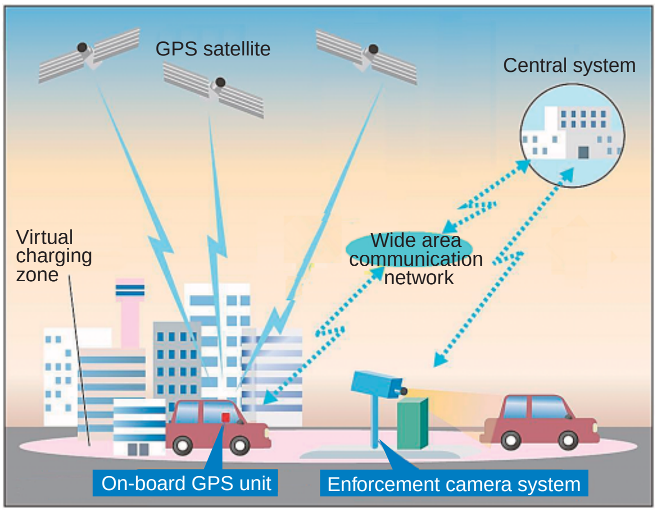

Development of the Next Generation Road Pricing System with GPS Technology

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With the aim of realizing the next generation road pricing system, we have developed a system consisting of an on-board unit which is capable of highly accurate positioning. In this system, the on-board unit can measure the travel distance and detect the charging zone without matching map information, by using a high performance GPS (global positioning system) which combines an on-board unit and a dead reckoning navigation function. The reports so far released on road pricing systems using GPS use a method in which measurement of the travel distance and calculation of the charges are performed by the central system by matching the location on map information. This system necessitates the analysis of the travel locus and matching with a map for all vehicles at the central system, requiring a huge amount of data processing. This system, by employing a GPS using highly accurate dead reckoning navigation, has realized the positional accuracy necessary for charging and has established a distance-based charging system to calculate the charge in real time in the vehicle without matching map information. Mitsubishi Heavy Industries, Ltd. (MHI) has conducted evaluation tests by selecting test routes in Singapore, including the high-rise building district (urban canyon) of Singapore which offers a very severe operational environment for GPS. As a result, a distance measurement error within 2% was attained, making a good start for the realization of a GPS pricing system.

1. Introduction

MHI has developed and delivered the roadside equipment and on-board units for an ERP (electronic road pricing) system using DSRC (dedicated short range communication) which started service in Singapore in 1998. Since the start of the service, the ERP system has been operating stably, gaining customers' trust.

Following the DSRC type ERP system, a new system using GPS which has been put into practical use by targeting heavy goods vehicles on autobahns in Germany is considered to be promising and movement toward standardization of the system is now in progress.

When utilizing GPS, we need at least three GPS satellites to receive signals for positional data and at least four satellites to receive signals for position and time data. The four or more satellites needed for GPS positioning can be traced in a stable manner on highways, with an open sky and a clear view, and the positional accuracy necessary for practical use can be assured. However, when introducing the positional measurement method using GPS in city areas with tall buildings, which are the ERP target areas, problems such as GPS signals being blocked by buildings and flyovers and reflection (multi-path) of signals are bound to arise. Therefore, in general, it is difficult to secure the positioning performance of GPS in city areas.

When using GPS as the vehicle position measurement method in the ERP system, it is necessary for us to address these problems in city areas. Using a highly sensitive GPS to receive weak GPS signals in city areas could be one possible way. However, as susceptibility to the effect of multi-path signals increases, we should face the other issues.

In recent years, Road User Charging has become recognized as a concept based on the idea that a car driver receives the benefits of road services and is subject to charging according to their travel distance.

Establishing a road pricing system by using GPS in city areas was also studied in London and a demonstration experiment was done. In the efforts toward road user charges, the measurement of the actual travel distance and the duration as well as a charge calculation based on these measurement results are necessary.

There have been discussions as to whether the travel distance based on distance and duration should be calculated in the vehicle or by the central system. There have been reports on the method in which the central

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system accumulates vehicle position data transmitted from the on-board units with a GPS and matches them against map information for processing.

In the course of matching map information and travel locus by the central system, the travel path and time duration need to be obtained for each individual vehicle. This raises problems concerning the processing load for a massive number of vehicle and protection of road users' privacy. On the other hand, for on-board processing, road matching processing and charge calculation would be performed by the on-board unit, and increases in the processing load and cost of the on-board unit need to be addressed.

2. Outline of Next-Generation Pricing System

2.1 Objectives

To explore the possibilities of on-board processing, we developed a prototype on-board unit which detected virtual charging zones, calculated the travel distance inside the zones, and calculated the charge amount on the vehicle by using a combination of GPS and highly accurate dead reckoning (DR) navigation. Using this prototype, we conducted dynamic tests and evaluated its performance.

To evaluate the performance, three virtual charging zones in Singapore, which well represented urban environments, were used for the dynamic tests.

2.2 System configuration

The system consisted of an on-board unit equipped with a GPS receiver and a GPRS (general packet radio service) communication modem, and a central system to receive the charges amount transmitted from the on-board unit. The virtual charging zones were set in the on-board unit. The on-board unit acquired the current position data from the GPS receiver and judged whether the vehicle had entered or left a virtual charging zone.

While the vehicle was in a virtual charging zone, the travel distance was calculated and, upon leaving the zone, the charge amount was transmitted from the on-board unit to the central system via the GPRS communication network. The central system displayed current the vehicle position transmitted from the on-board unit at intervals of 5 seconds on a map so that the travel locus of the test vehicle could be monitored.

2.3 On-board unit

Figure 1 shows the configuration of the on-board unit. It consists of a GPS receiver, a CPU board, and a GPRS communication modem to communicate with the central system.

The antenna receiving signals from the GPS satellite is connected to the GPS receiver, and the odometer pulse signals from the vehicle are input. The GPS receiver is equipped with a uni-axial turn-rate sensor to obtain the direction of travel of the vehicle which is input to the dead reckoning navigation system along with odometer pulse signal. As for the output from the GPS receiver, the measurement results of the GPS single unit and the measurement results by the dead reckoning navigation are weighted in accordance with the input signals from the satellite and input to a Kalman filter, where the calculated results are output.

The virtual charging zones surrounded by four points are set beforehand in the on-board unit.

The on-board unit receives positional data from the GPS receiver at intervals of one second, and calculates whether the vehicle has passed the border of a virtual charging zone. When entry to a zone is detected, the travel distance is accumulated from that entry time until the vehicle is detected leaving the charge zone. As soon as leaving the zone is detected, the accumulation of travel distance is stopped and the charge based on the distance is calculated by the CPU in the on-board unit. The travel distance in the zone and the charge amount are then transmitted to the central system via the GPRS communication network.

The on-board unit can store the position data received from the GPS, the accumulated travel distance and charge amount as log data in its internal memory.

The central system receives the distance and the charge amount from the on-board unit, and stores them in its database. In this system, as zone detection and distance accumulation are performed by the on-board unit of each car, there is no need for the central system to generate locus data or match map data. Therefore, calculation and communication by the central system will be less affected even when the number of on-board units increases.

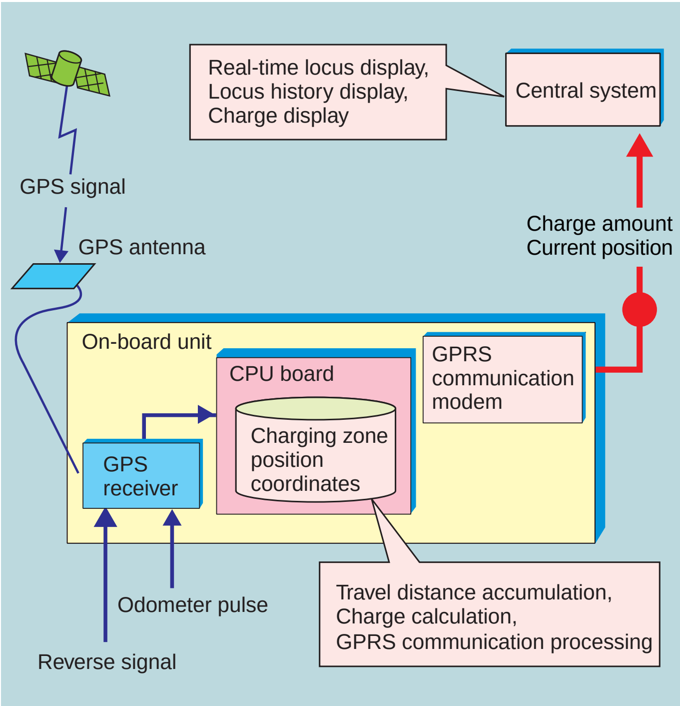


Fig. 1 Processing diagram of on-board unit

3. Results of Dynamic Tests

Dynamic tests were conducted in business district with many high-rise buildings (urban canyon), commercial districts with many shopping centers, and on a suburban road (**Fig. 2**).

As an example of the test runs, **Fig. 3** shows the results of runs round the commercial district, as illustrated by overlapping. The section enclosed by dotted lines in the figure shows the virtual charging zone registered in the on-board unit.

The travel loci from the runs overlap each other, indicating that the GPS located positions stably.

(a) Urban canyon area

(b) Commercial district

(c) Suburban district

Fig. 2 Dynamic tests

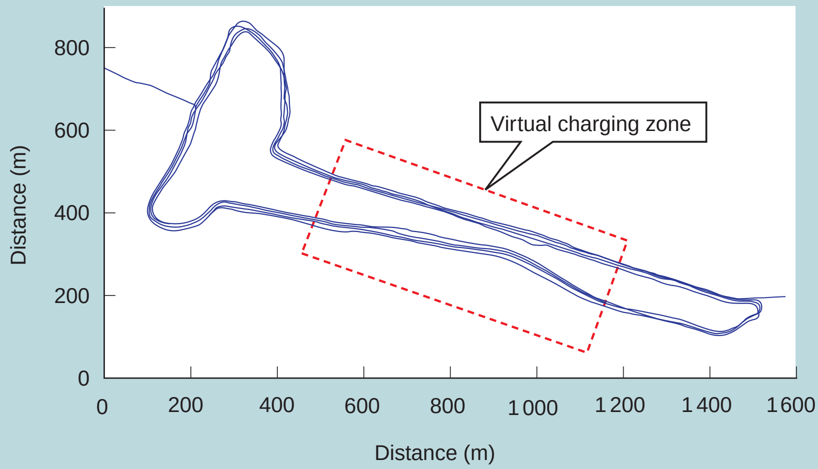


Fig. 3 Dynamic test loci including virtual charging zone (commercial district)

3.1 Evaluation method

Dynamic tests (including entries and leavings) were conducted for the virtual charging zones which were set for each travel route. The travel distances inside the zones and the detection accuracies at the cordon line were evaluated.

For the evaluation the coordinates of the detected borders of the virtual charging zones and the travel distances inside the charging zones were retrieved from the log file, and then the cordon line detection accuracies as well as the travel distance measurement accuracy were calculated.

3.2 Result

(1) Cordon line detection accuracy

Figure 4 shows the borders of the virtual charging zones and the actual border detection positions. In the illustrations, the virtual charging zones were located on roads in urban canyon, commercial districts, and suburban districts. In each of the illustrations, the arrows show directions of travel and the circles indicate the positions at which an entry or leaving was detected by the on-board unit.

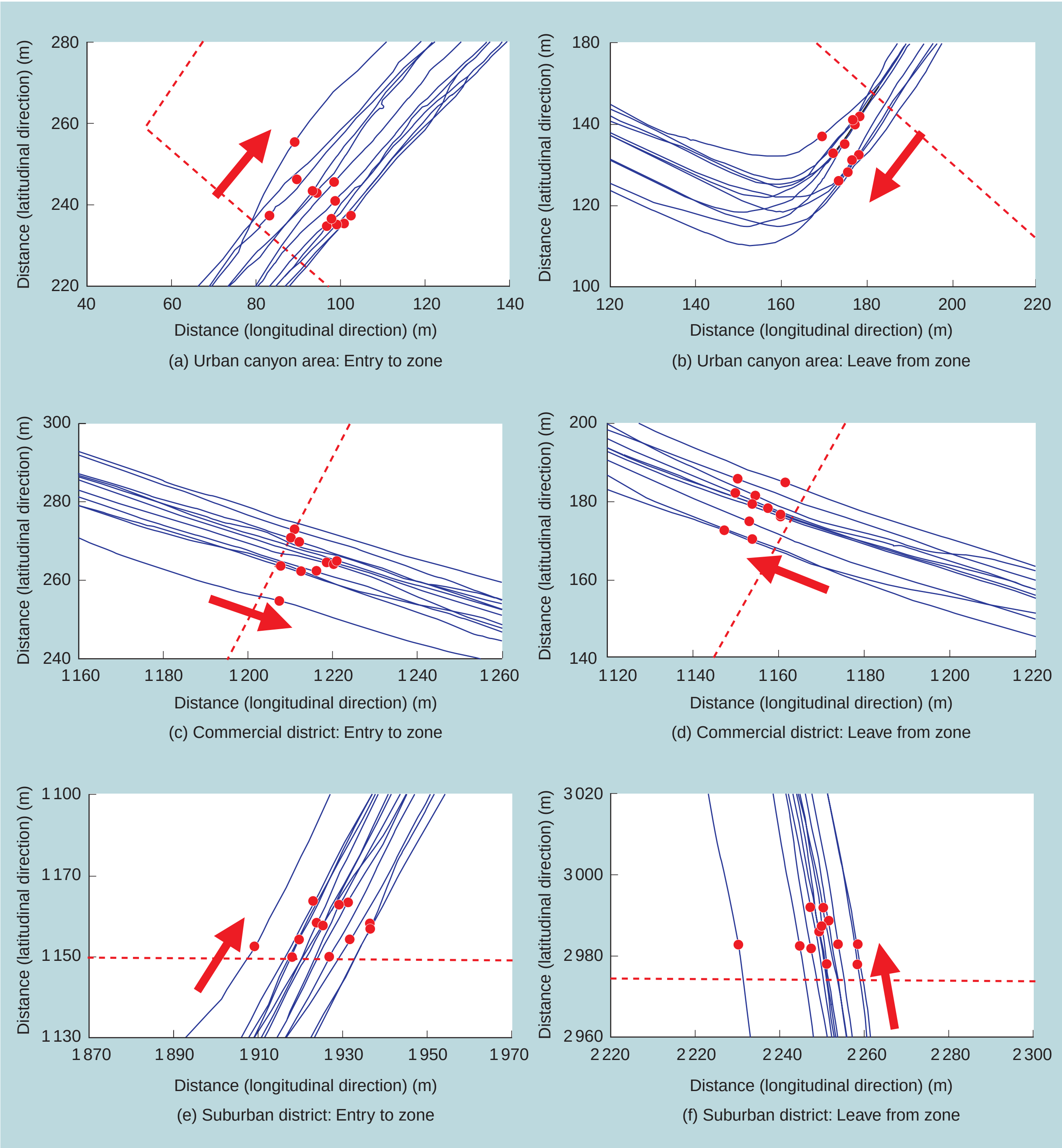
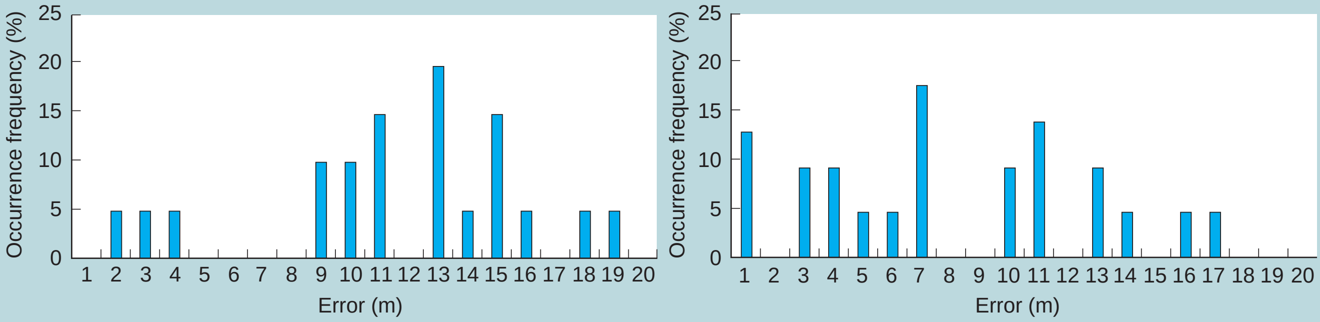
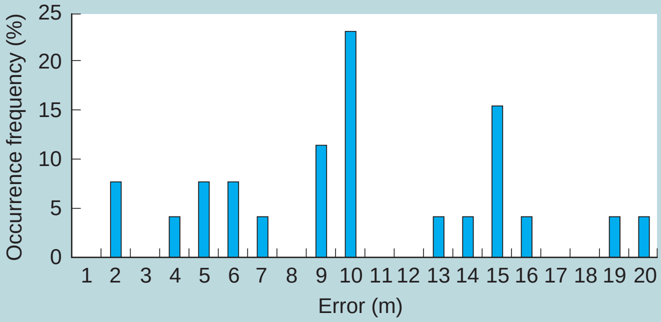


Fig. 4 Cordon line detection of virtual charging zones



(a) Cordon line detection error: Urban Canyon area

(b) Cordon line detection error: Commercial district



(c) Cordon line detection error: Suburban district

Fig. 5 Detection errors of virtual charging zone borders

Table 1 Accuracy of distance measurement

	Reference distance (m)	Maximum distance error (m)	Maximum error (%)
Urban canyon area	587	11	1.9
Commercial district	725	9	1.2
Suburban district	1 889	8	0.4

Figure 5 shows the distances between the cordon lines and each zone detection position for the virtual charging zones. In all zones, all errors in cordon line detection fall within 20 m. As the measured GPS points were plotted after the vehicle had passed over the border, a buffer zone will have to be provided at each charging cordon line. In consideration of the test results, the buffer zone should be about 20 m long in the direction of travel. For the purpose of practical operation, further evaluation will be necessary with varying parameters such as vehicle speed and satellite receiving conditions.

(2) Distance measurement accuracy

Table 1 shows the accuracies of distance measurement taken inside the virtual charging zones. As shown in Table 1, the maximum error in the accumulated travel distance remains within 2% for all of the districts.

4. Conclusion

The method which is most commonly used today for road user charges necessitates the calculation of a travel locus, the detection of the cordon line, and the calculation of charges to be performed by the central system. However, our new system allows processing in the vehicle, and its accuracy has been tested and evaluated through dynamic tests. As a result, it was verified that an on-board unit alone could achieve the practical use level for cordon line detection and distance measurement without position correction based on map information.

In the future, an evaluation test of the entire system is scheduled in association with actual charges made to vehicles and enforcement technology.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