PAPER Special Section on Spread Spectrum Techniques and Applications

A Vehicular Driving Assistant System Using Spread Spectrum Techniques

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SUMMARY In the ITS (Intelligent Transport Systems), it is an essential condition (mixed environment) that vehicles that have communication equipment and vehicles that do not have it simultaneously run in the same road. In this paper, a vehicular driving assistant system that is applicable to the mixed environment is proposed. The proposed system uses spread spectrum techniques and consists of several new systems such as a PN code assignment system, new vehicle position systems, and a vehicle map update system. In the proposed system, the wireless broadcast CDMA is used for inter-vehicle communications. This paper also shows preexaminations of the proposed system by using an autonomous traffic flow simulator including inter-vehicle communications. It is shown that the traffic safety can be improved by using inter-vehicle communications.
key words: *intelligent transport systems (ITS), PN code assignment, PN coded magnetic markers, PN coded pulse radar, inter-vehicle communications*

1. Introduction

In recent years, the number of vehicles is explosively increasing. In such a situation, the increasing incidence of traffic accidents now becomes a serious social problem. To solve this problem, the Intelligent Transport Systems (ITS) have been developed remarkably.

To increase the traffic safety, there have been intensive studies on inter-vehicle communications that exchange the front-seat information (e.g., velocity information, braking information) among individual running vehicles [2]. Given that spread spectrum (SS) communication systems provide anti-interference and multiple access capability, many researches on inter-vehicle SS communication systems have been reported [3]–[5]. However, there have been few studies on explicit (top-down control by a control station) PN code assignment methods for CDMA communications.

On the other hand, it is hard to mount communication equipment into all of the running vehicles at the same time. Therefore, not all of the running vehicles have communication equipment. Furthermore, it can be considered that vehicles with broken communication equipment run simultaneously on the same road. In the ITS, the essential condition that should be considered is that vehicles that have communication equipment (ITS vehicles) and vehicles that do no have it (Non-ITS vehicles) run on the same road. In this paper, this condition is called the mixed environment. Unfortunately, there are few studies on such mixed environments. It is necessary to establish a new inter-vehicle communication system that is applicable to the mixed environment.

In this paper, to solve these problems, we propose a new vehicular driving assistant system that is applicable to the mixed environment using SS techniques [6], [7]. The proposed system consists of several systems. Here, a dynamic PN code assignment system for wireless broadcast CDMA communications is proposed. Moreover, in this system every ITS vehicle uses the PN coded pulse radar system to obtain other vehicles' position information. In addition, to provide an extremely high accuracy positioning system, the PN coded magnetic marker system is proposed. Furthermore, as a preexamination of the proposed system, the effectiveness of inter-vehicle communications for improving the traffic safety under the mixed environment is investigated. The investigation uses an autonomous traffic flow simulator including inter-vehicle communications that was developed by the authors [8], [9].

This paper is organized as follows. In Sect. 2, inter-vehicle communications are discussed. A conceptual model and the configuration of the proposed vehicular driving assistant system are described in Sect. 3. Section 4, presents the investigation on the traffic safety improvement under the mixed environment. The conclusions are drawn in Sect. 5.

2. Inter-Vehicle Communications

The communication paradigm of the inter-vehicle communication network will be different from that of present cellular personal communication networks. The inter-vehicle communication network's characteristics are explained as follows:

1. There is no base station (self-centered network or platooning network)
2. Assuming that a self-centered network concept is used, each center of the network is a vehicle itself. The vehicle sends its front-seat information to close vehicles. Moreover, because every vehicle runs autonomously, the network's feature is changeable.

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3. Information from close vehicles is the major requirement for the network.
4. Real time communications and high quality information are required.

These characteristics make the inter-vehicle communication network become a unique autonomous distributed network. It means that a new network paradigm is needed for this network.

The contents of exchange information on inter-vehicle communications are divided into two kinds of information. One is the information that does not directly relate to vehicle driving and traveling. This information is called as "rear seat information" (e.g., tourism information, weather information, and voice communications). The other is the information that directly relates to vehicle driving and traveling such as vehicle position information, velocity information, so on, called as "front-seat information." In this paper, the front-seat information is used.

In addition, in this section, the required paradigm or technical points of the inter-vehicle communication network are summarized as follows:

(1) Mixed environments

As described in the previous section, mixed environments are essential conditions in the ITS. Matsushita et al. evaluated the relation between equipment mounting ratio and packet propagation ratio [4]. They use optical media for communication among the vehicles. What is shown in their results are that non-ITS vehicles become communications' hinders when optical media are used, moreover, while the communication equipment's mounting ratio is low, the inter-vehicle communication is not available. However, there are few studies on the inter-vehicle communication network that uses the wireless broadcast CDMA under mixed environments.

(2) PN code assignment method

When the wireless broadcast CDMA is adopted as the communication method, to detect all used codes in a communication area, it is needed to use limited number of PN codes. Therefore, studies on the PN codes assignment method are needed. The authors proposed the autonomous PN code assignment method using multicode sense CDMA [5]. However, in this paper, we propose another assignment system using a top down method.

(3) High accuracy positioning system

In the inter-vehicle communication network, the vehicle position information is required to measure the relative distance among vehicles. There are several positioning methods to obtain the vehicle position information. Krakiwsky's paper [10] presents the GPS is the most used positioning system around the world. Unfortunately, the GPS can only range the vehicle position within 30 [m], moreover, the differential GPS's accuracy is 1 to 10 [m]. The accuracy of GPS is not enough to fill the high accuracy demand for vehicle positioning system. A new high accuracy positioning system for vehicles is needed. To provide the high accuracy position information and relative distance among the vehicles, the inverse-GPS scheme is proposed by the authors [11]. This system does not require infrastructure. However, large equipment is required for each vehicle. In this paper, a new extremely high accuracy vehicle positioning system using road infrastructure is proposed.

3. A Vehicular Driving Assistant System

The proposed vehicular driving assistant system consists of several new systems described as follows:

(1) A PN Code Assignment System

(2) Vehicle Positioning Systems

   a. The PN Coded Magnetic Marker System

   b. The PN Coded Pulse Radar System

(3) A Vehicle Map Update System

In this study, an expressway is assumed as its road environment.

3.1 PN Code Assignment System

A new approach on a PN code assignment system that uses several infrastructures as the media is proposed. As shown in Fig. 1, two infrared beacons are used. The beam range of these beacons is 3.5 meters. These beacons are constructed with the same distance on every road lane (e.g., 100 [m]). This environment is called a PN code assignment subsystem. These beacons are called the first beacon and the second beacon, respectively. PN codes for inter-vehicle communications are assigned to all of the equipped vehicles when they pass

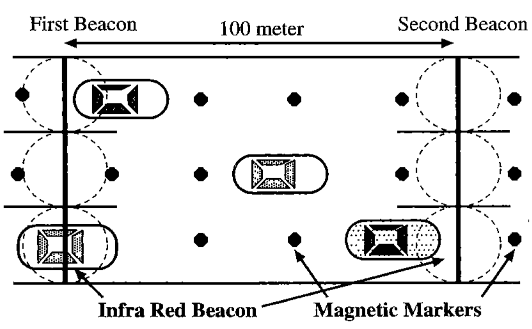

Fig. 1 PN code assignment subsystem.

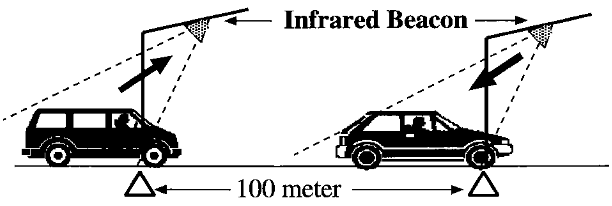

Fig. 2 PN code assignment process.

these beacons (See Fig. 2). Since the proposed system uses wireless broadcast CDMA communications, to detect other close vehicles' PN codes, each vehicle uses multi-user detection. For this reason, limited number of PN codes is suitable for this system. It is appropriate to use short codes. The assignment process is described as follows:

(1) At the start point (e.g., a collection gate), when an ITS vehicle passes through the first beacon's beam area, this vehicle sends its vehicle ID to the beacon. The beacon receives this information and sends it to ground equipment for PN code assignment process.

(2) It is assumed that the first beacon uses infrared rays to detect a vehicle that passes it. Therefore, the system can obtain non-ITS vehicles' information. According to detection results, the ground equipment makes a vehicle map.

(3) After assigning a PN code to every ITS vehicle and adds its information to a vehicle map, the ground equipment sends this map to the second beacon. This beacon broadcasts a vehicle map. When an ITS vehicle passes through the second beacon, it receives the map (See Fig. 2) and finds the code that it should use. This map contains the information of ITS vehicles and Non-ITS vehicles that passed the first beacon. This map is called as an initial vehicle map.

Figure 3 shows the communication area of the infrared beacon. From the physical design of infrared beacon that was presented in [12], we assumed that downlink data transmission and uplink data transmission are 1024 [kbits/s] and 64 [kbit/s], respectively. Vehicles take 0.13 seconds to pass the IR beacon's communication area and the maximum transmittable data of downlink and uplink transmissions are 133 [kbit] and 8.3 [kbit]. This capacity is enough to transmit the vehicle's ID and around vehicles' Map.

In this system, every vehicle broadcasts its front-seat information within its own communication area. Each vehicle's transmitter has a programmable PN code generator to make the assigned PN code. In addition, every vehicle's receiver always detects all the other vehicles' signals simultaneously (multi-user detection). Figure 4 shows the proposed inter-vehicle communications scheme.

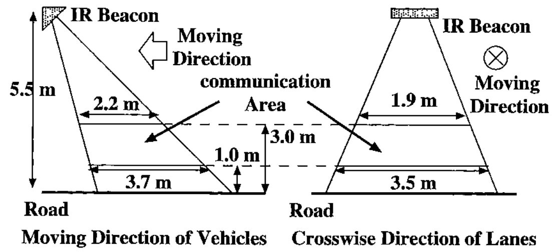

Fig. 3 IR Beacons' communication area.

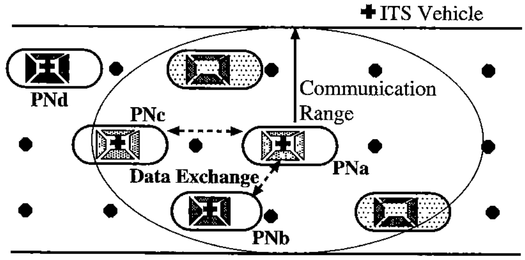

Fig. 4 Inter-vehicle communications scheme.

By exchanging the front-seat information, each ITS vehicle has other ITS vehicles' position information. While each vehicle obtains its own position information by using the PN coded magnetic marker system explained in Sect. 3.2. However, because of various velocities of vehicles, it is possible that the same code is used for close vehicles. To avoid this problem, PN code assignment subsystems are needed to be constructed with the appropriate distance (e.g., 1 [km]). Therefore, PN codes can be reassigned appropriately.

3.2 Vehicle Positioning System

To obtain the position information of other vehicles including Non-ITS vehicles, the following two new systems are proposed.

3.2.1 PN Coded Magnetic Marker System

As mentioned above, PN code assignment subsystems are arranged at a fixed interval. To obtain high accuracy position information among two PN code assignment subsystems, the PN coded magnetic marker system is proposed. Magnetic markers are usually used for vehicles' lateral control, and they are usually embedded simply such as S, S, S, ... or S, N, S, N, ... However, we propose that magnetic markers are embedded like a PN code, in particular, an M-sequence (See Fig. 5). By such embedded markers, each ITS vehicle can obtain its own absolute position information from the magnetic markers. Here, an M-sequence whose code length $L = 2^m - 1$, is assumed as markers' embedded pattern. Moreover, the N pole and the S pole are assumed as 1

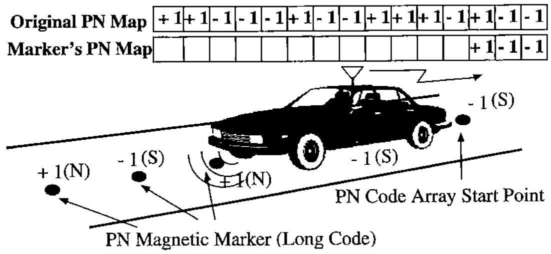

Fig. 5 PN coded magnetic marker system.

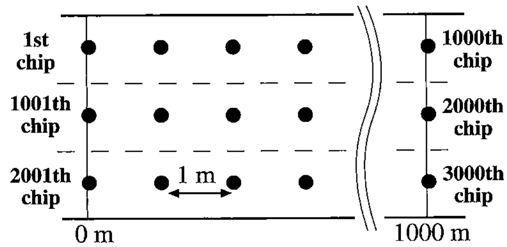

Fig. 6 PN coded magnetic markers' arrangement.

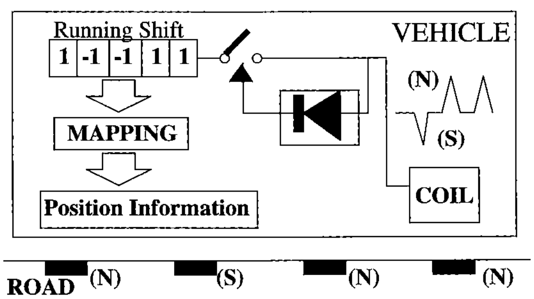

Fig. 7 Position detection system.

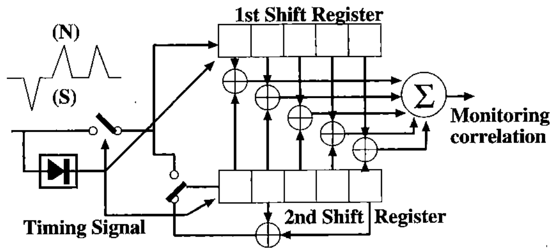

Fig. 8 Mapping improvement system.

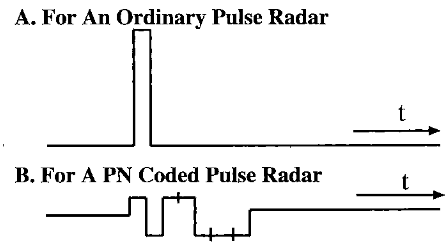

Fig. 9 Concept of PN coded pulse radar system.

and −1, respectively. For example, suppose that magnetic markers are embedded every 1 [m] and the distance among two assignment subsystems is 1 [km], 1000 markers are required (A 1023 chip maximum length M-sequence is usable for one lane. Even if there are three lanes, a 4095 chip M-sequence is sufficient). Moreover, markers are arranged as shown in Fig. 6. In this example, by observing ten successive magnetic markers, the absolute position information can be obtained. This example also shows that the length L is determined by the distance among two assignment subsystems and lanes' number. However, markers can be embedded at various distances when the position detection system is enable to process it. In addition, by obtaining the information of successive m markers, this system allows the lane change.

Figure 7 shows the position detection system that is very simple and easily feasible. For improving the mapping performance in the presence of noise, we propose a high accuracy position detection system using RASE [13] like system (See Fig. 8).

By exchanging the obtained position information among the ITS vehicles, each vehicle can measure the relative distance between it and other ITS vehicles. Thus, by using the information, ITS vehicles can run safely. In this system, a PN code fixed assignment is used. The extension and details of the proposed positioning system are described in [7].

3.2.2 PN Coded Pulse Radar System

To obtain other close vehicles' information around an ITS vehicle, the PN coded pulse radar system is proposed. This system uses single pulse like an ordinary pulse radar. However, as an ordinary pulse radar uses a simple single pulse, different carrier frequencies should be assigned to every simultaneously running ITS vehicle. This method requires many carrier frequencies. Due to the fact that usable frequencies are limited, it is difficult to carry out this method in ITS.

Different from an ordinary pulse radar, the proposed system uses many PN codes instead of many carrier frequencies (See Fig. 9). As the duration of one pulse equals to one chip duration of spreading code, the system uses long code to code the pulse using the same principles used in the SS-PPM [14], [15]. By compressing pulses with the matched filter, each ITS vehicle can select and obtain its own reflected pulses. So, without increasing the bandwidth, the CDM radar can be realized (See Fig. 10). The obtained information consists of ITS-vehicles' information and Non-ITS vehicles' information. Here, this information is called the radar information.

Like the PN codes for communication, PN codes for radar system can be assigned dynamically. However, while the code is used only for one vehicle, it is appropriate to use a preassignment method for this system.

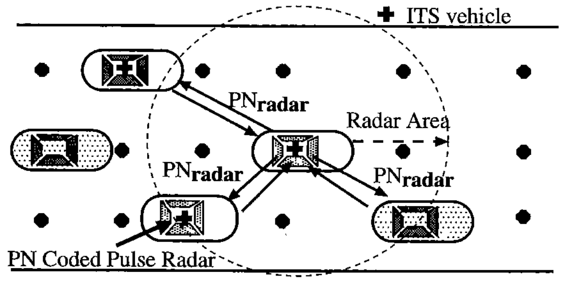

Fig. 10 PN coded pulse radar system.

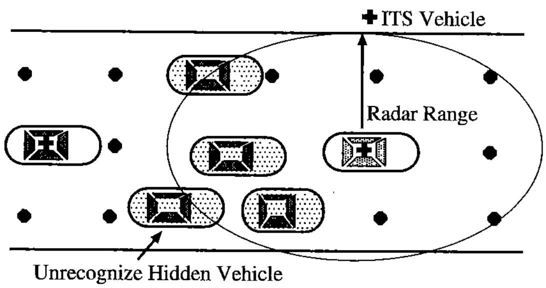

Fig. 11 An example of unrecognized non-ITS vehicle.

3.3 Vehicle Map Update System

In mixed environments, an ITS vehicle can use the initial vehicle map to get information about Non-ITS vehicles. Since every vehicle runs autonomously, the initial map becomes invalid soon. To provide Non-ITS vehicles information around an ITS vehicle, it is needed to update the vehicle map. However, in the proposed system, the radar information provides an updated vehicle information. The radar information is obtained by using the PN coded pulse radar system. This information consists of close ITS vehicles' information and close Non-ITS vehicles' information. To satisfy the requirement of the updated vehicle map, the radar information is used to update the vehicle map.

However, the radar information covers only other close vehicles' information. Therefore, the vehicle map does not have information of the hidden Non-ITS vehicles as shown in Fig. 11. To solve the hidden Non-ITS vehicles' problem, every ITS vehicle exchanges its own vehicle map. Thus, each ITS vehicle has an updated vehicle map in the larger area that consists information of ITS vehicles and Non-ITS vehicles. So, the hidden Non-ITS vehicles' information can be obtained from this map.

4. Traffic Simulation Under Mixed Environments

As a preexamination of the proposed system, the investigation on the effectiveness of the proposed vehicular driving assistant system for improving the traffic safety was carried out using an autonomous traffic flow simulator including inter-vehicle communications [8].

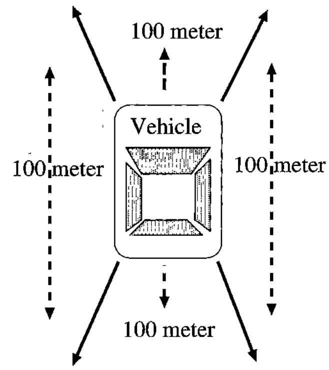

Fig. 12 Driver's visibility area.

Table 1 Autonomous driving parameters.

Characteristic	Definition	Value(s)
Visibility Area	The area that is viewable by the driver	100 [m]
Desired Velocity	The maximum velocity that the driver sets	90, 100, 110 [km/h]
Total Delays	The summation of human response time (the delay from the driver notices the danger until he takes an action) and the machine's response time	N(0.3,1.5)
Velocity Control	Each vehicle can control its own velocity by reduces or accelerates the velocity	± 5 [m/sec^2]
Lane Changing	Each vehicle is allowed to change its lane in order to keep its desired velocity or avoid the danger	

4.1 Simulation Model

In this simulator, the length and width of the vehicle model, are assumed as 4 [m] long and 1.5 [m] wide, respectively. A three-lane highway road whose width and length are 3.5 [m] and 20 [km], is assumed. The simulation cycle time is 0.1 second. Moreover, it is assumed that there is a driver in each vehicle. Figure 12 shows the driver's visibility area. In addition, it is assumed that each driver has several parameters listed in Table 1. As a result, every vehicle has its own ability to take an action such as, changing lane, velocity reduction, and so on. This means that every vehicle runs autonomously. Here, ITS equipment is assumed as a driving assistant system that gives the driver beep warning sounds when the road's condition is unsafe. Therefore, by using only a beep sound to give a warning, the system does not give the driver a heavy mental burden. In addition, drivers are assumed to give priority to information from the driving assistant system. For ITS vehicles, they exchange their front-seat information such as vehicle ID, position, velocity, and braking information. As the simulation's basic parameters, the traffic amount and the total delays are used. Here, the

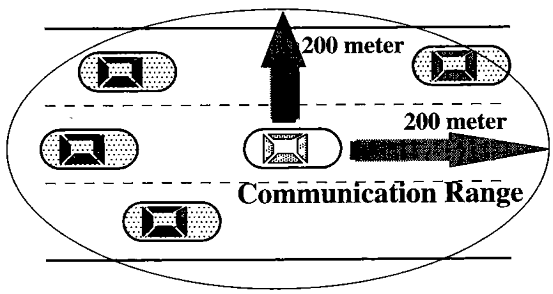

Fig. 13 Inter-vehicle communications network area.

traffic amount can be expressed as:

$$T = K \times V \quad (1)$$

where T, K and V represent the traffic amount [vehicle/h/lane], the vehicle density [vehicle/km/lane] and the average velocity [km/h], respectively. In these simulations, the average velocity is 100 [km/h] and vehicle density is 18 [vehicle/km/lane], respectively. For the input method of vehicles, at the start point, the traffic amount under the poisson distribution is used. Moreover, as every driver has his own respond delay, it is needed to represent it and to investigate delays' dispersion. Thus, to represent the dispersion of human responses, distributions with the mean 0.3 seconds and the variances between 0.0 and 2.0 are assumed as the total delays. However, negative distribution's values are assumed as 0.0 second.

Figure 13 shows the inter-vehicle communication network area. In this communication network the following characteristics are assumed: the data transmitted without any delay and the communication cycle is 0.1 seconds.

4.2 Simulation Results

From several simulations using different total delays' parameter (N(0.3,0.0), N(0.3,1.0), N(0.3,1.5) and N(0.3,2.0)), we found that there are no significant differences among these results. Therefore, the total delays with N(0.3,1.5) is used in the following simulations. Figure 14 shows inter-vehicle communications equipment mounting ratio simulation results under mixed environments. In these simulations, as simulation's parameters, the inter-vehicle communications equipment's mounting rate (mounting ratio) and the accident occurrence ratio, are used. Here, as mounting ratio parameters, 0%, 30%, 50%, 70%, 80%, 90%, and 100% are used. The accident occurrence ratio is defined as the probability that one or more traffic accidents occur within each simulation. Here, each simulation is carried out for 90 minutes' traffic flow, the highway road's length is 20 km and the road consists of three lanes. Furthermore, 10 simulations are carried out for each mounting ratio. The accident occurrence ratio 0% means that no

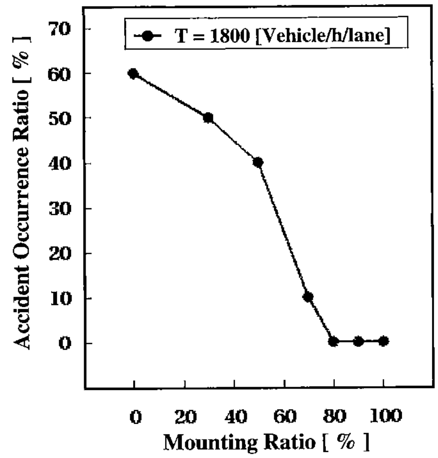

Fig. 14 Simulation results.

traffic accident occurs throughout all the simulations. Moreover, it is assumed that communications between subsystems and vehicles and communications among vehicles, are guaranteed in perfect condition. Each ITS vehicle exchanges its information with another ITS vehicle within its communication area (See Fig. 13). On the other hand, Non-ITS vehicles run to use other vehicles' information from the viewing range (See Fig. 12). These results clearly show that by using inter-vehicle communications as a driving assistant the accident occurrence ratio decreases. It means that the traffic safety is improved. Moreover, we found that the accident occurrence ratio decreases largely when the mounting ratio exceeds 50%. For this reason, drastic reduction of traffic accidents is expected by using the inter-vehicle communication system.

5. Conclusions

In this paper, a new framework of a vehicular driving assistant system that uses spread spectrum techniques has been proposed. The proposed system is applicable to the mixed environment. It consists of several new systems. These new systems offer several advantages. First, as to the PN code assignment system, by using ground infrastructures for PN code dynamic assignment, limited number of short codes can be used effectively. Second, as to the vehicle positioning system, by embedding magnetic markers (N pole or S pole) like a PN code, vehicles can obtain its absolute position information with extremely high precision. Moreover, by using PN code instead of a simple pulse, every ITS vehicle can obtain other close vehicles' position information at the same time and at the same carrier frequency. Third, as to the vehicle map update system, by using other close vehicles' position information obtained from the radar system, the vehicle map is updated. From this map, an ITS vehicle can obtain close Non-ITS vehicles' information. Furthermore, by exchanging this map among the ITS vehicles, every vehicle map can be updated including hidden Non-ITS vehicles' information.

In the proposed system, the wireless broadcast CDMA is used for inter-vehicle communications. Here, PN codes dynamic assignment and multi-user detection are used. Moreover, the fixed assignment code is used for the PN coded magnetic marker system. In addition, for the pulse radar system, the preassignment PN code is used. Furthermore, by using the traffic flow simulator developed by the authors, the effectiveness of inter-vehicle communications on the traffic safety was investigated. The results clearly show that the traffic safety is improved by using inter-vehicle communications. Details of the proposed system (such as communication systems, protocols, signals, and human interfaces), analysis of human responds' dispersion and performance evaluations based on the details are further works.

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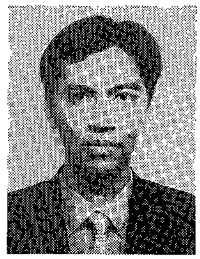

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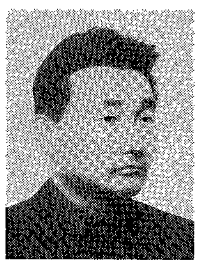

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