where it is hardly affected by extrusion pressure. Influence of the molding pressure and temperature, and product reliability are also confirmed.

Fig.19

HANDS-FREE VOICE RECOGNITION TELEPHONE FOR AUTOMOBILE

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Japan

90009

ABSTRACT

Mobile phone, unlike domestic or office telephones, are designed for use in a confined space and while the user is in control of a vehicle. As a result, various considerations must be made with regard to ease of operation and safety. The authors have used voice recognition technology to simplify the dialing operation and have developed a system in which conventional manual dialing in mobile phone has been replaced with dialing by uttering the name of the party to be called.

The building of a voice recognition system necessitates the investigation of word choice and of the voice characteristics of the speaker. Furthermore, the application of voice recognition technology to mobile phone is complicated by various factors from within the vehicle itself, such as engine noise, or the conversation of other occupants, and external factors, such as road noise. The authors have developed a practical mobile phone system after studying the recognition rate of the newly developed system by modifying various parameters related to human factors and to driving conditions.

1. Introduction

The usefulness of the mobile phone is beyond question, and the increased use of these devices in recent years has been astounding. Nevertheless, the peculiar environment in which mobile phone are used, namely, while driving and in a confined space, means that various considerations must be made with regard to safety and case of operation. The system developed by the authors greatly facilitates the dialing procedure by replacing conventional manual keypad inputting with a system that uses voice recognition technology. This has been achieved by attaching voice recognition equipment to a hands-free telephone. Since November 1989 the system has been available as an option on models of the TOYOTA CELSIOR sold in Japan.

Safe driving involves constant observation of the road, other vehicles, and traffic signals and signs, and the responsible driver cannot afford to take his eyes off the road for prolonged periods to operate a keypad and switches. When mobile phone is used by a passenger seated in front seat beside the driver, and or in the rear seat, it is possible for him to have a time to input keys of several digits to make a call without any harms for driving. If the keypad is built into the steering wheel for driver, dialing while driving is greatly facilitated, although, again for safety reasons, this only applies to keypads with a small number of keys. The ideal would be to perform abbreviated dialing in a single operation or even to dial without touching the keys at all. Such hands-free telephones with abbreviated dialing functions are already available commercially and are aimed at simplifying the dialing procedure.

Nevertheless, even these systems do not altogether eliminate the work of the driver: the driver still has to check that he has entered the correct party's number from among those registered in his abbreviated dialing directory. Moreover, some abbreviated dialing methods use the exchange number of the party to be called as the abbreviated number, with the drawbacks that the use may still have to memorize many numbers and that the number of parties which can be registered is restricted to a few.

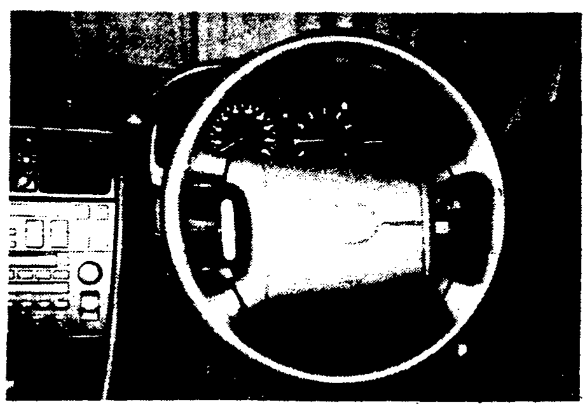

Figure 1 Driver's View of Steering Wheel (TOYOTA CELSIOR)

One solution to the problem of ensuring safety and ease of operation is to use voice recognition technology, which not only enables the driver to obtain the required party's number without taking his eyes off road, but also greatly increases the number of parties in the directory. Microphone and hook switch built into left side of steering wheel pad.

On other hand, in spite of the huge advances in electronic technology related to voice recognition, such as those in microcomputers and DSP, a variety of factors, including road noise, from inside the automobile, and changes in the user's voice, still make it impossible to achieve a 100 % recognition rate with equipment that is small enough to be mounted in a mobile.

In developing the present voice recognition dialing system, the authors have fully utilized system structure, operating method, voice recognition algorithms, and peripheral technologies such as circuit technology. The result of this and the numerous experiments that followed is a system with virtually no problems in practical use in terms of both recognition rate and ease of operation.

Details of the voice recognition algorithm and the circuit technology used in this system are given in this conference announcement, entitled 'A Speaker-Dependent Voice Recognition Algorithm for Voice Dialing in the Automotive Environment' (Nippondenso publication).

2. System Design Concept

1) System structure

The first consideration in building the system was whether to design it exclusively for mobile phone or to design a building-block system that could be expanded. Mobile phone systems are an optional item, and several types are available: handset, hands-free type, driver's seat type, and rear seat type, and those in which the user can choose any combination of these types. The system developed by the authors has building-block structure and can be added to hands-free telephones that can be used in various combinations.

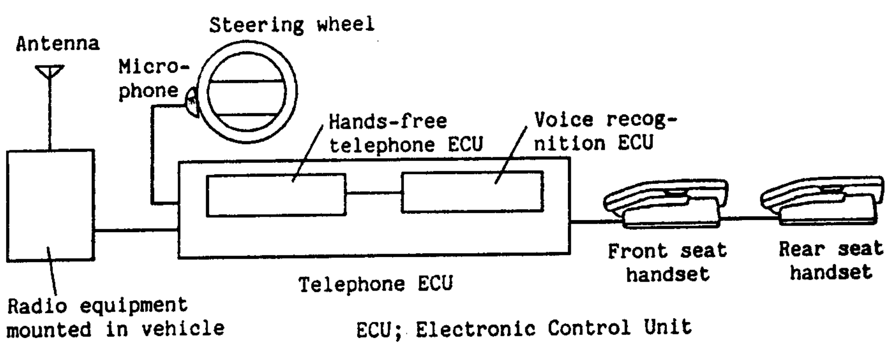

Figure 2. System block diagram showing relationship between hands-free telephone and voice recognition system

2) Selection of voice recognition system

Voice recognition technology enables a choice between speaker-independent recognition and speaker-dependent recognition and between isolated word recognition and connected word recognition. A further choice arises as to the words used for recognition:
Should the name of the party to be called or the party's number be used? For the reasons given below, the authors chose a 'speaker dependent isolated word recognition method.'

a) Speaker-dependent recognition method: The recognition rate using the speaker-independent recognition method is relatively low at present. Besides, because the system is bulky, it is not possible to incorporate it into an ECU that can be mounted in an automobile. Another disadvantage of this system is that it can recognize only words previously registered in the computer, meaning that only specified words can be used.

b) Isolated Word recognition methods (Pattern matching methods): This method has higher recognition rate for the connected word recognition because of its problem, such as a difficulty in segmentation of phoneme unit, and an effects of co-articulation liaison when the words uttered. Furthermore complicated hardware composition makes it both unsuitable for installing in automobiles and the production cost high.

c) Use of name of party to be called: This has the advantage of not requiring the driver to memorize a long list of telephone numbers, since he is obviously more likely to know the party's name than his number. Moreover, if a string of digits is to be recognized, the connected word recognition method must be used.

3) How many parties are to be registered?

In consideration of the actual conditions of use, the effect on recognition rate, responsibility, memory capacity, etc., the number of parties was set at 20.

4) Improvement of recognition rate (to reduce rejection when name is not recognized or misinterpreted)

There are various factors which give unfavorable effects to the recognition rate. As human factors, there are such case that a speaker cannot pronounce in the same say it was registered, of the selective way for near homonyms. And as external factors, there are noises both inside and outside of automobiles, in addition, of radiated noises out of electric circuits.

The system specification has decided after many experiments covering various related factors.

In preparatory experiment, the recognition rate are measured in the following factors, energy stress in pronunciation of consonants and vowels, under noisy environment, and with application of many near homonyms.

There are difference in energy stress level between vowels and consonants. It is said that of vowels are about 30 dB higher at the maximum than that of consonants.

This can be observed clearly, as shown in Figure 3 which indicates the voice patterns of typical surnames in Japan; Sato, Kato, Muto. In this example, the homonyms of Sato and Kato have same voice pattern with the exception of "S" and "K" sounds. Also, the voice pattern of Muto having slight difference from the above two surnames is shown at the last column.

As seen from the sample of Sato and Kato, the utterance time of consonant is too short, and furthermore energy stress level is considerably low, thus making the extraction of feature very difficult. While, between Kato and Muto, different vowels of "a" and "u" makes the extraction of feature comparatively easier.

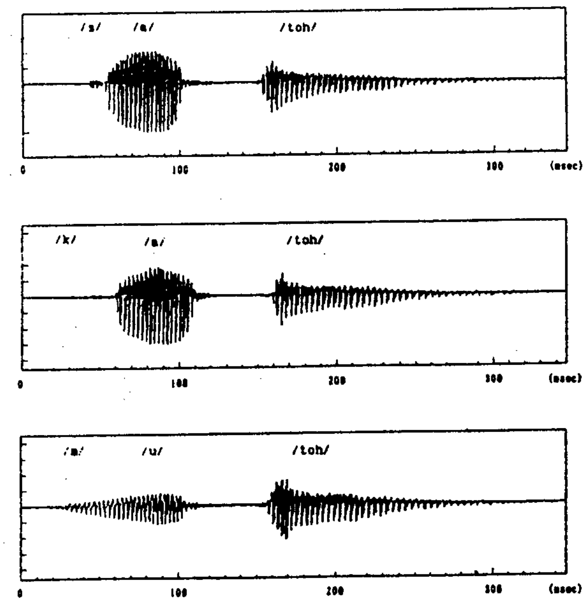

Figure 3 Sounds Pressure Wave of Sato, Kato, and Muto

This experiment was conducted in noiseless environment, however, under actual driving of automobiles, the system must extract the features out of the composite pattern of voice and noise, and this difficult fact leaves some more room which has to be overcome by technology, to make the system fitted into more practical use.

The authors carried out a number of experiments and have demonstrated that the two systems shown below are effective in improving recognition rate.

Accordingly, both system have been incorporated into the present system.

a) Need for retrying

The recognition rate is increased by retrying after the party's name has been misinterpreted. The system functions in the following way.

In the case when speaker's voice was misinterpreted or rejected, the system requests to the speaker to repeat the word once more and this repetition can be done upto three times. The results of tests to determine the effectiveness of retrying are shown in the following Figure 4.

(The Results of Tests to Determine the Effectiveness of Retrying Figure 4)

In figure 4 the recognition rate for the first party on the first attempt is 87.6 %, with rate increasing to 95.1 % and to 97.9 % after the second and third attempts, respectively.

Even after three attempts, it is difficult to achieve a 100 % recognition rata.

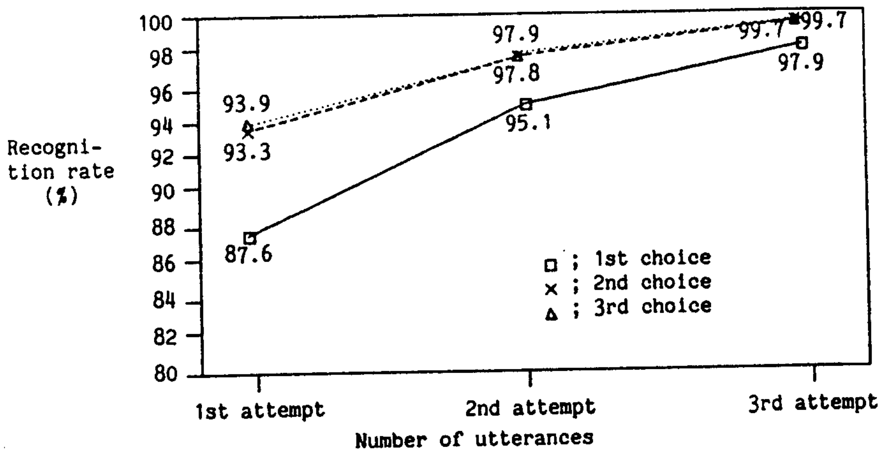

Figure 4 Voice Recognition Rate

The above experiments show that it is possible to increase the apparent recognition rate by retrying.

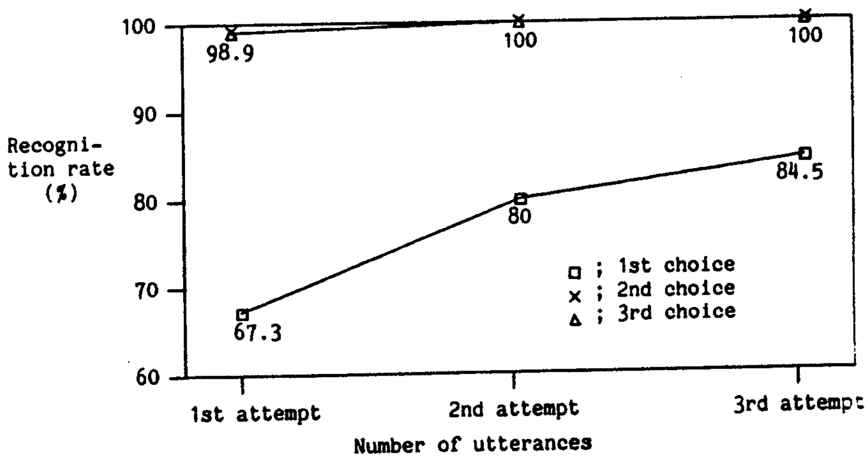

Figure 5 Recognition Rate for Words 'Sato' and 'Kato'

Test conditions for Figure 4 and Figure 5:
Participants: 3. Experts
Words used: 20 typical Japanese surnames.
Driving conditions: ordinary road, expressway.
Disposition of windows: completely closed.
Electrical loading: blower motor low, high.

b) Second and third choice of party to be called

It is possible to arrange words inside the ECU in accordance with their similarity to one another.

The recognition rate for the word which has the similar sound is shown in Figure 5.

Table 1 Examples of words arranged in order of similarity to one another

Name of party to be called	First choice (misinterpreted)	Second choice	Third choice
SUZUKI	SASAKI	SUZUKI	NAKAMURA
YAMAMOTO	YAMADA	YAMAMOTO	NAKAMURA
SATO*	KATO	SATO	TANAKA

*: The example in the bottom row is that used in Figure 5.

These examples show the case in which the names of the parties to be called are arranged in order of similarity to the called name. The name was misinterpreted at the first choice but recognized correctly at the second choice. The driver obtains the required party by pushing the key on the abbreviated dialing keypad on the hands-free microphone assemblage. Figure 5 demonstrates the effectiveness of this method of selecting the second or third party when the number of the words which have the similar sound is large.

In the system developed by the authors, the selection of the second or third name is made by means of the abbreviated dialing switch mounted next to the microphone.

The system developed by the authors thus consists of a so-called man machine system interface which combine voice recognition with 'multiple calling' and 'selection of second or third name,' and presents no problems in actual use where the selection of the party to be called is concerned.

5) Ease of system activation and operation of ringing off switch

Although the ideal would be to be able to control all of the operations by voice alone, problems of noise and recognition rate make this impracticable at the present stage of development. In the system developed by the authors a microphone and a built-in operation switch have been mounted on one side of the steering wheel pad to enable the driver to switch the telephone system on, to give the go-ahead for the number of the party whose name has been recognized to be dialed, to interrupt the recognition operation, and to ring off. Dialing of the wrong party can thus be prevented if the name is misinterpreted. A separate switch is provided for the two purposes of selection of second and third names and abbreviated dialing.

3. System Configuration and Specifications

1) System configuration

The configuration used is as follows: a basic hands-free telephone consisting of a radio (covering base station and air interface), a telephone computer, a handset,a microphone and abbreviated dialing keys assemblage, speakers (used in common with audio system), an audio mute circuit, etc.

The voice recognition equipment was coupled to the hands-free telephone, and a voice registration and confirmation switch and a recognition result confirmation switch were installed.

System components (See photographs)

(a) Microphone and abbreviated dialing keys Assemblage Photo. 1
(b) Telephone Control Switch Photo. 2
(c) Hand Set (in the console box) Photo. 3
(d) Telephone Computer (in the luggage room) SIZE 220×130×45 mm Photo. 4

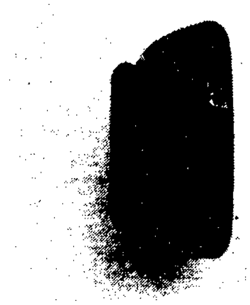

Photo. 1 Microphone and abbreviated dialing keys Assemblage

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- 8 -

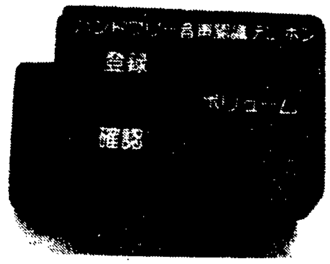

Photo. 2 Telephone Control Switch

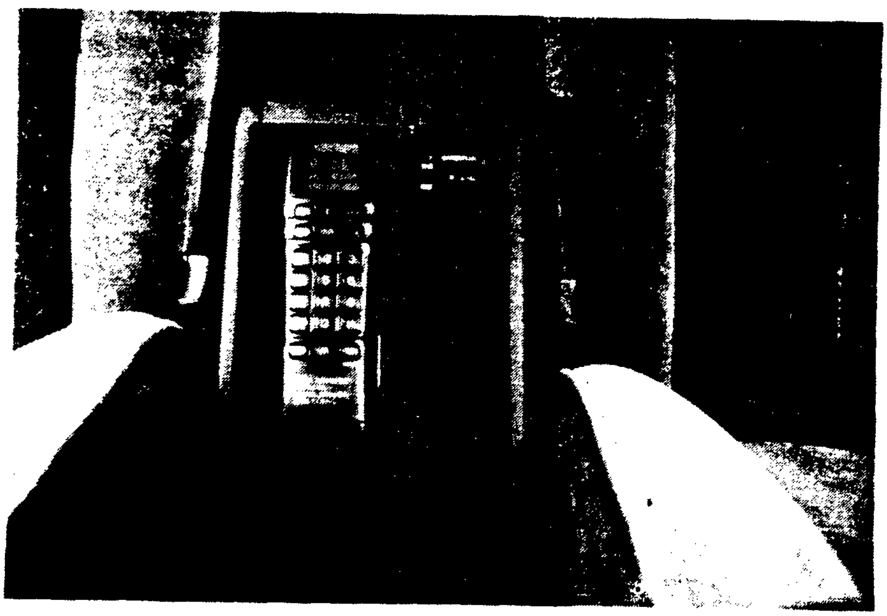

Photo. 3 Hand Set for Front Seat and Telephone Control Switch in the Center Console

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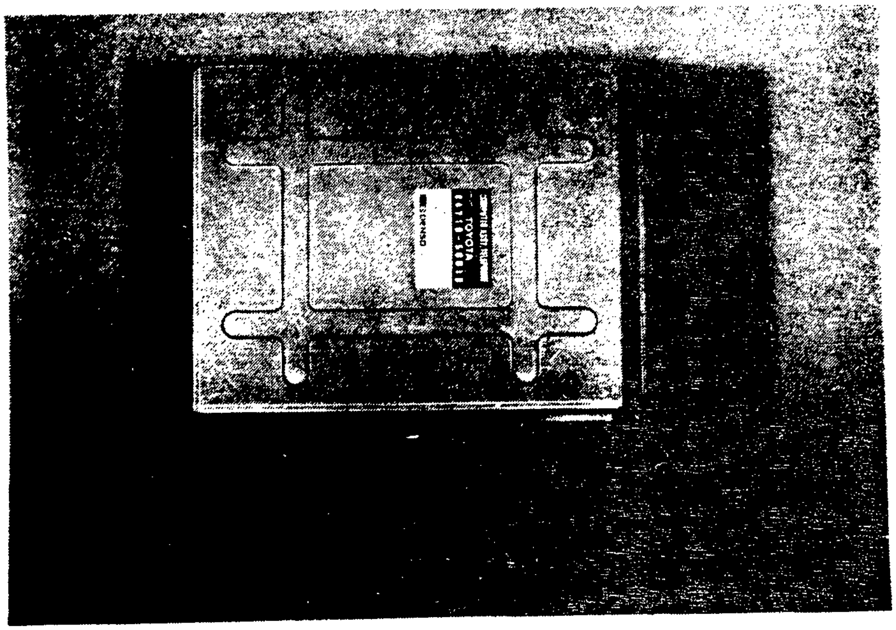

Photo. 4 Telephone Computer in the Luggage Room

2) System specifications

The system specifications of the voice recognition section are shown in Table 2.

Table 2 System Specifications

Item	Specifications
Words used	20 words registered by user (surnames or company names, for example TOYOTA, Ito, Sato, etc.)
Voice inputting method	Hands-free microphone
Microphone	Nondirectional electrostatic microphone
Speaker	Specified speaker
Number of times voice trained	At least 2 times per word
Duration of utterance	Less then 1.5 seconds
Recognition confirmation method	Talk-back response to user's voice (response time less than 1 second)
Operating method	Registration by pressing registration key then uttering word; confirmation by pressing confirmation key
Conditions during registration	Vehicle at rest
Control output (audio)	Mute signal output during voice inputting
Control output (air conditioning)	Blower motor on low during voice inputting
Composite tone (bit rate)	Guide tones: 'please,' 'called party's name please', registration tones, etc.; 32 kbps
Composite tone volume adjustment	By adjusting telephone control switch volume

3) Outline of Voice Recognition Circuit

a) Preprocessing: The detection of the voice interval depends on the level of background noise and changes the threshold value. The preprocessing filter used is one that approximates the characteristics of human hearing.

b) Analysis: Cepstram analysis method was used to obtain an approximation of the spectrum form of the voice. FFT (fast fourier transform) in twice and one logarithmic transformation are conducted. In this transformation, a spectrum envelope and its corresponding fine construction portion can be analyzed, compared and identified. This method has an advantageous point that enables the system to extracts the features of voice pattern with relatively less data.

T. Shinohara

As parameter, the 10 order Cepstram factor is applied.
DSP (5MIPS) was used as a hardware.

c) Matching: Dynamic programming (DP) matching was used.
A special-purpose gate array was used.

d) Recognition: The voice inputted is arranged in the ECU in order of proximity to the 20 previously registered words and the closest word is outputted.

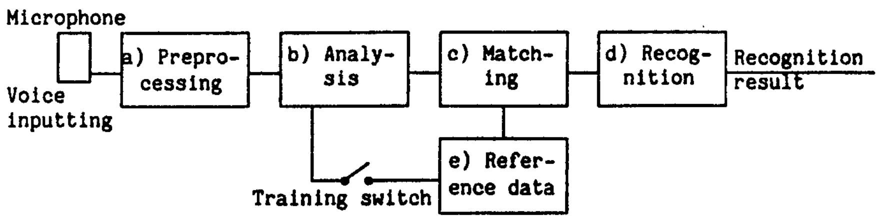

Figure 6 Block Diagram of Voice Recognition Circuit

4) Operation Functions

This system is a hands-free telephone system to which a voice recognition dialing function has been added. Communication by voice recognition begins with hands-free dialing. The user must register beforehand by voice the telephone number, the abbreviated number, and the corresponding names of the parties to be called. A maximum of 20 names can be registered.

The voice recognition section can be roughly divided into three parts; which are, 1) Voice registration, 2) Dialing, and 3) Confirmation of register contents.

Followings are dialing diagrams, one for the case of normal operation, and the other for the case when the required name is misinterpreted first time and the second name has to be selected by retrial, also a flow chart for recognition operation.

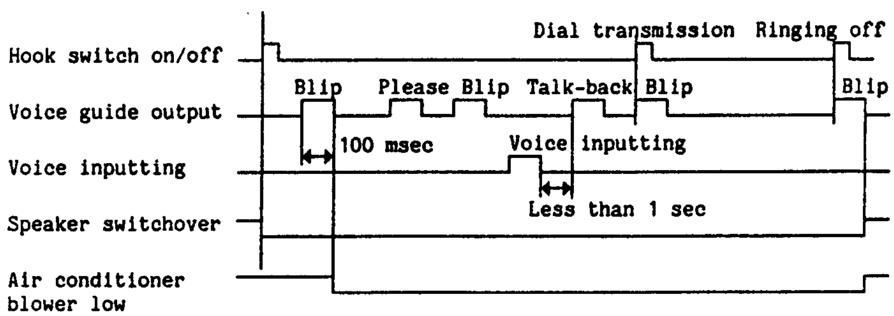

Figure 7 Basic dialing sequence

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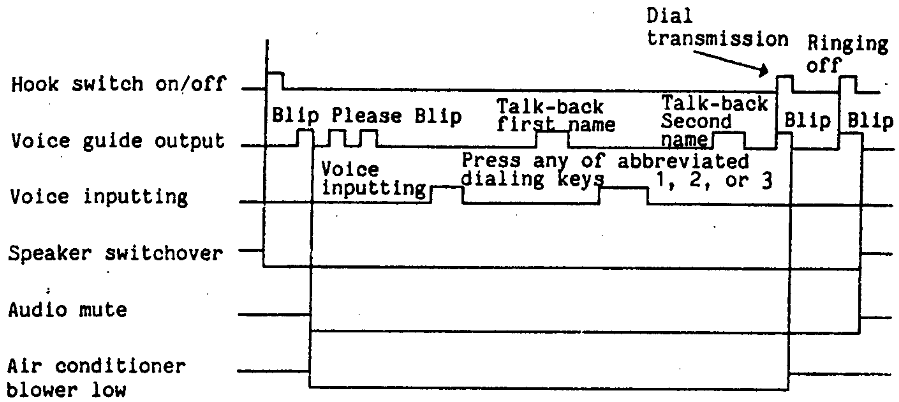

Figure 8 Sequence when First Name Misinterpreted and Second Name Selected and Outputted

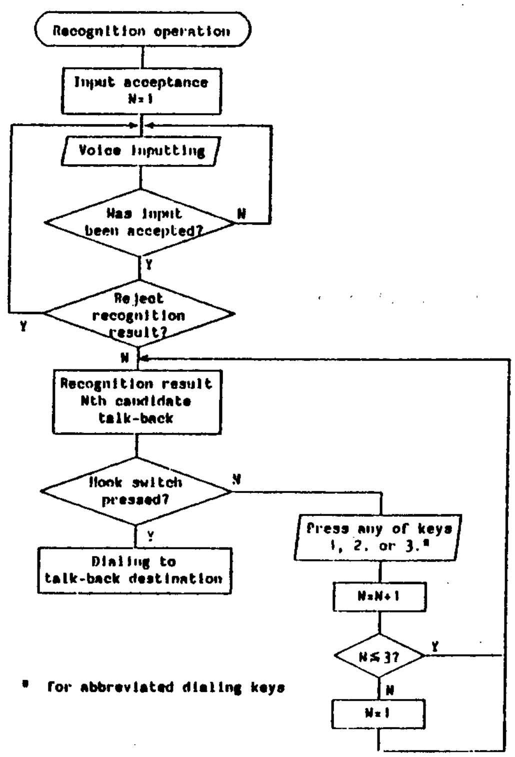

Figure 9 Recognition Operation Flow Chart

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4. Voice Recognition Test Results

To determine the practicality of the system developed by the authors various tests were carried out using as parameters human and environmental factors.

1) Test items and contents

By carrying out tests corresponding to real conditions of use, the authors investigated the recognition rate for many words which has the similar sound, the recognition rate in cases where a long time had elapsed between registration and utterance, and the recognition rate for different driving conditions and electrical loading conditions, etc.

Test items

a) Effect of choice of word on recognition rate: Personal names, company names, place names (The results of recognition of personal names and company names are included in this paper.); vehicle at rest.

b) Recognition rate for the words which have the similar sound: recognition rate using the words such as Ito, Sato, Ando; vehicle at rest

c) Effect on recognition rate of secular changes between registration time and utterance time; vehicle at rest

d) Recognition rate with combinations of conditions, including vehicle at rest, driving on expressway and ordinary roads, vehicle electrical loading on and off.

2) Test conditions

Five participants, 3 utterances each 20 words for registration and recognition test (typical Japanese surnames: Suzuki, Sato, Tanaka, Yamamoto, etc.; company names)

3) Results and Considerations (Figure 10 to Figure 13)

a) Effect of choice of word on recognition rate (Figure 10-(a), 10-(b))

Although there were certain typical Japanese surnames, such as Sato, Ito, and Yamada, which had a low recognition rate, the overall success rate was 92.0 % at the first attempt, 95.3 % at the second attempt, and 96.3 % at the third attempt.

When company names were used under the same conditions, the average recognition rate at the first attempt was 96.3 %, and 99.0 % at the second or third attempts. The recognition rates for the names 'NTT' and 'Hitachi' were rather low. In general, however, the recognition rates for company names were high, possibly because there were few words which have the similar sound..

b) Recognition rate when many words which have the similar sound were registered (Figure 11)

When typical similarly sounding surnames such as Ito, Kito, and Bito only were registered, the overall rate at the first attempt was 80.3 %, although the recognition rate was low for names such as I<u>to</u>, Chi<u>to</u>, <u>Naka</u>da, and <u>Naka</u>ba.

The misinterpretation and rejection rates for the words such as Ito, Kito, Bito, and Nito and Nakada, Nakaba, and Nakama were high.

As mentioned in 2-4, this is due to the fact the energy stress of consonants is considerably smaller than that of the vowel, thus making it difficult to extract the feature of voice pattern.

The recognition rate could be increased considerably by deliberately restricting the number of the words which has the similar sound among the 20 registered words in actual use.

The system developed by the authors has a function which enables the user to select the second or third name. In this way, the recognition rate remains high, even when there are many words which have the similar sound, as in the example above.

c) Effect of secular changes (Figure 12)

In data obtained from experiments in which a time interval of one and a half years had elapsed between registration and utterance, the recognition rate at the first attempt was 90.6 %. The effect of not using the system for one year or as much time interval is thought to be small.

d) Recognition rates under different driving conditions (Figure 13)

With the vehicle at rest, the windows closed, and the air conditioner blower motor low, the recognition rates were 93.3 % at the first attempt, 96.1 % after two attempts, and 97.2 % after three attempts. The corresponding rates when the vehicle was being driven along an expressway at about 100 kilometers per hour with the windows open and the blower motor on high were 73.3 %, 80.0 %, and 81.7 %.

The recognition rates obtained in tests under conditions which were combinations of the above and which included driving on ordinary roads yielded corresponding results of 85.6 %, 92.0 %, and 94.9 %.

5. Further Objectives

Although the authors have succeeded in producing a practical hands-free telephone dialing system for automobiles, among issues they would like to tackle in the future are the improvement of recognition rate, the miniaturization of circuits, and the reduction of sensitivity to various types of noise.

6. Conclusion

To lighten the load of the driver and to increase safety, the authors are researching various systems in which voice recognition can be used to control the audio system and the air conditioner, and several such systems have already been put into practical use. The authors have improved operability by replacing manual dialing with a voice recognition system. They have also investigated the recognition rates for a variety of personal names and company names, the rates for when there are many near homonyms, and the rates for when the vehicle was at rest or moving and was subjected to different electrical loading conditions.

Present-day technology does not enable a 100 % recognition rate in the automobile environment. In spite of this, by concentrating on operability and peripheral circuitry, the authors have developed a system the exhibits no problems in practical use.

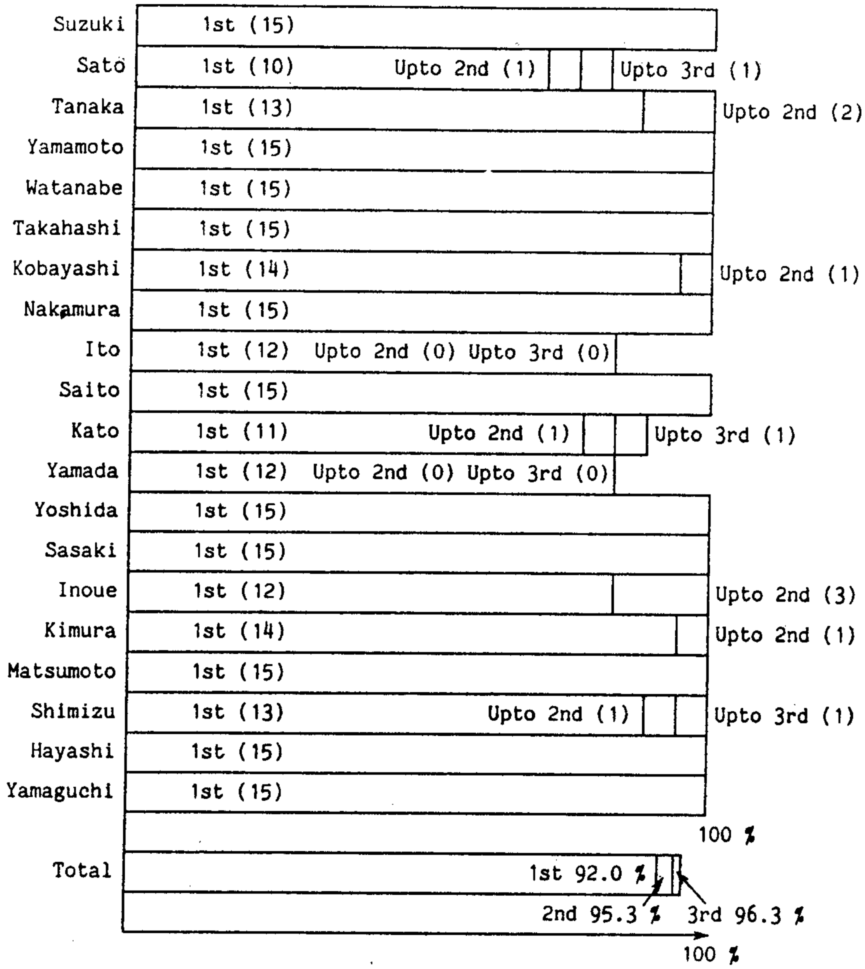
Acknowledgments

The authors would like to express their gratitude to Mr. Azuma, Mr. Yamamoto, Mr. Kumon, Mr. Ishihara of TOYOTA MOTOR CORPORATION and Mr. Kondo, Mr. Akiyama, Mr. Uono of NIPPONDENSO CO., LTD. and also to all those who participated in the development of this system for their guidance and cooperation.

7. References

1) B. Faerber, "Speech Control Systems In Vehicles" ISATA 89110
2) Brian L. Scott and Charles R. Kee, Jr" Speech Recognition in the Automobile: Coping with Noise in the Automotive Environment" SEA 870389
3) H. T. Zwahlen, C. C. Adams Jnr. P. J. Schwartz "Safety Aspects of Cellular Telephones in Automobiles" ISATA 88058

Test Items (a) Words-Names [The cumulative total]



A examples 1st: 1st attempt recognition rate
2nd: 2nd attempt recognition rate
3rd: 3rd attempt recognition rate

Figure 10-(a) Recognition Rate by Selection of Words

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Test Items (a). Words-Company Names [The cumulative total]

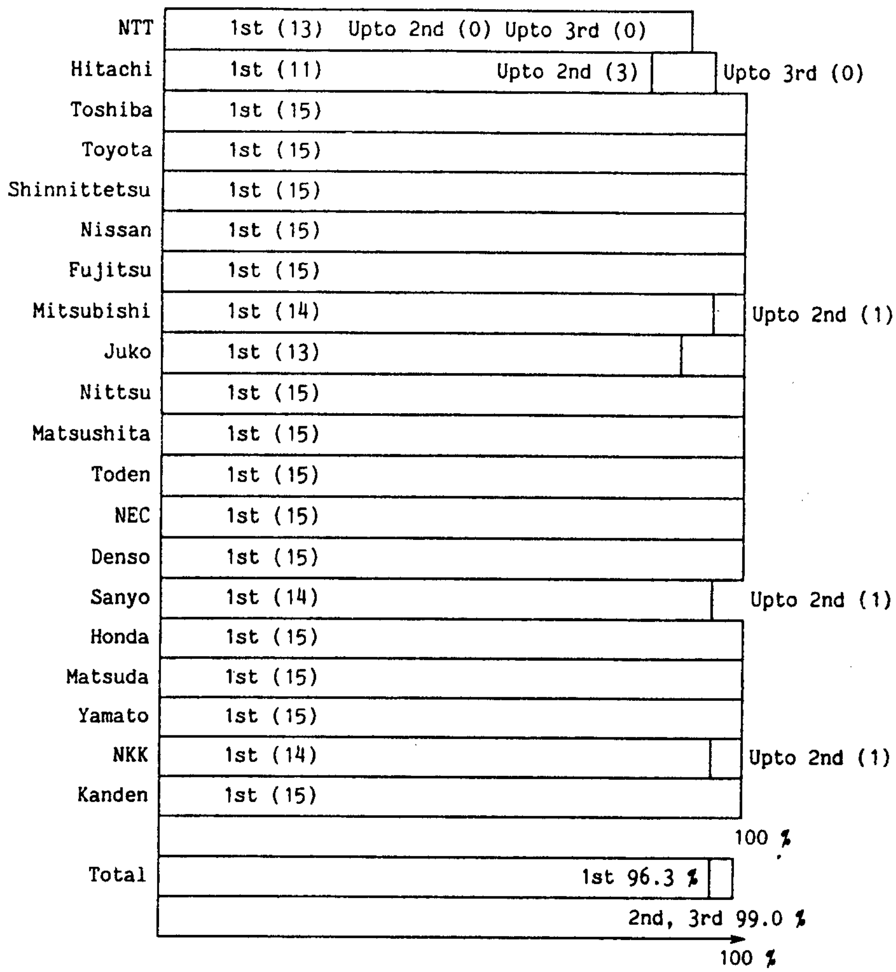

Figure 10-(b) Recognition Rate for Company Names

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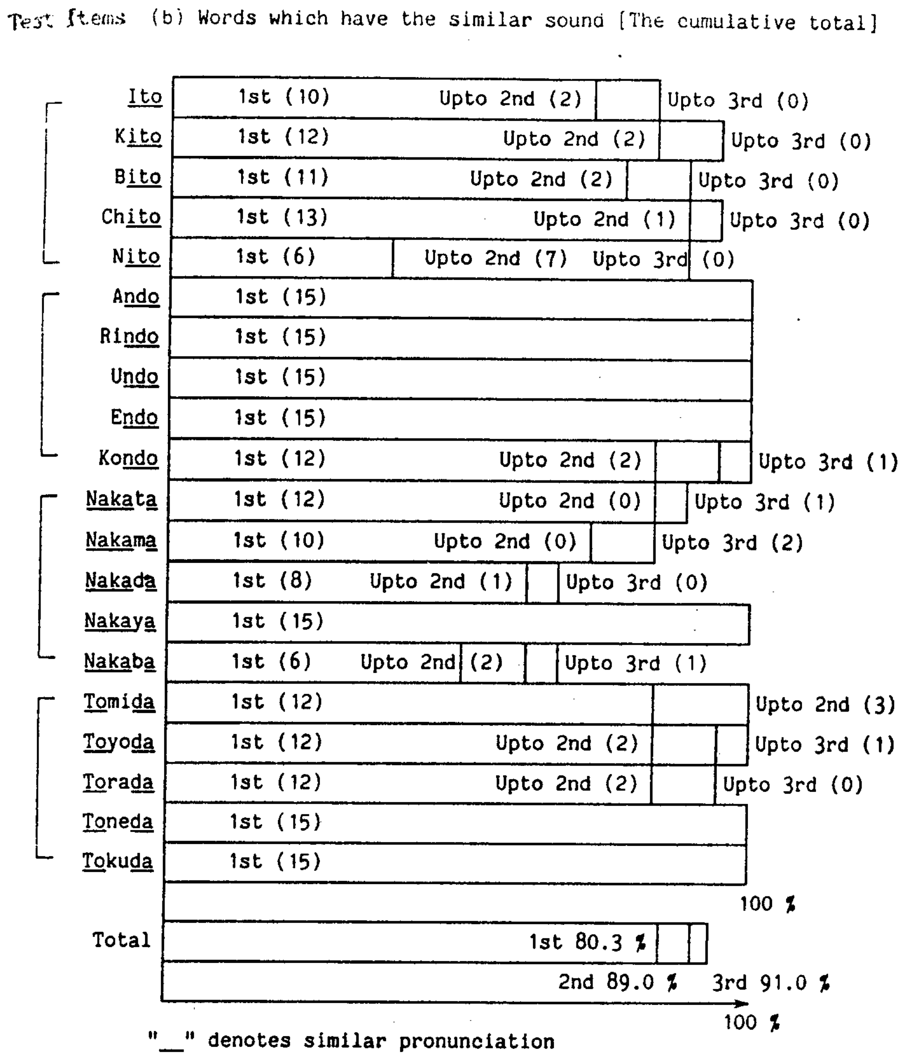

Figure 11 Recognition Rate for Words-Homonyms

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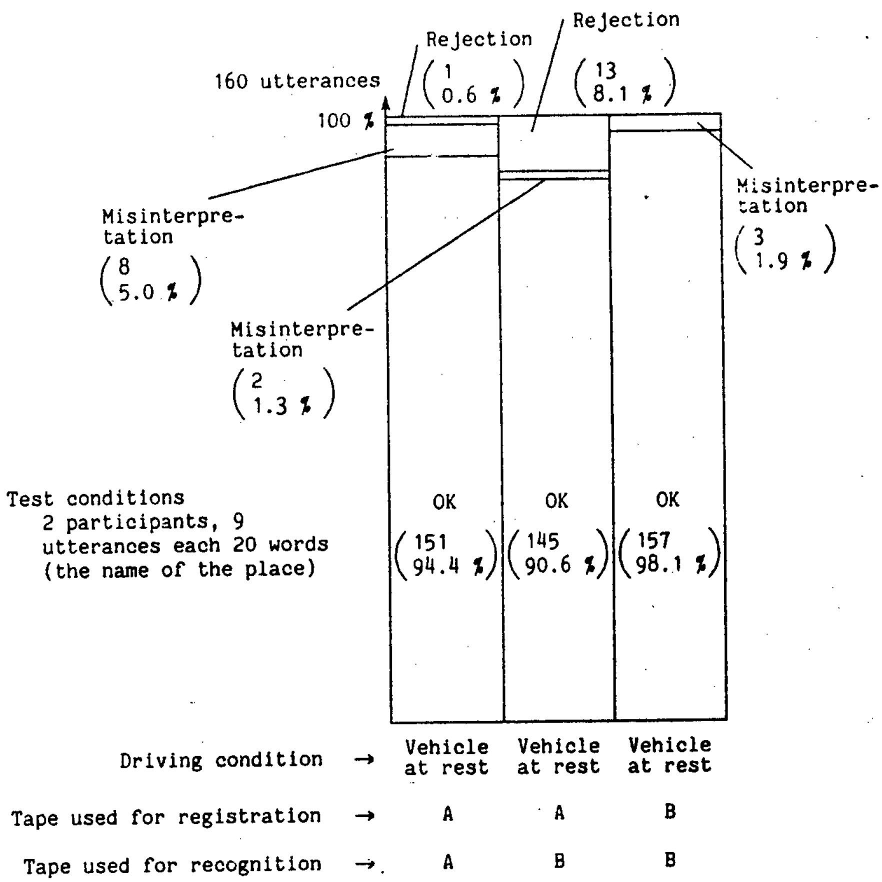
• TEST ITEMS (C) Effect on recognition rate of secular changes



The following tapes are used for this experiment.

Remarks:
- Tape A: The cassette tape used for voice recording in Dec. 1987.
- Tape B: The cassette tape newly voice recorded in Apr. 1989.
- There is one year and a half time interval between Tape A and B.
- The voice on the tape A and the tape B is recorded by same person.

Figure 12 Recognition Rate of Secular Changes Between Registration Time and Utterance Time

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Test Items (d). Combination of conditions driving on expressway and ordinary roads [The cumulative total]

*1: Windshield wiper *2: Blower motor
*3: Window *4: Driving conditions

*1	*2	*3	*4	Recognition
OFF	LO	Completely closed	Vehicle at rest	1st (166) 2nd (7) 3rd (2)
OFF	LO	Completely closed	Ordinary roads Root 115	1st (169) 2nd (6) 3rd (2)
OFF	HI	Completely closed	Ordinary roads Root 115	1st (148) 2nd (19) 3rd (8)
LO	LO	Completely closed	Ordinary roads Root 115	1st (167) 2nd (7) 3rd (3)
LO	HI	Completely closed	Ordinary roads Root 115	1st (157) 2nd (7) 3rd (4)
OFF	LO	Little Opened	Ordinary roads Root 115	1st (168) 2nd (4) 3rd (2)
OFF	HI	Little Opened	Ordinary roads Root 115	1st (146) 2nd (14) 3rd (7)
OFF	LO	Completely opened	Ordinary roads Root 115	1st (156) 2nd (11) 3rd (4)
OFF	HI	Completely opened	Ordinary roads Root 115	1st (153) 2nd (17) 3rd (3)
OFF	LO	Completely closed	Tomei Ex-pressway	1st (159) 2nd (13) 3rd (2)
OFF	HI	Completely closed	Tomei Ex-pressway	1st (143) 2nd (13) 3rd (10)
LO	LO	Completely closed	Tomei Ex-pressway	1st (166) 2nd (3) 3rd (1)
OFF	LO	Little Opened	Tomei Ex-pressway	1st (141) 2nd (18) 3rd (7)
OFF	HI	Little Opened	Tomei Ex-pressway	1st (132) 2nd (12) 3rd (3)
OFF	LO	Completely closed	Ordinary roads Root 1	1st (168) 2nd (7) 3rd (3)
OFF	HI	Completely closed	Ordinary roads Root 1	1st (153) 2nd (16) 3rd (5)
LO	LO	Completely closed	Ordinary roads Root 1	1st (165) 2nd (8) 3rd (3)
LO	HI	Completely closed	Ordinary roads Root 1	1st (139) 2nd (14) 3rd (7)
OFF	LO	Little Opened	Ordinary roads Root 1	1st (149) 2nd (16) 3rd (17)
OFF	HI	Little Opened	Ordinary roads Root 1	1st (134) 2nd (20) 3rd (10)
			Total	1st 85.6 % (3079) 2nd 92.0 % (232) 3rd 94.9 % (103)

100 %

Test condition
3 participants, 3 utterances each 20 words (typical Japanese surnames)

Figure 13 Recognition Rate for Combined Conditions of Vehicle at Rest, Driving on Expressway and Ordinary Road, and Vehicle Electrical Loading ON and OFF

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SPEAKER-DEPENDENT VOICE RECOGNITION ALGORITHM FOR VOICE DIALING IN AUTOMOTIVE ENVIRONMENT

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1. INTRODUCTION

Voice recognition consists in the automatic extraction by a computer of information concerning the semantic content of sound waves emitted by humans, and constitutes an ideal form of man-machine interface.

Research with the objective of realizing devices such as robots which can distinguish spoken words, voice typewriter and voice command cars has already been in progress for many decades.

The present authors have developed a number of voice recognition apparatuses and succeeded in the practical realization of these systems, principally in the area of applications to factory automation.

On the basis of these voice recognition techniques, a speaker dependent isolated word recognition device has been developed, intended for installation in automobiles, and various tests have confirmed that the performance characteristics of this device are of a practical level.

This voice recognition device has been integrated with an automobile telephone system and thereby applied to the realization of a voice dialing system.

2. A VOICE DIALING SYSTEM

Voice dialing consists in interconnecting a voice recognition device and a mobile phone and using the human voice to effect the calling operations conventionally performed by methods such as ten key or 1-touch dialing. Even while driving the vehicle, the driver merely utters the name of the destination, such as "office", etc., this speech signal is recognized by the voice recognition device, and thereafter the operation of calling the corresponding previously registered telephone number is performed automatically.

The advantages of voice dialing system include the following.

1) Since only the voice of the driver is used, dialing can be safely performed while driving.
2) The driver need not remember or ascertain the telephone number.
3) Operation is convenient even in the interior of an automobile.

Of course, the capabilities of such a system are largely governed by the performance characteristics of the voice recognition device employed in the system.

However, a great deal of extraneous noise is encountered while driving. Engine noise, the vibration noise from road, the noise by passing trucks, etc. to make an unfavorable acoustic environment that makes the accurate operation of the voice recognition device difficult.

Moreover, the fact that the device must be installed in an automobile requires a highly compact hardware assembly.

Thus, the realization of a voice dialing system for mobile phone necessitates the development of voice recognition device which satisfactorily copes with these two problems.

Full details concerning the present system are given in the conference presentation entitled " A HANDS-FREE VOICE RECOGNITION TELEPHONE FOR AUTOMOBILES".

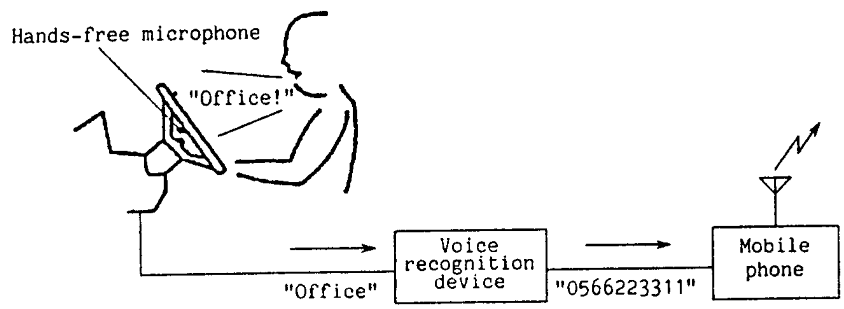

Figure 1. Voice Dialing System

3. VOICE RECOGNITION ALGORITHM

Figure 2 shows a block diagram of the algorithm for the speaker dependent isolated word recognition device developed by the authors.

This is a speaker dependent voice recognition device, requiring prior registration (training) of the voice to be recognized. Accordingly, the device has two modes, i.e., training and recognition.

The speech signal through the microphone are filtered and amplified in the preprocessor, and then the specific features of the speech signal, which are expressed as numerical parameters, are extracted in the frequency analyzer.

In the training mode, the sequence of these feature parameters is then stored in the reference pattern synthesizer in the form of a reference pattern representing the features of the speech signal.

On the other hand, in the recognition mode, when an unknown speech signal is inputted, then a sequence of feature parameters is created by the same process, then the corresponding unknown pattern is matched against the reference patterns in the matching processor. Then, the reference pattern with the greatest degree of similarity to the unknown input pattern is selected as output by the decision processor.

The capabilities of the voice recognition device in this process depend principally upon the two functions of frequency analysis and pattern matching.

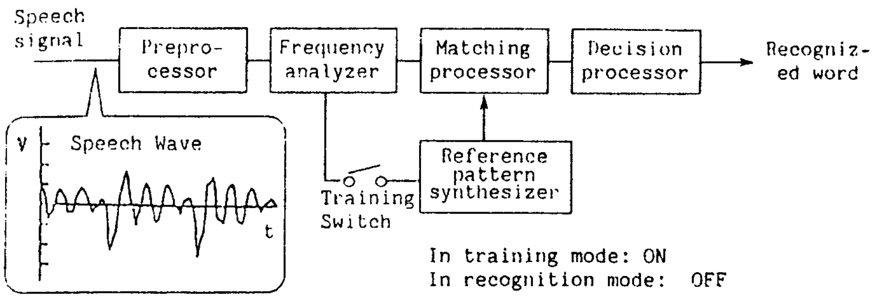

Figure 2. Schematic Block Diagram of Voice Recognition Device

3-1. Frequency Analysis (Feature Parameters)

The method of spectrum analysis employed in the frequency analyzer, i.e., the parameters selected as representing the features of the speech waves, should preferably be such that these features can be represented by a small quantity of data without discarding essential information of the speech signal.

The method of analysis also affects the scale of the hardware used in implementing the analysis.

If the features of the speech signal can be represented by a comparatively small amount of data (i.e., number of bits), then the amount of computation necessary for the subsequent matching process will also be relatively small, likewise, the amount of memory space required for the storage of reference patterns will be relatively small, and therefore a voice recognition device with good response can be realized by a compact hardware assembly.

In the voice recognition device developed in the present research, the cepstrum was used for frequency analysis.

The cepstrum $C(\tau)$ permits the approximate isolation and extraction of the spectrum envelope and the source signal of the speech signal. Assume that the speech results from a nearly periodic acoustic source S(f) driving a system with a transfer function V(f). The transfer function V(f) is considered as a filter equivalent to the vocal track. The output g(t) of this system (i.e., speech) is the convolution of s(t) and the impulse response v(t) of the vocal track equivalent filter, expressible as follows.

$$\begin{cases} g(t) = \int_0^t s(\tau)\, v(t-\tau)\, d\tau \\ G(f) = S(f) \cdot V(f) \end{cases} \qquad 3\text{-}1$$

Here, G(f), S(f) and V(f) denote the Fourier transforms of g(t), s(t) and v(t), respectively. In view of formula 3-1, one may regard S(f) as a carrier wave which is modulated by V(f) and thereby emitted as an information-bearing wave.

Hence, the information contained in the speech signal can be represented by V(f). Thus, by taking the logarithm of the Fourier transformation of the speech signal, V(f) and S(f) are separated, and the result of expressing only this envelope V(f) in the spectrum domain is the cepstrum. Thus, the information of the speech signal is compressed by a large factor, and the salient features of the speech are represented by a relatively small quantity of data.

This method compresses the speech data to about 1/25 of the original quantity, and this compressed data provides the parameters which constitute the basis for the voice recognition process.
This method of processing is schematically indicated in Figure 3.

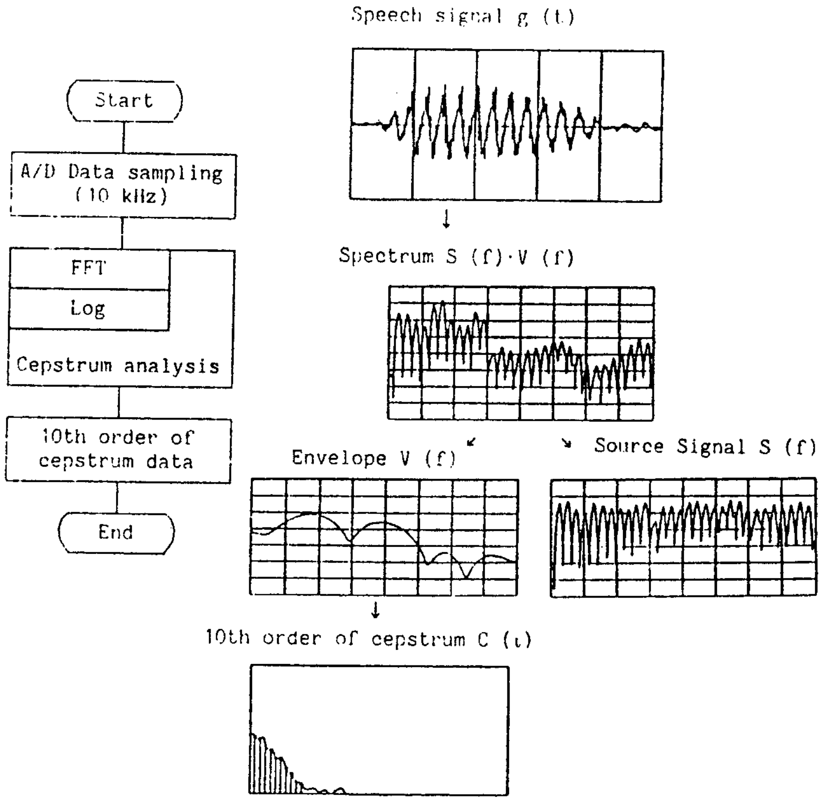

Figure 3. Cepstrum Analysis

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3-2. Pattern matching

The time length of even the same word uttered by the same individual will generally vary, and even if the time lengths are identical, the time structures of the utterance are generally nonlinear. Ordinarily, if enunciation is rapid, then the vowels are contracted, while the consonants tend to maintain their inherent length. Therefore, when attempting to match patterns with different time lengths, an accurate assessment of similarity cannot be obtained by merely equalizing the time lengths.

To solve this problem, a DP (Dynamic Programing) matching method is applied. The DP matching effects a correction for the shift along the time axes of input pattern and reference pattern.

Suppose that the two speech patterns (i.e., a sequence of feature vectors) which should correspond are A and B, expressed as follows.

$$\begin{cases} A = a_1, a_2, \cdot \cdot \cdot, a_I \\ B^n = b^n_1, b^n_1, \cdot \cdot \cdot, b^n_{Jn} \end{cases} \qquad 3\text{-}2$$

Here, A represents the input pattern, and B^n is the n-th of a set of N reference patterns, while a_i and b_j denote the individual parametric vectors characterizing A and B^n, respectively.

In voice recognition processing, the unknown input pattern A is compared with all the reference patterns, subject to time normalization, and the program finds that word $\hat{n}$, among the N registered words, which is closest to the unknown input pattern. The time normalization of speech patterns consists in applying a nonlinear transformation to the time axis, thereby absorbing the differences in pattern length and thus eliminating the unessential differences between patterns arising from differences in time length. The technique to be efficiently carried out this process of time normalization is the DP Matching.

More specifically, a sequence of feature vectors of the two patterns A and B^n are not matched linearly, rather, all corresponding parts within a definite permissible region called a adjustment window are compared, and the minimum of the distances (corresponding to the greatest degree of similarity) determined in this manner is regarded as the distance between A and B^n. That is, within the region of the adjustment window between the initial point (1, 1) and the final point (I, J), the recurrence formula 3-3 is calculated, thereby determining the distance between A and B^n after time normalization.

Here, d(i, j) denotes the distance between the two feature vectors a_i and b_j, and g(i, j) is partial distance (degree of similarity).

Initial conditions $\quad g(1, 1) = d(1, 1)$

Recurrence formula (DP equation) $\quad g(i, j) = d(i, j)$

$$+ \min \begin{cases} g(i, j-1) \\ g(i-1, j-1) + 2d(i, j) \\ g(i-1, j) \end{cases} \qquad 3\text{-}3$$

Distance between patterns $\quad D(A, B) = g(I, J)$

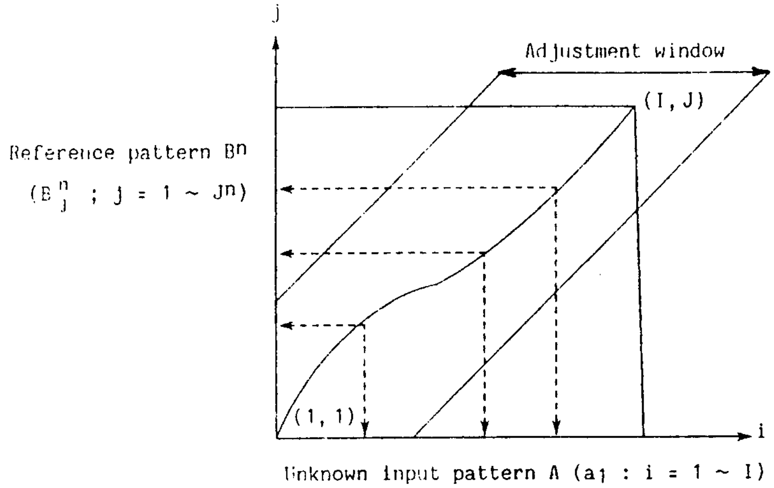

Figure 4. DP Matching

4. MEASURES FOR COPING WITH NOISE WITHIN RUNNING VEHICLES

The interior of a running motor vehicle is subject to considerable noise originating both inside and outside the vehicle. Conventional voice recognition devices have generally been designed to analyze the speech signal through the noise-canceling microphone held in close proximity with the mouth of the speaker in order to pick up voice signals with a good S/N ratio. However, if additional burdens are not to be imposed upon the driver, then the use of a hands-free microphone is indispensable.

However, a hands-free microphone is prone to pick up ambient noise, and thus provides a speech signal with a poor S/N ratio.

Under such conditions, measures to cope with noise in the vehicle are indispensable in order to realize a voice recognition device capable of high recognition accuracy.

Accordingly, the present authors first performed an analysis of noise in the motor vehicles.

The noise which degrade the recognition accuracy of voice recognition devices in the interior of running motor vehicles can be roughly classified into noises originating within the vehicle and those originating in the external environment.

The noise such as engine noise, exhaust noise and other noises originating within the vehicle have comparatively slow changes in characteristics (power, frequency characteristics, etc.) and can be regarded as stationary noise.

On the other hand, the noise caused by passing trucks and other vehicles as well as vibration noise from road, etc., have fast changes in characteristics within very short times, and may be regarded as nonstationary random noise.

The improvement of the recognition accuracy of such a voice recognition device requires measures to cope with both of these two varieties of noise. Figure 5-1 shows the noise in the interior of a running motor vehicles.

The power is largely concentrated in the frequency range below 600 Hz. In order to cut off the noise in this band, a high pass filter approximating frequency weighting characteristics for auditory sensation was realized in the form of a digital filter and used for a preliminary frequency analysis.

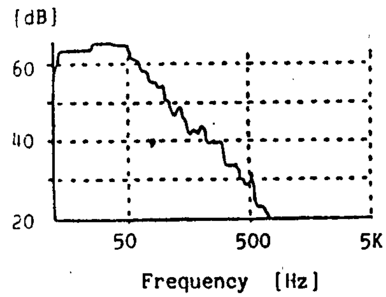

Figure 5-1.
Frequency Characteristics of Noise in Interior of Motor Vehicle

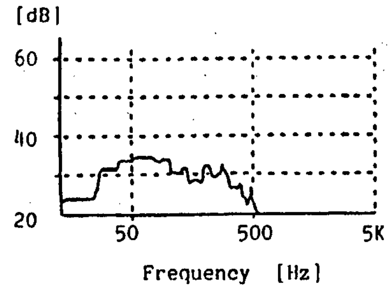

Figure 5-2.
Noise in Interior of Motor Vehicle After Filtering

Figure 5-2 shows that the effects of noise could be greatly reduced, thus permitting considerable improvement of the S/N ratio of the input speech signal through a hands-free microphone.
The detection of the speech interval from the input signal is accomplished by calculating the input signal power and distinguishing the range above a certain fixed value as the speech interval; and the adaptation of the detection level to the noise power reduced the degree of degradation in the recognition accuracy and thereby allowed considerable improvement of recognition performance.

5. REALIZATION OF HARDWARE

The hardware was designed with a view to execution of the voice recognition algorithm in real time by a compact apparatus. For the purpose of verifying the results of speech recognition and improving the quality of the man-machine interface, speech synthesis as well as speech recognition functions are incorporated. A block diagram of the hardware configuration is shown in Figure 6, and specifications are shown in Table 1.

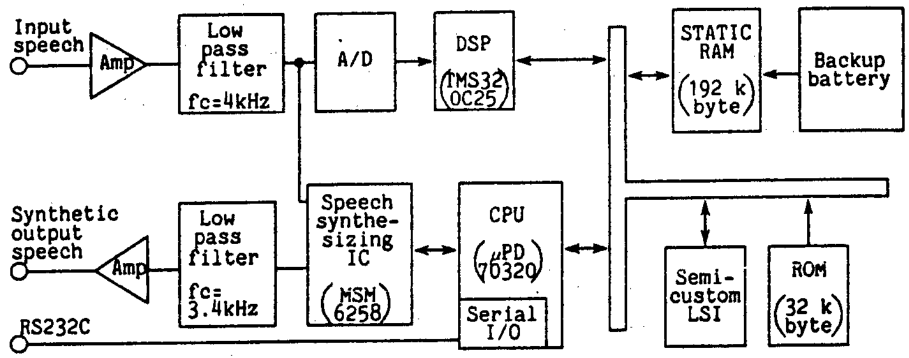

Figure 6. Block Diagram of Voice Recognition Device

Items	Specification
Input speech	Speaker dependent, isolated words
Recognized vocabulary size	Maximum 20 words
Recognition speed	Within 1 second after completion of utterance
Length of utterance duration	Maximum 1.5 seconds
Quantization	8-bit, 10 kHz sampling
Parameters	Up to 10th order cepstrum coefficients
Speech synthesis method	ADPCM (32 kbps)
Size	200 x 135 (mm)

Table 1. Specifications of Voice Recognition Device

5-1. Hardware Configuration

The central components of the present device are a digital signal processor (DSP: TMS 320C25, Texas Instruments) and a 16-bit general purpose microprocessor (CPU: μPD70320, NEC Corporation). The respective tasks of these two processors are allotted so as to exploit the respective characteristics of the two types, and parallel processing is employed for enhanced speed with a view to the numerical processing of large quantities of data in real time.

That is, the DSP rapidly executes the FFT and performs cepstrum analysis, while DP matching is performed by a semi-custom LSI and by the CPU, which also performs decision processing and memory management as well as control of the speech synthesizing IC for voice response and the overall control of the entire device. The speech synthesizing IC (MSM6258, OKI Electric Industry Co., Ltd.) incorporates built-in A/D and D/A converters and permits speech coding and decoding in real time with a single chip.

Speech data sampled at a frequency of 8 kHz is compressed to 32 kbps by ADPCM method and stored in memory.

Also, a 192 kbyte static RAM is provided for storing the reference patterns used for voice recognition as well as the speech synthesis data used for voice response. The static RAM which has the digitized speech data is backed up by a lithium battery, so that even if the ordinary power source is cut off, this data is preserved. Communication with external devices is accomplished by means of a serial I/O port in the 16-bit general purpose CPU. Operating commands as well as replays of the recognition results, etc., are all communicated-by this I/O port. As shown in Figure 7, the entire device is compactly mounted on a single printed circuit board.

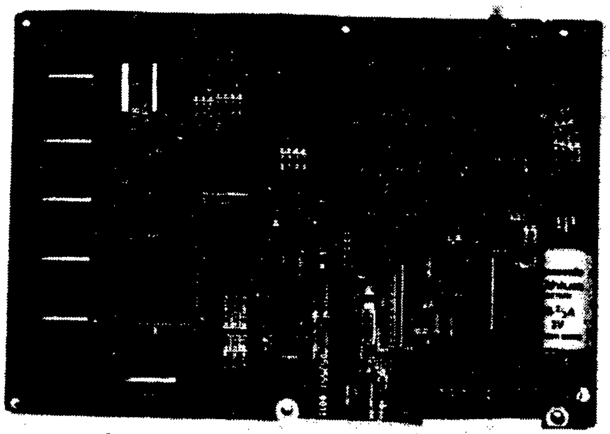

Figure 7. Voice Recognition Devices on a Single Printed Circuit Board

5-2. Recognition Processing Flow

The speech signal input through the hands-free microphone is amplified in a preprocessing circuit and the frequency band of the signal is truncated by a filter, after which the data is quantized by an 8-bit A/D converter at intervals of 100 μsec, and then read into the DSP.

In the DSP, cepstrum analysis is executed for each accumulation of sampling data, and this information is converted into a 10-dimensional feature vector. The DSP transmits this parametric data to the CPU.

In the training mode, the CPU assembles this data in blocks corresponding to each input speech and stores these blocks in memory as reference patterns which form the data base for the recognition process. Simultaneously, this input speech is encoded by the speech synthesizing IC and stored in memory as speech synthesis data for verification purposes.

In the recognition mode, the CPU along with the semi-custom LSI execute the comparison (DP matching) of the unknown input speech pattern and all the reference patterns, and the code of the registered speech with the smallest distance from the unknown pattern is then outputted through the RS232C circuit as the result of the recognition process. Simultaneously, the speech synthesis data stored in memory which corresponds to the result of the recognition process is transmitted by the CPU to the speech synthesizing IC and a synthetic speech is generated. Processing speed is increased by completely parallel execution of analysis by the DSP and matching by the CPU.

6. EVALUATION OF RESULTS

Various recognition experiments were performed in order to evaluate the performance of the voice recognition device described above.

This device was incorporated into a voice dialing system for ordinary users, and the performance of the device was first evaluated by experiments with subjects having no prior experience.

The results of these experiments are shown in Figure 8.

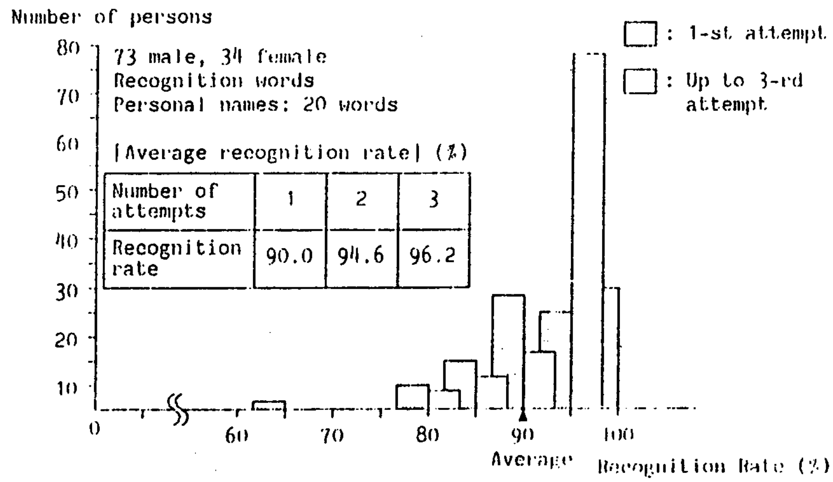

Figure 8. Results of Recognition Experiments with Subjects Having No Prior Experience of Voice Recognition Devices

The subjects of the experiments comprised 107 male and female with ages ranging from twenty-odd to sixty-odd years, the words for recognition comprised 20 personal names, and each subject performed 60 trial utterances.

An overall recognition rate of 90% was attained on the first try, and a recognition rate of more than 95% was obtained by allowing up to three utterances.

Considering the adverse acoustic conditions in the automobile environment and the use of a hands-free microphone, these recognition accuracy could be regarded as highly satisfactory.

In general, the recognition rate of voice recognition devices tends to increase steadily as a concomitant of user familiarization. This factor combined with the favorable results of the above-described experiments indicates that the performance characteristics of the present voice recognition device are entirely adequate for practical use.

As regards means for recovery in cases when recognition is not accomplished, the system has various mechanisms appropriate for the man-machine interface, and this problem constitutes no obstacle to the realization of the voice dialing function.

7. CONCLUSION

A small-scale voice recognition device displaying practical performance characteristics when installed in an automobile was developed, and the practicality of this device was verified by various experiments.

Hereafter, the directions requiring further effort in this connection are the development of voice recognition devices with still more stable recognition characteristics by improvement of the recognition algorithm, as well as achievement of further miniaturization by architectural studies.

8. ACKNOWLEDGMENTS

The authors hereby express their gratitude to all the persons who kindly cooperated in the performance of the experiments and also to Mr. Akiyama, Mr. Hasebe, Mr. Nakamura of NIPPONDENSO CO., LTD. and Mr. Shinohara, Mr. Maeda, Mr. Ishihara of TOYOTA MOTOR CORPORATION.

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H. ASADA

NEURAL BASED MULTI-SENSORY SYSTEM

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Abstract

In this contribution we present an advanced concept of neural based multi-sensory systems. It realizes two important features: on the one hand the neural net is trained what the sensors are supposed to detect in a known environment. On the other hand it learns the intrinsic nonidealities of the sensors. Successfull experiments have been carried out with pressure where the network has learned the temperature dependence in addition to the sensor sensitivity. Further experiments were carried out for gas mixtures to determine the gas spectrum.

1 Introduction

Among all technologies, the MOS-technology appears to be the most promising for fabrication of VLSI-compatible sensors for many application areas, e.g. automotive engineering, environmental protection, etc. While basic MOS-devices can sense light, temperature, and magnetic field without any technological modification, some special sensors may require additional processing steps. Generally, most sensors suffer from their own deficiencies, such as poor stability, drift, noise, and dependence on processing parameters, bias, and temperature. In addition, some sensors (in particular chemical sensors) exhibit cross-sensitivity, i.e. they are not sensitive just to a single quantity, physical or chemical, but to several different ones. To obtain a useful result for sensing of desired quantities, the detection calls in such case for a variety of sensors. The useful signal can then be obtained by decorrelation of various sensor signals. This might become quite tedious due to lack of analytical models, or even impossible, as we have to untangle all possible effects. To summarize it: while a sensor array may yield a lot of useful information, the evaluation means work in a multi-dimensional state-space with nonlinear dependencies.

Thus we face the following situation: on the one hand, the MOS-technology has the capability to realize various sensors and sensor arrays and it can provide a considerable computing power. On the other hand, we still lack methods how to evaluate highly complex and interrelated sensor signals.

As the above mentioned problem is related to the problem of pattern recognition where neural networks enjoy considerable success, it can easily be imagined that these networks could be applied to solve our problem as well.

2 Neural Networks

A neural network consists of a massive parallel connection of simple units in ideal case working asynchronously - thus introducing new forms of signal processing. Each unit, called neuron, forms a weighted sum of all its inputs and yields an output depending on the tranfer function, often sigmoid [1]. Learning of the network is defined as the modification of the weights so as to encode an presented pattern into the neural network.

There are at least two additional major advantages of neural networks against classical von-Neumann-computers besides massive parallelism: (1) fault-tolerance in hardware and software, and (2) possibility of implementation of self-learning systems.

The learning capability of neural networks makes possible construction of neural based multi-sensor systems which could be taught what the sensors are supposed to detect in a known environment during the training phase. Furthermore, the sensors could learn their innate characteristics in order to be able to eliminate all deleterious effects. And last but not least learning capability can enable performing self-diagnosis, i.e. faulty parts or defective sensors could be detected by the system and disabled or replaced by redundant ones.

In our experiments we use a feedforward multilayer perceptron network which feeds the activation values in a forward pass to the next layer. In a separate backward pass learning is done by propagating back the error from the output layer through the network to the input layer.

3 Sensors

We have carried out successfully experiments with pressure and gas sensors where the network has learned the temperature dependence in addition to the sensor sensitivity.

3.1 Pressure Sensor

The pressure sensor is formed by a capacitor consisting of a polysilicon membrane and silicon substrate and was fabricated using planar etch processing (Fig. 1). This technique is compatible with standard CMOS processing and results in very small sensors in contrast to back side processing.

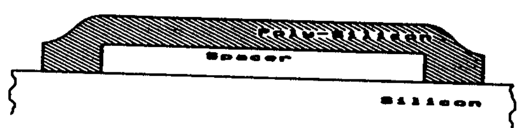


Fig. 1: Profile of pressure sensors

Polysilicon-membranes are produced by etching an underlying layer [2]. Membrane diameters of 50 μm to 140 μm were fabricated via etch channels. After this the etch channels were sealed in a vacuum process. Deflection of the membrane due to pressure gives rise in a change of capacitance.

Fig. 2 shows the measured data for the pressure sensor. The capacitance is a nonlinear function of the pressure and the temperature.

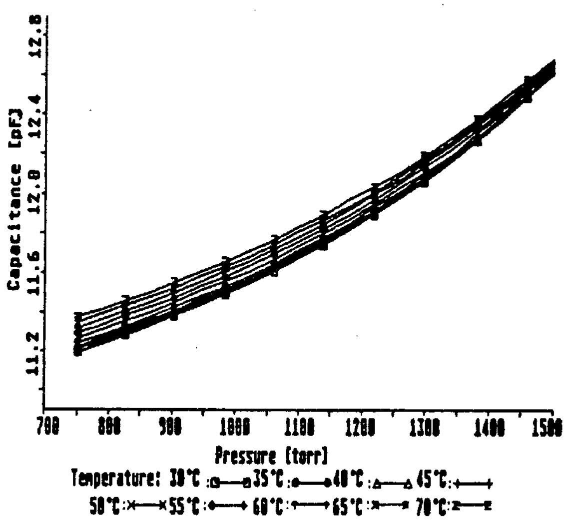


Fig. 2: Measurement of temperature dependent pressure sensor

As expected, the capacitance is a non-linear function of the pressure. In addition, there is a non-linear temperature dependence which decreases with increasing pressure.

3.2 Gas Sensors

Solid state gas sensors exhibit very high cross-sensitivities so that it is extremely difficult within a gax mixture to identify an individual gas and its concentration. Besides, these sensors suffer from drift, possess nonlinear characteristics, and are temperature dependent.

For our experiments we used gas sensitive MOSFETs. They can be build using variations of palladium-gate electrodes in conjunction with standard MOS-technology. Varying the gate structure yields different sensitivities to hydrogen, ammonia, methanol, carbon monoxide, etc [3]. Nevertheless, owing to the above mentioned cross-sensitivities it is extremely difficult to identify an individual gas and its concentration.

We carried out experiments for gas sensors with H_2 and NH_3 to determine the gas concentration. Two sensors with different characteristics for both gases were used: sensor

A is selective to NH_3 but also has a cross sensitivity to H_2 and sensor B is only selective to H_2. Thus to determine NH_3 concentration we have to eliminate the cross-sensitivity of sensor A. Fig. 3 shows the measured data of the two sensors for different gas concentrations of H_2 and NH_3.

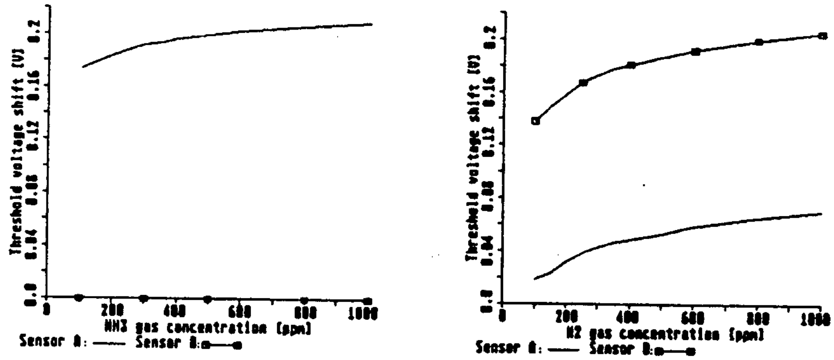


Fig. 3: Measurement of different gas sensors

4 Experimental Results

To verify the ideas above we have designed an experimental system consisting of several sensor types and a 4-layer network with perceptron architecture. The network was simulated with software tools [4] but hardware for the neural network is being developed [5]. For learning we employed the back-propagation [6] algorithm which minimizes the mean square error between the actual output and the desired output. The network consists of an input layer which forms interface to the sensors, two hidden layers, and an output layer as an interface to deliver the desired results. Fig. 4 shows this network configuration.

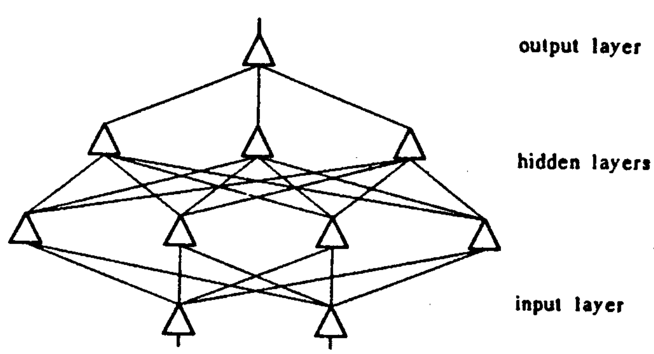


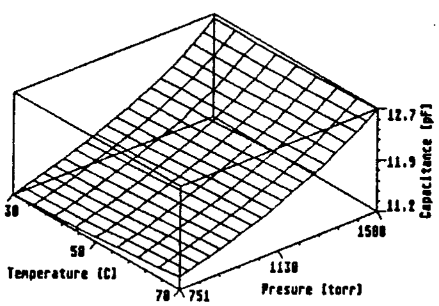
Fig. 4: 4-layer perceptron network

Carefully performed measurements with a good reference to provide a teacher turned out to be essential. The teacher provides the desired output data for a given input. The neural network learns by comparing its actual output and the desired output, and adjusting the synaptic weights till the difference is minimized. After the system has learned sufficient amount of sensory information it can evaluate sensor signals by performing associative recall via the trained neural network. In order to shorten the training period, the network was designed in such a way that it can interpolate and thus the number of measurement points can be significantly reduced. Hence the network is able to learn the characteristics of the sensors instead of simply interpolating between measured data points.

4.1 Pressure Sensor

In case of the pressure sensor, we have taken measurements for 9 different temperatures at 20 different pressure values. For training of the network we only used the data of 5 temperatures at 9 presures. Thus we get two input signals to the network: 1. capacitance, and 2. temperature. Fig. 5a shows the measured capacitance of the pressure sensor as a function of the temperature and the pressure.

This data which shows the non-linear dependencies as mentioned above were taken as the input sensor signals of the neural network. After training of the network we obtain the output pressure at th output layer of the network shown in Fig. 5b. It can be seen that the nonlinear temperature dependency was eliminated by the network and, in addition, the nonlinear relationship between the capacitance and pressure was linearized. The absolute error is less than 50 torr for the trained network.



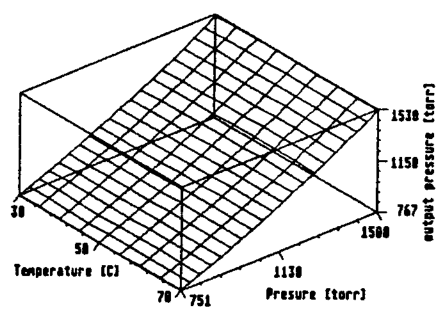


Fig. 5a: Measurement   Fig. 5b: Simulation

for temperature dependent pressure sensor

4.2 Gas Sensors

We use the same network topology as described for the pressure sensor. The number of units in the input layer was 2, in the first hidden layer 4, in the second 6, and in the output layer 2, one for each gas. The input values to the network are the threshold voltage shifts from Fig. 3, and the output values of the network represent the detected gas concentrations. The simulation results are shown in Fig. 6.

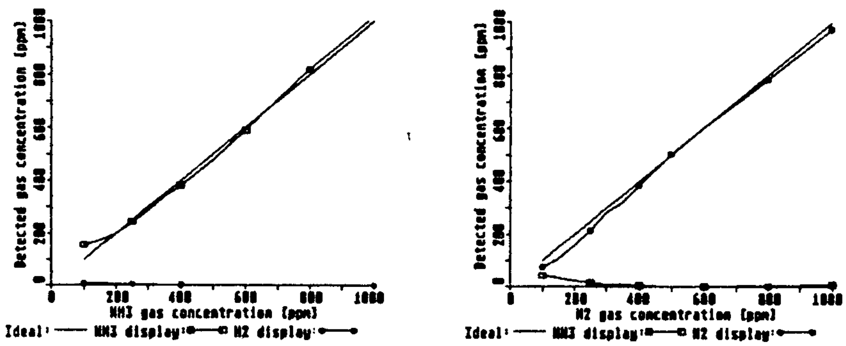


Fig. 6: Simulation results for gas sensors

5 Implementation Issues

The presented concept of neural based multi-sensory systems is highly suitable for MOS integration, though some sensor types may require extra processing steps as mentioned above. The sensors can be arranged in one- or two-dimensional array and may require some preprocessing readout circuitry before they are fed into the neural network.

Various multi-sensor systems could be envisioned but one of the most interesting tasks would be building a gas analyzer. Gas analysis is used for separating and identifying the components of a gas mixture. As pointed above however, the gas sensors exhibit very high cross-sensitivities. Thus we need many sensors of the same type on the same substrate to eliminate the inherent sensor deficiencies, and various sensor types in order to be able to compute the gas spectrum and thus eliminate the cross-dependencies.

Nevertheless, it should be mentioned that high performance of neural networks cannot be reached when using software simulations on a von-Neumann-computer. Thus it is neccessary to implement both the sensors and the neural network in CMOS-technology [5].

6 Conclusion

The neural based concept is shown to be an attractive architecture for realization of multi-sensory systems. The multi-sensory input delivers its massively parallel information directly into the neural network, thus taking full advantage of neural parallel processing capability. Further salient features of the neural processing are learning and fault-tolerance. The experiments have confirmed that the proposed approach can be used for intelligent microsystems with multi-sensory input.

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TRANSMISSION CONTROL SYSTEM FOR CONSTRUCTION MACHINES

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Abstract

To improve this shift feeling, it is indispensable to control engagements of transmission clutches. We realized highly smooth shift feeling by optimizing the time and the pressure of clutch engagements and disengagements through electric pressure control valves which are individually equipped for each clutch.

This system has been already applied to our off-road dumptrucks. This paper introduces how the system controls the transmission (T/M) clutches on each shift occasion.

1. Introduction

In recent years, the technology of mechatronics has seen a remarkable development, particularly in its application to passenger cars. This technology not only dramatically improved the motoring performance of passenger vehicles but also made them far more comfortable they had been before.

Our company, Komatsu boasts of itself as a pioneer in the application of mechatronics technology to construction equipment. As early as 1977, Komatsu introduced electronically-controlled automatic transmission systems to dump trucks.

Jast a passenger cars have much improved their driving performance, people now also seek a more sophisticated driving performance from their construction vehicles. Well-spaced gearing and a smoother transmission, which would realize a more comfortable drive in going up slopes, as well as in shifting, has been one of the most strongly requested developments.

We have developed a system to electronically control clutch operation in accordance with the load imposed on the vehicle's power train. With this system, we have used Komatsu-developed clutch oil pressure control valves for individual clutches. We refer to this computerized mechanism as "the individual electronically-controlled modulation system," or K-ATOMiCS* its acronym.

In this report we will describe the algorithm of our newly-developed jerk-reducing clutch control system and the outline of a trial in which K-ATOMiCS* were employed in a dump truck.

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* Komatsu-Advanced Trasmission with Optimum Modulation Control System

2. Necessity for Control in Clutch Engagement

The degree of jerk when shifting depends on the driver's sensitivity and cannot be precisely measured. It may widely vary from person to person.

In evaluating the degree of jerk when shifting, the Jerk Value (rate of acceleration to time) is generally used. Human beings, however, do not always feel a jerk strongly even if it is a strong one in terms of the Jerk Value. What they feel is influenced by what they expect to feel.

For instance, when a driver accelerates a car, the driver usually does not think the acceleration uncomfortable, or rather may think it pleasant, because he wants or expects the acceleration. On the other hand, while a car is moving with no acceleration, the driver tends to be sensitive to acceleration or deceleration because he expects no interference to change the velocity. Under such circumstances, even a small torque fluctuation, coming through the transmission, can make the driver uncomfortable.

Therefore, by precisely controlling clutch operation, with the view of controlling transmission output torque, according to engine output, the jerk upon shifting can be reduced. A control program, in addition, should differ from gear to gear because how a driver feels is affected by many factors, including the velocity of the vehicle when shifting.

When shifting into a higher gear while accelerating, a large torque is generated and gives the torque curve as shown in Figure 1. In this particular case, problems are as follows;

1) Cutoff of torque supply, brought about by release of clutch, causes an initial, momentary jerk.

2) Period of torque supply cutoff causes a lapse in acceleration.

3) Impact on clutch engagement causes a second jerk.

4) Gradual momentary increase in output torque after clutch engagement, until clutch synchronization, is felt as a continuous jerk.

The phrase "jerk when shifting" used in this report to this point means what is experienced by the driver from a series of torque fluctuations as shown in Figure 1.

Problems numbered 1), 2) and 3) can be solved by coordinating T/M output torque and engaging clutch torque. Problem 4) can be solved by controlling the oil pressure of engaging clutch in accordance with engine output.

Figure 2 shows the ideal torque curve and clutch oil pressure curve which would be brought by the untillzation of K-ATOMiCS.

Problems 1), 2) and 3) are solved in the following way. Supply enough oil to engaging clutch to complete filling before releasing the other clutch. After releasing clutch, gradually increase oil pressure of the engaging clutch. The purpase in coordinating torques is to precisely control the residual pressure of the released clutch and the initial pressure of the engaging clutch. Figure 3 illustrates an idealized clutch model.

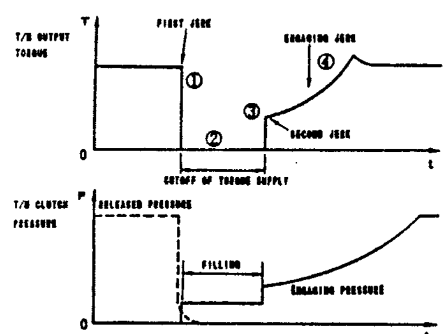

FIG. 1 EXAMPLE CONTROLLED CONVENTIONAL SYSTEM

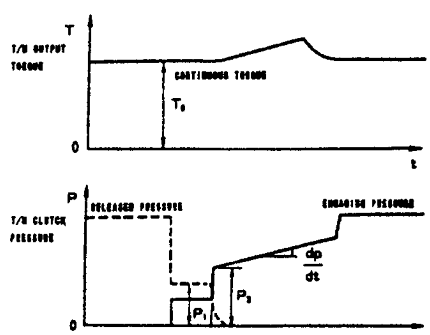

FIG. 2 EXAMPLE CONTROLLED K-ATOMiCS SYSTEM

The torque transmitted by the clutch is given by the following equation.

$$Tc = \mu \cdot A \cdot Rm \cdot N \cdot P \text{ -------------------- } (2 \cdot 1)$$

Tc : Clutch Torque
μ : Coefficient of Friction
N : Number of Frictional Face
A : Piston Area
P : Pressure in Clutch
Rm : Mean Radius in Clutch

Supposing that the value (μ) is fixed, the clutch torque (Tc) is given as a function of the clutch oil pressure (P). In order to coordinate output torques before and after a shift change, the T/M output torque, which is calculated from the engine torque, and the torque capacity of the engaging clutch should be equal. The released clutch torque should be equivalent to the output torque because of the necessity of protecting the clutch during the shifting.

Consequently, in making the released clutch torque ($\rho_2 \cdot Tc_1$) and the engaging clutch torque ($\rho_4 \cdot Tc_2$) equivalent to the T/M output torque (To), a smoother torque curve is obtained. In order to achive the above-mentioned torque values, the clutch pressures (P_1 and P_2) must be abtained by the equations (2.3) and (2.4).

Engine torque is estimated from the accelerator position and the engine revolutions per minute.

$$To = \rho_{12} \cdot Te \text{ ------------------------------------- } (2 \cdot 2)$$

$$To = \rho_2 \cdot Tc_1 = \mu \cdot A_1 \cdot Rm_1 \cdot N_1 \cdot \rho_2 \cdot P_1$$

$$P_1 = \frac{\rho_{12} \cdot Te}{\mu \cdot A_1 \cdot Rm_1 \cdot N_1 \cdot \rho_2} \text{ --------------- } (2 \cdot 3)$$

$$To = \rho_4 \cdot Tc_2 = \mu \cdot A_2 \cdot Rm_2 \cdot N_2 \cdot \rho_4 \cdot P_2$$

$$P_2 = \frac{\rho_{12} \cdot Te}{\mu \cdot A_2 \cdot Rm_2 \cdot N_2 \cdot \rho_4} \text{ --------------- } (2 \cdot 4)$$

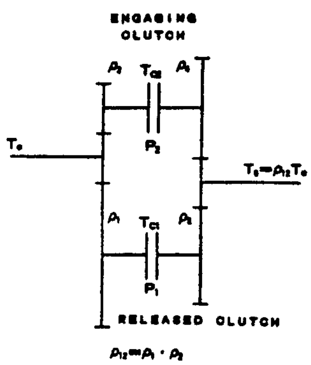

FIG.3 IDEALISTIC CLUTCH MODEL

Te : Torque of Engine
To : Torque of T/M Output Shaft
Tc_1 : Torque in Released Clutch
Tc_2 : Torque in Engaging Clutch
ρ_{12} : Gear Ratio in Released Clutch
$\rho_1 \sim \rho_4$: Individually Gear Ratio
P_1 : Pressure in Released Clutch
P_2 : Pressure in Engaging Clutch
A_1 : Piston Area in Released Clutch
A_2 : Piston Area in Engaging Clutch
Rm_1 : Mean Radius in Released Clutch
Rm_2 : Mean Radius in Engaging Clutch
N_1 : Number of Frictional Face in Released Clutch
N_2 : Number of Frictional Face in Engaging Clutch

As mentioned above, when clutch torques are coordinated, the problem remaining to be solved is problem 4). What follows is the relationship between the oil pressure increasing rate and the Jerk Value.

Acceleration of the vehicle (α) is given by the equation (2.5). The Jerk Value (J) is obtained by differentiating acceleration by time, as shown by equation (2.6).

$$\alpha = \frac{T \cdot \rho}{Rt \cdot W/g} = \frac{\mu \cdot A \cdot Rm \cdot N \cdot P \cdot \rho}{Rt \cdot W/g} \text{ ---- } (2 \cdot 5)$$

$$J = \frac{1}{g} \cdot \frac{dP}{dt} = \frac{\mu \cdot A \cdot Rm \cdot N \cdot \rho}{Rt \cdot W} \cdot \frac{dP}{dt}$$

$$= K \cdot \frac{dP}{dt} \quad \text{---} \quad (2 \cdot 6)$$

$$\left(\text{Provided that } K = \frac{\mu \cdot A \cdot Rm \cdot N \cdot \rho}{Rt \cdot W}\right)$$

α : Acceleration of Vehicle
W : Weight of Vehicle
ρ : Gear Ratio (From Clutch To Tire)

R t : Radius of Tire
J : Jerk Value
g : Gravity

As a result, given gear ratio and total weight of the vehicle, we can obtain the oil pressure increasing rate (dP/ dt) gives us an optimum Jerk Value through equation (2.6).

Therefore, jerk during an accelerating shift-up can be reduced, by controlling the residual pressure of the released clutch, the initial pressure and the clutch oil pressure increasing rate of the engaging clutch.

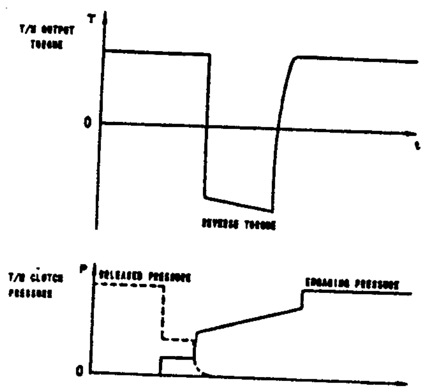

FIG. 4 SHIFTING DOWN IN ACCELERATION
(NO SYNCHRONIZE TIME)

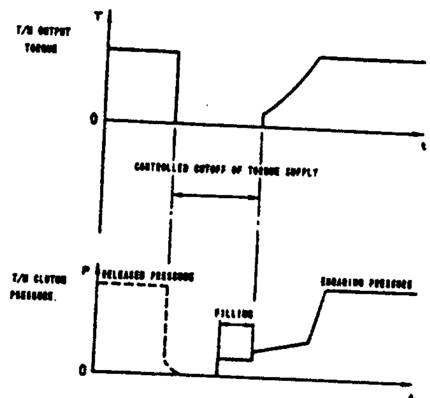

FIG. 5 SHIFTING DOWN IN ACCELERATION
(CONTROLLED CUTOFF OF TORQUE SUPPLY)

ACCEL POSITION	SHIFT DIRECTION	OPERATOR'S WILL	IDEAL TORQUE PATTERN	CONTROL POLICY
FULL	UP	FAST ACCELERATION	SHORT TIME	ENGAGEMENT SHORT TIME
HALF		SLOWLY ACCELERATION	CONTINUOUS TORQUE	MATCH WITH RUNNING TORQUE
OFF		NOT ACCELERATION		
FULL	DOWN	FAST SPEED	SYNCHRONIZE TIME	PREVENTION OF REVERSE TORQUE
HALF		REGULAR SPEED		
OFF		STOP		MINIMIZE TORQUE FLUCTUATION

FIG. 6 CONTROL POLICY OF TRANSMISSION

A shift-down with the accelerator opened invites a strong jerk if we use the above-mentioned control situation, which is for an accelerating shift-up. In a shift-down with a large load imposed on the power line, the gap between T/M output revolutions and input revolutions works as a brake and decelerates the vehicle with a reverse torque. Reverse torque, generated by the revolution gap, turns into a positive torque at synchronization of the clutch. (See Figure 4.)

Therefore, the engaging clutch must synchronize at the engagement so that engagement will not generate reverse torque.

An interval when torque supply cutoff is necessary between the release of clutch and its engagement. As shown in Figure 5, during this interval, oil pressure of the engagement clutch is raised to make relative revolutions of the engagement clutch exceed the zero mark, when engagement has begun.

As explained above, clutch engagement timing and oil pressure should be controlled according to driving condition to reduce jerk. (See Figure 6.)

3. Outline of K-ATOMiCS

1) Structure of System

The transmission of a dump truck consists of a gear train, clutch systems, an oil pressure control unit and a computerized controller unit.
Figure 7 shows the structure of the K-ATOMiCS system.

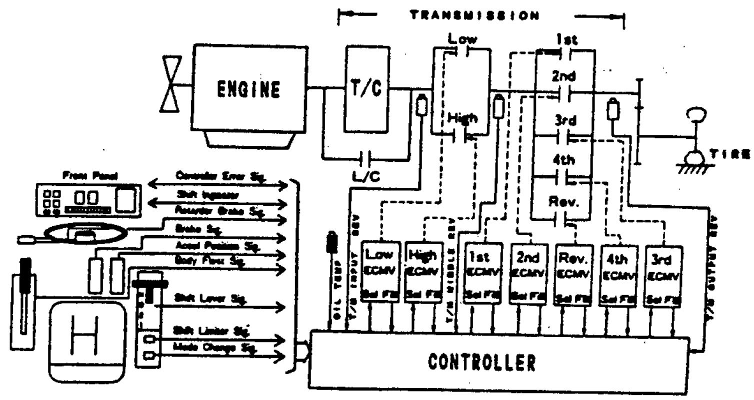

FIG. 7 STRUCTURE OF K-ATOMiCS SYSTEM

i) Gear Train and Clutches

The gear train consists of a sub-transmission with High and Low gears and a main transmission with 1st, 2nd, 3rd, 4th and Reverse gears. The transmission unit, comprised of five sets of planetary gears and seven sets of clutch systems, allows seven forward phases of shifting and one phase for backing. A torque converter is equipped with the lock-up clutch system, which works on every forward gear to enable a responsive and economical drive.

ii) Oil Pressure Control Unit

An electronically controlled actuator unit (ECMV) is installed to each clutch and independently controls the oil pressure of each of the seven sets of clutch systems. The ECMV, replacing a mechanical control valve system, enables easier, computerized control of oil pressure, which was extremely complicated under conventional mechanical control systems. It also streamlined the oil pressure control program and drastically reduced the number of components and weight of the unit.

iii) Computerized Controller Unit

Figure 8 shows the structure of the controller.

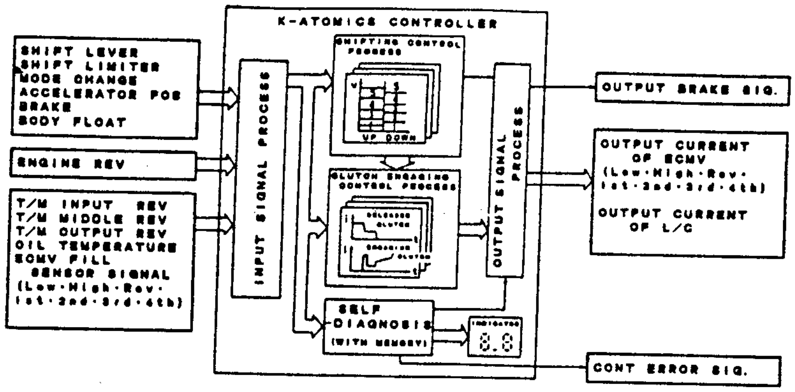

FIG. 8 STRUCTURE OF CONTROLLER

The unit offers an optimal choice of shift position and accurately controls clutch operation according to the driving conditions of the vehicle, which are ascertained from the accelerator position, mode switching, shift position and brake position. The operating condition of the transmission itself, which is known from the fill sensor and the revolutions of transmission parts, is also taken into account to decide what is the best control for the clutch and what is the optimum shift position.

The controller, giving commands on shifting clutch engagement and abnormality detection, has enabled more comfortable driving under any conditions.

K-ATOMICS has employed an improved self-diagnosis process over the previous ones as the newly developed system uses a far greater number of electronic components than conventional systems. With such a complicated mechanism, a self-diagnosis system is indispensable in identifying any details in abnormality and reporting these to the driver.

This abnormality detection system, introduced in the new model, features a program to indicate and memorize any detected malfunction which offers a better service to users.

2) Clutch Control Valves (Electric Control Modulation Valve)

Figure 9 shows the oil flow circuit of the ECMV. The ECMV is an actuator system developed for transmission clutches. Installed on individual clutches, it accurately controls clutch pressure.

In any clutch system, a larger oil flow operates a clutch more quickly, because a larger oil flow requires a shorter filling time. On the other hand, in order to reduce jerk upon engagement of the clutch, a precise oil pressure control is required.

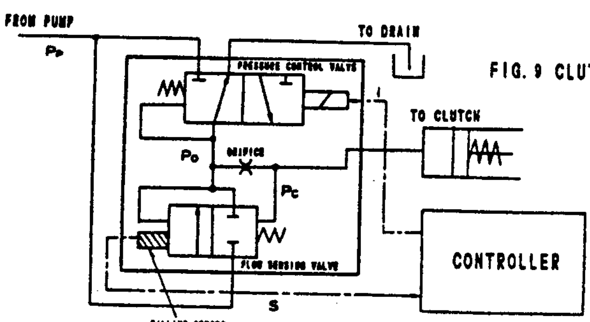

FIG. 9 CLUTCH CONTROL VALVE (ECMV)

We have made the ECMV into a compact actuator which quickly regains the necessary pressure for clutch operation and provides precise control of the clutch even at a low pressure. It consists of two types of valves--one is the flow sensor valve which is activated upon filling and the other is the pressure control valve which shows high control performance. The followings are descriptions of the two valves.

i) Pressure Control Valve

The pressure control valve adjusts clutch oil pressure to make it balance with the thrust coming from the proportional solenoid. The solenoid transduces the electric current from the controller into this force.

The pressure control valve also generates trigger oil pressure which actuates the flow sensing valve.

ii) Flow Sensing Valve

The control pressure given by the pressure control valve is transmitted to the clutch port through an orifice in the spool of the flow sensor valve. As a result, on filling, a pressure gap generates between both sides of the orifice. This pressure gap activates the flow sensing valve and a large oil flow is pumped into the clutch, thus reducing filling time.

A filling sensor, which detects the position of the flow sensing valve, is installed in the system to report on the completion of filling and on clutch oil pressure to the controller. The sensor also contributes to clutch engagement control and self-diagnosis of the system

4. Application of K-ATOMICS to Dump Trucks

The followings are the results of actual trials.

1) Shifting Up In Acceleration

The K-ATOMICS-equipped vehicle showed a smoother shifting performance as well as more accelerative driving than conventional models. The test vehicle equipped with the newly-developed system climbed a 100-meter slope starting from zero velocity 0.6 of a second faster than the average for conventional models. (See Figure 10.)

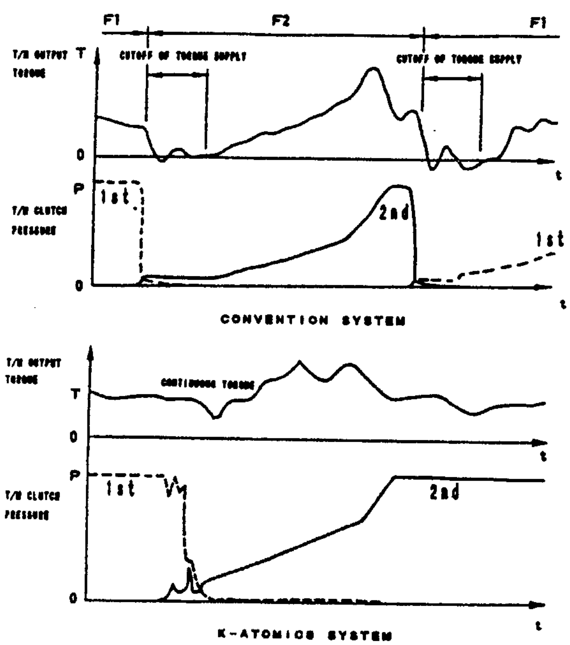

FIG. 10 EXAMPLE SHIFTING UP IN ACCELERATION

2) Shifting Down in Acceleration

K-ATOMICS grately improved shifting performance during power-on shift-down by providing an optimum torque-off period (as illustrated in Figure 11-b) according to engine revolutions.

Conventional clutch systems could not provide a torque-off period and therefore could not avoid generating reverse torque (as illustrated in Figure 11-a), which effected a big jerk. K-ATOMiCS has solved this problem.

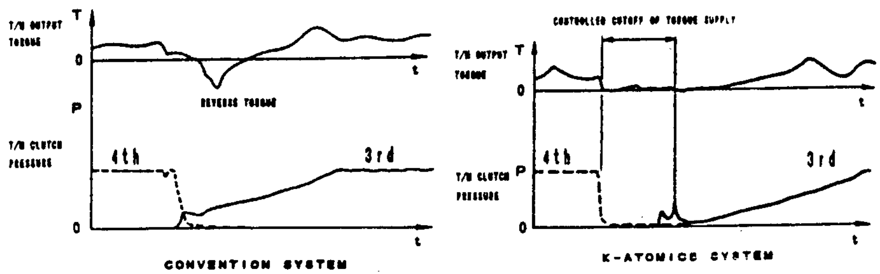

FIG.11 EXAMPLE SHIFTING DOWN IN ACCELERATION

3) Shifting Down with Accelerator Closed

K-ATOMiCS showed a greater jerk-reducing performance when shifting down with the accelerator closed than the two cases mentioned above.

With the accelerator closed and the brakes released, however, the clutch is less burdened by heat caused during engagement. Therefore, by lowering the initial pressure and the engaging oil pressure increasing rate after registering the driving conditions sent by the signals from the accelerator and the brakes, the K-ATOMiCS achieved a longer engaging period to considerably reduce the jerk on shifting.

5. Afterword

K-ATOMiCS, a boon to mechatronics technology, has sweepingly streamlined mechanical processes in clutch systems and has drastically improved shifting performance by employing microprocessors which accurately control clutch pressure to comply with driving conditions.

At present we have not applied this system, other than to dump trucks, and there are some problems with construction equipment yet to be tackled. These problems include deceleration while shifting and the fatigue of clutch disks, both of which are caused by the weight of the vehicle in question. In view of these problems, a electronically controlled transmission system could be further improved in its reliability and durability. We believe the K-ATOMiCS has enough potential to be able to solve these problems and we are planning to apply it to construction vehicles other than dump trucks.

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DEVELOPMENT OF A HIGH RESPONSE PROPORTIONAL HYDRAULIC CONTROL SYSTEM FOR NEW, ELECTRONICALLY CONTROLLED TORQUE SPLIT 4WD : NISSAN ATTESA E-TS

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Abstract

A hydraulic control system for controlling the engagement pressure of a wet multiplate clutch by means of a proportional pressure reducing valve has been developed for use with electronically controlled torque split 4WD. This system provides real-time control of the torque split to the front and rear wheels, enabling the vehicle to display excellent cornering performance. This paper describes the hydraulic system for 4WD vehicle use and the solutions to various problems encountered in applying a proportional pressuer reducing valve to a production vehicle. The results of dynamic simulations and experiments are presented to show how the hydraulic system provides good response and stability over the entire range of oil temperatures and to illustrate how other conditions related to hydraulic pulsation, hysteresis and inner oil leakage have been optimized.

1. Introdution

The market for 4WD passenger cars of the on-load type has been expanding rapidly in recent years. One of the major characteristics of this trend is the application of electronic control to the front/rear torque split of these 4WD vehicles to obtain enhanced levels of performance. 1), 2) Most of the torque split systems in use have a hydraulic drive mechanism which means hydraulic control plays a major role in the operation of the system. However, if the level of vehicle control is to be advanced further so that the torque split is controlled in real-time during cornering, it will be necessary to develop hydraulic control systems that provide higher levels of accuracy and responsiveness.

A basic question that must be addressed when applying a hydraulic control system to a car is how to achieve an optimum balance of hydraulic system performance characteristics over a wide temperature range. This paper presents the results of numerical analysis and experiments to show how this has been accomplished in the hydraulic system employed in a new electronically controlled torque split 4WD system, called Nissan ATTESA E-TS. (ATTESA E-TS is an acronym which stands for Advanced Total Traction Engineering System for All terrains and Electronic Torque Split.)

2. Electronically Controlled 4WD

The configuration of the ATTESA E-TS system is shown in Fig. 1. Engineered around a rear-wheel-drive layout, this system provides real-time control over the front/rear torque split during cornering according to the vehicle status and road surface conditions. This control feature enables the system to achieve a better balance of handling and stability on a much higher plane than any other system to date.

As indicated in the figure, drive torque is transmitted directly to the rear axle, while it is conveyed to the front axle by means of a hydraulic multiplate clutch incorporated in a transfer unit. By verying the hydraulic pressure applied to the multiplate clutch, the torque split to the front and rear wheels can be controlled continuously from a rear-wheel-drive mode (0:100) to the rigid 4WD mode (50:50). The clutch engagement pressure is determined by a controller on the basis of signals received from a wheel speed sensor at each wheel and a lateral acceleration sensor. The controller outputs a command signal to a hydraulic unit which generates the desired hydraulic pressure that is applied to the clutch.

3. Hydraulic System Configuration

The on-board hydraulic system consists of the hydraulic unit, a riservoir tank, piping and a clutch cylinder built into the transfer unit. A motor-driven pump, accumulator, pressure control valve and other major hydraulic components have been integrated into the hydraulic unit for improved mountability and reliability. To reduce energy consumption, the motor-driven pump has been designed to operate intermittently within the range of the hysteresis characteristic of the pressure switch.

The pressure control valve is built with a direct drive type proportional reducing valve that displays little temperature dependence and provides excellent control accuracy and responsiveness. Figure 3 shows the construction of the pressure control valve. It generates pressure in proportion to the drive current applied to a proportional solenoid, making it possible to control the clutch engagement pressure to any level (Fig. 4). This pressure control valve has been designed to minimize inner leakage so as to reduce energy losses.

4. Optimuization of Static Characteristics

The accuracy of the system in controlling the torque split is dependent on the degree of control accuracy achieved over the hydraulic pressure applied to the wet multiplate clutch in the transfer unit. To assure good system control accuracy, it is necessary to reduce the amount of hysteresis in the current-vs.-pressure characteristics displayed by the pressure control valve. The amount of hysteresis that occurs is basically determined by the degree of overlap of the spool valve (Fig. 3), the spring constant of the return spring and friction generated by moving parts. However, the ultimate range can be adjusted using the frequency and amplitude of the dither applied to the proportional solenoid.

Since this system employs a motor-driven pump as the hydraulic pressure source, large inner leakage from the pressure control valve would result in excessive pump operation, causing energy efficiency to decline. The amount of inner leakage from the pressure control valve is dependent on the frequency and amplitude of the dither applied to the proportional solenoid to reduce hysteresis. Figure 5 shows the relationship between the dither frequency and amount of inner leakage on the one hand and the amount of hysteresis in the current-vs.-pressure characteristics on the other. Applying a high dither frequency reduces the amount of inner leakage, but it also causes a gradual increase in hysteresis. In addition, when the dither frequency increases to a certain level, it causes a slip-to-stick phenomenon, making the hysteresis valve unstable. As a result, it becomes impossible to maintain stable pressure control. The slip-to-stick phenomenon is particularly pronounced at low temperatures.

In the Nissan system, the dither frequency has been optimized on the basis on experimental data so that its static characteristics satisfy the requirements for both an acceptable increase in inner leakage at high temperatures and an acceptable increase in the hysteresis range at low temperatures.

5. Optimization of Dynamic Characteristics

An important factor in connection with the dynamic characteristics is the large fluctuation in hydraulic fluid viscosity, which can very by as much as two hundredfold as a result of temperature changes. For this reason, it is essential to fulfill the requirements for good response at low temperatures and dependable stability at high temperatures. Numerical simulations were carried out to analize the dynamic characteristics of the hydraulic system, and the optimum values were determined on the basis of the results.

5.1 Analysis of dynamic charactreristics of hydraulic system

The analysis focused on the portion of the system from the accumulator to the wet multiplate clutch and the motor-driven pump was omitted from the simulation model. In constructing the model, a special effort was made to give a detailed description of the choke, which tends to show strong temperature dependence. A brife explanation of the basic equations used in the model is given below.

(1) Equation of motion for spool valve

$$ms\ddot{x} + Cs\dot{x} + ks(x + x_0) = Fs - PvAf - Ff \qquad (1)$$

In this equation, the mass, ms, included that of the plunger and equivalent mass of the hydraulic fluid in the oil passages. The damping coefficient, Cs, included the equivalent damping of the orifice.

The thrust of the proportional solenoid, Fs, was treated as a function of the solenoid displacement, x, and current, i. The valve used in the calculation was found from a map of actual thrust measurements.

(2) Flow rate characteristics of spool valve

$$Qs = CAs\sqrt{2\ (Ps - Pv)/\rho} \qquad (x > 0) \qquad (2)$$

$$Qr = CAr\sqrt{2\ (Pv - Pr)/\rho} \qquad (x < -Ov) \qquad (3)$$

$$Qs = Qr = 0 \qquad (0 < x < -Ov) \qquad (4)$$

where, the flow rate coefficient is a function of the Reynolds number, Re.

(3) Continuous equation

$$Qv = Qs - Qr + Af\dot{x} \qquad (5)$$

(4) Output orifice

Formulations 3) for the steady-state characteristic of a cylindrical choke were used as the equations for the choke.

$$Pv = RoQv + \xi\rho Qv|Qv|/2\ (\pi Do^2/4)^2 \qquad (6)$$

$$\xi = (0.819 - 0.00791 Lo/Do)^{-2} - 16\pi/\sigma \qquad (\sigma > 10^3) \qquad (7)$$

$$\xi = (1.16 + 6.25\ \sigma^{-0.41})^2 - 16\pi/\sigma \qquad (1 < \sigma < 10^3) \qquad (8)$$

(5) Piping

The piping between the hydraulic unit and multiplate clutch was approximated on the assumption that the mass and viscosity resistance of the fluid were concentrated at a single point.

(6) Multiplate clutch load characteristic

Among the load characteristics, the stiffness of the multiplate clutch, Fkc, used in the calculation was found from a map of actual measured values.

$$Qc = Ac\dot{y} + Vc\dot{P}c/\beta \qquad (9)$$

$$mc\ddot{y} + Cc\dot{y} + Fkc = AcPc \qquad (10)$$

Notations

Qs: supply flow rate
Qr: return flow rate
Qv: valve flow rate
Qc: multiplate clutch flow rate
Ps: supply pressure
Pr: back pressure
Pv: valve pressure
Pc: clutch pressure
Af: feedback pressure surface

As, Ar: open area
Ov: overlap
ks: spring constant of return spring
x_0: initial deflection
Ff: steady-state flow force
Do: choke diameter
Lo: choke length
Ro: viscous registance (= $128\mu Lo/\pi Do^4$)
σ : choke number (= $Qv/\nu Lo$)
ν : dynamic viscosity coefficient
μ : viscosity coefficient
ρ : hydraulic fluid density
mc: clutch piston mass
Cc: clutch piston damping coefficient
y : cylinder displacement
Ac: cylinder area subjected to pressure
Vc: cylinder volume
β : modulus of volumetric elasticity of hydraulic fluid

The experimental results for the step-response that was obtained when the multiplate clutch pressure was varied from 0 to 1 MPa are shown in Fig. 6 (a). The calculated results obtained under the same conditions are shown in (b) in the figure. The calculated hydraulic pressure waveforms reproduce the experimental data with good accuracy.

5.2 Optimization of Response and Stability

Using the simulation model, a study was made of the delay in the step-response. Figure 7 shows the results of an investigation into the pressure dependence of the response delay. A response delay is seen until the multiplate clutch pressure rises to 90% of its target value. The response delay varies according to the pressure and becomes larger as the magnitude of the step increment decreases. The temperature dependence of the response delay is shown in Fig. 8. A pronounced increase in the delay is seen below 0℃. This large increase in the response delay with a small step increment at low temperature could present a problem for vehicle control.

It was noticed that the interval before the clutch faces came in contact accounted for a large porion of the response delay. Figure 8 shows the substantial improvement in response that was obtained by applying a slight pre-pressure to the clutch. This shortening of the interval before contact was achieved by improving the presure control accuracy without causing any dragging problem of the multiplate clutch.

The output choke was slso tuned to improve the stability of the hydraulic system. The simulation results obtained in an investigation of the choke diameter are presented in Fig. 9. Under a condition of no pre-pressure, the choke diameter had to be increased to obtain improved response at −25℃. However, there was still excessive delay and, in addition, the surge rate also increased. With the pre-pressure system, both the response delay and the surge rate were reduced, thereby achieving good responsiveness as well as excellent stability.

6. Conclusion

Achieving a good balance of performance characteristics over a wide temperature range is an essential requirement when designing hydraulic control systems for automotive use. This paper has discussed the results of experiments which examined the compatibility between inner oil leakage at high temperature and hysteresis at low temperature. The results of numerical simurations were also presented in examining the trade-offs between high-temperature stability and low-temperature responsiveness. It was seen that the former requirements could be met by selecting a suitable dither frequency and that the latter requirement could be met by adapting a system of applying pre-pressure to the clutch and by choosing a suitable choke diameter. It was shown that the resulting system displays optimum hydraulic characteristic

The results of the foregoing investigations were used in designing the hydraulic control system for the new electronically controlled torque split 4WD ATTESA E-TS system. This new system provides real-time torque split control with excellent accuracy and responsiveness.

Acknowledgments

The authors would like to thank Kayaba Industry Co., Ltd. for its cooperation in the development of hydraulic nuit. They also want to thank Professor Kazuo Nakano at the Tokyo Institute of Technology for his valuable suggestions regarding the analytical model.

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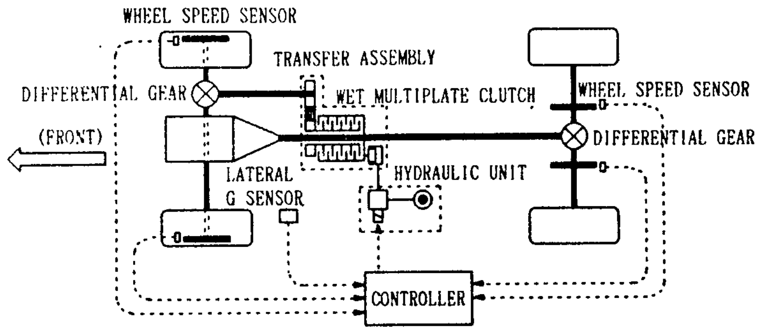

Fig. 1 Configulation of ATTESA E-TS system

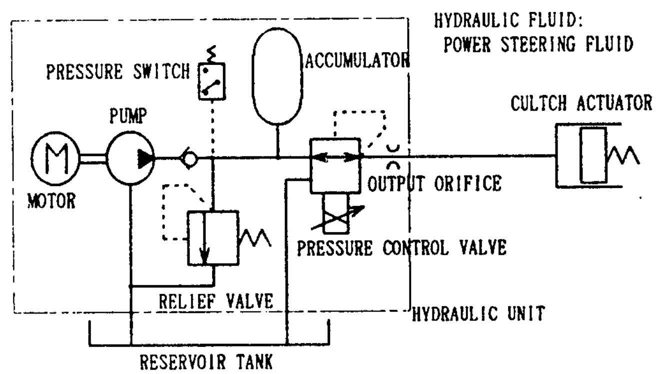

Fig. 2 On-board hydraulic system

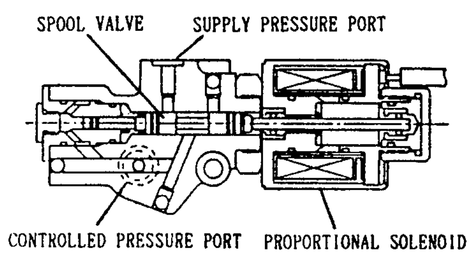

Fig. 3 Construction of pressure control valve

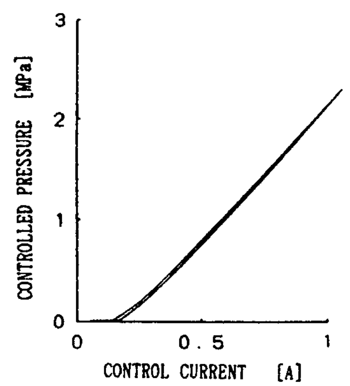

Fig. 4 Controlled pressure vs. control current

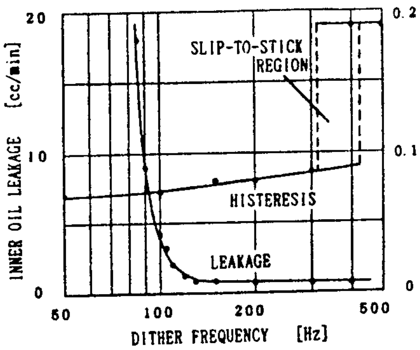

Fig. 5 Optimization of dither frequency (experimental)

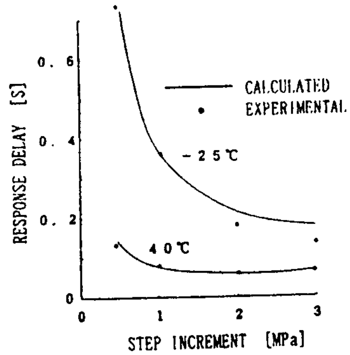

Fig. 7 Pressure dependence of response

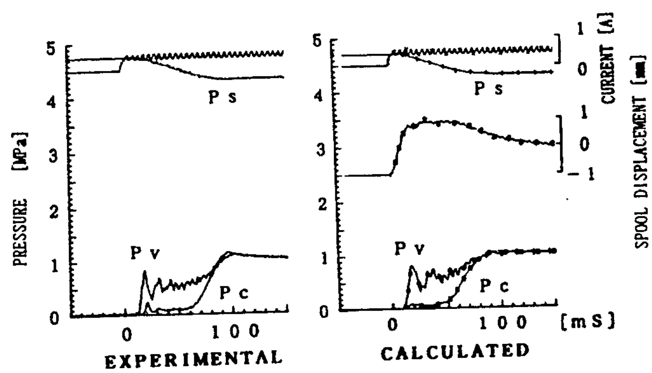

Fig. 6 Comparison of calculated and experimental step response results

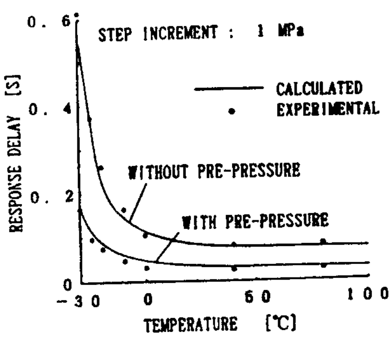

Fig. 8 Improved response obtained with pre-pressure system

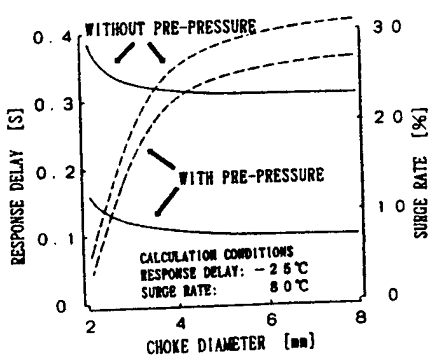

Fig. 9 Optimization of output orifice (calculated)

ELECTRO - HYDRAULIC POWER STEERING

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90008

ABSTRACT

This paper describes the development of the Electro-Hydraulic Power Steering System, which uses a DC motor to drive the power steering pump. This system has been developed for a mid-shipped engine car, in the past, it had been difficult to equip this type of car with a power steering system because of the oil piping distribution. The Electro-Hydraulic Power Steering System consists of a steering angle sensor, a speed sensor, an electronic control unit (ECU) and a DC motor. The ECU varies the input voltage of the DC motor to control the power steering pump. The result is the Electro-Hydraulic Power Steering System which has the optimum power-assist characteristics for steering.

INTRODUCTION

Power steering systems are designed to make the work of steering a vehicle easier and to help the driver be more relaxed and comfortable. For this reason, the percentage of vehicles equipped with power steering is steadily increasing.

Vehicle models in which power steering is installed include FF vehicles and FR vehicles, in which the engine is mounted in the front of the vehicle and there is consequently a heavy load on the front tires. The use of power steering for mid-shipped engine models has also been studied in order to reduce the steering effort in these vehicles even further.

However, in the vehicles with the engine mounted toward the rear, the routing of the hydraulic tubing required for existing power steering systems is difficult and there are losses in hydraulic pressure due to the length of the tubes. The installation of power steering in this type of vehicle was therefore difficult. This made it obvious that development of a new power steering system was necessary.

ELECTRO-HYDRAULIC POWER STEERING SYSTEM

An Electro-Hydraulic Power Steering (EHPS) system using DC motor was introduced in the 1990 Toyota MR2, Toyota's mid-shipped engine sports car. This system has the following features.

1) The speed of the DC motor used to drive the power steering pump is controlled through voltage control by a computer, making it possible to attain the optimum steering torque characteristics for the vehicle's speed.

2) The power steering pump is operated directly by a DC motor. It discharges the oil volume required for power assistance and thus reduces fuel consumption.

3) The component parts of the power steering system can be located in the front of the vehicle (the end opposite the engine); this improves weight distribution and also helps improve steering stability in a mid-ship vehicle.

SYSTEM DESCRIPTION

Fig. 1 shows the system configuration and Fig. 2 shows the parts layout.

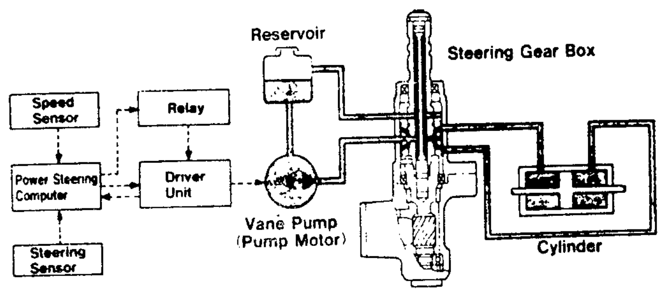

Fig.1 System Configuration

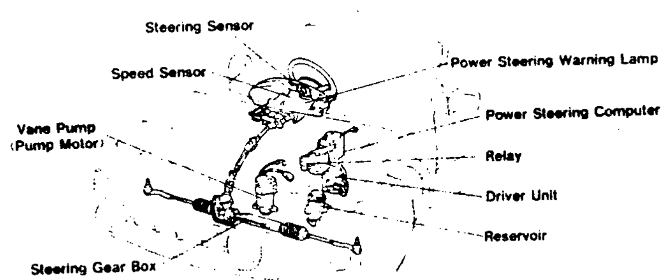

Fig.2 Parts Layout

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The EHPS system consists of a steering gear box, a power steering pump with integral motor, a relay, a steering sensor, a speed sensor, an electronic control unit (ECU) and a driver unit.

A block diagram of the system is shown in Fig. 3. The ECU determines the control voltage to the DC motor which drives the power steering pump in accordance with signals from the speed sensor, then sends the command values to the driver unit. The driver unit outputs a voltage to the DC motor through PWM control. The result is that the vehicle speed determines the speed of the motor, and this in turn determines the pump flow volume and the amount of assistance.

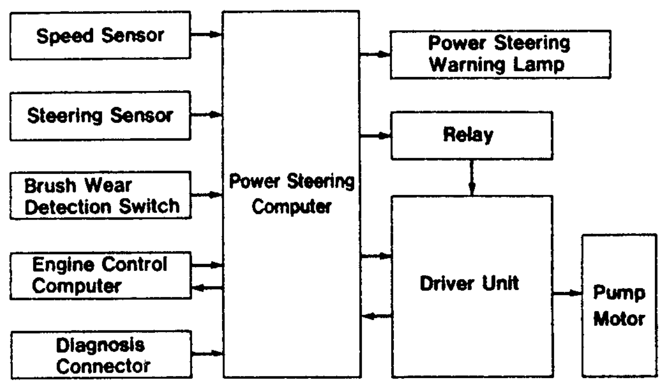

Fig.3 Block Diagram

POWER STEERING PUMP AND MOTOR CHARACTERISTICS

The characteristics of the power steering pump and motor are as follows.

Rack Axial Force Characteristics

$$F_D = K_1 \frac{T_M \times i}{L_N} + P \times A \qquad (1)$$

Flow Characteristics

$$Q = A \times S_R \times \frac{\dot{\theta} \times 60}{2\pi} + Q_0 \qquad (2)$$

Formulas (1) and (2) are used to obtain the following.

$$F_D = K_1 \frac{T_M \times i}{L_N} + 2\pi P \left(\frac{Q - Q_0}{60 \times S_R \times \dot{\theta}} \right) \qquad (3)$$

Where, F_D . . . Rack Axial Force

T_M . . . Driver Input Torque

i . . . Gear Ratio

L_N . . . Knuckle Arm Length

P . . . Pump Supply Pressure

A . . . Power Cylinder Pressure Receiving Area

Q . . . Pump Flow Volume

Q_0 . . . Amount of Leakage

S_R . . . Power Cylinder Deviation Amount per Steering Wheel Rotation

K_1 . . . Axial Force Coefficient

$\dot{\theta}$ . . . Steering Angle Velocity

In formula (3) the first item indicates the axial force borne by the driver and the second item indicates the axial force borne by the power steering pump.

Using formula (3), the pressure - flow volume characteristics of the pump were decided so that the steering torque borne by the driver would be 0.7 kgf-m or less. The following formulas, which describe motor characteristics, were used to calculate the motor torque and speed from the pump pressure and flow volume.

Motor Torque Characteristics

$$T = K_2 \frac{P \times q}{2\pi} \quad (4)$$

Motor Speed Characteristics

$$N = \frac{Q + K_3 \times P}{q} \quad (5)$$

Where, T . . . Motor Torque

q . . . Pump's Inherent Discharge Volume

N . . . Motor Speed

K_2 . . . Motor Torque Coefficient

K_3 . . . Pump Leakage Coefficient

Fig. 4 shows the pump pressure - flow volume characteristics, Fig. 5 shows the motor characteristics and Fig. 6 shows the motor's construction.

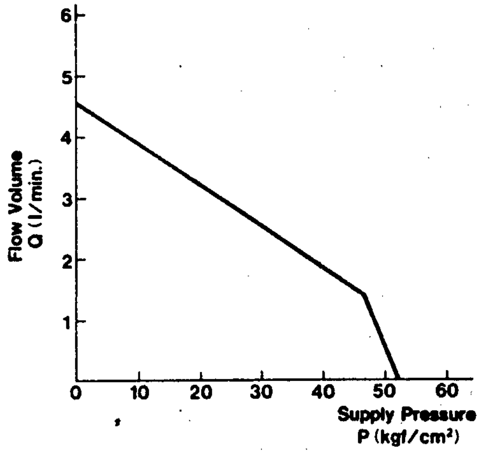

Fig.4 Pump Pressure-Flow Volume Characteristics

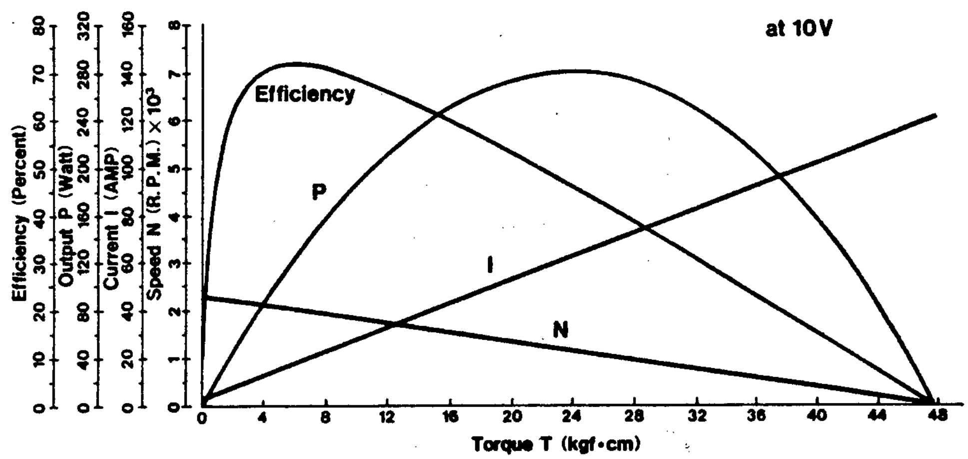

Fig.5 Motor Characteristics

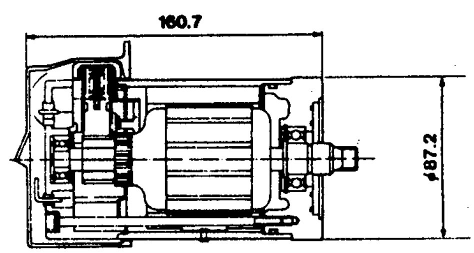

Fig.6 Motor Construction

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CONTROL VOLTAGE SPECIFICATIONS

Fig. 7 shows the steering torque - pump voltage characteristics. The optimum steering torque is obtained from these characteristics and the characteristics of the control voltage to be applied to the DC motor are determined in accordance with the optimum steering torque. The control voltage characteristics are shown in Fig. 8.

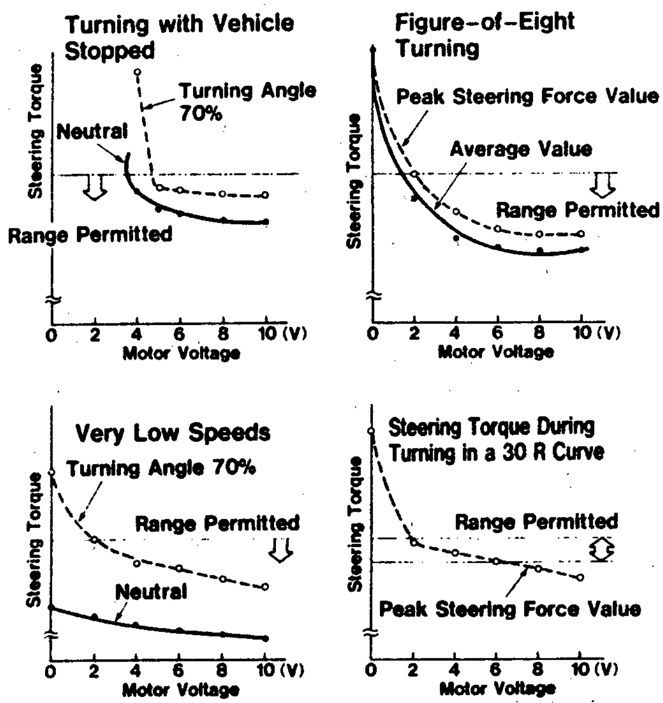

Fig.7 Motor-Steering Torque Characteristics During Various Steering Operations

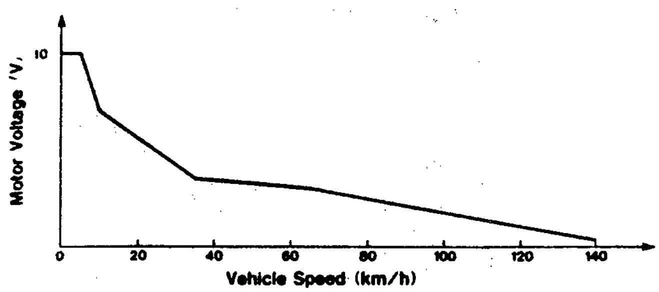

Fig.8 Motor Control Voltage

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DRIVER UNIT

The driver unit outputs control voltages ranging from 0 to 10 V to the DC motor through PWM control.

The current flowing the DC motor can reach 100 A in cold environments because the viscosity of the power steering oil is higher when it is cold. For this reason, power MOSFETs connected in parallel are used as a power control device.

POWER CONTROL DEVICE

PWM control of currents up to 100 A is possible using a single device. However, such devices are expensive and their switching loss (that is, heat generation) is large; these factors make it difficult to attain a driver unit with a compact, thin and light-weight construction, which is a critical requirement for units to be installed in a vehicle. To meet this requirement, five power MOSFETs, which are inexpensive and feature low ON resistance, are connected in parallel and used for the power control device. The parallel connection circuit diagram is shown in Fig. 9. The advantages and disadvantages of using a single device and of using power MOSFETs connected in parallel are compared in Table 1.

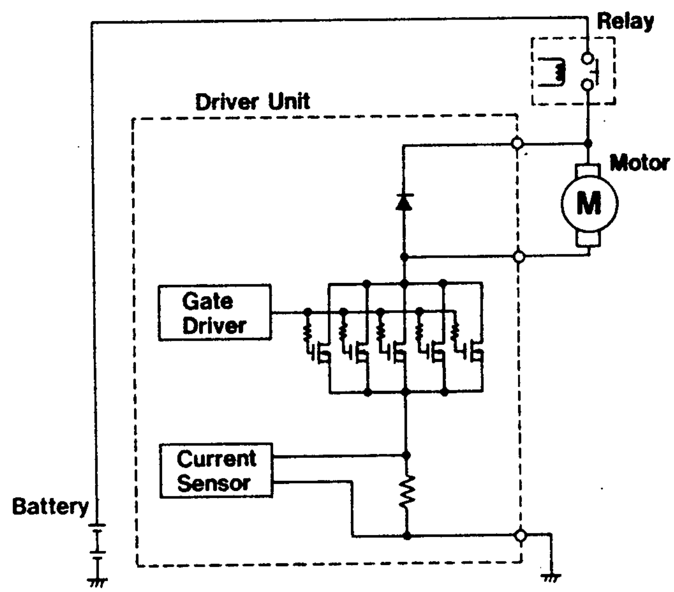


Fig.9 FET Parallel Connection Circuit Diagram

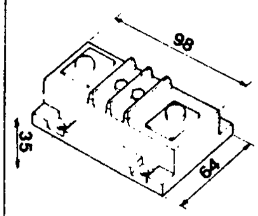
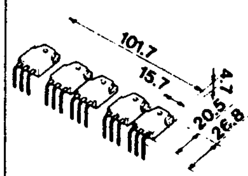
	Single Device(Example)	Power MOSFETs Connected in Parallel(2SK 797)
Quantity Used	1	5
Rating	600V, 200A	60V, 40A
ON Resistance	10 mΩ (When on voltage is 2V, 200A)	3.6 mΩ (When 40 A/device is input)
External View		
Advantages	The pre-drive stage circuit is simple.	The amount of generated heat is small. The portions which generate heat can be scattered as desired.
Disadvantages	Generates a lot of heat and a large heat sink is required. The portions which generates heat are concentrated in one place.	Due to variations in characteristics, there are deviations in heat generation.

Table 1 Comparison of Single Device and MOSFETs Connected in Parallel

With five MOSFETs connected in parallel, if there are variations in switching among the MOSFETs, the flow of current is concentrated in the device with a lowest Voltage between Gate and Source (V_{GS})

Also, if there are variations in the ON resistance among the MOSFETs, the flow of current is concentrated in the device with the smallest ON resistance. The effect of this is that the temperature in that one device increases to an extremely high level. For this reason, the V_{GS} voltage and ON resistance of the devices are measured and they are sorted accordingly.

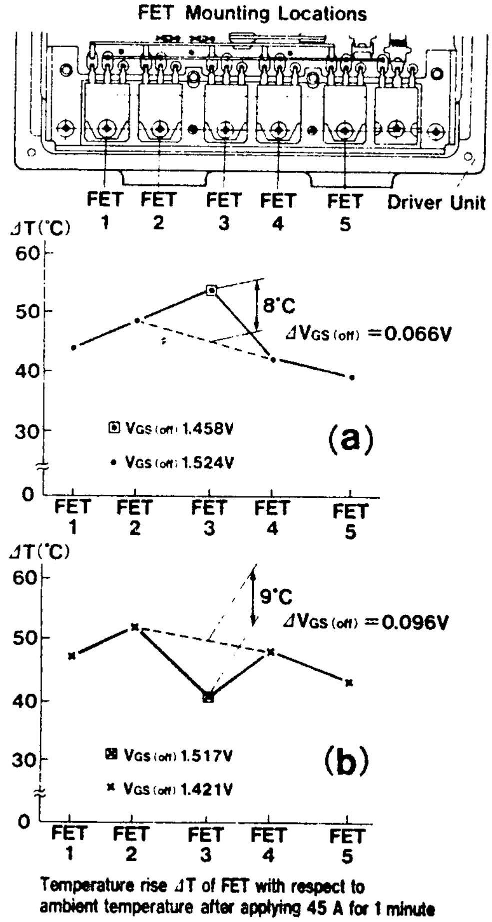


Fig.10 Differences in Temperature Increase Due to the V_{GS} Difference

Five devices sorted into the same group are used as a set to configure one power control device.

Temperature rises in power control devices consisting of five MOSFETs, one of these five having a different V_{GS} voltage from the others, were measured and the results are shown in Fig. 10.

The device with a V_{GS} 0.066 V lower than the other devices shows a temperature rise 8°C higher than the others as shown in graph (a). Conversely, the device whose V_{GS} is 0.096 V higher than the other devices shows a temperature rise 9°C lower than the others as shown in graph (b). When MOSFETs are actually combined, they are grouped to allow a maximum V_{GS} difference of 0.1 V to allow for practical consideration of manufacturing efficiency. Although this difference will generate a temperature difference of up to 11°C, the heat sink has been designed to be able to deal with the estimated temperature difference, keeping the FET junction temperature below the restriction value.

CONDITIONS UNDER STEERING

When we think of the operations involved in driving a vehicle, few steering operations are performed while the vehicle is stationary. For this reason, designs which give consideration to continuous performance of this type of operation turn out to be centered too much on this one feature and inappropriate. Therefore, the actual steering wheel operation states in a vehicle were measured, and each steering wheel operation expressed using a pattern. Each component was designed to meet the resulting specifications.

Steering wheel operation states can be classified the following four categories.

First is the state when the steering wheel is turned while the vehicle is stopped or while it is traveling at extremely low speeds. In this state, the load on the motor is large and the current value can be thought of as being at or below the value when the steering wheel is turned on a road with a high friction resistance when the vehicle is stopped.

Second is the state when the steering wheel is turned while the vehicle is traveling at medium or high speeds. In this state, the load on the motor is in the intermediate range and the current value can be thought of as being at or below the value when the steering wheel is turned in figure-of-eight turning at medium speeds.

Third is the state when the steering wheel is operated in straight line driving. In this state, the load on the motor is low and the current value can be thought of as being at or below the value when the steering wheel is operated while the vehicle is being driven straight at low speed. Normal steering wheel operation is a combination of these three states.

The steering wheel load pattern, determined to test durability, is shown in Fig. 11. The duration of each state within one cycle has been determined from experimental data. This pattern is the basic load pattern. Durability was confirmed using this pattern.

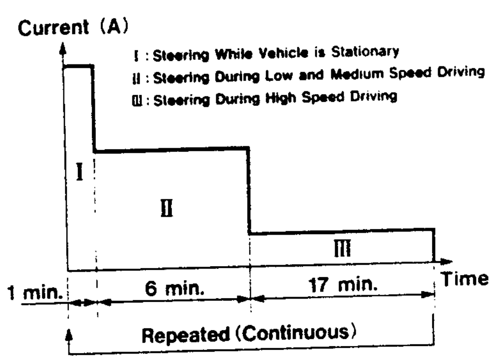


Fig.11 Basic Load Pattern

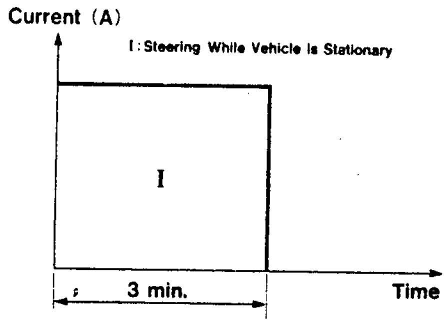


Fig.12 High Load Pattern

Fourth is the state in which steering wheel operation is temporarily extended for a long period of time. For the high load pattern in this case, the power steering pump high load pattern shown in Fig. 12 was used.

ECU

An 8 bit microcomputer is used for the ECU. The ECU controls the voltages supplied to the motor based on signals from the speed sensor, as described above. The ECU also includes a function whereby the temperature of the motor's coil and of the FET junction are monitored by estimation calculations based on the current flowing at each sampling in order to prevent breakdown due to overheating.

METHODS OF ESTIMATING HEAT GENERATION

The current flowing in the motor and in the FETs results in heat generation. This current changes in proportion to the pump pressure during use of the power steering function, in other words, it changes in proportion to the torque required by the motor. Therefore, when the steering wheel is operated roughly, or if the pump malfunctions, the heat generated in the coil or in the FET junction will cause overheating and destruction of these components unless use of the power steering function is discontinued. One way to provide protection against this problem is to use a temperature sensor, such as a thermistor or thermostat, for the motor and FETs. However, in order to accurately sense the temperature of motor or of each power MOSFET, a number of temperature sensors must be used, making this protection method impracticable. Also, since the coil of the motor is rotating, it would be difficult to measure its temperature directly anyway.

To solve the problem, the overheat protection function has been developed for use with the power steering system; by detecting the value of current flowing to the motor, the temperature rise in portions where heat is generated is estimated by computer.

If the maximum permissible temperature is reached, the flow of current is cut off to prevent overheating.

The important point in using the current flow to estimate the increase in temperature through calculation is to conduct experiments to determine how the temperature of the motor coil and FET junction rises when a particular current is flowing. The temperature rise in each part differs when the same current flows to these portions. In addition, the maximum permissible temperature also differs depending on the portion. Temperature rise and fall at each portion in response to different current values was measured and the results proved that:

- When a large current is flowing, an FET reaches the maximum permissible temperature earlier.
- When a medium to small current is flowing, the motor coil reaches the maximum permissible temperature earlier.

Therefore, consideration should be given to the temperature rise in the motor coil when a medium or small current is flowing and to temperature rise in the FETs when a large current is flowing in order to perform estimation calculations to protect both of them.

Fig. 13 shows the current - temperature rise rate characteristics used to perform calculations for estimation of temperature rise with the temperatures at portions of heat generation taken as a parameter. Using this graph, the rate of temperature change in the heat generating portion is read from the current flowing there, and the amount of temperature change detected in each sampling is added cumulatively to estimate the temperature of the portion.

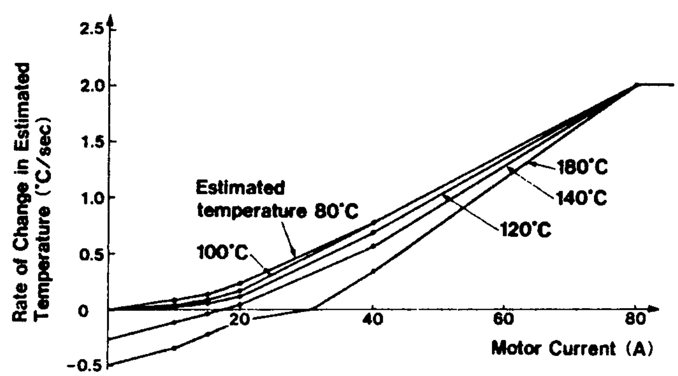


Fig.13 Characteristics of Motor Current and Rate of Temperature Increase

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The temperatures calculated for each heat generating portion and the actual motor temperatures (actually brush temperature is measured because coil temperature is approximately the same as motor brush temperature at low to medium current) are shown. The graphs in Fig. 14, confirm that the actual temperature matches the estimated temperature under the various conditions of power steering use.

Fig. 15 shows how temperature rises in the high load pattern. Here too, the estimated temperature rise is found to agree with the actual temperatures.

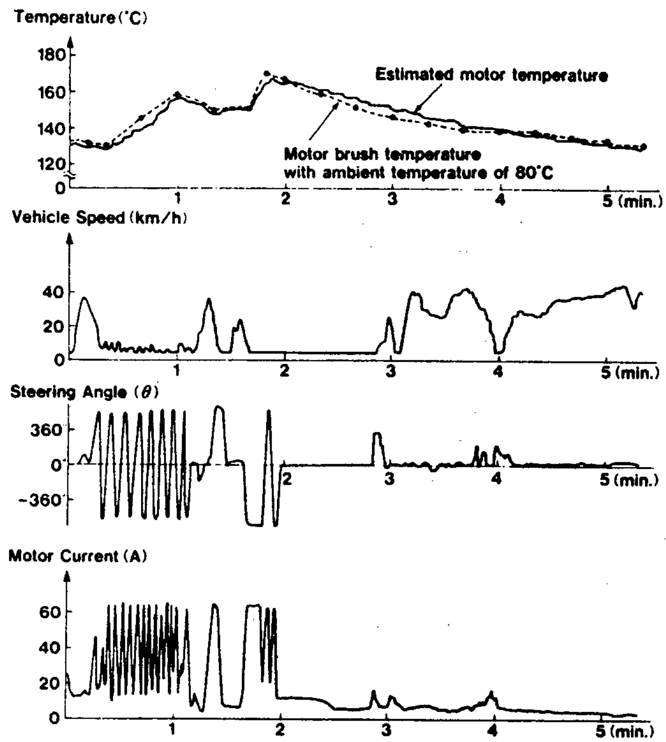

Fig.14 Results of Comparison of Estimation Calculations with the Vehicle

Y. Amano

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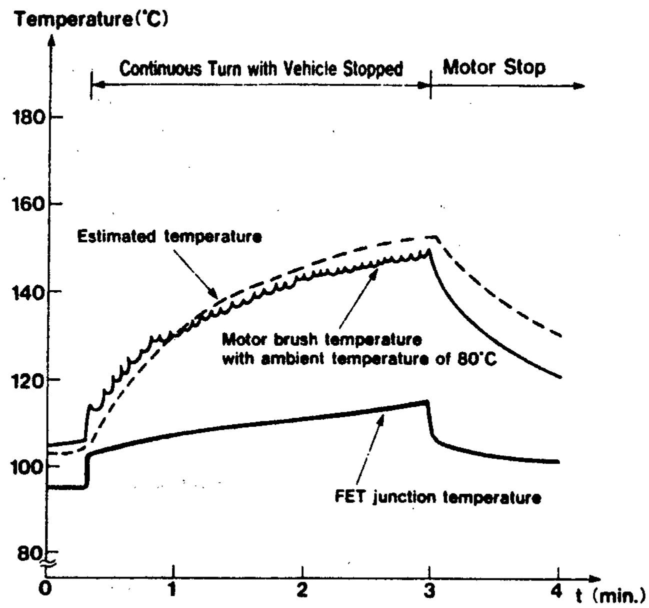

Fig.15 Results of Comparison of Estimation Calculations with the Vehicle with High Load Pattern

SUMMARY

An EHPS system which changes the speed of its DC motor in accordance with the vehicle speed and controls the flow volume from the pump, thereby achieving the optimum steering torque characteristics, has been developed. Using power MOSFETs connected in parallel as the power control device, the system controls the DC motor over the range of 0 to 100 Ampere. In addition, a protective function was developed to prevent failure due to overheating: the system's microcomputer and software are able to estimate the temperature of the motor coil and the FET junction. The estimations were found to closely agree with the actual temperatures.

ACKNOWLEDGMENTS

We would like to extend our warm thanks to Mr. Nakano, manager at Toyota Motor Corporation, Mr. Nakamura, the department manager at Toyoda Machine Works and Mr. Oshikawa, the assistant department manager at Asmo, as well as to the many others who provided assistance and cooperation in the development of the EHPS.

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NEW GENERATION CONTROL ARCHITECTURE FOR THE ROBOT OF THE '90s

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ABSTRACT

New application problems and the evolving concept of the robot as such, increasingly demand further improvement and upgrading of the associated controller.
The novel C3G-9000 architecture presented attempts to solve most such problems including:
- Cost reduction.
- Control of complex systems/cells, including multi-arm configurations with optimization of peripheral control and system logics.
- Intelligent optimized control of motor drives, through compensation of inertial changes on joints and monitoring of actual exploitation of the mechanical structure.
- Modular design of HW and SW platform, based on 32 bit processors and DSP units, open to future expansion.

1. INTRODUCTION

COMAU, which is one of the world's largest system integrators in the area of automotive industry automation, is also a major robot integrator, with more than 2500 systems installed to date. Since 1988, moreover, COMAU has entered the stand-alone robotics market through its Robotics Division, which designs, manufactures and markets its own machine line.
In approximately 12 years of activity, the COMAU has produced more than 3000 robots, and designed 35 models with different mechanical structures and three successive generations of controllers.
A wide range of application sectors has been covered, from Handling (high speed/medium precision) through mechanical assembly (high speed/high precision) to Laser cutting and welding (medium speed/high precision/high movement quality).

In this context, the newly introduced C3G-9000 Controller is intended to meet the emerging needs for the robot of the '90s.
In particular, the objective was to provide an optimal solution to the problems posed by the following trends:
- To an ever-increasing extent, the robot controller must perform the functions of a general purpose automation cell controller, managing multi-arm systems and complex peripherals.

- Integrators and end-users must be provided with standard HW and SW solutions, particularly in the area of generalized motion control.

- The system must be based to the greatest possible extent on the OSA (Open System Architecture) concept so that commercially-available HW and SW modules can be inserted without difficulty.

- The programming environment must be highly integrated with the execution environment so that the normal EDIT - COMPILE - RUN - DEBUG programming sequence can be eliminated or concealed from the user.

- The programming language must be oriented towards the definition and implementation of 'Application Interfaces' dedicated to specific application sectors, concealing the concept of 'language' from the application programmer inasmuch as is possible.

- The controller must adapt readily to different robot mechanical structures, thus reducing personalizing requirements to the benefit of product and spare part standardization.

- The controller must adapt to specific 'movement' requests for different applications, providing generalized and adaptable primitives at language level, and supplying the correct trade-off between the various qualitative components of motion (i.e. speed, acceleration, precision, repeatability and vibration) at 'servo' level.

- The servos must be capable of adapting in real-time to highly variable operating situations associated with different load conditions and the different attitudes assumed by the arm.

- The controller must provide easy integration with the most important sensor subsystems, such as Vision and Force. Integration must be real at both HW and SW (programming) levels to furnish the integrator with a single integrated application ambient.

- The controller cost must come down, both through direct HW savings made possible by high integration, through indirect savings in mechanical structures resulting from the greater 'intelligence', and from the final application savings made possible by the use of the integrated PLCs, integrated sensors and standard motion-control solutions.

- Finally, easily interfaceability shall be provided with external factory environments, including the major data networks (Ethernet, MAP, ...) and Peer-to-Peer type control networks (PLC).
  In addition, there is a growing need for easy interfacing with CAD simulation and off-line programming environments. This does not apply only at data transfer level: above all, procedures must be available for aligning and calibrating the different environments and identifying 'real' robot physical parameters.

2. SYSTEM ARCHITECTURE

System is defined at the following logical/physical levels.

2.1 Cell

The cell is the set of all logical and physical 'objects' making up the system, and controlled on an overall basis from this level.
In particular:
- 'State', common to all objects in the Cell (manual, auto, programming, emergency ....).

- 'Operator Panel' and 'Teach Pendant', common to all machines of the Cell.

- 'Communication', towards the LAN network.

- 'Monitoring', of all Cell activities.

The Cell may consist of a maximum of 4 machines, which typically cooperate in a shared activity.

2.2 Machine

Machine is defined as a set of Arms which are normally joined by a logical and/or mechanical link (e.g. X - Y table associated with a manipulator, 2-robot gantry with one shared way, etc.)
Each machine can have a maximum of 2 Arms (or 8 in a future implementation) and 8 Axes. At power supply level, each Machine can be independently isolated.

2.3 Arm

The Arm is defined as a set of Axes cooperating in unitary fashion and coordinated so as to produce a defined trajectory. All the Axes of a given Arm are often (but not necessarily) interconnected via mechanical constraints, and are in all cases managed in unitary fashion by a single Interpolator (SW).
Each machine is thus provided with the same number of independent Interpolators as there are controlled Arms.
Each Arm may consist of a number of Axes ranging from 1 to 8.
In the context of each individual Machine, each Arm can be isolated independently at motor supply level.

2.4 Axis

The Axis is defined as the 'atomic' element at the lowest level of the drive chain.
The Axis exists at the physical level but not at the logical level, given that the minimum object which can be controlled at programming level is the Arm (in any case, it is possible to define Arms consisting of a single Axis).
A maximum of 8 Axes is envisaged for each Machine, giving a total of 32 Axes in the Cell.

In addition to being the basic constructional elements for individual robots, Axes are also offered by COMAU as sets of standard off-the-shelf units for use by the system integrator. In particular, COMAU offers:
- Motor-resolver assemblies with various power ratings.
- Standard gear motor sets with different torque levels (derived from robot gear motors).
- Cable sets of various lengths and sections for connection with controller.
- Drives of various power, of the same series as used for robot control.

Obviously, it is also possible to control special Axes, where all objects in the chain are defined and supplied by the user.

The objects making up the Axes, used on COMAU robots and offered as standard application units for motion control purposes, are economical and extremely reliable, as they consist of brushless motors with a single incorporated transducer (resolver pancake) for closing all servo control loops (position, speed, brushless current switching).
Sinusoidal current control ensures extremely smooth motion with low torque ripple.
The special RPT (Resolver Position Tracking) circuit designed and manufactured by COMAU (patent pending) is an economical and reliable means of making these Axes absolute, inasmuch as they are provided with a single resolver.

2.5 Possible configurations

C3G-9000 architecture makes it possible to set up systems with a broad range of complexity, thus permitting widely varying applications.
Cells may range from simple, economical units with a single Arm and one control cabinet, to highly complex Cells consisting of up to 8 Arms (up to 32 Axes) with several cabinets.
Whatever the complexity, each Cell features a single operator interface, while all logic connection between the various Cell objects are readily implemented via the PDL2 multi-tasking programming language (environment).

3. HARDWARE ARCHITECTURE

The C3G-9000 Controller's logic unit is based on a standard VME bus, with 32-bit processing modules for basic Cell control functions and motion coordination (interpolators) for individual Arms, and a DSP module for managing servo activities on the individual Axes.

The basic Controller logic unit (up to 8 controlled Axes) is implemented on only two VME boards, which include user memory (up to 4 Mbytes max).
The Controller is entirely based on RAM memories with battery backup, which contain both system SW and user program. These memories are initially loaded through external PCs or through optional integrated 3.5" floppy disk unit. This ensures easy control and rapid distribution of new system SW releases to the user.
As the Controller is also fully personalized through SW (there are NO switches, jumpers or potentiometers in the Controller!), the possibility of error is extremely low even after installation and maintenance operations.

The basic system (which can control one machine with a maximum of 8 Axes) is completed by a further two VME boards, including one dedicated to Cell safety and service I/O management, and one Input/Output (16I + 16O) board entirely reserved for the user.
Further Servo boards (up to 3), each of which can manage one Machine with a maximum of 8 Axes, can be added to expand the

number of Machines up to 4 and the number of Axes up to 32. Controller is completed by supply unit and power modules for driving the motors, which are available in a wide range of powers and modularities (1, 2 or 3 Axes per module, depending on power supplied).

As all servo-loop management takes place at DSP unit digital level, the power module is extremely simple and economical, provided that it is only required to operate as a current servo-amplifier (speed, brushless switching and position loops being closed at Controller level).

Basic unit is completed by the following: CRT-keyboard programming unit (optional), Teach Pendant terminal (optional), integrated floppy disk unit for program loading (optional), main supply unit (available in different sizes to satisfy the different powers involved) and IP54 cabinet with heat exchanger suitable for ambient temperatures up to 45°C (optional air conditioner is also available).
System expansion up to a maximum of 32 axes is accomplished by adding cabinets and supply units similar to the basic unit, connected to the main cabinet and controlled by the same Controller.

Particular care was taken to comply with the principal European and international safety standards applying to this type of Controllers, specifically VDI 2853.
Consequently, major circuits are duplicated and all basic safety rules are implemented and/or replicated in electromechanical logic.
On request, Controller can be supplied with a reduced-voltage motor supply circuit for 'manual' operation.

System is provided with complete I/O management controlled either through user language (PDL2) or a SW function implementing an integrated PLC which is always present and capable of managing small to medium size peripherals (up to around 200 I/Os).
For managing larger peripherals (up to 1024 I/Os), a PLC HW module is available for installation on the VME bus, and is fully compatible with the software PLC function.
Using this module also makes it possible to manage a remote I/O subsystem with physical I/O distribution on remote bases (up to 15) and long distances (up to 1000 m).

A full range of VME I/O modules is available at both local and remote level:

DC MODULES	AC MODULES	OTHER MODULES
16 I+16 O/0.5A	32 I	16 O/relays
32 I	16 O/2A	8 I+4 O/analog
32 O/0.5A	16 O/2A-protected	
32 O/ 2A		
16 O/ 2A-protected		

4. SOFTWARE ARCHITECTURE

Controller Operating System is based on a high efficiency multiprocessor multitasking type kernel hooked up to the VME interprocessor interrupt structures.

Pascal-like PDL2 user language supports multitasking (over 250 tasks at user level) as well as window technique at both system and user level.

Considerable attention was devoted to defining and implementing a user-friendly programming environment based on the following structures:

- Syntax Editor (Editor + Compiler) capable of intercepting syntax errors during the program write stage and directly producing the object code, so that a subsequent compilation phase is not needed.

- Integrated Editing and Teaching environment, so that programmer can directly access motion function (manual and automatic) during program editing phase.

- Interactive Debugger whereby a robot RUN cycle can be interrupted either manually or whenever predetermined conditions occur, and whereby it is possible to restart from the point of interruption after the necessary checks and corrections.

- Lotus-like Menu and Windows for self-explanatory access to the various environments and functions.

In this way, a highly integrated and user-friendly 'environment' has been provided, which can conceal the conventional EDIT - COMPILE - RUN - DEBUG program development loop from the user. However, it is still possible to edit a program off-line on any PC or external computer, and subsequently download the ASCII file which has thus been generated. All files (programs, data, texts) are managed as per MS-DOS standards to permit direct transfer from external PC (via RS-232) or internal floppy disc.

The set of primitives dedicated to motion is complete, designed to cover the needs of all applications known to date, and readily expandable for future needs. Particular attention was devoted to providing special functions such as 'FLY' and 'PATH'. A 'SPLINE' type function is also envisaged for the future.

To permit ready adaptation to the needs of different mechanical structures and applications, the trajectory generator features complete user-level programability for parameters characterizing motion, viz.:

- SPEED - ACCELERATION - DECELERATION - JERK.

Moreover, the trajectory generator interacts with the servo-loops for the various axes to permit real-time adaptation to actual joint load conditions (to anticipate saturations). The communication protocol towards any external (HOST) computer is based on MMS standard, and can be connected in turn to two different lower level communication structures:

- RS-232, at medium speed and low cost for low sophistication environments.
- ETHERNET, for high level integration environments.

The PDL2 language is particularly oriented towards the creation of high level structures to provide optimal solutions to specific application problems. Moreover, it is based on the intensive use of menus and windows, to conceal the conventional concept of 'program' from the user side.
In the future, it is likely that this technique, which is called 'Application Interface', will revolutionize the conventional robot programming method, especially when used in technologically complex applications such as arc welding, lasers, water-jet, sealing, etc.).

5. SERVO ARCHITECTURE

As indicated earlier, the system is based on the use of brushless servomotors with a single incorporated transducer (resolver pancake) whereby all main loops are closed, except for the (analog) current loop which is closed at motor drive level.
As all main loops are closed through digital processing, the calibration potentiometers (or switches) typical of analog loops are not used.

A special calibration program makes it possible to identify and set each loop's basic parameters for the real operating conditions of the various Axes. A special algorithm then permits ample system adaptivity to load and/or position variations during the work cycle, and informs the trajectory generator so that it can make the necessary adjustments.

The result is two-fold: on the one hand, the robot is fully protected against incorrect conditions and/or programming errors, while on the other hand, mechanical components can be used at maximum performance levels in all geometric positions and load conditions whenever cycle so requires.

Servo activity is displayed on panel at operator request and provides information concerning the interfaced mechanical subsystem's degree of utilization so as to permit program correction and/or optimization, when necessary.

The RPT circuit is housed in robot base and maintained active even with Controller off and/or disconnected. As indicated above, it guarantees 'absolute' type machines with low cost and high reliability (single transducer, and the gear type multi resolver casing eliminated on all joints).

In addition, all data used to characterize connected mechanical units are memorized on the RPT circuit, thus permitting easy and immediate restart in the event of Controller failure and/or replacement.

6. CONCLUSIONS

COMAU believes the C3G-9000 Control to be an effective answer to the robotic needs of the '90s. Thanks to its high modularity, the system can be put to advantageous use either on small, low-cost single arm applications or on highly complex applications, where large multi-arm robotized cells can be implemented with up to 32 Axes and integrated PLC.

The high available computing power (32 bit) and the use of the VME bus provide an HW and SW platform which is sufficiently open for the inevitable updates which will be required for future application situations.

Digital servo (DSP) structure permits further implementations and improvements in motion type and quality.
The use of intelligent algorithms (adaptivity) makes it possible to exploit mechanical structures to the fullest in a conscious and controlled manner.

Finally the Control's capacity for full personalizing at software level permits easy status updating for customers, which can be accomplished quickly and directly via telematic networks.

The introduction of 'intelligent' Controllers such as the C3G-9000 will hasten the development of new robot lines, designed expressly to adapt to the new possibilities and to take advantage of the inevitable trends towards lower cost and higher performance.

- END -

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