Driving Safety Support Systems Utilizing ITS Radio System

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We are striving to develop the Driving Safety Support System (DSSS) that aims to prevent accidents by providing drivers with necessary information for safe driving. We developed a DSSS with infrared (IR) beacons, which has been practically used since July 2011. Now, we have shifted our target to the development of a DSSS with an intelligent transport system (ITS) radio system that can provide sensor data and other dynamic information that is not available with IR beacons. This paper describes the requirements for the DSSS with an ITS radio system, such as communication area and sensor detection area, and presents the result of a verification test.

Keywords: vehicles, infrastructure, coordinated system, safety, ITS radio system

1. Introduction

The number of traffic accident victims has continued to fall in Japan in recent years, marking 4,411 people in FY2012. However, approximately one-half of such victims are the elderly and this requires urgent countermeasures.

We have been working to develop the Driving Safety Support System (hereafter, DSSS) in order to reduce traffic accidents through providing safety information to drivers, in the hope of creating a society with safe roads. As a result of our efforts, the DSSS utilizing infrared beacons was actually put into operation in July 2011.

Table 1 summarizes the subsystem functions of the DSSS, which we aim to bring into actual use. These functions were designed to help reduce traffic accidents and created through accident analyses. They provide information through a pre-installed infrastructure about events that cannot be directly observed by the driver of the vehicle. It is generally considered that single-vehicle accidents can be reduced by implementing various countermeasures within the vehicle's self-controlling system, while the DSSS is intended to address accidents at intersections in particular, such as preventing collisions involving a right-turning vehicle.

Table 1. Target systems of DSSS

No	Systems
1	Crossing Collision Prevention System
2	Crossing Pedestrians and Bicycles Collision Prevention System
3	Right-turn Collision Prevention System
4	Left-turn Collision Prevention System
5	Crossing Pedestrian Recognition Enhancement System
6	Rear-end Collision Prevention System
7	Signal Recognition Enhancement System
8	Stop Sign Recognition Enhancement System

Out of the subsystems shown in **Table 1**, the DSSS with infrared beacons has thus far covered a part of subsystem 1, as well as 6, 7, and 8. Ideally, all the types of information listed in **Table 2** should be covered by the DSSS. However, the infrared beacons can only provide static or snapshot information at a certain point in time due to its nature of using light as a medium. This is the reason for the limited coverage of the subsystem functions.

Table 2. Information for DSSS

Info. Type	Name	Contents	System No
Static	Road Configuration Info.	Route Distance Connection Info.	1-8
	Traffic Signal Info.	Phase and Timing info.	3-5, 7
	Traffic Regulation Info.	Stop Sign Info.	8
	Vehicle Info. (Snap Shot)	Existence	1, 6
Dynamic	Vehicle Info.	Position, Speed, etc	1, 3, 4
	Pedestrian and Bicycle Info.	Position, Speed etc	2, 5

To achieve the remaining subsystem functions, we needed to be able to handle dynamic information, which requires continuous wireless communications covering a certain area. Thus, we developed a radio system for the intelligent transport systems (ITS radio system) and utilized this technology in field tests of the Right-Turn Collision Prevention System for a vehicle and a pedestrian and the Left-Turn Collision Prevention System for a vehicle and a motorbike or bicycle.

The challenges associated with the ITS radio system when used in the DSSS are the communication coverage and quality, as well as sensor detection coverage and detection accuracy. We conducted a system validity test to examine these issues. This paper reports on the test results of the Right-Turn Collision Prevention System, in particular, to which we gave the main focus during the test.

2. DSSS Trial at Intersection with Signals

Various verification tests of the DSSS at an intersection with signals have been conducted at the Naka-Kasai 1-chome Intersection in Edogawa-ku, Tokyo. **Figure 1** shows the system installation map and **Fig. 2** shows the system configuration. This paper focuses on the Right-Turn

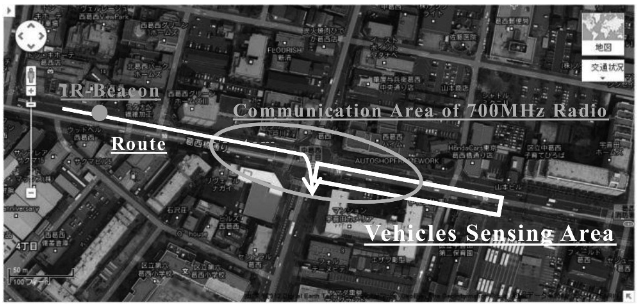

Fig. 1. Positioning of the System Devices (Partial)

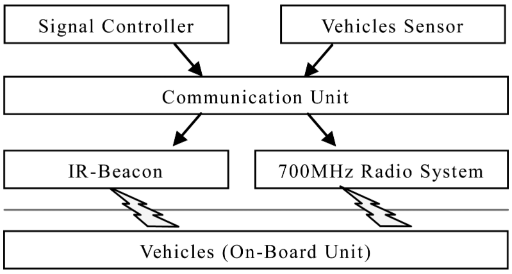

Fig. 2. Configuration of the Tested System (Partial)

Collision Prevention System that uses a 700 MHz-spectrum ITS radio system[*1].

The Right-Turn Collision Prevention System used in an intersection with signals has the following features. The system is designed to help drivers who are intending to turn right at the intersection to start their right-turn procedure safely. A driver in a vehicle waiting to turn right sometimes experiences difficulty in observing vehicles proceeding forward in the oncoming lane due to oncoming right-turning vehicles at the intersection. The system detects the positions and speeds of vehicles traveling straight on using sensors and continuously feeds this information to the right-turning driver via a 700 MHz-spectrum ITS radio system. Based on this information, an in-vehicle device judges whether the right turn can be carried out safely and alerts the driver if he or she moves the vehicle in a dangerous situation.

Verification of the system was carried out in the following three areas: (1) Assessment of communication characteristics (coverage area); (2) Assessment of sensor performance (detection area); and (3) Assessment of service application. The sections below provide details of each assessment.

2-1 Assessment of communication characteristics (coverage area)

The area covered by the Right-Turn Collision Prevention System was as follows.

The service coverage by this system was determined as the area between a point 30 meters prior to the edge of the road at the intersection (upper end of the service area) and the far-end line of the crossing where the right-turning vehicle is intended to proceed (lower end of the service area). The vehicle communication area was determined to be the area in which the system can make the information ready to provide in the said service coverage area. In practice, the vehicle communication area was equivalent to the service coverage area plus the area extended from the upper end of the service area to the distance required for the service user vehicle. This distance was calculated by the formula: (Regulated speed (= 50 km/h) + 10 km/h) x processing time required by the in-vehicle device (= 1 s) (**Fig. 3**).

Figure 4 shows part of the measurement results for the vehicle communication area. The results demonstrate that 0% packet loss occurred across the stretch of 200 meters

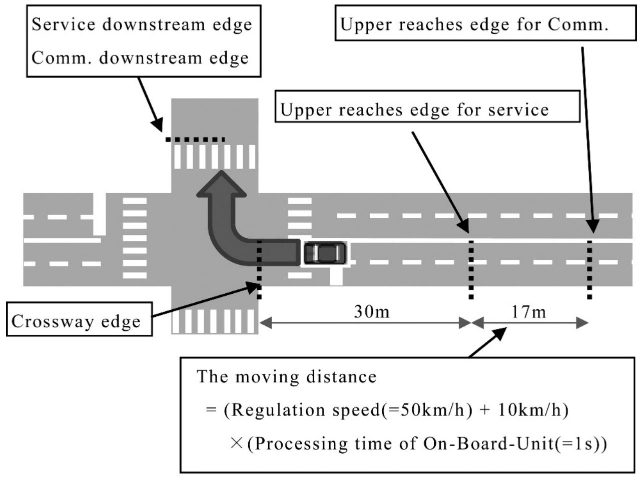

Fig. 3. The Vehicle Communication Area (Right-Turn Collision Prevention System)

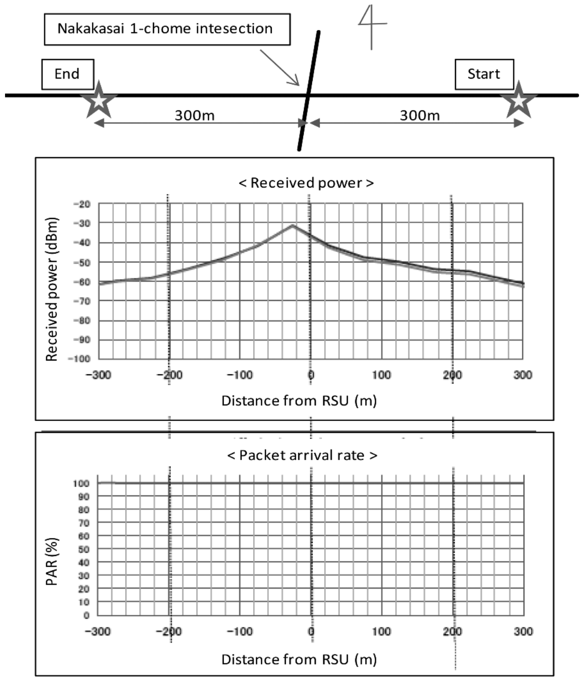

Fig. 4. Measurement Results in the Vehicle Communication Area

in both the east and west directions from the intersection where the 700 MHz-spectrum ITS radio system is installed.

2-2 Assessment of sensor performance (detection area)

The sensor detection area was determined as follows. The subject of sensor detection is the car traveling straight on in the lane opposite the service user vehicle. The lower end of the detection area was determined to be the center of the target intersection, and the upper end was determined to be 150 meters before the center. This includes the delay time from the point when the sensor detects the oncoming car to the time when the system can provide the service, and this time was determined by the distance that the oncoming car travels. Cars intending to turn right in the opposite lane were excluded from detection by the sensors (**Fig. 5**).

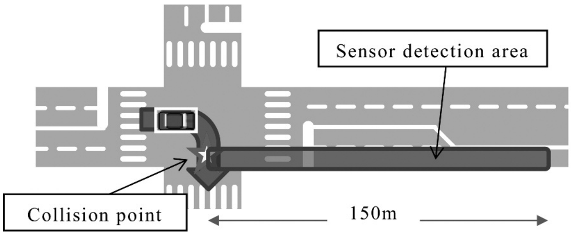

Fig. 5. The Sensor Detection Area

Figures 6 and 7 show the test results within the sensor detection area using the image sensors[*2]. The sensor detection area was covered by two image sensors, i.e. cameras, and **Fig. 6** shows the upper stream view while **Fig. 7** shows lower stream view.

Fig. 6. Sample View from the Upper Stream Camera

Fig. 7. Sample View from the Lower Stream Camera

2-3 Assessment of service application

Figure 8 shows the sample service flow of the Right-Turn Collision Prevention System. The results of our operation verification confirmed that the service was delivered as intended, responding to the operation by the service user driver.

We also examined the influence of any system delay time. The system delay time was defined as the difference between the time when the oncoming vehicle passes a potential collision point and the time when the oncoming vehicle passes the same point received through the ITS radio system. This difference was determined by comparing the data plot of the service user vehicle's distance to the intersection stop line and the data plot of sensor detection results of the service user vehicle received through the ITS radio system. This difference also includes the sensor detection error.

It was found that the combination of the image sensors used in this test and the 700 MHz-spectrum ITS radio system causes a delay of 300 to 400 ms on average, and a 700 ms delay at maximum. It was also found that this system delay grew longer when the target vehicle was farther from the camera. This suggests that the greater the distance between the oncoming vehicle and the camera, the farther the distance error of that vehicle estimated by the system.

This system delay time was confirmed in the system verification test, however, the delay was not significant enough to be perceived while using the service.

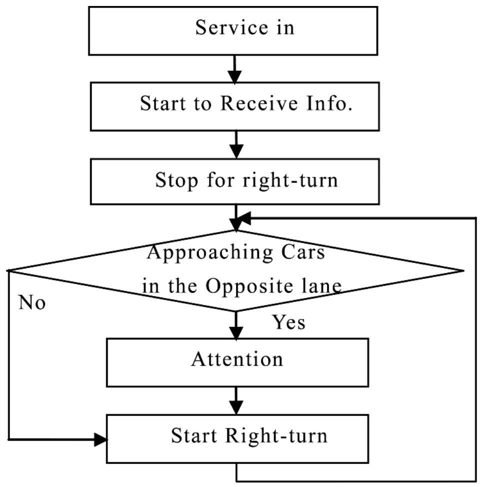

Fig. 8. Sample Service Flow

2-4 Verification of system validity

System validity was assessed through a questionnaire provided to four test subjects. The questionnaire covered (1) Changes in awareness by warning; (2) System reliability; and (3) Service validity. **Table 3** lists changes in their awareness through the system warnings.

Table 3 suggests that support to increase the driver's awareness was valid. The fact that all the subjects responded "No" to the question, "The warning was unnecessary as the situation could be anticipated" indicates that the subjects understood the necessity of the warning even though it was for vehicles of which they were already aware. Also, none of the subjects made the erroneous judgment of "I thought I could turn right as soon as the warning disappeared."

Table 3. Changes in Awareness by the Warning

Questions	Answers(%)	
	Yes	No
Voluntary alertness was raised	100	0
The warning was unnecessary as the situation could be anticipated	0	100
I thought I could turn right as soon as the warning disappeared	0	100

Table 4 shows the results of system reliability. It is necessary to design a system that discourages drivers from over-depending upon the system or delegating too much of their own responsibility to the system to ensure that drivers ultimately trust their own judgment. However, the average value of the system reliability was lower than the mean value. This may indicate that the actual system reliability was generally low. One of the causes may be the occurrence of a mismatch in timing of the actual traffic conditions and the warning issuance due to sensor detection failure and errors in determining vehicle position and speed, etc.

Table 4. System Reliability

Questions		Ratings	Answer (Average Values)
Do you trust this system?	Reliability	1:Not at all 2:Somewhat 3:Reasonably 4:Substantially 5:Fully	3.00
Can you comfortably make your next action based on this information?	Level of delegation		1.75
Are you confident in not having an accident as far as you pay attention to the provided information?	Dependability		1.00

Table 5 shows the service validity questionnaire results. The subjects responded positively about almost all questions. This suggests that the service provided by this trial system was generally valid.

Table 5. Service Validity

Questions		Ratings	Answers (Average Values)
Is the system helpful for safe driving?	Level of helpfulness	1:Not at all 2:Somewhat 3:Reasonably 4:Substantially 5:Fully	4.00
Was the information easy to understand?	Level of understandability	1: Not at all 2: Somewhat 3:Substantially 4: Fully	3.75
Could you understand the situation you should be aware of?	Understandability of the situation		3.75

3. Discussion

The questionnaire responses indicated that the support was valid as intended to raise the drivers' awareness, and the service validity was also confirmed by the generally positive responses in the questionnaire.

On the other hand, some issues concerning system reliability were observed. These include inadequate warnings that did not match with the actual situation that were caused by detection failures by the sensors and errors in measuring vehicle positions and speeds. Although the basic performance of the system is satisfactory, it became clear that the sensors needed to be improved for better accuracy. Future improvements should therefore focus on sensor accuracy, methods of warning, and the timing of the warning.

4. Conclusions

The verification test of the DSSS at an intersection with signals confirmed that the system serves as intended delivering its functions without any major problem. However, the system reliability needs to be improved by refining sensor accuracy. It will be necessary to address this sensor accuracy issue in the future, as well as continuously improving the warning methods and timings.

We have already started working on testing the DSSS at an intersection without signals as the next trial. The trial is an attempt at collision prevention between a vehicle joining a main road from a minor road, and another vehicle or pedestrian. A trial system is currently under development and is being tested.

5. Acknowledgements

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Technical Terms

*1 700 MHz-spectrum ITS radio system: The wireless system that utilizes the 760 MHz band with a width of 10 MHz. This band was secured for ITS purposes for use in safety and environmental services when the radio usage was reorganized along with TV signal digitalization. Compliant with ARIB STD T-109 standards.

*2 Image sensors: Sensors to measure vehicle position and speed by real time processing of images of the vehicle captured by cameras installed along the roadside.

Reference

(1) Universal Traffic Management Society of Japan, The activity report of Universal Traffic Management Society of Japan in 2011 (Jun. 2012)

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