THE GPS/INS INTEGRATION AND KINEMATIC PHOTOGRAMMETRY FOR MOBILE MAPPING SYSTEM

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ABSTRACT

Mobile mapping system consists of navigation sensors and digital imaging sensors. The system collects its position and orientation data and field image data, moving along road's or railroad's tracks. By extracting 3-D coordinates and attributes information of roads, buildings and traffic facilities from the measurement data, the system efficiently creates and updates precise GIS database for a variety of applications. There are two essential technologies in mobile mapping. One is the GPS/INS integration that makes it possible to measure accurately and continuously positions and orientations of a moving platform. And the other is the kinematic photogrammetry which is capable of a precise 3-D measurement of objects from stereo images without any ground control points.

We have developed the Hybrid Inertial Survey System(HISS) aiming at a medium accuracy mapping applicable to road investigation, facility management and data acquisition for car navigation systems. The HISS, integrated with the differential GPS and the INS, achieved a positioning accuracy of 1 to 2 meters between tall buildings or under elevated roads in downtown areas. We also propose a new method to determine the position and orientation of camera's perspective center varying moment by moment. This uses a mathematical model that can compute georeferencing of images. In this way, features on and around roads can be spatially positioned and incorporated into GIS database.

1. INTRODUCTION

In the approaching 21st century, the Japanese government issued its Comprehensive Plan for the Promotion of Intelligent Transport System(ITS), adding to the expectation that a new industry will be created. ITS has some development fields such as Upgrade Navigation System or Safety Driving Assistance that call for the geometric data or multimedia contents around roads. At the same time, the government also promoted the National Spatial Data Infrastructure. Geographical Information System(GIS) database has been built throughout the country.

In urban areas, there are many buildings or facilities around roads or railroads. If only the conventional methods such as field surveys, aerial photogrammetric mapping and manual digitization were used for GIS data acquisition, enormous cost and time might be spent. In addition, it is very difficult task to update regularly so that the information in the database exactly represents the real world. For the purpose to overcome these problems, the technique to acquire up-to-date data efficiently has been desired.

We have developed the prototype of mobile mapping system that aims at a medium accuracy mapping applicable to road investigation, facility management and data acquisition for car navigation systems. This system presents the best solution to supply the market with the spatial data of good quality rapidly and inexpensively.

2. MOBILE MAPPING SYSTEM

2.1 System Concept

Figure 1 shows our concept of mobile mapping system. The system consists of a data acquisition part and a data analyzing part. The former integrates navigation sensors such as receivers of Global Positioning System(GPS) and an Inertial Navigation System(INS) with digital imaging sensors such as stereo pair cameras on a moving platform. It collects position and orientation data of moving platform and field image data running along road's tracks. The latter extracts 3-D coordinates and attributes information of roads, buildings and traffic facilities from stereo images. It efficiently and inexpensively creates and updates precise GIS database for a variety of applications.

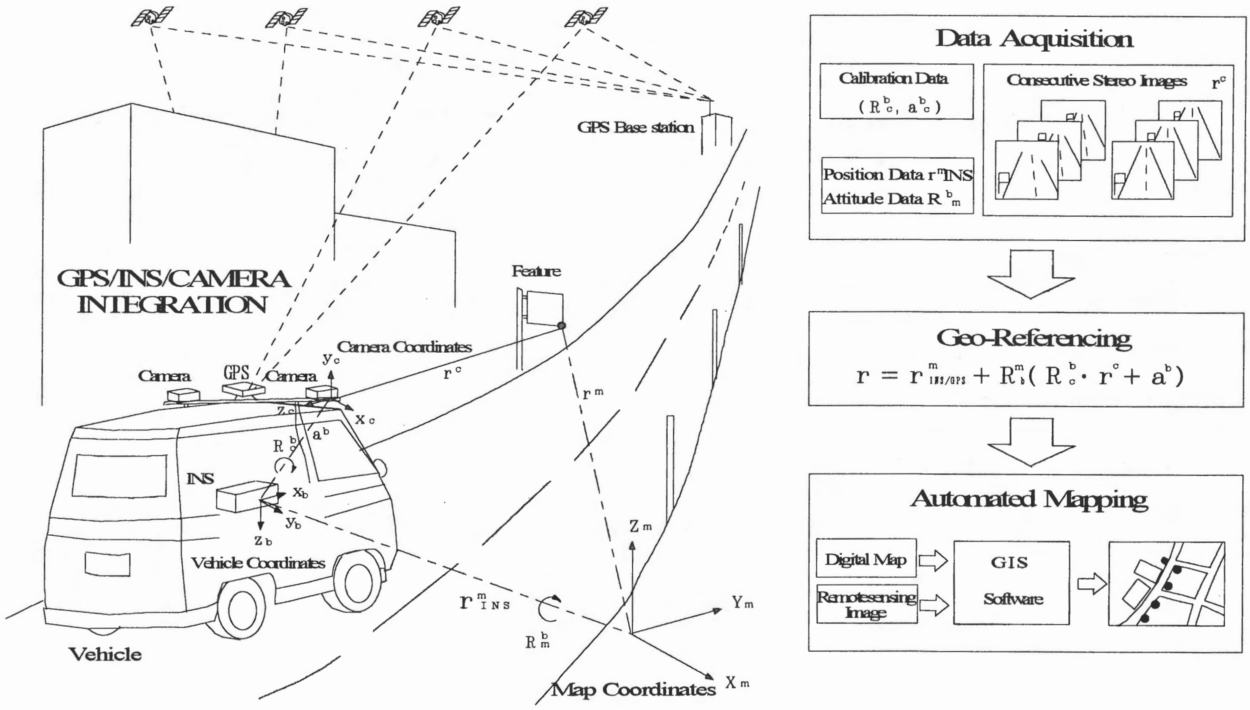

Figure 1 Concept of mobile mapping system

2.2 GPS/INS Integration

Figure 2 shows the concept of GPS/INS integration. To make mobile mapping system to fit for practical use, it is indispensable to maintain the positional accuracy of moving platform even in such circumstances as the GPS signal hidden behind buildings or trees. The INS can measure positions autonomously with high precision in a short time. But as the time elapses, the positioning error is accumulated owing to drift of gyroscope. Therefore it is difficult to use INS alone for the mission that needs the high precision surveying for a long time. By integrating the INS with the GPS, these two systems can complement disadvantages of the other system mutually. Therefore the GPS/INS integration system makes it possible to measure accurately and continuously the position and orientation of a moving platform. To evaluate the availability of this system, we have developed the Hybrid Inertial Survey System(HISS) designated by figure 3. The HISS consists of a strapdown INS and a

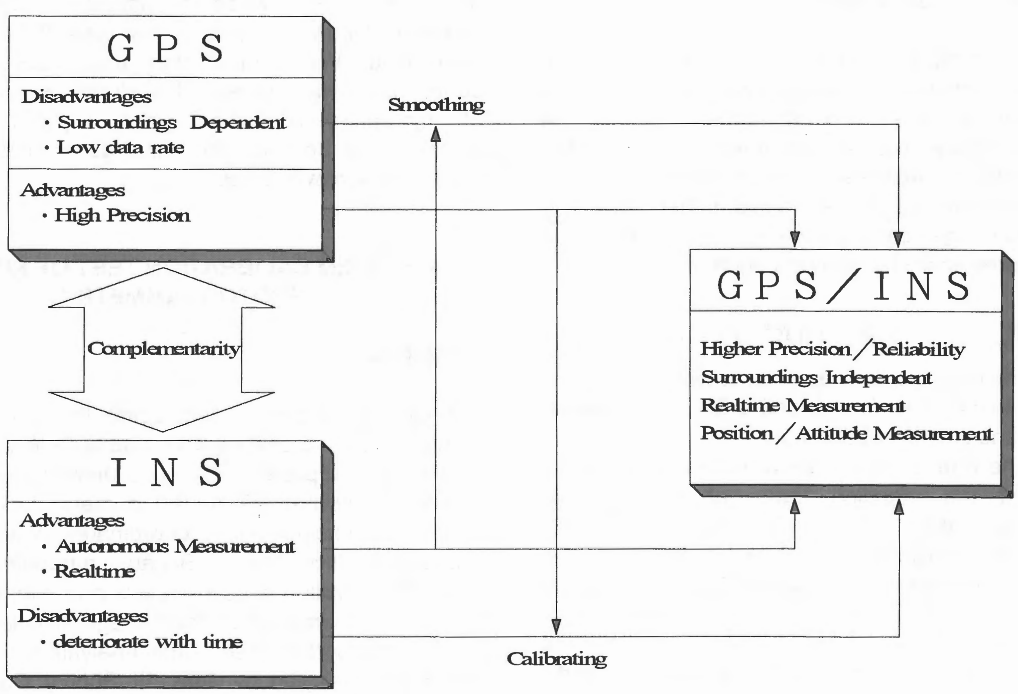

Figure 2 Concept of GPS/INS integration

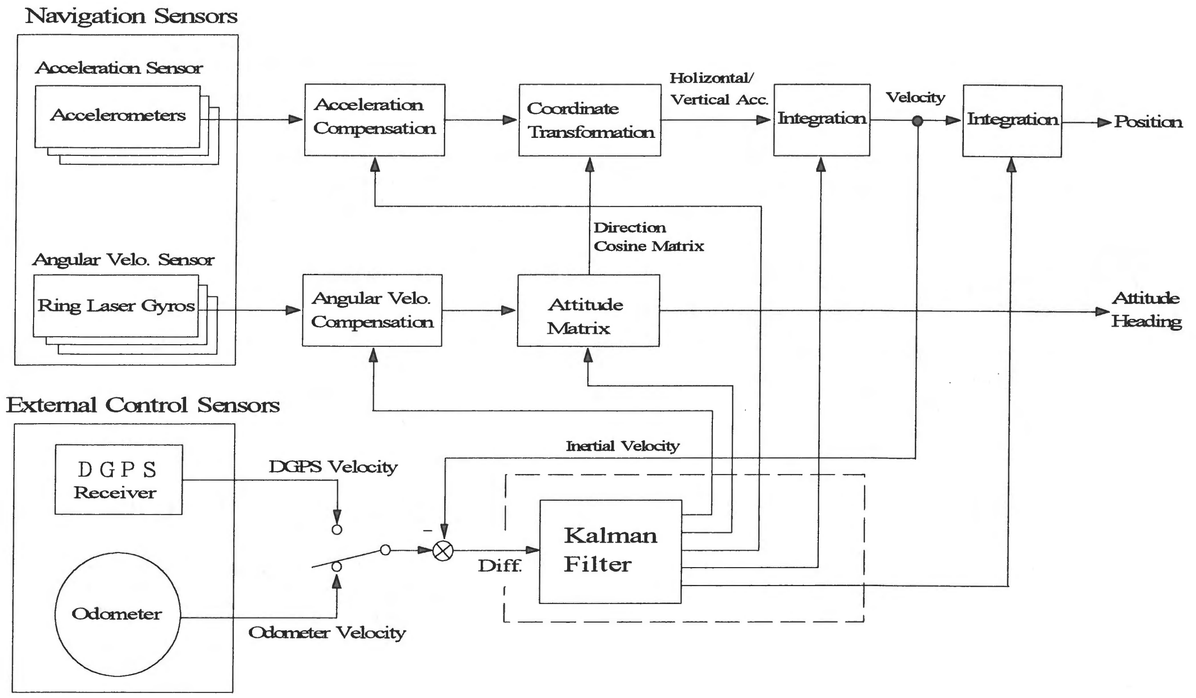

Figure 3 Block diagram of HISS

pair of GPS receivers (Ashtech G-12), and a wheel odometer. Correction data coming from the GPS reference station are transmitted via the digital portable phone in real time. The Kalman Filter utilizes as measured observables the velocity coming from the differential GPS, if available, or odometer inputs. Measured observables are compared with the inertial velocity. And then, the filter can correct position, attitude, horizontal and vertical velocity, inertial error sources and odometer error sources.

2.3 Kinematic Photogrammetry

For mobile mapping, it is indispensable to determine the position and orientation of camera varying moment by moment without any ground control points. A mathematical model that can dynamically compute the exterior orientation parameters, i.e. the camera's position and attitude is provided. Based on this model, objects in collected field images can be linked to the corresponding map coordinates easily by following equation (1).

$$\boldsymbol{r}^m = \boldsymbol{r}^m_{GPS/INS}(t) + \boldsymbol{R}^m_b(t)\left(\boldsymbol{R}^b_c \cdot \boldsymbol{r}^c + \boldsymbol{a}^b\right) \quad (1)$$

$\boldsymbol{r}^m$: the map coordinates of an object

$\boldsymbol{r}^m_{GPS/INS}(t)$: the map coordinates of the GPS/INS position at the time of exposure(t)

$\boldsymbol{R}_b^m(t)$: the rotation matrix between the body frame and the mapping frame at the time of exposure(t)

$\boldsymbol{R}_c^b$: the constant rotation matrix between the camera frame and the body frame

$\boldsymbol{r}^c$: measured image coordinates of an object

$\boldsymbol{a}^b$: the constant vector between the camera perspective center and the center of the body frame

In this way, features on and around roads can be spatially positioned and incorporated into GIS database.

3. FIELD TEST OF GPS/INS INTEGRATION

Field test of GPS/INS integration was carried out in Atsugi City using a vehicle equipped with the HISS. Figure 4 illustrates the trajectory of the measurement vehicle by the differential GPS positioning at the streets. It shows that the positioning accuracy was deteriorated to the order of 10m, when the differential GPS was not available. Likewise, figure 5 illustrates that by the HISS positioning. We verified that the HISS could take continuous measurement of positions without breaking off, and achieve a positioning accuracy of 1 to 2 meters all the times between tall buildings or under elevated roads in downtown areas.

4. SYSTEM CALIBRATION TEST OF KINEMATIC PHOTOGRAMMETRY

4.1 Method

The system calibration test using the strapdown INS (Table 1) and a digital camera (Table 2) was carried out for the two purposes. One is to determine the interior orientation parameters of the camera, i.e. lens focal length (f), principal points coordinates (x_p,y_p) and lens distortion coefficient (k_1,k_2). Because a bundle adjustment with self-calibration is used for this purpose, the exterior orientation parameters of each image are also solved at once. The program used in this analysis is the "ADIMS" that was developed by Asia Air Survey Co., Ltd. The other is to decide the relative position and orientation

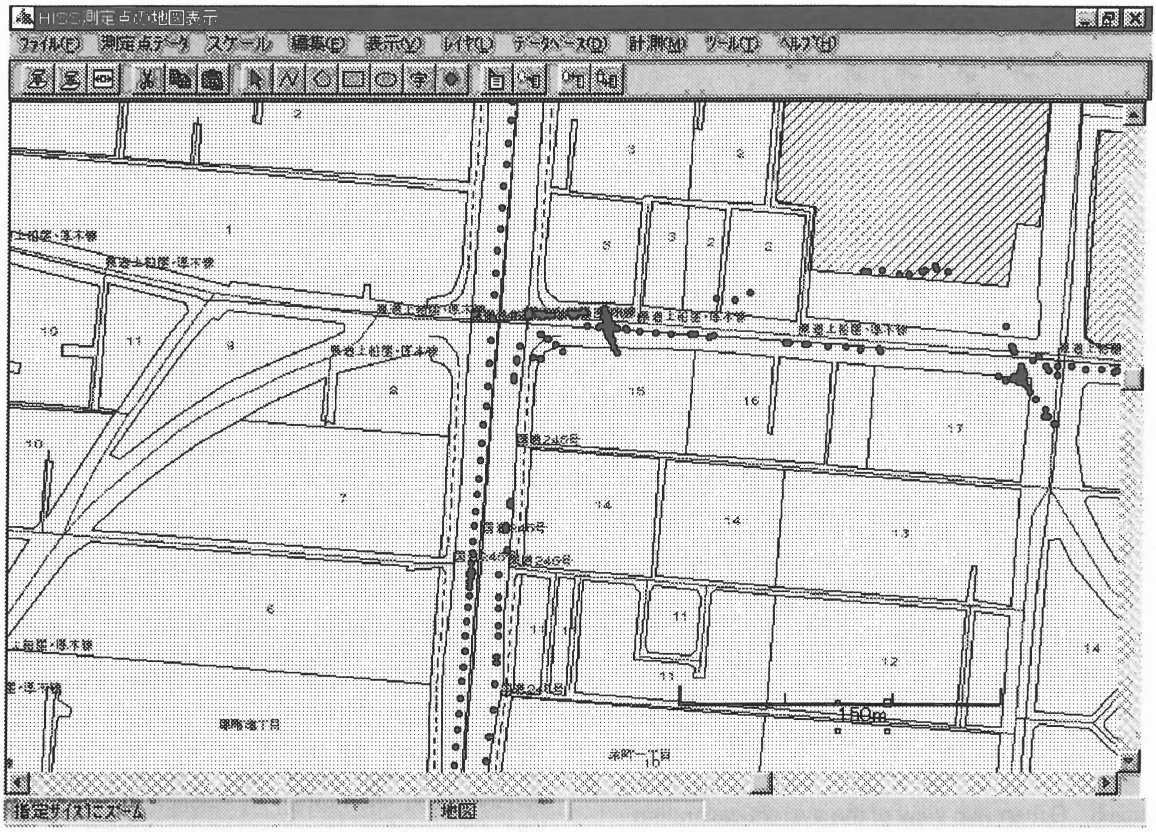

Figure 4 Differential GPS Positioning

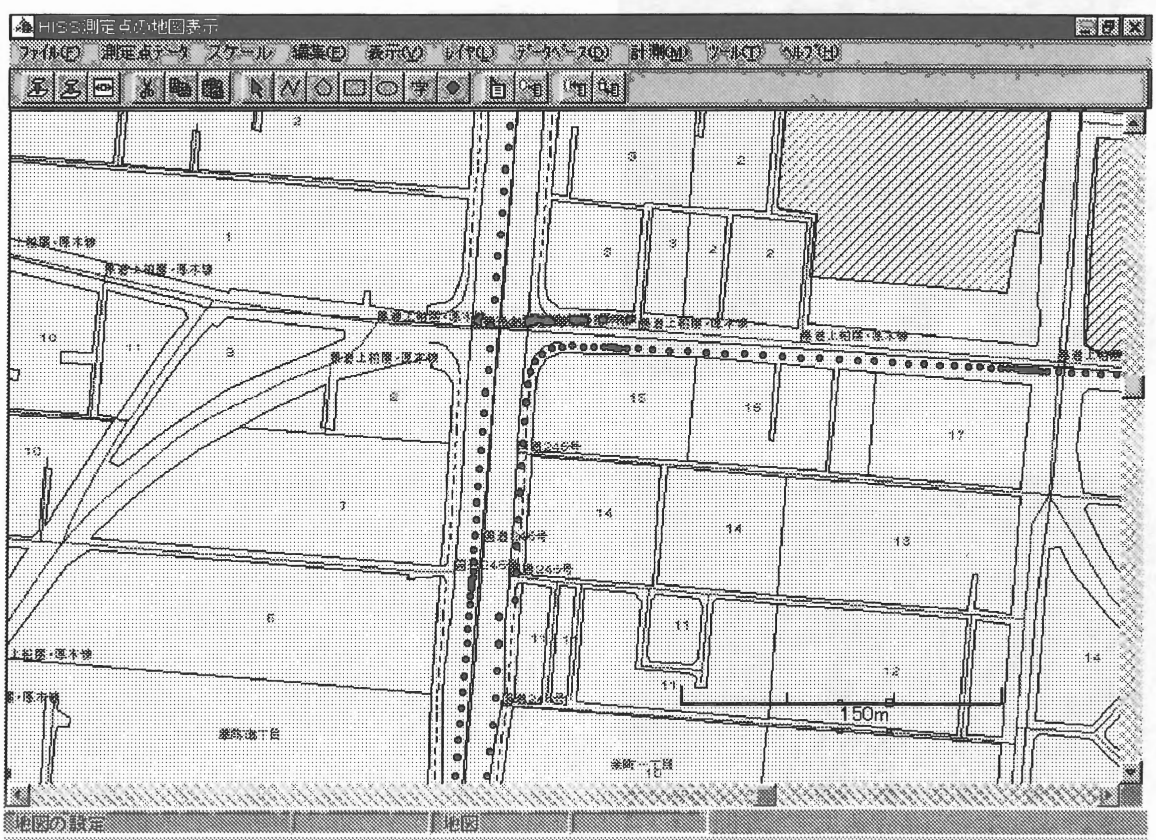

Figure 5 HISS Positioning

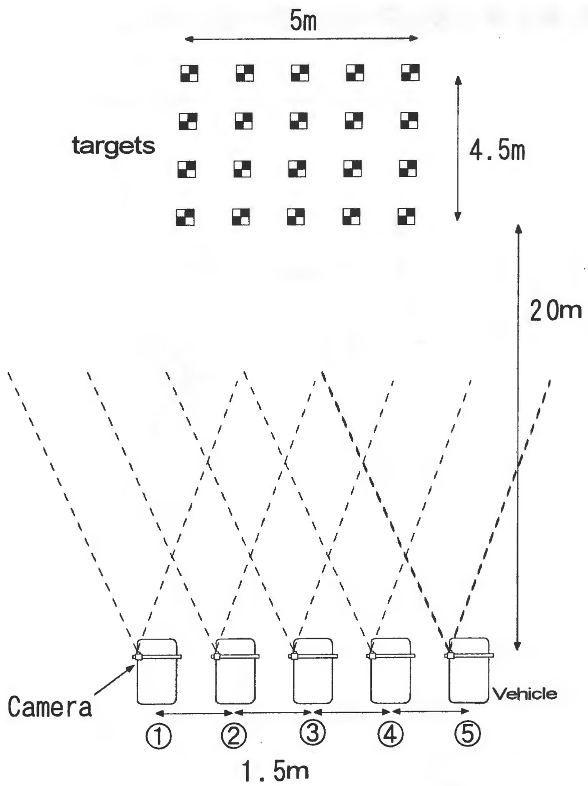

Figure 6 Schematic view of the system calibration

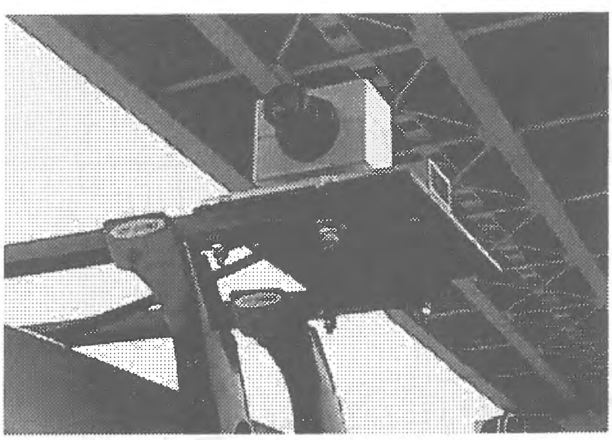
Figure 7 Digital camera with 16mm lens

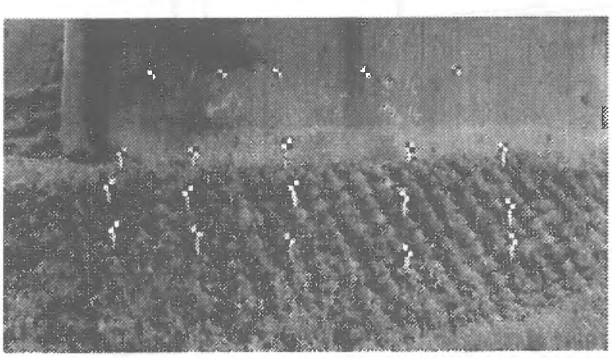
Figure 8 Targets image of system calibration

Table 1 Specifications of the strapdown INS

Accuracy (pure inertial mode)	Attitude(degree)	±0.1
	Heading(degree)	±0.3
Data transfer rate (Hz)		51.2

Table 2 Specifications of the digital camera(HMC-1170)

CCD	chip size :	10mm×8.7mm
	unit cell size :	6.7μm×6.7μm
	number of pixels :	1280×1024
Lens	focal length :	16mm
Body	weight :	470g
	size :	100×83×79.5mm

between the camera and the GPS/INS. Figure 6 shows the schematic view of the test. 20 targets which size is 15cm×15cm were arranged at 20m away from the vehicle. The mapping coordinates of targets were surveyed by the total station. Figure 7 shows the digital camera equipped with a vehicle. When the vehicle was stopped at each point of ①~⑤ in figure 6, each image was taken by the camera and the INS data were recorded at the same time. However they are not synchronized each other. In addition, because the GPS was not used in this test, each position of the GPS antenna was surveyed by the total station. Figure 8 is an example of the image of targets taken by this camera.

4.2 Results

Table 3 shows the results of interior orientation. Table 4 shows the results of the relative position $\boldsymbol{a}^b$ (ΔX,ΔY,ΔZ) and orientation (Δroll,Δpitch,Δyaw) related with $\boldsymbol{R}_c^b$. The variation of the relative position is comparatively large in x- and z-direction. The variation of the relative orientation related with $\boldsymbol{R}_c^b$ is within the error range of the INS accuracy in pure inertial mode. Accordingly, we cannot evaluate accurately this results in this test. However this error of the INS introduces a positioning error of only ±1.7cm for objects 20m away from the vehicle. It is not problem for a medium accuracy mapping.

Table 3 Interior orientation parameters of the camera

		Result	STDV
Correction of focal length	Δf(mm)	0.1206	0.0744
Correction of principal point	Δx_p(mm)	-0.1331	0.0285
	Δy_p (mm)	0.0337	0.1670
Lens distortion coefficient	k_1	5.830E-04	4.150E-04
	k_2	1.337E-05	5.810E-05

Table 4 Calibration results of relative position $\boldsymbol{a}^b$ (ΔX,ΔY,ΔZ) and orientation (Δroll,Δpitch,Δyaw) related with $\boldsymbol{R}_c^b$

	ΔX(m)	ΔY(m)	ΔZ(m)	Δroll (degree)	Δpitch (degree)	Δyaw (degree)
①	0.036	-0.974	-0.035	0.096	-1.011	1.434
②	0.045	-0.982	-0.071	0.114	-1.009	1.812
③	0.044	-0.982	0.010	0.108	-0.994	1.466
④	0.068	-0.981	-0.019	0.084	-0.911	1.601
⑤	0.094	-0.984	-0.037	0.156	-0.920	1.552

5. CONCLUSIONS

We developed the HISS that put the theory of the GPS/INS integration into practice. By field test, it achieved a position accuracy of 1 to 2 meters even in the area where the GPS is not available. Through the fundamental test of system calibration, we verified the validity of the kinematic photogrammetry using the INS without any ground control points.

Now we are planning to develop the integration technique between the GPS/INS positioning and the digital stereo image measurement. To put the mobile mapping system into practice, the following problems must be solved.

- Hardware
  - Time synchronization between the GPS/INS and the stereo camera
  - Mechanical design to prevent the vibration of the stereo camera

- Software
  - Automatic recognition for objects on and around roads
  - Input technique to the GIS database

Mobile Mapping is the coming generation technology that is fused with aerospace technology and the information technology (IT). It will be the most effective tool to support and realize ITS in the approaching 21st century. Moreover, it has the great potential to create new industries such as the service of multimedia contents.

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