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High Accuracy Local Map Generation Method Based on Precise Trajectory from GPS Doppler

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ABSTRACT: The previous knowledge of road environments is vital for driver assistance systems, and an accurate map, which provides information on the roads to be traveled, is desired. Accurate road information map preparation is still costly because a highly accurate positioning system and manual mapmaking operations are required. This paper proposes a method for automatic high accuracy map generation at low cost, using a standard in-vehicle camera and a standard GPS. The positioning results from GPS have relatively large error, so that the accuracy of a map based on these positioning results is not adequate. Our proposed method enables accurate map generation of a local area by a vehicle, and improves global accuracy by optimal integration of many local maps. This paper describes accurate local map generation based on precise trajectories derived from GPS Doppler, and evaluates the effectiveness of this method using actual data.

KEY WORDS: **(Standardized)information, communication, and control, vehicle navigation system, environment recognition**

(Free) ITS, Digital Map, GPS Doppler [E2]

1. Introduction

The realization of driver assistance using control points is now desired, since developments in various driver assistance systems have made this more feasible. For example, there are proposals for a system that gives a driver a warning or controls the vehicle before a stop sign or a beginning of a curve. Accurate road information(e.g. road shape, stop sign position, the number of lanes) is essential for these systems, and accurate maps containing such road information are desired. The required positional accuracy of this map for driver assistance systems is considered about 1m. However, the current maps for a vehicle navigation system are not adequate for driver assistance systems because the information and the accuracy are insufficient. Generating a map with the desired accurate is currently very expensive, because a highly accurate integrated positioning system and enormous number of manual operations for extracting road information are currently required. It is not realistic for this current map generation method to be applied to widespread accurate map generation. This paper proposes a new method of accurate map generation using a standard GPS used for vehicle navigation systems and an in-vehicle camera of the type used for driver assistance systems. This proposed method can hold down the costs of accurate map generation.

The conventional map generation method using GPS and the in-vehicle camera obtains information from the in-vehicle camera based on the camera center from GPS positioning result. Using the standard GPS, the positioning results have large errors, and as a result, the positions given to the items observed by the in-vehicle camera have large errors. To deal with this problem, this paper proposes a new map generation method using trajectories derived from GPS Doppler instead of positioning results from the GPS. In this new method, each vehicle generates a local map in which relative positional relationships are accurate. Next, the local maps generated by probe techniques are collected in a control center and then a global map is generated by connecting the local maps. The absolute position accuracy of the global map is also improved by optimal integration of many local maps.

This paper discusses some related studies in Section 2, and proposes our high accuracy map generation method in Section 3. This paper focuses on accurate local map generation, and the accurate local map generation method is explained in detail in Section 4. Finally, our proposed method is evaluated by comparison with actual data in Section 5.

2. Related Research

A generation method of a survey level map has been developed[(1)] and a mobile mapping system that uses this method has been widely used by map database suppliers. This method uses a highly accurate integrated positioning system, an industrial high resolution camera and a LiDAR system on the vehicle roof.

The relative position of an item captured by the camera can be determined by matching with the LiDAR information. In addition, the global position of an observed item is then calculated based on the accurate vehicle position supplied by the highly accurate integrated positioning system. This method can determine the road shape, accurate position of road markings on the road, and the number of lanes. However, this method needs a highly accurate integrated positioning system, and needs many manual operations because automatic extraction of road information from raw sensor data has not yet been achieved. Therefore, map generation over a wide area by this system is very expensive, and it is not practical to update the road information continuously.

On the other hand, mapping techniques using ordinary cars as probe vehicles has become a common method to get information[(2)]. This technique can estimate road shapes based on the positional record of a standard GPS on the probe vehicles. Moreover, in recent years some map generation methods using an in-vehicle camera[(3)(4)] have been proposed because vehicles that have in-vehicle cameras for driver assistance systems are on the increase. For example, there is a road boundary map generation method using an in-vehicle camera and the standard GPS. This method detects the road boundary in the in-vehicle camera images and estimates the road boundary global position based on positioning results from the standard GPS. This method is not an expensive, because it uses a standard GPS. However, the positioning of the boundaries on the map is not accurate because this is based on the positioning results from the GPS. This GPS positional accuracy is a few meters at best, and the error might become over 30m in urban areas where the GPS signal conditions are bad. The map generated based on GPS positioning results includes GPS positioning errors. Therefore, the road shapes, and boundaries, which are, is estimated from GPS positioning results have relatively large errors. The accuracy of these maps is not adequate for driver assistance systems.

This paper proposes a new method to generate highly accurate enhanced digital maps automatically for driver assistance systems. The method uses a standard GPS and the in-vehicle camera that is equipped in driver assistance systems such as LKA (Lane Keep Assistance). This method enables accurate map generation by collecting multiple information from the GPS and in-vehicle camera. The main feature of our new method is the generation of a local map whose relative position relationships are accurate because they are based on precise trajectories instead of GPS positioning results.

3. Overview of Automatic Accurate Map Generation

This section gives an overview of our proposed high accuracy map generation method. This method firstly generates a local map using the in-vehicle camera and GPS in a vehicle. Next, a highly accurate global map is constructed by integration of multiple local maps which have thus been created. A general conception of the local map and the global map is shown in Fig.1, and the procedural framework of this proposed method is shown in Fig.2. This proposed method does not directly generate an accurate global map, and the most important feature of this method is its two steps of map generation. Firstly, a map whose relative position relationships are accurate but whose global position accuracy is not high is generated in a small area (this map is called a "local map" in this paper). A general conception of this local map is shown at the left in Fig.1. Secondly, a map whose absolute position accuracy is high is generated over a wide area (this map is called a "global map" in this paper). This highly accurate global map is realized by connecting and optimizing accuracy of multiple local maps. A general conception of this global map is shown in right-hand of Fig.1.

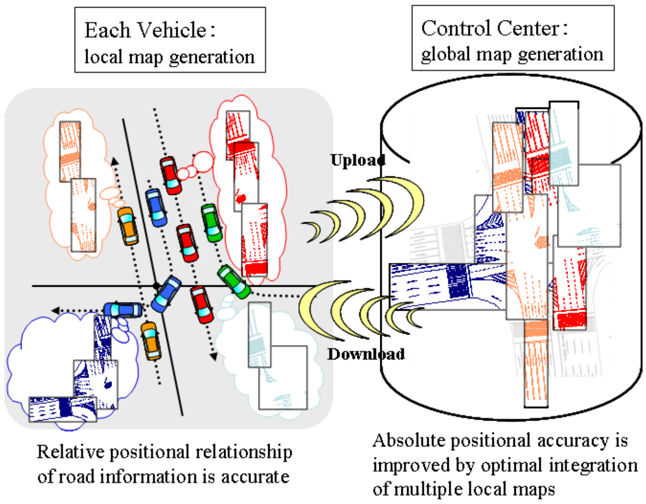

Fig.1 General conception of the proposed method

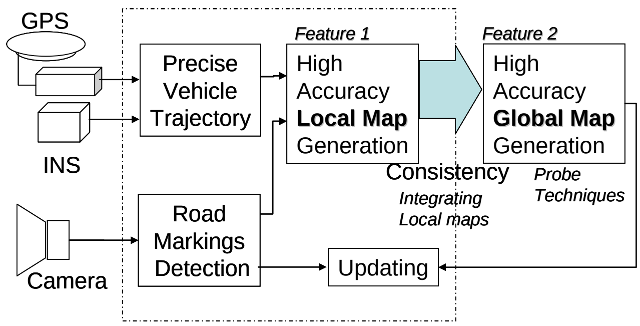

Fig. 2 Procedural framework of the proposed method

This unique 2-steps map generation is very important since it enables high accuracy map generation even if only an in-vehicle camera and standard GPS receiver are equipped on the probe vehicles. The procedures of this proposed method are as follows.

1. The in-vehicle camera acquires road information that is necessary for driver assistance systems. This road information includes road markings (traffic control signs such as an arrow, a stop sign, and a cross walk) and lane markings on the road.
2. This road information acquired from the camera is projected on a plane, and correlated not with vehicle positioning results from the GPS receiver but rather with precise vehicle trajectory derived from GPS

Doppler and INS(Inertial Navigation System). Low cost INS consists of yaw-rate gyro and vehicle speed, and the conventional trajectory estimation method uses INS. However, the cumulative errors occur due to the bias errors. This proposed method estimates the precise vehicle trajectory by integration of GPS Doppler and INS. This local map has accurate relative positional relationships in this local area (Feature 1). Nevertheless, the absolute positional accuracy is not adequate because the origin point of the trajectories is obtained from the positioning of the GPS receiver.

3. Multiple local maps are acquired from vehicles, and each local map's origin point is linked to the GPS raw data with positioning results. The relative position between multiple local maps is accurately estimated by associating road markings on each local map, and these multiple local maps can be connected to cover a wide area. The relative positions between origin points of multiple local maps correspond to the relationships between the GPS positioning results of these points. This method estimates absolute positions where there is good correspondence between relative position and GPS raw data. In this step, the local maps are connected to a global map, and the absolute position accuracy is improved (*Feature 2*).
4. The generated local map is always matched to an existing global map. The consistency is checked, and the information included in this map is updated as necessary.

The procedure 2. and 3. are the main features of this proposed accurate map generation method. This paper focuses on the first feature; highly accurate local map generation based on precise trajectories. Here we explain the details of this feature of our proposal, and demonstrate the effectiveness of this method. The second feature of our proposal will be described in a separate report.

4. High Accuracy Local Map Generation

This section explains high accuracy local map generation in detail. Some map generation methods[3][4] using GPS positioning results and outside monitoring sensors such as a LiDAR system or a camera have been proposed. These previous studies used a high accuracy GPS such as RTK-GPS[5] (Real Time Kinematic - GPS) because the main target was accurate reconstruction of 3D structure. With a standard GPS, the positioning errors prevent accurate reconstruction. Fig. 3 concretely illustrates the problem. The projection of an image from the camera based on the positioning result reflects the positioning error and camera direction error. Our proposed method in this paper generates a local map using the estimated trajectory instead of positioning results. This precise trajectory derived by GPS Doppler enables high accuracy local map generation.

4.1. Precise trajectory determined by GPS Doppler

The GPS Doppler is explained briefly in this section. Two types of signals for positioning are transmitted from a GPS satellite; the PN code and the carrier signal. Fig.4 schematically illustrates a simple feature of these two types of GPS signals. A GPS pseudorange corresponds to the relative distance between the receiver and the GPS satellite. The pseudorange is measured by PN code. On the other hand, GPS Doppler shift indicates the relative velocity between the receiver and the GPS satellite. The GPS Doppler is measured by the frequency shift of a carrier signal. Just as 3D position in the world coordinate system is estimated from 4 or more pseudoranges, 3D velocity is estimated from 4 or more GPS Doppler shifts. Fig. 5 shows the relationship between 3D velocity and GPS Doppler shifts.

The distance resolution of the PN code is about 300m, while that of the carrier signal is about 0.2m. The precision of 3D velocity estimation by GPS Doppler is higher than the precision of positioning using GPS pseudorange changes, because GPS Doppler is based on carrier signal frequency shifts.

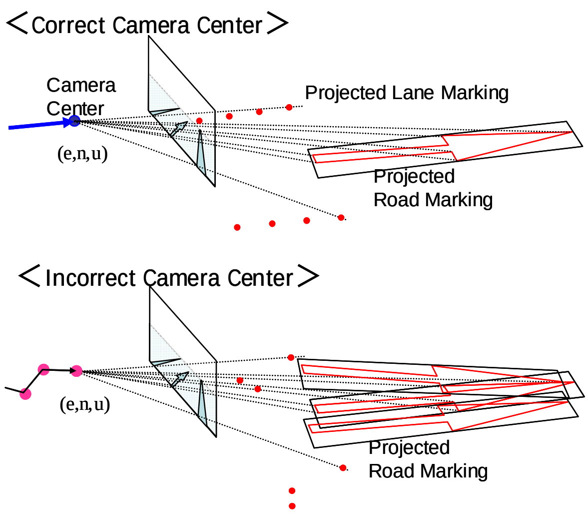

Fig. 3 Example of problem condition

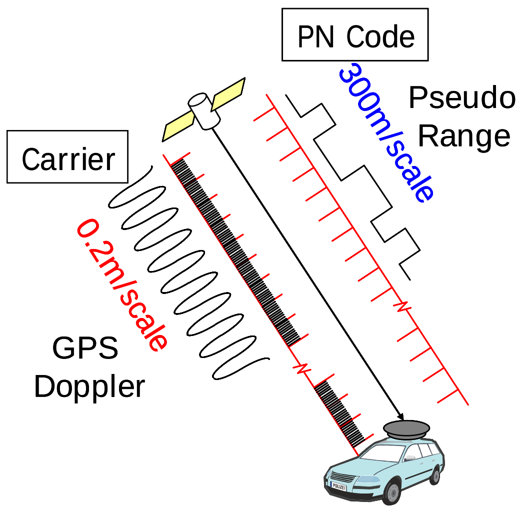

Fig. 4 Example of PN code and carrier signal

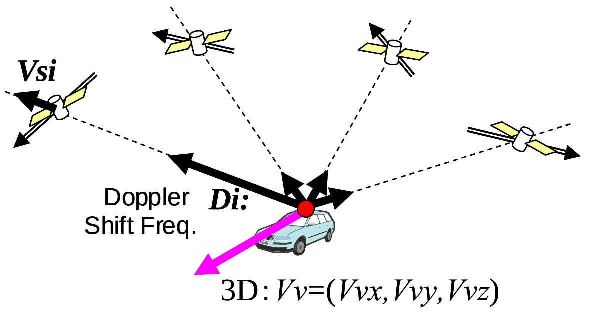

Fig. 5 GPS Doppler and 3D vehicle velocity

The heading of the vehicle can be estimated from the 3D velocity supplied by GPS Doppler, and then the camera direction can be estimated if the positional relationship between the vehicle and the camera is known. Moreover, when estimating trajectory from this 3D velocity, the cumulative error is small because GPS Doppler does not have a drift error, as does an INS (Inertial Navigation System). We have developed a precise trajectory estimation method using GPS Doppler[6], and in our evaluation the trajectory error after 1km of driving was about only 1m in a suburban area where the GPS signal was relatively good. This paper proposes a high accuracy local map generation method based on the precise trajectory supplied by GPS Doppler. However, if there is an insufficient number of measurable GPS Doppler shifts, the trajectory is estimated by integration of GPS Doppler shifts and INS.

4.2. Procedure of high accuracy local map generation

An individual vehicle estimates its own trajectory by using GPS Doppler, and generates a local map by projecting the images from the in-vehicle camera on the map plane. The local map generation overview is shown in Fig.6, and the map generation procedure is illustrated in Fig.7.

1. Individual vehicle trajectory is estimated based on GPS Doppler with the origin point determined by GPS positioning.
2. The circumscribed rectangles indicating road markings and lane markings on this image are detected.
3. Detection results by the in-vehicle camera are projected on the plane.
4. Newly projected marks are correlated to already projected ones. If the new mark and an existing mark are identified as the same object, the newer one remains.

A highly accurate local map is generated along this precise trajectory by repeating the above procedure. The trajectory estimation error from GPS Doppler is promising about 1m after 100m of driving. The required accuracy of the map for driver assistance systems depends on the application. Because the rough requirement is thought to be about 1m, the local map range was set at about 100m in this study.

The absolute accuracy of this local map is not high because the origin point of this trajectory is taken from a standard GPS, whose accuracy is about a few meters at best. However, the relative positional relationships within the local area are highly accurate, and the map direction is also accurately estimated, because the cumulative error is very small and the trajectory direction can be accurately determined. In the case of connecting local maps to expand map area for global map generation, this local map performance makes the connecting and optimizing easier.

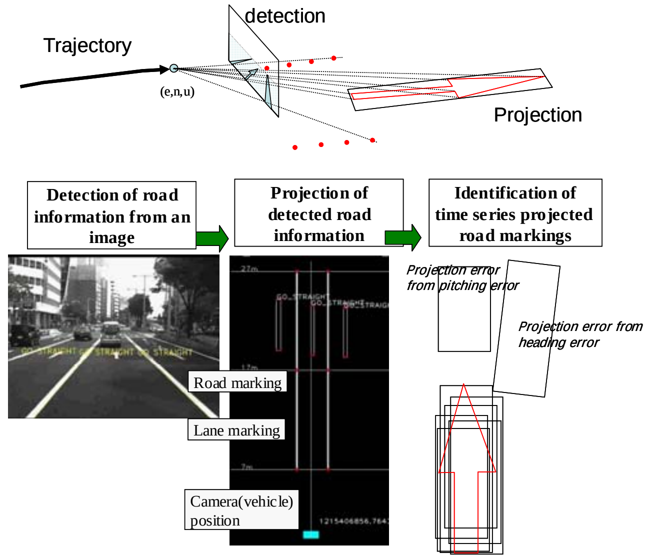

Fig. 6 Overview of local map generation

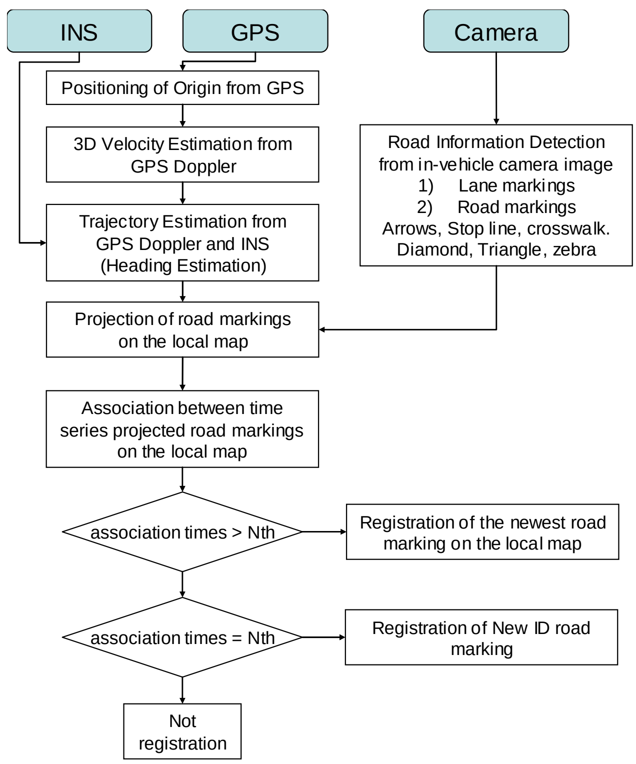

Fig. 7 Local map generation procedure

5. Evaluation

The effectiveness of this proposed high accuracy local map generation method was evaluated as follows.

5.1. Test conditions

An in-vehicle camera (Point Grey Research, Flea2[(7)] VGA FOG:36deg) and a GPS receiver (Novatel OEMV[(8)]) were installed in a vehicle. Front images at 30Hz from the in-vehicle camera and GPS raw data(pseudorange and Doppler) at 20Hz from the GPS receiver were acquired. A highly accurate integrated positioning system (Applanix Poslv610[(9)]) was also installed, enabling reference 3D positions and reference 3D velocity to be acquired at 100Hz. Actual data was acquired 4 times by driving the test course shown in Fig. 8(a) of about 1km. In addition, in order to evaluate map generation accuracy, high accuracy road map data of 10cm accuracy was also surveyed and a map was prepared.

This experiment evaluated 4 items. 1)detection of road information for driver assistance systems, 2) effectiveness of use of trajectories derived from GPS Doppler instead of GPS positioning results, 3)reproducibility of local maps in multiple runs, and 4)the accuracy of relative positions of road markings in the local map generated by our method.

5.2. Result of high accuracy local map generation test

1) Detection of road information for driver assistance systems

An accurate map for driver assistance systems has to include road information such as lane markings, stop signs, and arrows indicating direction to drive. The in-vehicle camera has to detect this information. Detected road information is drawn over an accurate aerial photograph in Fig. 8(b). A conventional map for vehicle navigation system typically just consists of lines. In this map, the road markings can be detected.

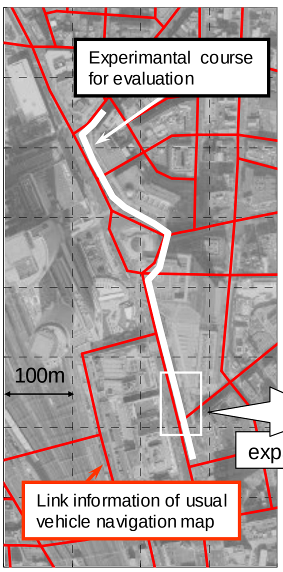

Fig. 8(a) Experimental course

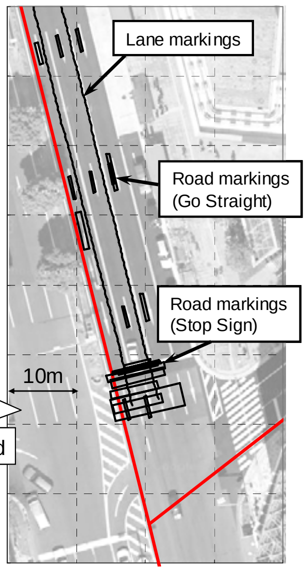

Fig.8(b) Example of road information detection

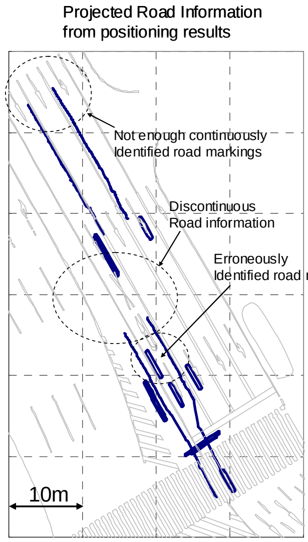

Fig. 9(a) Map generation based on GPS positioning

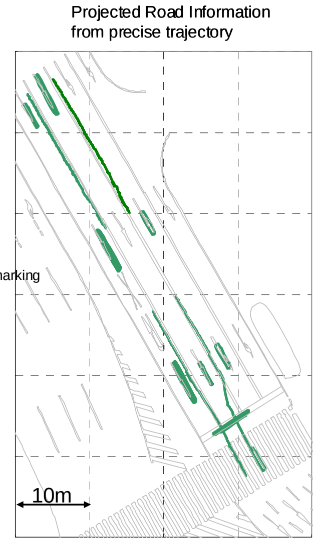

Fig.9(b) Map generation based on trajectory from GPS Doppler

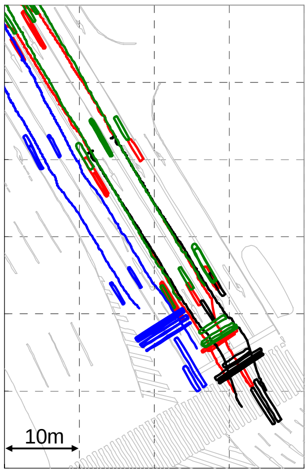

Fig. 10(a) 4 times local maps

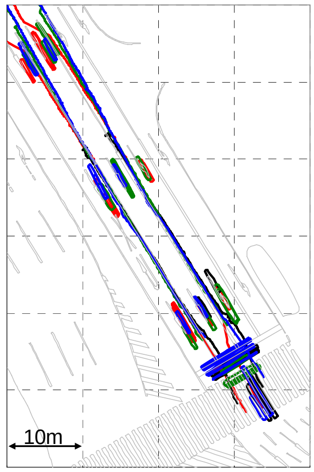

Fig.10(b) Connected local maps

2) Effectiveness of using trajectory derived from GPS Doppler

Local maps generated from GPS positioning results and from the trajectory determined by GPS Doppler are shown in Fig. 9(a) and Fig. 9(b) respectively. These results are drawn over a highly accurate road map prepared from data that was surveyed with 10cm accuracy. The position of the origin point of the local map generated by our method is set to be that of the corresponding position in the reference map. In the map based on GPS positioning results, the road marking position error is seen in Fig. 9(a), while the results based on trajectory from Doppler, our proposed method, are seen in Fig. 9(b). It is clear that accurate relative positional relationships are established.

3) Reproducibility of local maps

Multiple local maps generated by driving in same areas 4 times are shown in Fig.10(a). Each local map origin point is based on the positioning results from the GPS receiver. Therefore, the positions verified against the reference map are not correct, but the road directions in each local map are same. Our proposed

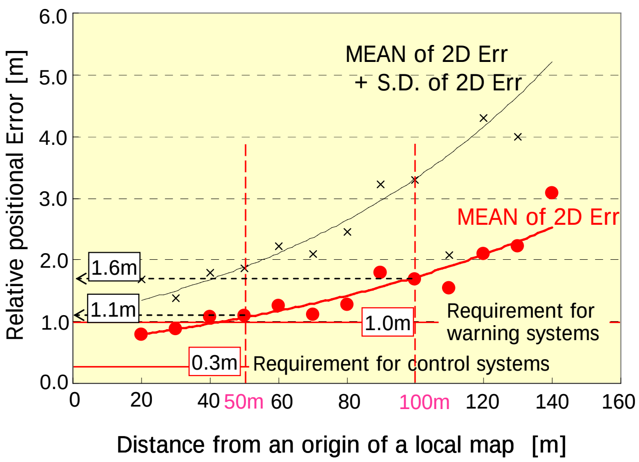

Fig. 11 Relative positional accuracy of road markings in generated local maps

method can thus consistently estimate road direction accurately. This makes the integration of multiple local maps easier. Fig. 10(b) shows 4 local maps that were superimposed map by parallel translation. In this experiment, integration of local maps was done manually. Nevertheless, the searching required for this integration was easier because the road directions were estimated accurately.

4)Relative position accuracy of road markings in local map

The generated local maps have many road markings. The relative positional relationship of these markings has to be accurate 30 local maps in all were generated by driving the 1km experimental course 4 times. The relative positional accuracy of markings was evaluated by comparison with the reference map. Fig. 11 shows the evaluated relative positional accuracy of road markings in the generated local maps. The relative position of an evaluated point to the origin point of that local map is determined and then the position of the origin point is set to be that of the corresponding point in the reference map. The mean and the standard deviation of 2D positional error are plotted in Fig.11. The relative positional error becomes larger at greater distances from the map origin point because of the cumulative error of trajectories. The mean 2D error is about 1.6m after 100m.

5.3. Discussion

Our proposed high accuracy local map generation method was evaluated using actual driving data. The accuracy of the map made using camera positions based on trajectories derived by GPS Doppler is better than that based on GPS positioning. Moreover, the trajectory obtained by our method indicates the vehicle heading, so that the local map direction can be determined accurately. Thus, connection and correlation of multiple local maps becomes easier. This proposed high accuracy local map generation method has the potential to expand area coverage greatly and improve the accuracy of absolute positions, by correlating of the relative positions of different local maps and the GPS raw data of each local map origin point.

We confirmed that relative positional relationships are determined accurately in local areas by our method. The required accuracy of local maps is thought to be about 1m over a 100m route, because the road information from the map is relied upon for about a 100m interval before the next control point. The accuracy of our generated local map does not reach this target accuracy. It is thought that the error is caused by trajectory error, road marking detection error, error of camera attitude on the plane, and so on. The road marking detection method, trajectory estimation accuracy, and the camera attitude estimation method need to be improved in future research.

6. Conclusion

This paper proposed a new method that can automatically generate accurate maps for driver assistance systems using only an in-vehicle camera and a standard GPS. Our proposed method has main 2 features: accurate local map generation based on precise trajectories from GPS Doppler instead of GPS positioning, and accurate global map generation by connecting and correlating multiple local maps made with the above probe techniques. This paper focused on the local map generation, and evaluated the effectiveness of our proposed method using actual driving data.

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