THE COMPARATIVE DG ACCURACY ANALYSIS OF A LAND BASED MMS USING LC AND TC INS/GNSS INETEGRATION SCHEMES

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ABSTRACT: The most commercially available INS/GPS integration strategy is known as the loosely coupled (LC) scheme in which the GPS derived positions and velocities are integrated with the INS derived navigation information. The LC takes advantage of a simpler and more flexible architecture to derive navigation information, but the limitation is that the GPS KF will not provide position and velocity solutions as position and velocity updates for the INS KF if less than four satellites are tracked by the GPS receiver. Another commonly available integration strategy is known as tightly coupled (TC) scheme, which processes GPS raw measurements rather than the GPS navigation information to execute measurement updates. It performs well even if less than four satellites are tracked. In the TC, there is only one KF, which processes the accelerations and angular rates from the inertial sensors for navigation. Additionally, the KF also processes the pseudo -range, pseudo-range rate and carrier phase measurements from the GPS receiver. These measurements are used by the filter not only to estimate the navigation solutions, but also the inertial sensors correction parameters, which are used to compensate for the errors of accelerometers and gyros. Therefore, this study aims at investigating the impact of LC and TC INS/GNSS integration schemes on DG accuracy using the land based MMS developed at Department of Geomatics of National Cheng Kung University. The performance analysis is conducted by performing DG with 70 to 80 checking points from those images taken kinematically via proposed MMS van using the POS solutions processed with LC and TC schemes with variable number of visible satellites and comparing with known coordinates of those checking points, respectively.

1 INTRODUCTION

In recent years, Geospatial Information Systems (GIS) is applied in many applications. However, the cost of data acquisition by traditional survey is always a limitation for GIS applications. It is an essential but difficult challenge for establishing GIS database efficiently.The Mobile Mapping System (MMS) is a solution to improve this situation. The absolute position of the interested object can be acquired through direct geo-referencing (DG) because of its high mobility and automation. The platform of MMS can be aircraft, ships, land vehicles or men. It can integrate CCD cameras, video cameras, Laser Scanner, Inertial Navigation system (INS), Dead Reckoning (DR), and Global Navigation Satellite System (GNSS) (El-Sheimy, 2005).This study proposes the architecture of land vehicle-based mobile mapping system as well as the calibration methodology used to verify the performance of the proposed system. The objective of this study is to progress mobile mapping technique and promotes its application in Taiwan.

2 SYSTEM ARCHITECTURES

2.1 Outward Appearance

Fig. 1 illustrates the outlook of proposed MMS van. It comprises the positional and orientation sensors, the CCD cameras, and the time synchronization sensors. The implementation of this system is given below in details.

2.2 The configuration of proposed MMS Van

The configuration of this van includes the power supply, the interior designs and roof rack. The proposed power supply system is able to provide the voltage of 2500 Watts for all the sensors onboard. In addition, the battery used for this system can be re-charged online through vehicle's power supply. Therefore, it can provide seamless power supply for various onboard sensors regardless of operation time. The interior space is in order to mount the central control PC as well as other required accessories in the vehicle. Because vehicle is not a rigid body, thus the roof rack is designed for improving the problem, by keep all the sensors working under identical environments

2.3 Positional and Orientation Sensors

The positional and orientation system (POS) implemented in this study is composed of a tactical grade Inertial measurement unit (IMU) SPAN-CPT with NovAtel ProPak-V3 receiver, as shown in Fig. 2. The GPS measurements were collected by the duel-frequency receiver, OEM-V, which is embedded in the SPAN-CPT and the ProPak V3 receiver located on the Civil-NET™ station setup by the Century Instrument Company as a base station. The raw GPS measurements were processed differentially using the GrafNav^{TM} 8.10 software to provide measurement updates while processing IMUs with LC integration. The GPS updates are only used when the carrier phase ambiguities are fixed. This study aims at investigating the impact of LC and TC INS/GNSS integration schemes on DG accuracy using the land based MMS developed at Department of Geomatics of National Cheng Kung University. The system is suitable in Taiwan where signal obscured is widespread; it can be a mainstream architecture potentially in the seamless positional and orientation system (Chiang et. al, 2008).

2.4 CCD Cameras

Two Basler scouts and two AVT Stingrary digital CCD cameras are applied in this study. Fig. 2 shows the pictures of those cameras. Because those cameras are equipped with electronic shutters, the ability of image acquisition of the proposed MMS van is enhanced significantly.

Fig. 1: The proposed mobile mapping system (MMS)

Fig. 2: SPAN-CPT & NovAtel ProPak -V3 and Basler scout & AVT Stingray

2.5 System Operation

Based on those features mentioned above, the MMS van can obtain the image time tags and the corresponding INS/GPS POS data by interpolation. In this case, the DG formulation is used to calculate object position (El-Sheimy, 1996), as shown in Fig. 3 and Equation (1).

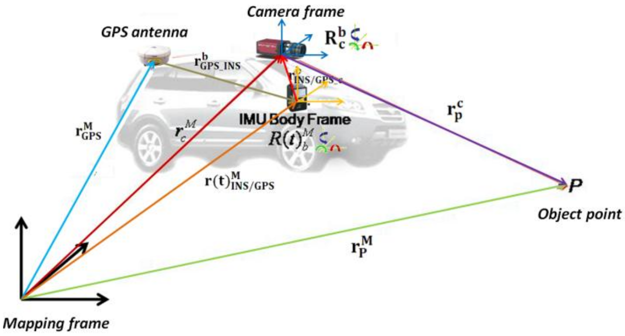


Fig. 3: The concept of DG

$$r_P^M = r(t)^M_{INS/GPS} + R(t)^M_b (r^b_{INS/GPS\_c} + \mu^p_\rho R^b_c r^c_p) \quad (1)$$

Where, r_P^M= the position vector of an object in the chosen mapping frame
$r(t)^M_{INS/GPS}$= the position vector of INS/GPS in the m frame at time (t)
$R(t)^M_b$= the 3-D transformation matrix which rotates the body frame (or INS frame) into m-frame;

r^{b}_{INS/GPS_c}= the lever arm vector which is from the body frame to the camera frame
μ^{P}_{p}= a scale factor specific to a one-point/one-camera combination which relates the image coordinates to the object coordinates
R^{b}_{c}= the boresight transformation matrix which rotates the camera frame into body frame
r^{c}_{p}= the vector of image coordinates given in the c-frame

The elements of r^{c}_{p} is obtained from measuring image coordinates; μ^{P}_{p} is determined by the stereo techniques; $R(t)^{M}_{b}$ and $r(t)^{M}_{INS/GPS}$ are interpolated from INS/GPS integrated POS at the exposure time (t); those elements are known. The vector between the phase center of the GPS antenna and the center of IMU (r^{GPS}_{b}) is an unknown parameter, but it is determined through a surveying process. The calibration process must be conducted if the DG formulation has to be complete. Those procedures include lever arm and boresight parameters, that determine r^{b}_{INS/GPS_c} and R^{b}_{c} separately.

Before processing calibration, the sufficient quantity of ground control points (GCPs) has been estimated. Then the lever arm and boresight parameters can be derived through the bundle adjustment.

Therefore, the top priority is to establish a sufficient accuracy control field after the complete constructed MMS hardware architecture. The control field is applied in the MMS calibration and the test of DG capability in this research. The following explains how to build a control field.

3 LOOSELY AND TIGHTLY COUPLED INTEGRATION

The most common integration scheme used today is loosely coupled (LC) integration. The typical LC integration architecture is shown as Fig. 4. The position and velocity of the estimated by the GPS KF is processed in the navigation Kalman filter to aid the INS, which is known as decentralized or cascaded filtering as well. This kind of integration has the benefit of a simpler architecture which is easy to utilize in navigation systems. However, the errors in the position and velocity information provided by the GPS KF are time-correlated, which can cause a degradation in performance or even instability of the navigation Kalman filter, if these correlations are not considered by some means. In the case of incomplete constellations, i.e. less than four satellites in view, the output of the GPS receiver has to be ignored completely, leaving the INS unaided.

The tightly coupled integration uses a single Kalman filter to integrate GPS and IMU measurements. Fig. 5 describes the TC integration architecture. The Fig. shows that the raw measurements are collected from the IMU and are converted to position, velocity and attitude measurements in the desired coordinate system using the INS mechanization algorithms. In the TC integration, the GPS pseudo-range, delta-range and carrier phase measurements are processed directly in the main Kalman filter (Hide and Moore, 2005). The aiding of the receiver tracking loops using velocity information provided by the INS is an essential characteristic of a tightly coupled system, too. The primary advantage of this integration is that raw GPS measurements can still be used to update the INS when less than four satellites are available. This is of special benefit in a hostile environment such as downtown areas where the reception of the satellite signals is difficult due to obstruction. Also, in the case when carrier phase GPS measurements are used, the IMU measurements will be used to aid the ambiguity resolution algorithm. However, the TC integration is not commonly used to integrate GPS and INS simply because of its additional complexity over the loosely coupled approach.

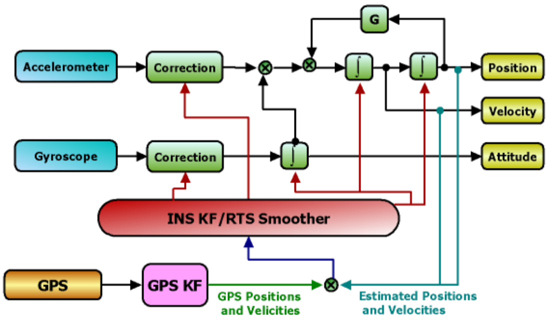


Fig. 4: A loosely coupled INS/GPS integration architecture

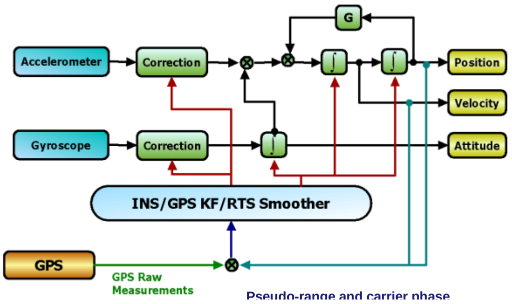


Fig. 5: A Tightly coupled INS/GPS integration architecture

4 RESULT AND DESCUSSION

4.1 The Verification of the DG Capability Affected by LC and TC schemes

Fig. 7 illustrates the trajectory of the capability of the DG tests. The proposed MMS van started at the point S, and drove down along the blue track. The trigger was controlled by DR with 8 meters interval, the cameras performed image acquisition after receiving trigger pulse, and the time synchronization sensor recorded the time tag simultaneously.

The DG module coded in Visual Studio 2008 C++ platform is applied to calculate the coordinate of the check points. As shown in Fig. 27. The information such as the coordinates of the control points, the IOPs, and EOPs can be imported to the program. To diminish the errors caused by the image point measurements, it can tag the correspondence image point of the check point in other images through back projection of collinearity formula, as shown in the A segment of Fig. 8. Moreover, the program uses this conception to search the images where the check points existed from dataset automatically. Those images searched are displayed at the bottom of the interface as shown in the B segment. The users can perform the image point measurements in each image, and the result of the space intersection are obtained from the various images that have the common interested points in sight, as shown in the C segment.

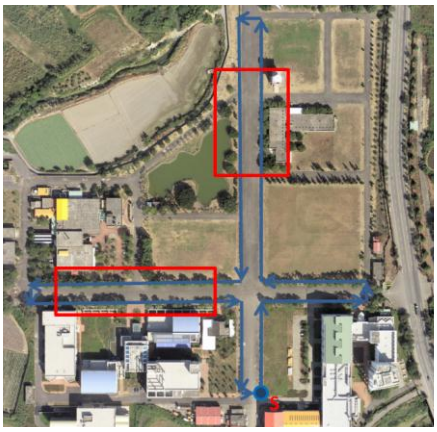
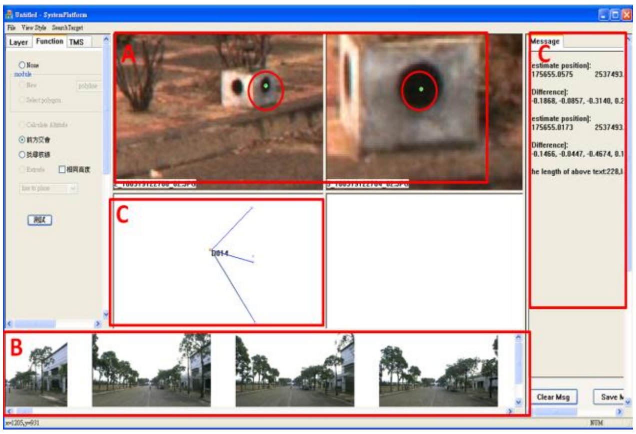


Fig. 7: The trajectory of the MMS test



estimate position]:
175655.0575 2537493.

Difference]:
-0.1868, -0.0857, -0.3140, 0.2

estimate position]:
175655.0173 2537493.

Difference]:
-0.1466, -0.0447, -0.4674, 0.1

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Fig. 8: The interface of the DG software

The reference coordinates of the check points are obtained through the precise control survey, and each check point is independence. Therefore, the coordinate from DG are then compared with their reference coordinate.

The DG software applied in this research uses those images acquired from the different view to process the space intersection. In this situation, the sufficient geometric condition and the clear image can be constructed and acquired.

4.1.1 The variation of visible GPS satellite

Fig. 9 show the **variation of visible satellite scenario** is simulated by removing satellites based on elevation angle to verify the relation of tracking and DG capability.

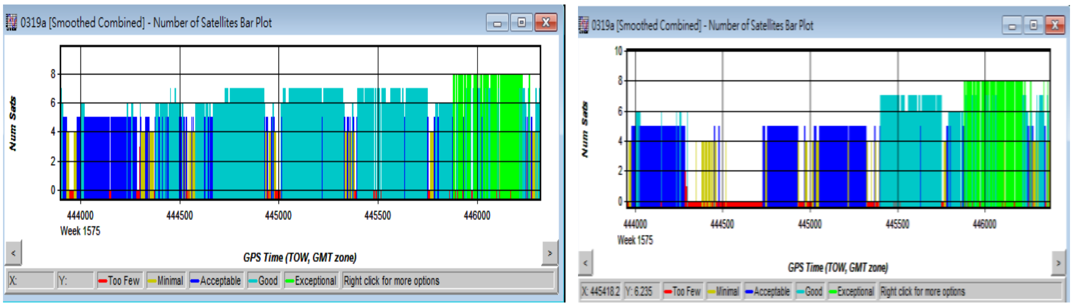

Fig. 9: GPS satellite number

The reference trajectory is generated with TC schemes with full GPS satellite reception and the elevation angle is 10 degree. The testing scenarios are processed by LC and TC schemes with reduced number of **visible GPS satellite**. The delta that is deviation between testing tracking and reference tracking represents the accuracy of testing tracking. Fig. 10, 11 and Table 2 illustrate the comparable analysis of positioning and orientation accuracy in POS solutions domain. Generally speaking, the performance of TC schemes is more stable them that of LC counterpart. As shown in Table 2, the TC scheme improves the horizontal positioning accuracy by 80% in average with reduced number of visible GPS satellite; on the other hand, the improvement in terms of vertical positioning accuracy is less around 50%. In contrast, the performances in term of attitude estimation accuracy between those schemes are similar.

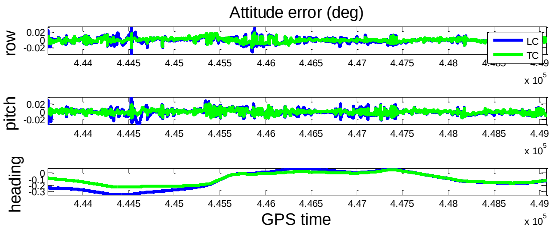

Fig. 10: The comparison of attitude errors

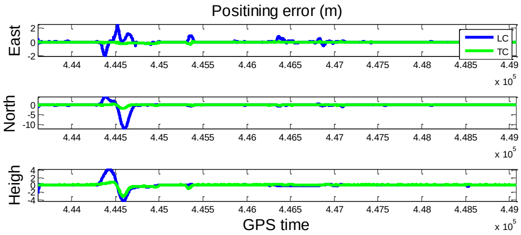

Fig. 11: The comparison of positioning errors

Table 2: Comparable error analysis in positioning domain

	LC error			TC error		
	AVG	STD	RMS	AVG	STD	RMS
East (m)	0.0314	0.2933	0.2949	-0.0193	0.0558	0.0591
North (m)	-0.1605	1.5572	1.5654	-0.0206	0.2049	0.2059
Height (m)	-0.0185	0.8030	0.8033	0.0035	0.3972	0.3972
Roll (Deg)	-0.0008	0.0062	0.0063	0.0000	0.0047	0.0047
Pitch (Deg)	-0.0012	0.0072	0.0073	0.0004	0.0049	0.0050
Heading (Deg)	-0.1181	0.1388	0.1822	-0.093	0.0900	0.1292

Furthermore, Fig. 12 and 13 provide performance comparison between the DG accuracy of those checking points by comparing the results provided by the DG modules measuring those checking points derived from those POS solutions provided by LC and TC schemes with reduced number of visible satellite with known coordinates pre-surveyed. The checking points covered by red rectangular shown in those figures were measured with NVS smaller than four, thus their positioning accuracies decrease rapidly with LC scheme in Fig. 12. On the other hand, the positioning accuracies of those checking points remain relatively stable when TC scheme is applied, as shown in Fig. 13.

In addition, Table 11 illustrates the comparable error analysis of those schemes in DG domain with full NSV and reduced NVS (<4). AS shown in Table 11, the performances in term of DG positioning accuracy based on LC and TC schemes are comparable. However, the DG positioning accuracy with TC scheme is improved by 80% in terms of 3-D positioning accuracy compared to the DG positioning accuracy with LC scheme. Therefore, based on the preliminary results shown in this study, the TC scheme is able to provide more robust and stable results for land MMS applications where GNSS signal reception are challenged by environments.

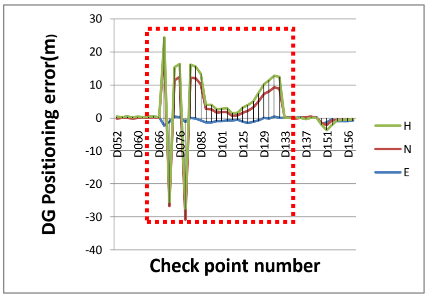

Fig. 12: The DG positioning error of using LC

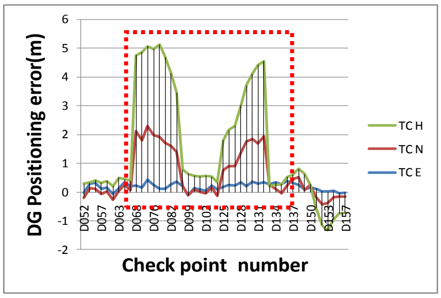

Fig. 13: The DG positioning accuracy using TC

		LC			TC		
		E	N	H	E	N	H
Full NVS	AVG (m)	0.096	0.007	-0.114	0.032	-0.019	-0.051
	STD (m)	0.076	0.106	0.117	0.074	0.066	0.155
	RMS (m)	0.122	0.105	0.163	0.080	0.068	0.161
	2D(m)	0.130			0.099		
	3D(m)	0.176			0.184		
NVS< 4	AVG (m)	-0.431	2.026	1.164	0.185	0.391	0.912
	STD (m)	0.693	8.129	1.553	0.133	0.768	1.176
	RMS (m)	0.810	8.292	1.927	0.227	0.854	1.478
	2D (m)	8.330			0.885		
	3D(m)	8.551			1.722		

Table 3: Comparable error analysis in DG domain

5 CONCLUSIONS

This research proposes the architecture of a land-based vehicle MMS, its calibration methodology and simulates the GPS outage and verifies the relation of tracking and DG result. A two-step approach was proposed to process lever arm and boresight calibration. In the result of the lever arm calibration, 2cm standard deviation can be achieved. But in the result of boresight, the standard deviation of the angle ranges from 0.23 to 1.2 degree. The convergence of meridian and the stability of the roof rack may be the factor.

The accuracy of DG capability in term of the positioning accuracy of the proposed is less than 15cm (HPE) and 20cm (3D) in GCPs free environments. The result is higher than the estimation obviously. Using the images which are all acquired from the different view, it is contributed significantly for the DG capability of MMS significance. Nevertheless, comparing to other globally available commercial MMS van, the DG performance of the proposed MMS is expected to be improved especially in the system calibration aspect.

The performance of TC schemes is more stable them that of LC counterpart. The TC scheme improves the horizontal positioning accuracy by 80% in average with reduced number of visible GPS satellite; on the other hand, the improvement in terms of vertical positioning accuracy is less around 50%. In contrast, the performances in term of attitude estimation accuracy between those schemes are similar. the performances in term of DG positioning accuracy based on LC and TC schemes are comparable. However, the DG positioning accuracy with TC scheme is improved by 80% in terms of 3-D positioning accuracy compared to the DG positioning accuracy with LC scheme. Therefore, based on the preliminary results shown in this study, the TC scheme is able to provide more robust and stable results for land MMS applications where GNSS signal reception are challenged by environments.

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