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Automated Vehicle/Highway System

Norio Komoda, Keiji Aoki, Takaharu Saito, Takashi Shigematsu, Hidetoshi Ichikawa
Toyota Motor Corporation

Abstract

This presents TOYOTA's concept, experiments and future scope of AVHS (Automated Vehicle/Highway System) which could contribute to a possible solution to automobile traffic/transportation issues in the 21st century.

Concept: This system enables smooth, automated cruising on highways by keeping the distance to the leading vehicle and avoiding obstacles. Compact, light-weight actuators are designed from a practical viewpoint. The system is intended to have broad benefits for vehicles with add-on devices as well as for automated vehicles.

Findings: The prototype runs smoothly over 100 km/h satisfying the above requirements with simple control algorithm. CCD lane sensor with compensation to disturbances can detect the lane except under severe weather conditions. The improvement of road structure and lane would make the sensor more robust. To make the system more reliable, misperception of vague lane is corrected by the onboard memory of 3-D road curvature as a backup. Onboard laser radar is feasible for obstacle or distance sensing and obstacle avoidance control with assist of road side TV camera with computer image analyzer, which can detect smaller obstacles and is a key solution. This forms a cooperative intelligent vehicle/infrastructure. With some compensation laser radar can detect the leading vehicle except under severe conditions such as small road curvature, bad weather, etc.

Scope: AVHS is expected to penetrate effectively because intelligent infrastructure can widely provide beneficial information for vehicles with telecommunication receivers as well as sure backup for automated vehicles. Further studies and discussions are necessary to obtain system reliability and social consensus.

Background

In Japan as well as in American and European countries, automobile traffic/transportation issues in the 21 C have been focused on in recent years in pursuit of effective and efficient ways to improve safety, congestion and environmental protection. In the following the related backgrounds are overviewed concerning Japanese traffic/transportation issues, the trend of AVCS (Advanced Vehicle Control System) and the historical overview of automated vehicle control systems. Our idea stands on the basis of this overview.

Automobile Traffic/Transportation in Japan

The following is our future prospect for Japanese automobile traffic/transportation (Fig. 1-4): The construction of highways should be eagerly pursued because of their much lower accident rate than that of normal roads. However, the future construction plans in Japan will not provide enough capacity to absorb the predicted increase of VKT (Vehicle Kilometers of Travel) if the future highway remains in its traditional form.

The accident statistics show that for the effective accident avoidance on normal roads, measures should be taken for rear end, head-on and side collision with vehicles, and collision with road side constructions. On highways, collision with road side construction and rear end collision are the major issues. The increase of aged drivers and pedestrians should not be neglected either.

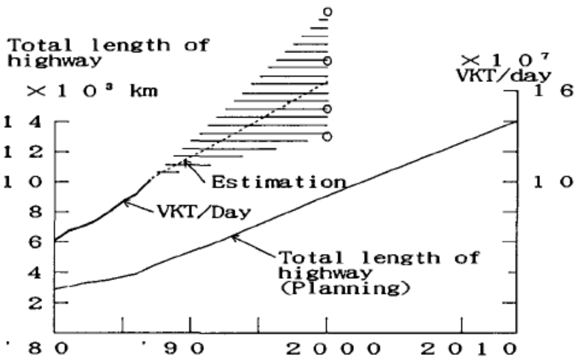

Figure 1. Total Length of Highway and VKT/day in Japan

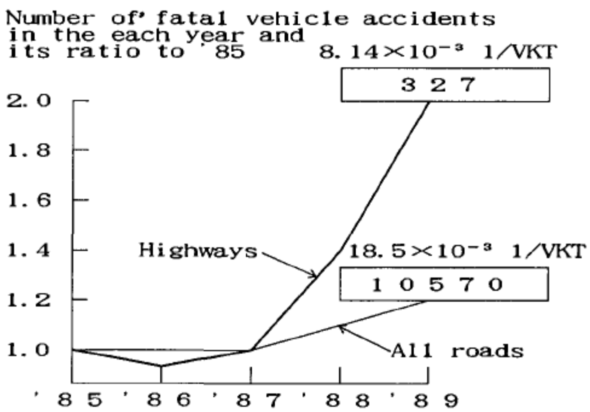

Figure 2. Number of Fatal Vehicle Accidents in Japan

The future congestion issue should seriously be considered both for highways and normal roads.

Thus the cooperative intelligent vehicle/infrastructure should possibly provide a key solution for the traffic/

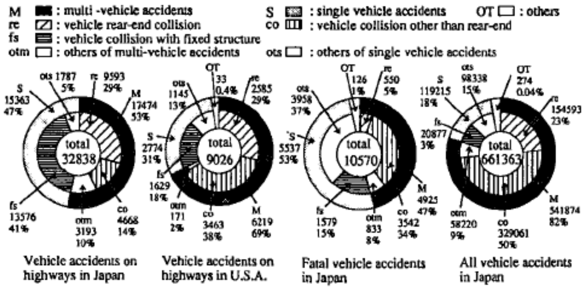

Figure 3. 1989 Accidents Statics (Number of Accidents)

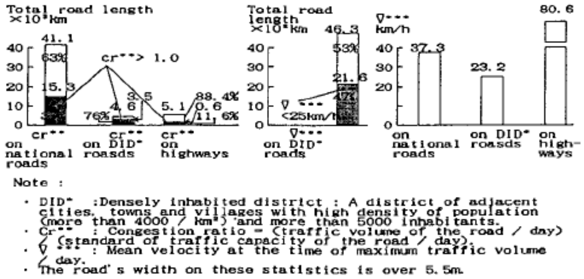

Figure 4. 1990 Congestion Statistics in Japan

transportation issues in the 21 C. While it would be effective both for highways and normal roads, from the viewpoint of technical feasibility the first plan should be for highways.

Overview on AVCS Technology

The trend is best understood when it is divided into 3 phases based on the typical evolutional features as shown in Fig 5.

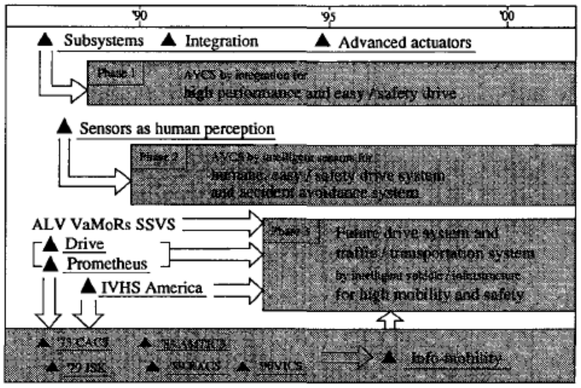

Figure 5. Overview of Trend on AVCS

Phase 1: The current AVCS Technology is going to cover almost all kinds of vehicle control subsystems and integrate them for smooth and high vehicle dynamic performance to the maximum of the tire friction circle as shown in Fig 6. The main subsystems including ABS, TRC, 4WS, 4WD and Active Suspension are currently being developed amidst tough competition. They could be more effective if equipped with more advanced active actuators. They are considered as fundamental factors for the so-called active safety system that provides the safety margin for accident avoidance maneuvers, although that margin depends on human factors.

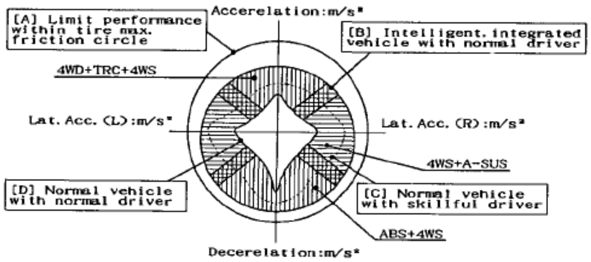

Figure 6. Effects of AVCS by Integration of Vehicle Intelligent Control Subsystems for High Performance, Easy and Safety Drive

Phase 2: Phase 2 systems are now moving from the research phase to the development phase. The important technical evolution in this phase is to substitute human perception and reaction with sensors and advanced active actuators. This could bring about a revolutionary change to the future of automobile safety and mobility. Various types of AVCS products could be introduced such as the rear end collision warning or avoiding system, lateral warning or control system, etc.

Phase 3: In addition to the AVCS in Phase 2, a more advanced and wide spread application of Info-Mobility System (intelligent traffic management system and vehicle-road telecommunication system) would make a great contribution to automobile traffic/transportation in the 21 C. This paper treats AVHS based on this background.

Historical Overview of Automated Vehicle Control System

As shown in Fig. 7, over 20 years many papers have been contributed mainly from technical interests in the most advanced technology at that time. We studied on these previous contributions thoroughly and selected carefully compact, light weight, cost-effective and reliable control devices to construct the best cooperative intelligent vehicle/infrastructure system available at this point.

Figure 7. Historical Overview of R&D on Automated/Autonomous Vehicle Control System

System Concept

The R&D project of AVHS gives challenging chances to R&D engineers in this field to accelerate the progress in the system development itself and to look for feasible technical byproducts in this time of emerging new technology.

This system is planned to enable the automated vehicle with lane and obstacle sensors to run automatically between ICs over 100 km/h on the cooperative intelligent highway lanes. It runs on the 2 lanes with intelligent infrastructure of the 2.6 km 3- (partly 4-) lane circuit with the parking lot or the IC. The presence of any other normal or automated vehicles on these 2 lanes is allowed.

The system provides smooth lane trace control, safe distance control, cruise control, obstacle avoidance by stopping or lane changing control and exit/entrance control using extremely simple control algorithms.

The onboard system has the following:

- Compact, lightweight and cost-effective actuators for the steering, brake and throttle systems.
- Cost-effective lane sensor and obstacle sensor (that senses only four-wheel vehicles and motorcycles) that cooperatively work with the intelligent infrastructure system, which provides backup for both onboard sensors. Onboard 3-D road curvature memory is also provided for the backup of onboard lane sensor.
- ECU and vehicle-road telecommunication system.

The intelligent infrastructure system has the following:

- White lane line for cruise and red lane line for exit/entrance, which are easy to see even under bad weather conditions.
- Obstacle detecting system which serves as a redundant system for the onboard detector, but also as a more robust, precise detector of smaller obstacles under severe disturbances.
- Traffic control center with the vehicle-road telecommunication system which provides (a) information to assist the automated vehicle to run smoothly and (b) information for traffic control.

Cooperative Vehicle/Infrastructure Concept:

- The investment should be reasonable and efficient compared to the broad benefit not only for automated vehicles but also for normal vehicles equipped with only some subsystems and/or the telecommunication receivers that make effective warning systems and/or semi-automated systems for accident avoidance.
- The investment would be relatively small compared to the much greater investment for highway construction in Japan even if the most advanced technologies are deployed for the cooperative intelligent vehicle/infrastructure. However, it would not be reasonable to pursue perfect backup under very severe disturbances.

Plan and Design of AVHS

The following are the special features of the prototype. The basic model is 1990 Toyota Camry (Fig. 8 and 9).

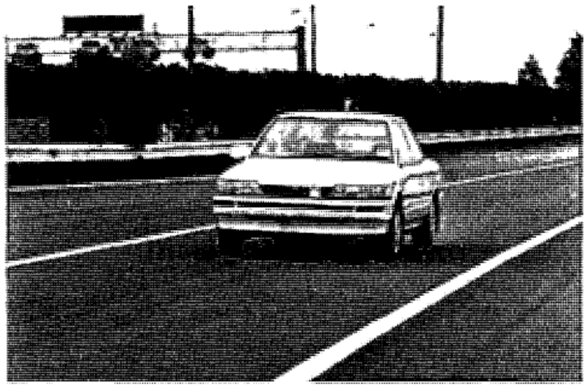

Figure 8. The Prototype Running Over 100km/h

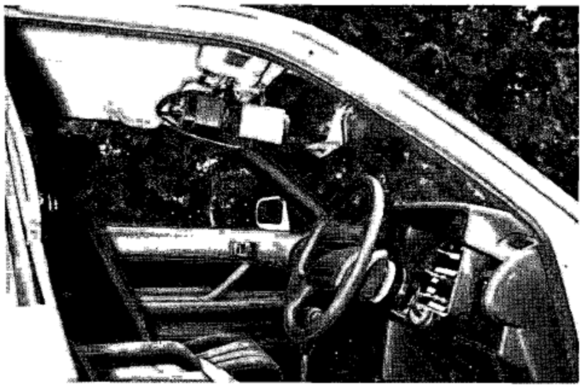

Figure 9. Steering Actuator and Color CCD Lane Sensing System

Onboard Systems

Actuators. The steering actuator is a lightweight, compact and high powered brushless DC motor which is installed coaxially with the steering main shaft of the hydraulic power assisted steering, as shown in Fig. 9 and 11. The specification of the motor is shown in Table 1. The driver can take over the steering wheel at any time.

Table 1. Actuator Specification

	Steering	Brake	Throttle
Type	brushless DC motor	spool valve and solenoid with high responce moving core	direct drive pulse motor
Spec.	voltage : 12 V torque : 3.5 N*m at 60 rpm current : 18 A at 3.5 N*m size ϕ100 × 45 mm	voltage : 12 V max. oil pressure: 14 MPa at 3.8 A size : ϕ100 × 125 mm	voltage : 12 V torque : 0.25 N*m at 1350 pps current : 3.5 A step angle : 0.9 ° size : ϕ60 × 60 mm

The brake actuator is driven by a hydro-electronic valve powered by the ABS pump and a lightweight, high-response solenoid with moving core, which are so installed in parallel to the master cylinder of the foot brake that the driver can actuate at any time. The specification is shown in Table 1.

The throttle actuator is a direct drive pulse motor (Fig. 12 and Table 1).

Sensors. The lane sensor is a color CCD sensor (TV camera) mounted at the inside rear view mirror immediately behind the top of the windshield glass as shown in Fig. 9. It watches for the lane line from 10 to 20 m ahead. The specification is shown in Table 2. The 3-D course curvature memory provides instantaneous backup in case of any failure of the lane sensor with assist from the vehicle position information from the roadside beacon.

The obstacle detector is a scanning laser radar mounted at the front radiator grill, as shown in Fig. 10. It watches mainly for vehicles and motorcycles from 5 to 120 m ahead. The specification is shown in Table 2. The detection of smaller obstacles depends on the intelligent infrastructure.

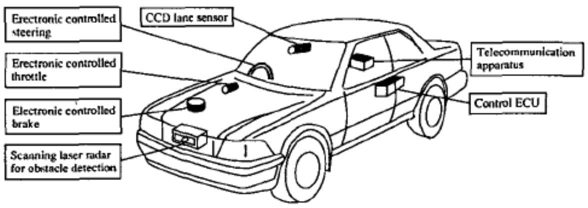

Figure 10. Onboard System

Table 2. Onboard Sensor Specification

	Lane sensor	Laser radar for obstacle detecting
Type	2 dimensional color CCD	scanning laser radar
Spec.	high resolution RGB output : 756 pixels × 485 lines electronic shutter : 1/125 ~ 1/10000 sec	detectable range : 5 ~ 120m scanning angle : ±15° beam vertical angle : ±1.5° scanning speed : 120 ms

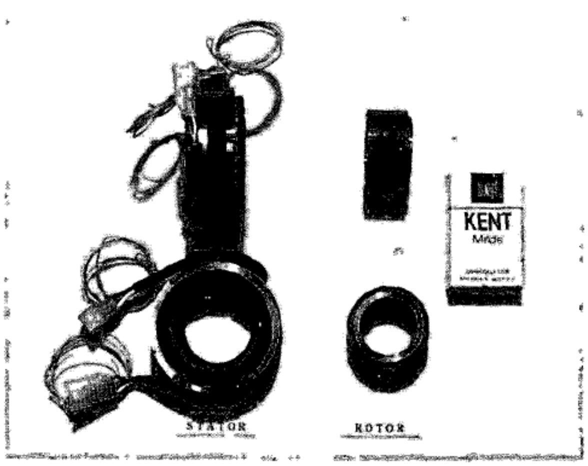

Figure 11. Electronic Controlled Steering Actuator

Figure 12. Electronic Controlled Throttle

The onboard traffic monitoring system is installed in the center instrument panel (Fig. 25).

ECU and telecommunication systems are installed in the luggage compartment.

Infrastructure System

Intelligent proving ground (Fig. 13). (1) The proving ground is 2.6 km-long oval circuit. The central 2 lanes of the 3-(partly 4-)lanes are used for AVHS, with the parking lot assumed as the IC for exit/entrance control. The specially painted bright lane line with many small spherical asphalt spots is perceptible in bad weather. (2) Ten beacons and a TV camera are implemented on the course. (3) The traffic control center is located at the assumed IC.

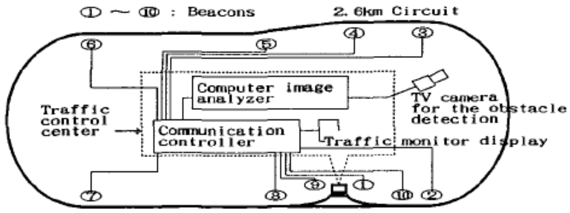

Figure 13. Intelligent Infrastructure System

The vehicle-road telecommunication is done between the antenna on the roof of the prototype and the 10 beacons located along the test track through the traffic control center. The information exchanged is used for traffic control and for smooth and safe drive control as shown in Fig. 14. The communication protocol is also shown in Fig. 14.

Road side TV camera and computer image analyzer for obstacle detection: The TV camera is implemented on a pole of 8.8 m-height to detect obstacles on the road from 10 to 30 m ahead or from 100 to 500 m ahead. The TV camera and the computer image analyzer in the control center function as a redundant backup system as well as a reliable obstacle detector for smaller obstacles. The specification is shown in Table 3.

The traffic monitor display is in the control center as shown in Fig. 26.

Findings

Lane Sensing and Steering Control

The prototype succeeds in running along the lane over 100 km/h using a simple steering control algorithm to detect the lane of 10 to 20 m ahead (Fig. 15-17). In this

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