Special Feature: Active Safety

Research Report

Development of the "PRECISE" Automotive Integrated Positioning System and High-accuracy Digital Map Generation

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ABSTRACT We have developed an accurate integrated positioning system for ADAS applications called "PRECISE", which provides positional accuracy for ADAS applications and map generation by original positioning technologies. The key features of the technologies are precise trajectory estimation from GPS Doppler and bundle-adjusted accurate positioning using all of the GPS data along the trajectory. Using a standard GPS device and a low-cost IMU, PRECISE has realized an accuracy of 5 m at 95% coverage (around Nagoya Station), exceeding the 57% coverage achieved by the conventional positioning method. PRECISE has been confirmed to be sufficiently accurate for information providing applications. In addition, using an in-vehicle camera and a prepared accurate map, PRECISE has realized an accuracy of 1 m at 85% coverage of the same urban area, so that PRECISE can be used for vehicle driving control applications.

We have also proposed an accurate map generation method using an in-vehicle camera and a standard GPS device. This map generation method stores road markings acquired from the in-vehicle camera along the trajectory obtained from GPS Doppler and generates a local map, the relative accuracy of which is high. Furthermore, this method accurately estimates the absolute position using virtually increased GPS satellites acquired from multiple local maps. The effectiveness of this map generation method has been confirmed by evaluation in suburban and urban environments, and however, the evaluation also confirmed that some problems remain for achieving a positional accuracy of 1 m in urban areas.

KEYWORDS ITS, GPS, Positioning, Trajectory Estimation, Bundle Adjusted Positioning, Image-Map Matching, Map Generation

1. Introduction

Various driver assistance systems for the improvement of safety and convenience have been developed in the course of research in the field of intelligent transport systems (ITS). In recent years, predictive safety applications or advanced driver assistance system (ADAS) applications, which can give information or a warning to a driver and vehicle driving control, are drawing attention. These systems operate based on the vehicle position, velocity, and information on the road ahead or on blind spots (road curvature, slopes, crossroads, stop signs, etc.), which is acquired from a digital road map. These systems need both accurate positioning and an accurate map, both of which should have road information. The map can enable robust detection of lighting conditions and weather and can improve the level of environment understanding based on road information stored in the map. The requirements of the positioning and the map are specified below.

(1) Positioning requirements

Accuracy: information providing: 5-m positional accuracy, which can determine the road being traveled and the crossroad on the road ahead.
driving intervention and control: 0.3- to 1-m positional accuracy, which can identify the position in the road (positional relation to a stop sign or a lane marking).

Reliability: positional accuracy that makes it possible to use the positioning results obtained in ADAS applications to make judgments must be guaranteed.

(2) Road map requirements

Accuracy: accuracy equivalent to positional accuracy of vehicle, road width, and useful road geometry (curvature, etc.)

Types of information: traffic control information for ADAS (stop signs, crossroads, lanes)
Updating and reliability: It must be

possible to determine whether a road is changed or a map is reliable.

A conventional vehicle navigation system, known as map matching, displays the vehicle trajectory estimated by the global positioning system (GPS) and an inertial measurement unit (IMU) (or inertial navigation equipment), so that this system coincides with roads on a digital map of a vehicle navigation system. The main function of the vehicle navigation system is route guidance, and this function only has to know on which road the vehicle is traveling. Since the interval between roads is approximately from several tens of meters to several hundreds of meters, an accuracy of from a few meters to several tens of meters is sufficient for route guidance. On the other hand, ADAS applications need to know where on the road the vehicle is and in what direction the vehicle is traveling, e.g., the lane on the road, the direction of movement relative to that lane, or the distance to a stop line or a curve ahead. The required positional accuracy is from a few tens of centimeters to a few meters, which is 10 times that of the conventional navigation system.

Some accurate positioning techniques for surveying and experiments have been developed. High-end integrated highly accurate positioning systems [(1)] (e.g., Applanix POSLV) achieve an accuracy of from a few centimeters to several tens of centimeters in an urban area by integrating a real-time kinematic GPS receiver, which measures dual-frequency carrier phase, and a highly accurate IMU, such as a ring laser gyro. However, these are not suitable as in-vehicle systems because their cost is extremely high (several million yen to tens of millions of yen). The ADAS applications require accurate positioning using low-cost sensors such as a single-frequency GPS receiver used for vehicle navigation systems and a low-cost gyro, such as a MEMS gyro.

The map used here also has requirements that can be difficult to meet. Road information for conventional navigation systems has roughly defined nodes and links with large positional errors. This error is said to be approximately 30 m or more in some locations. Moreover, the navigation map includes the route information needed for route guidance, but does not include restrictions on traffic, road shape (width, curvature, or slope), or intersection information, which is necessary for ADAS. Both collecting this road information and indicating it on the digital map are indispensable for ADAS. The digital map for ADAS not only needs to be accurate but also needs to be up to date, reflecting the actual present conditions, because the traffic restriction information is often changed due to road construction work.

The conventional accurate map generation method needs a special vehicle for surveying. An existing special mapping survey vehicle is equipped with RTK-GPS, high-accuracy IMU, and multiple cameras and laser scanners.[(2)] The vehicle can generate road information for a map such as traffic restrictions learned from reading traffic signs and lettering on the road surface, as well as road shape, after driving over a road only one time. However, accurate map generation over a large area using such a survey vehicle is not realistic, because of the extreme expense involved.

Thus, the present study aims to realize accurate positioning for ADAS applications and establish accurate map generation technology using low-cost sensors. The proposed accurate positioning system adds a few items to the low-cost sensors used in conventional vehicle navigation. The system thus includes a single-frequency GPS receiver, a low-cost gyro (yaw rate) sensor, as is used for car navigation or vehicle control, and an in-vehicle camera as is used for a back guide monitor or a driving recorder. These sensors, which may all be found in ordinary vehicles, are coordinated for the accurate positioning needed for ADAS applications.

In addition, accurate maps including road information for ADAS (e.g., road shapes and road markings) can be generated from ordinary in-vehicle sensor information at a low cost using this positioning technology. Using the same technology, these maps can also be verified and revised to reflect current information, e.g., on road construction work.

2. PRECISE, an Integrated Positioning System

2. 1 Policy for Accurate Positioning

Basically, with a standard GPS, a positional accuracy of within 10 m can be achieved in suburban areas. However, achieving an accuracy of 10 m in urban areas is difficult using the conventional positioning method. In urban areas, positional accuracy becomes worse because signals from GPS satellites are often blocked or multiple paths are generated by signal reflection and diffraction due to buildings.

On the other hand, the vehicle trajectory can be stably estimated using an in-vehicle gyro sensor, which, unlike GPS, is not influenced by the road environment. However, a low-cost in-vehicle gyro generally has bias errors. In estimating a long distance vehicle trajectory, the bias error might cause considerable accumulative errors. Furthermore, the gyro can measure orientation changes, but cannot measure absolute heading, relative to North. Therefore, the heading determined by these methods often has large errors because the GPS positioning results are used to determine absolute heading.

We then propose two important policies for accurate positioning. An overview is shown in **Fig. 1**.

(1) Accurate Positioning: The proposed method continuously determines whether accurate positioning is possible and uses only information gathered at points for which the position can be estimated accurately.

(2) Precise Trajectory Estimation: The vehicle trajectory is estimated based on an in-vehicle IMU. This trajectory is interpolated between points for which there is accurate positioning, thereby maintaining positional accuracy. Absolute heading is determined by velocity vectors based on GPS Doppler, and the heading is used to set the initial gyro direction and for gyro bias correction. Thus, a precise trajectory can be estimated.

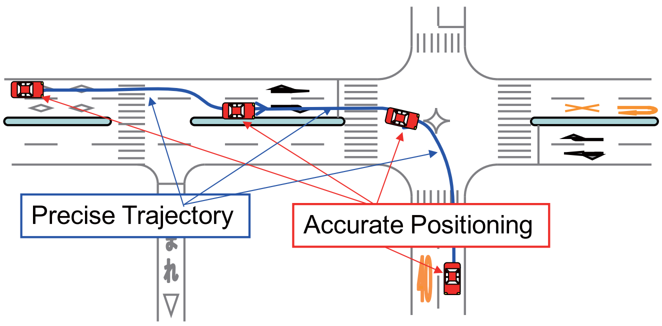

Fig. 1 Principle of “PRECISE” positioning technologies.

We have developed an accurate positioning system, called PRECISE (positioning with reliability enhancement by coupling IMU and satellites with external sensors), by integrating the methods for accurate positioning and precise trajectory estimation as above described. PRECISE first estimates with extreme accuracy the absolute heading of the vehicle based on GPS Doppler, which derives the relative velocity between the vehicle and GPS satellites. Accurate positioning is achieved in urban areas by precise trajectory estimation carried out by integrating data of the low-cost IMU and the above accurate heading.[3] A positional accuracy of 5 m is required for information-providing applications to be realized by unique integration of GPS and the IMU, as described above.

In addition, an accurate map for ADAS is generated by combining these accurate positions with road information (road shape, traffic sign, lanes, etc.) acquired from an in-vehicle camera. A positional accuracy of one meter, which is required for driving intervention and control applications to be realized by the addition of matching information between images from the camera and road information in the accurate map.

2. 2 Components of PRECISE

An overview of the components of the PRECISE integrated positioning system is shown in **Fig. 2**. The input of PRECISE includes the yaw-rate from the IMU, the vehicle speed, GPS raw data (Doppler shift frequency and pseudorange from each GPS satellite) received by a single-frequency GPS receiver, and in-vehicle camera images. Yaw-rate and vehicle speed

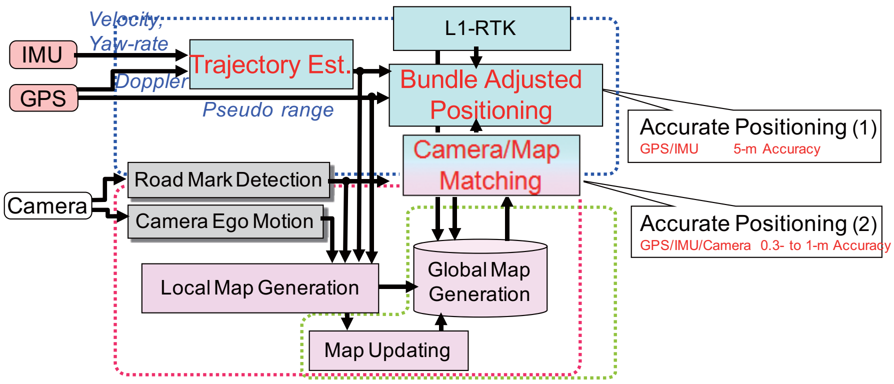

Fig. 2 “PRECISE” functions components.

from CAN-bus are used as is. Sensors, including GPS devices and in-vehicle cameras, can be standard in-vehicle type sensors, which do not have particularly high accuracy. Therefore, PRECISE can be realized at low cost.

PRECISE outputs three types of information according to the purpose of the particular automotive application, as follows:

(1) Absolute position (positional accuracy: 1 to 5 m)
Absolute position is estimated with the IMU and GPS only and is used for applications that provide information and warnings to the driver. Absolute position is also used for image-map matching in the function below.

(2) Position on the map (positional accuracy: 0.3 to 1 m)
Images from an in-vehicle camera in addition to GPS and IMU data are correlated with an accurate road map. This position on the map is applied to driving lane identification and vehicle control applications.

(3) Accurate road map generation
The accurate map used in (2) is automatically generated. This map generation uses the above absolute positions determined in (1) and the road marking recognition results of (2). Information collected from trips made by multiple vehicles can be used to generate and update nationwide large-area maps for ADAS much more easily than before.

The most important feature of PRECISE is its unique positioning algorithm enabling precise trajectory estimation. Conventional integration algorithms using GPS and IMU generally use a maximum likelihood estimation method such as Kalman filtering, which combines positioning results based on pseudorange data from GPS at one location epoch by epoch and IMU information. In contrast, PRECISE first estimates the trajectory based on yaw-rate from the IMU, vehicle speed, and GPS Doppler. Next, PRECISE decides the most appropriate total trajectory corresponding to the pseudorange data obtained as the vehicle proceeds along the trajectory, and based on this trajectory makes a final determination of position. We refer to this method as bundle adjustment. This precise trajectory estimation and bundle adjustment positioning is described in the following section.

2. 3 Precise Trajectory Estimation from GPS Doppler

GPS has two main types of signals: carrier wave and PN code, which is an on-off signal added to the carrier wave. The standard single frequency GPS receiver can receive only the L1 (1572.42 MHz) carrier wave, and the GPS Doppler is equivalent to the measurement of carrier wave frequency shift due to the shift in relative velocity between the vehicle and each GPS satellite. In contrast, the PN code is the repeated on-off pattern that is specific to each GPS satellite. The delay time is decided by correlating the code patterns. Pseudorange is equivalent to the distance measured based on the propagation delay time[4] between the vehicle and each GPS satellite.

The velocity of each GPS satellite can be calculated from ephemeris information. Thus, the vehicle velocity can be estimated if the relative velocity between the vehicle and each GPS satellite is measured. There are two ways to acquire the relative velocity, namely, from the time variation of the pseudorange and from the GPS Doppler shift frequency. The features of these two types of signal are shown in **Fig. 3**. The resolution of pseudorange is equivalent to approximately 300 m, and the resolution of GPS Doppler is equivalent to approximately 0.2 m, which is the wavelength of the L1 frequency. In the actual measurement, measurement can be preformed with a resolution of 1/10 of the wavelength. Therefore, the measurement of pseudorange is capable of an accuracy of 30 m, and GPS Doppler can accurately estimate velocity with accuracy of a few centimeters.

Four or more GPS satellites are necessary for vehicle velocity vector estimation based on GPS Doppler because four parameters (3D components and clock drift of the GPS receiver) have to be decided for

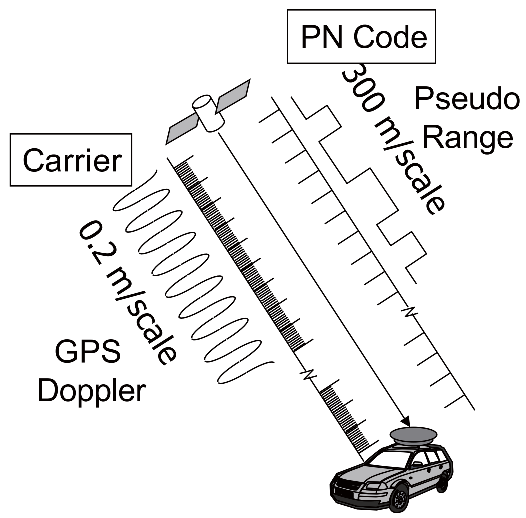

Fig. 3 Two types of GPS signal.

vehicle velocity estimation. This velocity vector can determine an absolute heading component and so can be applied to bias correction or initial heading determination of the gyro sensor.

Although there are some areas in which the velocity accuracy becomes worse or the vehicle velocity cannot be estimated due to signal blocking and multi-path signals in urban areas, the accuracy is good. The precise trajectory can be robustly estimated by combining IMU data and selected heading estimations by GPS Doppler that are determined to be accurate. PRECISE determines the heading reliability using the yaw-rate from the gyro sensor. Concretely, the heading that minimizes the difference between the heading estimated from GPS Doppler and the heading derived from the gyro is estimated. The heading estimation result is assumed to be accurate at positions at which the dispersion of residual differences is small. For locations at which the variance is small, the heading estimated from GPS Doppler is used for IMU correction. For locations at which the variance is large, the estimation is not accurate and is not used for correction.[5]

The results of this countermeasure against accuracy degradation are shown in **Fig. 4**. The graph indicates the estimation results in urban areas (around Nagoya Station). The trajectory error is greatly reduced by this method. This estimation method has a trajectory error of 1 m over a trajectory of 100 m in urban areas.

2. 4 Bundle Adjustment Positioning

The bundle adjustment positioning method uses the precise trajectory estimated from the IMU and GPS Doppler and GPS pseudorange information obtained at points along the trajectory.[3,6] The absolute position of the vehicle is estimated by maximum likelihood calculation based on the trajectory and pseudorange data. The principle of the bundle-adjusted accurate positioning is explained referring to **Fig. 5**.

In order to determine the vehicle position ($x(t)$, $y(t)$, $z(t)$) at time t, four pseudorange values are necessary because the number of unknown parameters is four (3D position and $Cb(t)$, which represents the clock bias of the GPS receiver). The vehicle position at time t-k can be estimated using the vehicle position at time t and the trajectory. If the clock bias $Cb(t\text{-}k)$ at time t-k can be determined by linear interpolation of clock drift $Cbv(t)$, the number of unknown parameters remains four along the entire trajectory. Therefore, bundle adjustment positioning is possible if data from four or more GPS satellites is received for the entire trajectory.

Bundle adjustment positioning can use much more GPS data for positioning because all of the pseudorange data acquired along the trajectory can be used for positioning. Therefore, the appropriate position is determined using more than four GPS data values, which provides an optimum estimation. In bundle adjustment positioning, the multi-path error is identified using pseudorange residual differences derived during optimum estimation, and the multi-path signal is removed.

3. Experiments and Evaluations of Positional Accuracy

Experiments in urban area have been conducted to evaluate the effectiveness of PRECISE. The

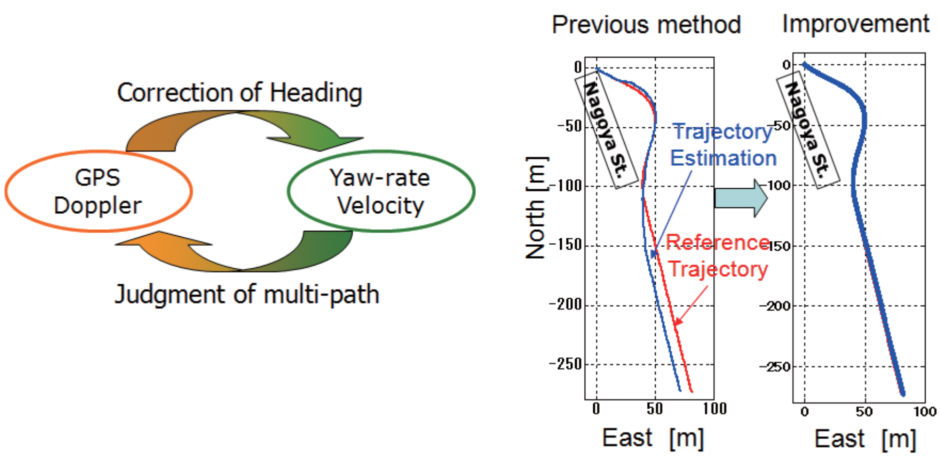

Fig. 4 Improvement of trajectory estimation.

experimental conditions are shown in **Fig. 6**. The course includes roads with underpasses and roads that pass by high-rise buildings around Nagoya station. For this evaluation, positions determined by an integrated highly accurate positioning system (Applanix POSLV610) are reference positions. This integrated highly accurate positioning system consists of a high-accuracy ring laser gyro, high-resolution velocity pulse, and RTK-GPS. The positional accuracy S.D. of POSLV is approximately 10 cm, even in urban areas.

The experimental results are shown in **Fig. 7** and **Table 1**. Figure 7 shows the percentage of positions with different levels of positional accuracy. The results of PRECISE are plotted along with the results of the conventional loosely coupled (LC) integration method. The LC method integrates the positioning result of GPS at one epoch with gyro data through Kalman filtering under the assumption that the GPS positional error follows a Gaussian distribution.(7) However, the GPS positional error does not follow a Gaussian distribution and includes outliers due to multi-path signals. Therefore, 5-m accuracy is achieved in only 57% of the entire area. This 5-m accuracy is required for information-providing applications.

On the other hand, PRECISE integrates the precise trajectory estimated by GPS Doppler, an IMU, and abundant bundle adjustment accurate positioning data, and the multi-path signals are removed by satellite selection, so that higher absolute position estimation accuracy is possible. Thus, 5-m accuracy was achieved in 95% of the urban area.

4. Positional Accuracy Improvement by Image-map Matching

The positional accuracy realized by the proposed positioning technologies using GPS and IMU is approximately 5 m. Two features of the positioning

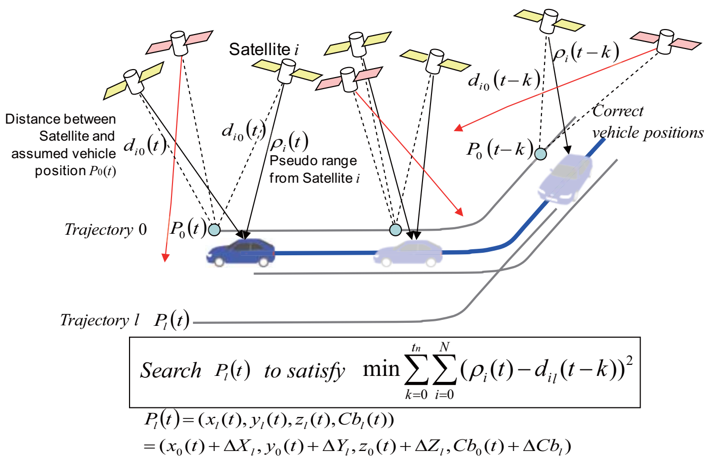

Fig. 5 Overview of bundle-adjusted accurate positioning.

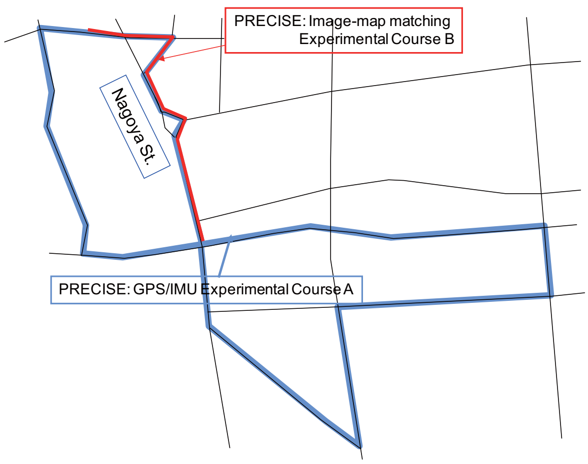

Fig. 6 Experimental courses.

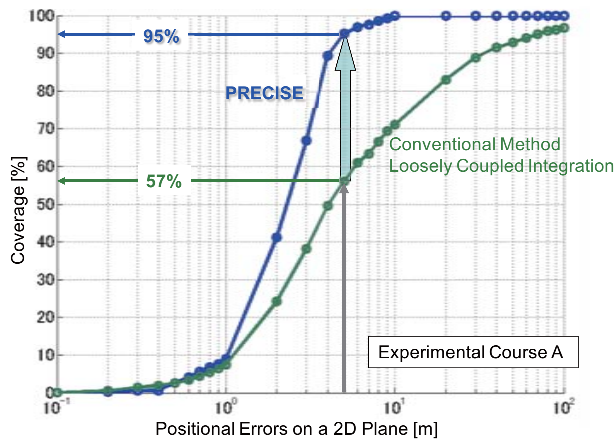

Fig. 7 Results of positioning by PRECISE using GPS and IMU.

technologies are precise trajectory estimation and bundle adjusted accurate positioning. An accuracy of 5 m is adequate for information-providing services or driver warning applications, but is not adequate for vehicle control, such as braking or steering, which requires an accuracy of 0.3 to 1 m. Therefore, PRECISE realizes a function that more accurately estimates position by means of a technology that matches an image and a prepared accurate map. The image of the surroundings is acquired by an in-vehicle camera, which is equipped for ADAS applications such as lane keep assistance (LKA).

The positions of road information on the road surface (speed limit, arrows, stop signs, crosswalks, lane markings, etc.) required for ADAS application are preliminarily stored in an accurate digital map for the image-map matching. These road markings are extracted from acquired images by an in-vehicle camera, and the above function selects the position of a road marking stored in the accurate map that best corresponds with a road marking on the ground that was photographed. PRECISE can make the image-map matching area smaller because the positional accuracy provided by GPS/IMU is approximately 5 m. Thus, accurate and robust positioning can be realized because not only the process time for matching becomes shorter but also accurate initial positioning reduces the chance of a mismatch between an actual road marking and a similar marking near the correct marking.

The realization of this image-map matching method undoubtedly requires an accurate map, which stores accurate positions of road markings. However, this map is not usually available. Thus, we prepared an accurate map for evaluation based on highly accurate vehicle positioning (acquired with POSLV610) and projected images from the in-vehicle camera. The prepared area of this accurate map is limited to a distance of 800 m (in Fig. 6), and the effectiveness of the image-map matching of PRECISE was evaluated in this area. The experimental results are shown in **Fig. 8**. This matching technology of the in-vehicle camera image and the accurate map achieved an accuracy of 1 m over more than 85% of an urban area.

Table 1 Results of positioning by PRECISE.

Integration method	Conventional LC method	PRECISE (GPS/IMU)	PRECISE (image-map matching)
Positional accuracy 1 m		45% →	85% (possibility)
Positional accuracy 5 m	57% →	95%	

Even though the evaluation area was limited, this confirmed that the PRECISE image-map matching function is sufficient for driving control applications.

5. Map Generation for ADAS Applications

An accurate map for ADAS that includes accurate road information required for driver assistance is desired for realizing ADAS applications as above. However, preparing this accurate map on a nation-wide scale is not realistic, because the current map generation cost is extremely expensive. Then, we propose an automatic accurate map generation method at low cost, which includes road information for ADAS applications using PRECISE functions.

5. 1 Overview of Automatic Map Generation Technologies

An overview of the automatic accurate map generation is shown in **Fig. 9**. The proposed accurate map generation method uses a standard GPS, a low-cost IMU, and an in-vehicle camera, which are used for PRECISE, and generates an accurate map by storing and sharing driving data from the driver's own vehicle or other vehicles. The two main features are described as follows:

(1) The road marking map is generated by projecting road markings, which are detected from an in-vehicle camera image, onto the ground. The relative positional accuracy of the road marking map is maintained because the road markings are stored along a precise trajectory based on GPS Doppler and the IMU. Although the absolute position is not

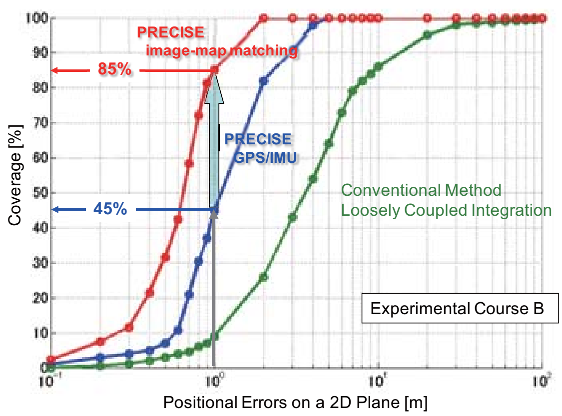

Fig. 8 Results of positioning by PRECISE using image-map matching.

so accurate, the relative position of road markings on the map is accurate. We refer to this map as the accurate local map. (Feature 1)

(2) Accurate local maps and GPS raw data (i.e., pseudorange) stored on each local map are combined at a map control center. The relative position between collected local maps, which are generated on the same areas, is accurately estimated by matching road markings. This method estimates an optimal absolute position on the local map based on the relative position between multiple local maps and stored GPS raw data, and generates an accurate global map for ADAS applications. (Feature 2)

Feature 1 ensures the local positional accuracy of the road information on the local map because the road information is stored along with the precise trajectory based on GPS Doppler and the IMU. The realized relative positional accuracy is 1 m in a 100-m area local map. On the other hand, Feature 2 generates a global map by connecting multiple local maps and estimates the optimal absolute position based on the relative position between local maps and stored GPS raw data. The GPS raw data used here is not limited to the current local map, for example, a local map generated in the same area one week ago, or a local map generated based on the driving data of another vehicle can be used for optimal position estimation. GPS raw data collected through the relative positions between local maps makes the situation equivalent to longtime static surveying by virtually increasing the number of GPS satellites, making it possible to accurately estimate absolute positions. The main concept of this method is shown in **Fig. 10**.

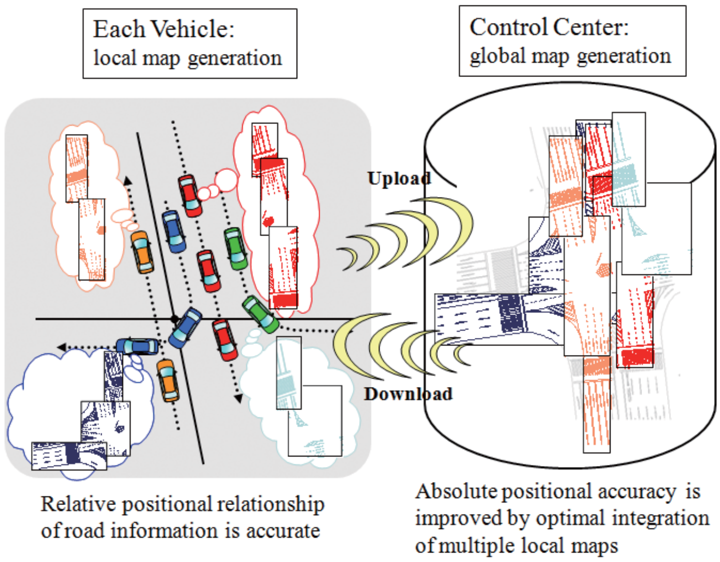

Fig. 9 Overview of the accurate map generation method.

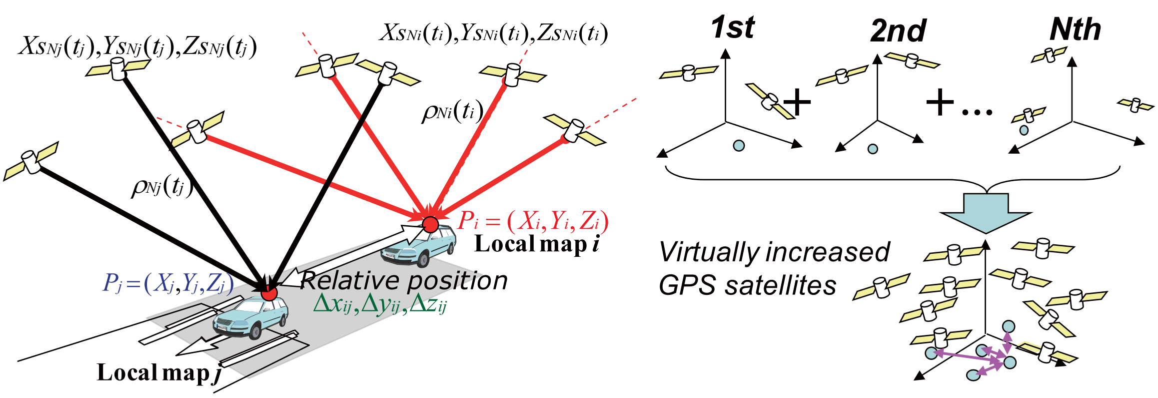

Fig. 10 Accurate positioning method using GPS raw data stored by multiple driving.

A number of methods that use past GPS data have been proposed. These methods use the positioning results and improve positional accuracy by averaging positioning results. However, the average position is susceptible to error because the positioning results sometimes include specific directional errors and GPS outage. The proposed method provides positional accuracy improvement by using GPS raw data, such as pseudorange data from a standard GPS, rather than positioning results. The accuracy of positioning results based on standard GPS is several meters at best. However, this method aims at achieving a positional accuracy of 1 m by exploiting multiple data.

5. 2 Trial Results for Map Generation

For the evaluation of the accurate local map generation, an actual vehicle equipped with a standard GPS, a low-cost IMU, a front-end camera (VGA, Fov 36 deg.), and a highly accurate integrated positioning system (Applanix POSLV) was driven in urban areas (Nagoya Station). GPS raw data and IMU data at 10 Hz, a camera image at 30 Hz, and the reference position data at 100 Hz were acquired. The local map generated using acquired data is shown in **Fig. 11**. This local map indicates that the stored road markings are overlaid on the reference map, which is specially surveyed. The generated local map fits the reference map well by translating to correspond with the reference map, because the relative positional relationship and the orientation of the generated local map is accurate due to the precise trajectory. These results show that an accurate local map can be generated.

In order to investigate the feasibility of improving the absolute positional accuracy by multiple GPS raw data, the positional improvement using multiple actual GPS raw data acquired in suburban and urban areas was evaluated. The actual data was acquired 10 times in a low-rise residential area for the suburban area and 10 times on a street lined by high-rise buildings for the urban area. The effectiveness of the positional accuracy improvement is shown in **Fig. 12**. The results obtained by the previous method are also shown in the same chart.

In both the results for the suburban and urban areas, the positional errors obtained by the proposed method are smaller than those of the previous method, and the proposed method improves the positional accuracy faster than the previous method. In the suburban areas, 2 S.D. (standard deviation) of 2D positional errors of the generated map becomes 1 m using 5 to 10 sets of GPS raw data, and the results promise that the proposed method can accomplish the positional accuracy required for an accurate map for ADAS applications. On the other hand, the positional accuracy obtained using 10 sets of GPS raw data in urban areas remains 10 m. Furthermore, the positional accuracy is 6 m even using 20 sets of GPS raw data.

The proposed method realizes accurate positioning by virtually increasing the number of GPS satellites. **Figure 13** shows the relationship between the positional error and the number of GPS satellites using 10 driving data sets. In suburban areas, the number of

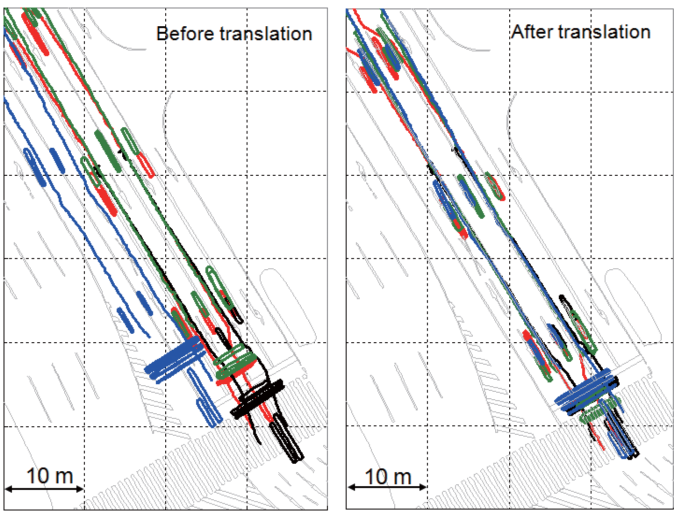

Fig. 11 Local maps translated to correspond to a reference map.

GPS satellites steadily increases according to the number of driving data collections, and the positional errors rapidly decrease. In urban areas, on the other hand, the number of GPS satellites increases lower in urban areas and the positional error variation is larger. Since GPS satellites located in a specific direction may be blocked by buildings, dilution of precision (DOP), which depends on the satellite constellation, is not much improved. Therefore, positional accuracy improvement remains an unsolved problem.

6. Conclusion

We have developed an integrated accurate positioning system for ADAS applications called PRECISE, which enables positioning with sufficient accuracy for ADAS applications and map generation by novel positioning technologies. The key features of the technologies are precise trajectory estimation from GPS Doppler and bundle-adjusted accurate positioning using all of the GPS data along the trajectory. Using a standard in-vehicle GPS and a low-cost IMU, PRECISE realized an accuracy of 5 m over 95% of an urban area (around Nagoya Station), exceeding the 57% achieved by the conventional positioning method. PRECISE has been confirmed to be sufficiently accurate for information-providing applications. In addition, using an in-vehicle camera and a prepared accurate map, PRECISE has realized an accuracy of 1 m over 85% of the same urban area, so that PRECISE can be used for vehicle driving control applications.

We have also proposed an accurate map generation method using an in-vehicle camera and a standard GPS device. This map generation method stores road markings acquired from an in-vehicle camera image along the trajectory based on GPS Doppler and generates a local map having relatively high accuracy. Furthermore, the proposed method accurately estimates the absolute position acquired from multiple

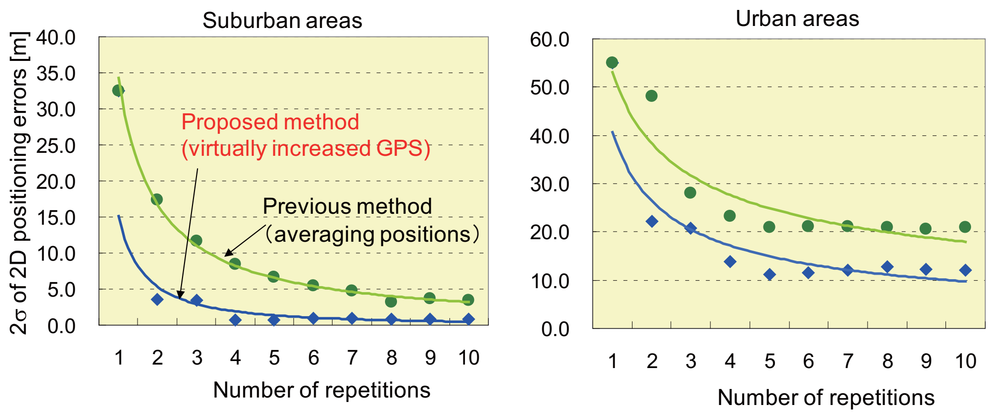

Fig. 12 Results of positional accuracy obtained using the proposed method

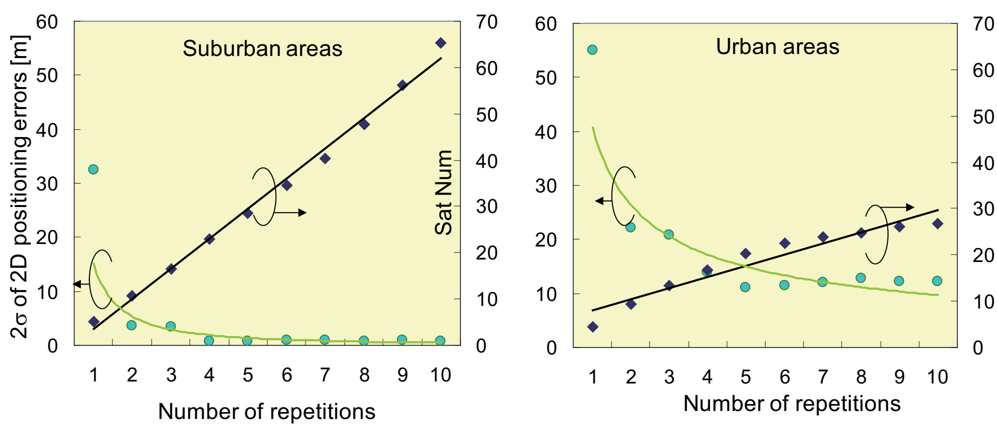

Fig. 13 Relationship between positional accuracy and the number of GPS satellites.

local maps by virtually increasing the number of GPS satellites. The effectiveness of this map generation method has been confirmed through evaluation in suburban and urban environments; however, it also confirmed that some problems remain for achieving a positional accuracy of 1m in urban areas.

In the future, we will attempt to further improve positional accuracy in various environments and to further advance the proposed accurate map automatic generation technologies for ADAS applications.

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- Information Processing Society of Japan

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- The Institute of Electronics, Information and Communication Engineers

Awards:
- IPSJ Yamashita SIG Research Award, 2002
- IPSJ Best Paper Award, 2002
- AVEC Best Paper Award, 2010

Jun-ichi Meguro

Research Fields:
- Land Vehicle Positioning and Navigation
- Road Environment Reconstruction

Academic Degree: Dr. Eng.

Academic Societies:
- The Institute of Navigation
- The Robotics Society of Japan
- Information Processing Society of Japan

Awards:
- SSRR 2005 BEST PAPER AWARD, 2005
- SICE Paper Award (Tomoda Award), 2006
- IPSJ Yamashita SIG Award, 2011

Noriyoshi Suzuki

Research Field:
- Digital Mobile Communication Systems and Integrated GPS/INS Systems for Land Vehicle Positioning

Academic Degree: Dr. Eng.

Academic Societies:
- The Institute of Electronics, Information and Communication Engineers
- IEEE

Awards:
- The Young Researchers' Award from IEICE, 1999
- The IEEE Consumer Electronics Society 2006 Chester Sall Award for the First Place Transactions Paper Award, 2008