ITS Demonstration by the University of Tokyo Team at DEMO 2000

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This paper introduces the activity of the University of Tokyo team at DEMO 2000 which was held at Tsukuba, Japan, in November and December 2000. Two demonstrations by ITS (Intelligent Transport Systems) vehicles of the team are shown. The one is an application of ITS, especially autonomous-vehicle technology, to welfare vehicles. The purpose of the demonstration is reducing the driving burden of people with handicaps. The other demonstration is advanced platooning control. Basic maneuvers for platoons, i.e. following, diverging, merging, separation and combination, are realized in a short range proving ground. Technical data of the demonstration vehicles are also described.

Key Words: ITS (Intelligent Transport Systems), AVCSS (Advanced Vehicle Control and Safety Systems), platoon, welfare vehicle, DEMO 2000

1. Introduction

Demonstration of ITS (Intelligent Transport Systems) was held in Tsukuba City, Japan, from November 21 to December 2, 2000, just before the 21st century. This demonstration is called DEMO 2000 and consists of DEMO 2000 Cooperative Driving held by Japanese Ministry of International Trade and Industry (MITI)*1 from November 21 to 27, 2000 and Smart Cruise 21 DEMO 2000 held by Ministry of Transport and Ministry of Construction from November 28 to December 1, 2000. From mid of 1990's, such an ITS demonstration has been repeatedly held in somewhere in U.S., Europe, and Japan*1. Compared with such precedent ITS demonstrations, DEMO 2000 is the biggest in the number of introduced new technologies, the number of demonstration vehicles participated, and the variety of foreign participants.

Core technology of DEMO 2000 Cooperative Driving system is an inter-vehicle communication technology, which has been developed by Mechanical Engineering Laboratory (MEL) and Association of Electronic Technology for Automobile Traffic and Driving (JSK), while that of Smart Cruise 21 DEMO 2000 is Advanced Safety Vehicle (ASV) technology. In addition to these two demonstrations, some other demonstrations were also held in each of Cooperative Driving and Smart Cruise 21.

The University of Tokyo team*2, which is composed of university laboratories within the vicinity of Tokyo, participated*3 in both of Cooperative Driving and Smart Cruise 21. The University of Tokyo team, like many other participants for such a new technology demonstration, had been struggled for finding the best mode of their demonstration, since it was difficult to anticipate boundary conditions in DEMO 2000 and it was not certain whether the group members who are mainly university students including graduate students could successfully operate the both demonstrations as planned. Professors of each group gathered to have a discussion and reached a conclusion that it would be a wonderful opportunity for academia to show the results of fundamental studies in the universities. As a result, original demonstration plan made by the University of Tokyo team at the beginning of 2000 could be implemented as a part of official DEMO 2000. Another difficulty for the group members in preparing the demonstration plan was to provide customization and tuning to a total of five vehicles (two for DEMO 2000 Cooperative Driving and three for Smart Cruise 21 DEMO 2000) within a limited period of time.

In this paper the above two demonstrations held by the University of Tokyo team will be described.

*1 Organization names such as Japanese ministries and agencies used in this paper are those used at the time of the demonstration.
*2 The University of Tokyo Team consists of the following six laboratories from four universities:
- Fujioka Laboratory of Department of Mechanical Engineering, the University of Tokyo
- Kageyama/Tsunashima/Nishi Laboratories of Department of Mechanical Engineering, College of Industrial Technology, Nihon University
- Aoki Laboratory of Department of Electrical Engineering and Electronics, Faculty of Engineering, Seikei University
- Shimizu Laboratory of Environmental Information Department, Keio University
*3 In addition to the University of Tokyo Team, Keio University Team also participated with a vehicle in SmartCruise21.
For the first round, Vehicle 1 was manually driven and Vehicle 2 automatically followed the Vehicle 1 (Fig. 2). The first round was based on the following assumption: if a person with handicap has to perform long-distance driving, let his/her vehicle automatically follow another vehicle running in the same direction, thereby reducing his/her tiredness due to long-distance driving by enabling the person not to perform driving operations (e.g., acceleration and braking operations) while his/her vehicle is following a lead vehicle. The lead vehicle (i.e., Vehicle 1) can be of friend's, acquaintance's, or someone's who was asked for at service areas in the highway. In such situation, he/she should perform short-time manual driving only before and after the long-distance cooperative driving.

Each step in Fig. 2 is as follows:

- i ) Ride into each vehicle
- ii ) Slow-speed manual driving: Both of Vehicle 1 (having no automatic driving function) and Vehicle 2 (with automatic driving function) are manually started and then the succeeding vehicle (i.e., Vehicle 2) follows the lead vehicle (Vehicle 1) with slow speed.
- iii ) Merging: After the lead vehicle being followed by the succeeding vehicle, the succeeding vehicle enters into automatic driving mode by switching the operation.

Fig. 1 Throttle and brake lever and steering grip

Fig. 2 Scenario of autonomous vehicle following

Such a vehicle control system is also called AVCSS (Advanced Vehicle Control and Safety Systems), since one of its main objectives is safety.

If this lever is pushed forward, an accelerator pedal is pushed through a link mechanism. If this lever is pushed rearward, a brake pedal is pushed through a link mechanism and deceleration is provided.
Vehicle following: The succeeding vehicle automatically follows the lead vehicle's arbitrary running.

Stop & Go: The above vehicle following operation also includes Stop & Go operation, and the usual inter-vehicle distance is 13 m at a speed of 30 km/h. While Stop & Go operation, the lead vehicle's running at a curve with a radius of 10 m is successfully followed by the succeeding vehicle.

Diverging: At a predetermined point (i.e., after one round driving for the present demonstration), the succeeding vehicle diverges from the lead vehicle by switching the operation and returns to manual driving.

At the second round, the automatic map following driving was performed using a map installed in the vehicle (see Fig. 3). Such an automatic map following driving can be realized when the precision of navigation systems is further improved. For the present demonstration, pylons were used for setting a test course and the test course was installed as an automatic driving route into the vehicle, based on such an assumption that this automatic map driving function was used for a daily trip to a supermarket or hospital. Figure 3 shows an each step of the automatic map-following driving.

Manual driving: After the first round for the lead vehicle-following driving is finished, the manual driving of the succeeding vehicle (i.e., Vehicle 2) is restarted.

Map following driving: For the second round, the automatic map-following driving is performed on the test course set by the pylons, with the maximum speed of 50 km/h.

Vehicle stoppage and completion of demonstration

Since this demonstration was performed using a proving ground in MEL, the scenery for a guest passenger is monotonous and not realistic. In the test vehicle, three displays were installed so that the passenger could see the driving status together with animation scenery of rural driving. Such an in-vehicle display is shown in Fig. 4. This display can be switched between a view set as a landscape seen from a driver seat and a bird's-eye view seen from the point above the vehicle. Numerical values and characters shown in the lower left part of Fig. 4 represent the current vehicle position, speed, and acceleration indicated by instruments.

Figure 5 shows the above two test vehicles when they start the demonstration.

### 3. Demonstration Scenario II (Smart Cruise 21 DEMO 2000): Platoon service

The platoon service is one of multiple automatic driving forms, where a plurality of vehicles (e.g., 2-10 vehicles) cooperatively perform automatic driving by communicating one another. The term “platoon” is originally a military term defined as “a small group of soldiers which is parts of a company” in a dictionary. The vehicle-following driving as described in the above section therefore can be considered as the simplest form of the platooning driving consisting of two vehicles. It is expected that a control system using platooning can enable power-saving driving and smooth traffic. It is further expected that, if such a platoon service can have higher reliability, it will bring an increase in traffic capacity and improvement in energy efficiency by reducing the inter-

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*Example of a project utilizing a simple form of platooning consisting of two vehicles includes CHAUFFEUR project by Daimler-Chrysler AG with objectives of labor-saving of trucks and improvement of energy efficiency. Also, there is IMTS project by TOYOTA, utilizing platooning for buses.*
vehicle distances compared to the case where conventional manual driving is used.

Conditions needed for platooning in terms of the vehicle control are fundamental technologies such as vehicle following, diverging, merging, platoon-detachment, and platoon-joining.

This demonstration was conducted using three vehicles on a test course in Public Works Research Institute (PWRI) of Japanese Ministry of Construction. The lead vehicle has a manual driving function and the rest of two succeeding vehicles have automatic driving functions. The maximum speed was 60 km/h, with an inter-vehicle distance of 15 m. Proving test course for this demonstration is shown in Fig. 6.

In this demonstration, the positions of the vehicles were detected by magnetic markers. The magnetic markers were buried in one lane on the north side of the proving ground (i.e., right side of Fig. 6) and in two lanes of straight courses on the east side (i.e., inner side of dog bones or the lower side of Fig. 6). Since the basic demonstrational driving operation as earlier described needs two lanes, it was necessary to set the scenario to be adapted to these 600 m straight courses in the east.

Figure 7 shows driving patterns that are arranged to enable passengers to experience the basic platooning technologies such as vehicle following, separation, diverging, merging, and platoon-joining in these two lanes of straight courses. Hereinafter, each step of the scenario will be described using Fig. 6 and Fig. 7.

i) At the starting position, where the three vehicle stop in front of an in-marker (i.e., ① of Fig. 6), the vehicles receive information regarding road geometry through the road-vehicle communication. Thereafter, the lead vehicle manually starts and the rest of two vehicles automatically start to follow the lead vehicle in succession.

ii) The three vehicles run on a gentle curve section, a round curvature section, and again another gentle curve section.

iii) Obstacle avoidance (Fig. 7-a): The lead vehicle detects an obstacle (e.g., a car parked in a street) by the laser radars and this detection information will be transferred to the succeeding vehicles via the inter-vehicle communication. Whenever the lead vehicle avoids the obstacle by manual operation, this avoidance behavior will be automatically followed by the two succeeding vehicles, thereby enabling the succeeding vehicles to avoid the obstacle.

iv) Return to main lane (Fig. 7-b): After the obstacle avoidance action, the three vehicles return to the main lane.

v) Separation and diverging (Fig. 7-c): The third vehicle transmits a diverging signal to the lead vehicle and then automatically departs from the platoon and diverges from the main lane.
vi) Merging and platoon-joining (Fig 7-d, 7-e): The diverged third vehicle begins acceleration and sends a merging request to the first and second vehicles performing platooning. Then, the second vehicle departs from the first vehicle and maintains a space between the first and second vehicles so that the third vehicle can enter the space inbetween. Thereafter, the third vehicle merges into the space and the second vehicle (i.e., a vehicle now in the third position) narrows the space and joins the platoon.

vii) Stoppage (Fig. 7-f): When the point in front of the out-marker position (i.e., Fig. 6-4 of platooning service goal point) is reached, the lead vehicle manually stops and the succeeding vehicles automatically stop in accordance with the lead vehicle's stoppage.

In the present demonstration, the three vehicles were manually started from the south side of the test course to Point 1 in Fig. 6. After the above automatic driving part of the present demonstration was finished, the vehicles were again manually driven from Point 4 to the stating point. One round took 12 minutes. The vehicles running on the proving ground are shown in Fig. 8.

**Figure 9** shows a display in a vehicle for showing an operation condition to passengers, driver, and operator, where rectangles represent the test vehicles and dots along a lane are magnetic markers. The display not only includes information sent from various instruments but also data sent via the inter-vehicle communications.

**Figure 10** shows a block diagram of hardware configuration used for the second and third vehicles (i.e., succeeding vehicles) in Smart Cruise 21 DEMO 2000.

Considering the various software for control systems used in previous researches, the software adopted in the present demonstration was a basic-type one that operates without fail.
and is easily adjustable (at that rate, control accuracy may be sacrificed).

The lateral control (i.e., steering control) was performed by preparation control. The information resulted from the preparation control was compensated by PID control.

The longitudinal control (i.e., acceleration and braking controls) was performed by a sliding control (i.e., input/output liberalization control, to be strict). Information derived from driving systems such as an engine, torque converter, and transmission is relatively nonlinear and the throttle opening therefore is not proportional to the vehicle acceleration. In order to compensate for this nonlinearity, the throttle opening to the vehicle acceleration was reversely precomputed so that the mapping resulted from the precomputation can be used for the nonlinearity compensation.
5. Conclusion

Three years back from DEMO 2000, DEMO '97 was held in San Diego, U.S. in 1997, where many teams from prestigious universities in cooperation with various manufacturers and traffic authorities from each state exhibited many demonstration vehicles and performed demonstrational driving. On the contrary, in Japan, the number of such university laboratories working on ITS (especially on AVCSS) by performing on-vehicle tests, is very small. Furthermore, Japan has not yet started such a full-scale cooperative research among educational and industrial fields or among educational, industrial and governmental fields.

There is an estimate by Japanese Ministry of Posts and Telecommunications that in 2015 the cumulative sales of ITS-related industries will be 60 trillion-yen. With a context where the development of information technology (IT) will be accelerated in the 21st century, ITS and AVCSS, which fully utilize such an IT technology, also must be developed accordingly. A driving support system that will be essential in the near future is not the one that merely shows information or sound the beep but the one that actually help drivers in need. The forthcoming ITS society requires such driving support system that works as necessary and is not too much officious.

In order to realize such an intelligent driving support system, vast range of R&D including basic and fundamental research are necessary; the collaboration of academic, industrial, and governmental sectors is essential for this R&D.

Heretofore, the publicly held demonstration service by the University of Tokyo Team at DEMO 2000 was described, hoping that readers can deepen their understanding toward our activities and that larger scale cooperative research activities among academic, industrial, and governmental sectors will be triggered.

Technical details were omitted from the above description because such information was already publicized and the space available for the present description was limited. Those who are interested in the technical details of the above demonstration service can refer to the documents shown in attached list of reference documents.

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References