RESEARCH ON POSITIONING AND POSING OF MOBILE MAPPING IN METROPOLIS

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WG ICWG V/I - Integrated Systems for Mobile Mapping

KEY WORDS: Mobile mapping, GPS Doppler measurement, Dynamic characteristic analysis, Network RTK, Position data filtering

ABSTRACT:

Mobile mapping, a revolutionary surveying and mapping technology with multi-sensor and 3S (GPS, GIS and RS) integration, is a typical approach to satisfy the upcoming demand for efficient data capture and updating of geo-spatial data in traditional methods limited situation. The positioning and posing sub-system provides direct georeferencing for mobile mapping. The issue on how to ensure the positioning accuracy in metropolis is highlighted. Generally, it is solved by integration with differential GPS and INS/DR. Another side, network RTK has more advantages such as real-time data processing, no base and no working range limitation, is more suitable for city mobile mapping, but its signals are significantly affected by city environment. The paper presents a solution to filter the network RTK dynamic positioning data, and improve the ability and reliability for mobile mapping direct georeferencing. We analyzed city mobile platform's positioning data in different GPS modes, including DGPS, network RTK, and got the dynamic characteristics. GPS Doppler measurement provides cm/s level 3D speed even in single GPS mode without the requirement of GPS ambiguity issue in 0.1s interval, then used to filter rude data in network RTK 1s interval positioning data. Experiments were performed with the mobile mapping field work in Yan'an Road of Shanghai, which involves overhead mainlines, viaducts, skyscrapers, and other typical city characteristics. The filter results proved that this filter method is effective in extinguishing errors in dynamic network RTK data and improving the reliability of mobile mapping positioning data.

1. INTRODUCTION

Mobile mapping technology has been researched and developed since the late 1980s. The original use of mobile mapping is for highway infrastructure management and transportation inventory (Li, 1997). With the civilian use of GPS technology, its continuous positioning and posing was settled by GPS and INS (inertial navigation system) or DR (dead reckoning) for the mobile track and then gave the DG (direct georefenencing) capability (Schwarz, 1993) to each spatial observing data, such as CCD image, laser scanning and etc. The mobile mapping system is capable of providing an absolute positioning accuracy of 0.3m and a relative accuracy of 0.1m for object points within a 30-m corridor, at vehicle speeds of 50~60 km/h (Li et al., 1994; Tao, 1999). Mobile mapping is one of the typical survey technology of the 3S (GPS, RS, GIS) integration and multi-sensor fusion (Li, 1997; GreJner et al., 2004). Now it is more and more widely applied in large-scale mapping (1:2000, or even larger scale) with no requirement on ground control points, and GIS database updating. Its outstanding advantages are high efficiency (field survey with the mobile platform speed as 60 km/h) and low cost (only 1/4 or even lower compared to traditional method) (Li, 2006).

The positioning and posing sub-system, which is a core part of MMS, provides MMS direct georeferencing for standalone surveying. The reliability and accuracy plays a very important role in MMS. How to improve positioning and posing capability, especially in the complicated circumstances of metropolis, is a highlighted issue. Mobile platform's uninterrupt track acquisition comes from GPS constraint and INS/DR's connection while GPS out of service (Li, 1997). Track accuracy is mainly influenced by the blocked span of GPS signal and weak GPS positioning ability in complicated city region, such as surrounded by overhead road, high buildings, crossing viaduct, tunnel and etc.

According to data-capture methods, the GPS data process mode can be classified as Differential GPS (DGPS), Real Time Kinetic (RTK), and network Real-Time Kinetic (network RTK) (Wang, 2001). In them, DGPS has three characteristics: a stable base station is required, data is post processed, and the working range is limited to 30 kilometres. RTK, besides real-time data processing and a 10-kilometer working range limitation, a stable base station which can emit radio signals to the MMT platform is used. Similar to RTK, network RTK also has the advantage of real-time data processing, yet it has no working range limitation while the base-stations' network is built in the whole area, for example, the whole region of Shanghai has been covered by 7 base-stations (Ji, 2007). Totally, network RTK is superior to the other two methods when MMS is working in areas such as the big cities where are covered by the base-stations' network. However, the radio signals sent out from base station may be significantly affected by the environment factors in urban areas. There are problems such as signal sheltering and multi-path caused by complex constructions just as the forest of city skyscrapers and overhead bridges. In general, network RTK need several seconds to get a steady solution for certain position, but land-based mobile mapping always works as a certain moving speed. DGPS can receive data in time interval of

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0.1s, and network RTK gets data as 1 second interval. Besides, data transmit in network RTK depends on wireless communication system, e.g. GPRS, and that is also quite complex influenced in city. All of these will affect the positioning and posing accuracy of mobile mapping compared to the usual DGPS mode, thus undermine the reliability of geo-spatial data surveying. New method should be developed on how to do the positioning work with dynamic network RTK in city.

2. PRINCIPLE

Currently, most GPS receiver can provide the measurement data of Doppler frequency variation while recording the pseudo-range data synchronously. Each GPS satellite's 3D position and speed can be calculated in high accuracy with the given ephemeris data anytime. The significant meaning of Doppler measurement is that rover's accurate dynamic state can be derived without the known of ambiguity of GPS range between satellite and receiver. Furthermore, the Doppler frequency variation between satellite and receiver is less influenced by the atmosphere compared to pseudo-range signal. No base station is needed to obtain the land receiver's dynamic state, just as 3D speed in the accuracy of 0.1 m/s. Besides, the accuracy also can be improved to mm/s level while base station is used (Sun, 2004; He, 2002; Xiao, 2003). This has important meaning about improving the mobile platform track's accuracy with static known point while network RTK positioning data for mobile mapping in weak conditions. Following is the concrete analysis of how to obtain GPS rover receiver's 3D speed with Doppler measurement data.

According to the Doppler kinetic theory, there is:

$$\dot{\tilde{\rho}} = \lambda \cdot df \tag{1}$$

where df is the Doppler measurement,
λ is GPS carrying wave's length and
$\dot{\tilde{\rho}}$ is relative speed vector between satellite and receiver antenna (including errors).

Then, after the satellite sub-speeds along with the global coordinate system axis is calculated with the given ephemeris data, the receiver antenna's corresponding sub-speed can also be calculated with the Doppler data. Because there are three unknown speeds and time variations to receiver, four satellites at least are needed together to resolve the unknown variations.

2.1 GPS dynamic speed calculation based on single receiver

The basic GPS pseudo-range observing equation is:

$$\tilde{\rho}_i^j = \rho_i^j(t) + dt_i(t) - dt^j(t-\tau_i^j) + I_i^j(t) + T_i^j(t) + \varepsilon_c(t) \tag{2}$$

where i is number of receiver,
j is number of satellite,
t is the time moment in GPS time system that receiver get signal,
τ_i^j is time consumed of signal from satellite to receiver,
$\tilde{\rho}_i^j$ is the pseudo-range between receiver i and satellite j,
ρ_i^j is the spatial-range between receiver i and satellite j,
dt^j is equivalent range in the time offset of satellite clock to GPS time system,
dt_i is equivalent range in the time offset of receiver clock to GPS time system,
I_i^j is the equivalent range delayed in ionosphere,
T_i^j is the equivalent range delayed in troposphere,
ε_c is the light-range of measurement noise.

Expanding ρ_i^j and combining I_i^j and T_i^j into one, then get:

$$\tilde{\rho}_i^j = \sqrt{(X_i - X^j)^2 + (Y_i - Y^j)^2 + (Z_i - Z^j)^2} + dt_i - dt^j + \Delta_i^j + \varepsilon_c \tag{3}$$

where (X_i, Y_i, Z_i) is receiver's spatial position,
(X^j, Y^j, Z^j) is satellite spatial position,
$\rho_i^j = \sqrt{(X_i - X^j)^2 + (Y_i - Y^j)^2 + (Z_i - Z^j)^2}$
Δ_i^j is the equivalent spatial range of atmosphere delayed.

Then, the basic receiver speed calculating equation of Doppler measurement can be derived as the differential coefficient on $(X_i - X^j), (Y_i - Y^j), (Z_i - Z^j)$ as following:

$$\dot{\tilde{\rho}}_i^j = [l_i^j \; m_i^j \; n_i^j \; 1] \begin{bmatrix} \dot{X}_i \\ \dot{Y}_i \\ \dot{Z}_i \\ d\dot{t}_i \end{bmatrix} - [l_i^j \; m_i^j \; n_i^j] \begin{bmatrix} \dot{X}^j \\ \dot{Y}^j \\ \dot{Z}^j \end{bmatrix} - d\dot{t}^j + \dot{\Delta}_i^j + \varepsilon_{\dot{\rho}} \tag{4}$$

where $\dot{\tilde{\rho}}_i^j$ is a measurement of pseudo-range variation,
$(\dot{X}_i, \dot{Y}_i, \dot{Z}_i)$ is the receiver spatial 3D speed,

$(\dot{X}^j, \dot{Y}^j, \dot{Z}^j)$ is the satellite 3D speed,

$d\dot{t}_i$ is the variation of receiver clock offset,

$d\dot{t}^j$ is the variation of GPS clock offset,

$\dot{\Delta}_i^j$ is variation of atmosphere delay,

$l_i^j = \frac{X_i - X^j}{\rho_i^j}, m_i^j = \frac{Y_i - Y^j}{\rho_i^j}, n_i^j = \frac{Z_i - Z^j}{\rho_i^j}$, $\varepsilon_{\dot{\rho}}$ is noise.

On the other side, satellite 3D speed can be obtained with the navigation data. Based on equation(4), if no considering on the variation of satellite clock offset, variation of atmosphere delay, there are four unknown parameters as $(\dot{X}_i, \dot{Y}_i, \dot{Z}_i)$ and $d\dot{t}_i$.

If GPS antenna can receive four or more satellite signals simultaneously, these parameters can be resolved. In the single receiver's Doppler measurement, no base is needed, and because the error from satellite and atmosphere factors can be not considered, its speed accuracy is limited as 0.1 meter/s. The higher accuracy solution should turn to differential GPS

2.2 GPS dynamic speed calculation based on differential GPS

According to equation (4), GPS base station's speed calculation can be described as:

$$\dot{\tilde{\rho}}_0^j = [l_0^j \; m_0^j \; n_0^j \; 1] \begin{bmatrix} \dot{X}_0 \\ \dot{Y}_0 \\ \dot{Z}_0 \\ d\dot{t}_0 \end{bmatrix} - [l_0^j \; m_0^j \; n_0^j] \begin{bmatrix} \dot{X}^j \\ \dot{Y}^j \\ \dot{Z}^j \end{bmatrix} - d\dot{t}^j + \dot{\Delta}_0^j + \varepsilon_{\dot{\rho}^0} \tag{5}$$

Base station is always stationary and its 3D speed is zero, and variation of atmosphere delay can be regarded as the same in base and rover, so equation (4)-(5) can get the differential Doppler basic speed calculation equation as following:

$$\Delta \dot{\tilde{\rho}}_{i0}^j + \Delta a_{io}^j \begin{bmatrix} \dot{X}^j \\ \dot{Y}^j \\ \dot{Z}^j \end{bmatrix} = [l_i^j \; m_i^j \; n_i^j \; 1] \begin{bmatrix} \dot{X}_i \\ \dot{Y}_i \\ \dot{Z}_i \\ d\dot{t}_i - d\dot{t}_0 \end{bmatrix} + \Delta\varepsilon_{\dot{\rho}} \tag{6}$$

Where $\Delta \dot{\tilde{\rho}}_{i0}^j = \dot{\tilde{\rho}}_i^j - \dot{\tilde{\rho}}_0^j$ and

$\Delta a_{io}^j = [l_i^j - l_0^j \;\; m_i^j - m_0^j \;\; n_i^j - n_0^j]$.

Then if differential again in different satellites to the same position of rover, the unknown value of receiver clock offset $d\dot{t}_i - d\dot{t}_0$ can also be erased and the following equation can be derived:

$$\nabla\Delta \dot{\tilde{\rho}}_{i0}^{jk} + \Delta a_{io}^j \cdot V^j - \Delta a_{io}^k \cdot V^k = [l_i^j - l_i^k \;\; m_i^j - m_i^k \;\; n_i^j - n_i^k] \begin{bmatrix} \dot{X}_i \\ \dot{Y}_i \\ \dot{Z}_i \end{bmatrix} + \nabla\Delta\varepsilon_{\dot{\rho}} \tag{7}$$

where $\nabla\Delta \dot{\tilde{\rho}}_{i0}^{jk} = \Delta \dot{\tilde{\rho}}_{i0}^j - \Delta \dot{\tilde{\rho}}_{i0}^k$,

$V^j = \begin{bmatrix} \dot{X}^j, & \dot{Y}^j, & \dot{Z}^j \end{bmatrix}^T$.

In Doppler speed calculation equations above, the measurements are obtained based on GPS phase carrying-wave, which has quite high accuracy and noise is only 0.01 Hz. Totally, speed calculation based on differential Doppler would reach the accuracy of mm/s level. Besides, the common question of GPS ambiguity resolution does not exist in the speed calculation.

2.3 Network RTK filtering by 3D kinetic state from Doppler or DGPS

In fact, DGPS can provide 0.1s interval's positioning data with good position accuracy, thus also reflect the mobile platform's dynamic characteristic in time compared to the network RTK's 1s interval position data sampling. The following is the 3D speed calculation by DGPS sequential data.

$$\begin{cases} \dot{X}_i = \left[(X_i - X_{i-1}) \cdot t_2 / t_1 + (X_{i+1} - X_i) \cdot t_1 / t_2 \right] / (t_1 + t_2) \\ \dot{Y}_i = \left[(Y_i - Y_{i-1}) \cdot t_2 / t_1 + (Y_{i+1} - Y_i) \cdot t_1 / t_2 \right] / (t_1 + t_2) \\ \dot{Z}_i = \left[(Z_i - Z_{i-1}) \cdot t_2 / t_1 + (Z_{i+1} - Z_i) \cdot t_1 / t_2 \right] / (t_1 + t_2) \end{cases} \tag{8}$$

In equation (8), $(X_{i-1},Y_{i-1},Z_{i-1})$ and $(X_{i+1},Y_{i+1},Z_{i+1})$ are the nearest before and after points of (X,Y,Z), t_1 and t_2 are the time intervals.

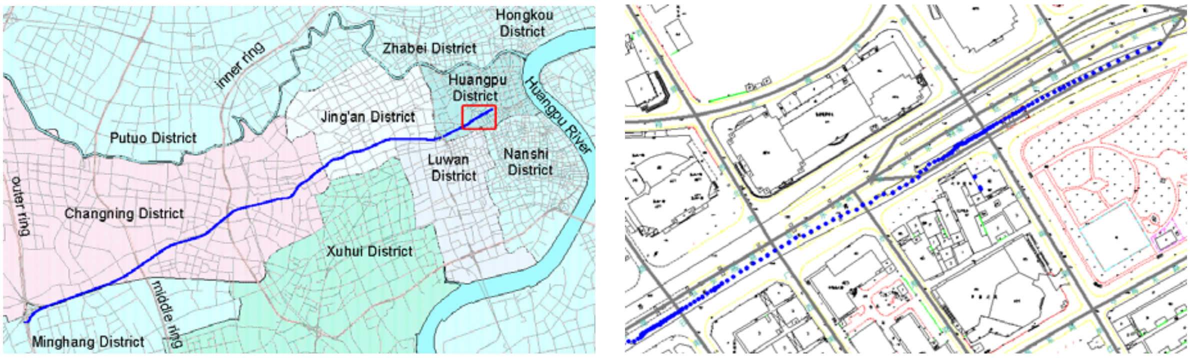
Positioning data from different GPS have the same time-tagged in the same spatial place of mobile mapping field work. Thus, the actual mobile platform characteristic (at least, more reliable and accurate description than the original network RTK reflected) such as instant 3D speed can be indexed from Doppler measurement or DGPS for corresponding network RTK sequential positioning data. Supposed the seed points in network RTK is correct by pre-check in the mobile route, the other points can be predicted by speed integrated gradually. Then check the whole network RTK data and filter the error points with certain 3D spatial distance thresholds, which are expressed as following equations:

$$\begin{cases} X_i^{'} = X_0 + \sum_{j=1}^{n} \dot{X}_j \cdot t_j, \left| X_i - X_i^{'} \right| \le \alpha \cdot T_x \\ Y_i^{'} = Y_0 + \sum_{j=1}^{n} \dot{Y}_j \cdot t_j, \left| Y_i - Y_i^{'} \right| \le \beta \cdot T_y \\ Z_i^{'} = Z_0 + \sum_{j=1}^{n} \dot{Z}_j \cdot t_j, \left| Z_i - Z_i^{'} \right| \le \gamma \cdot T_z \end{cases} \quad (9)$$

In equation (9), (X'_i,Y'_i,Z'_i) is the predicted position of (X_i,Y_i,Z_i), and (T_x,T_y,T_z) are the given 3D spatial thresholds, (α,β,γ) are coefficients that calculated according to the steps from the initial place. These linear varying coefficients are calculated by the check points in the field work route.

3. DATA

The mobile mapping field work is done on Nov 2007 in Shanghai, the biggest city of China. The experiment data collected from the period of Yan'an Road. It covers the typical surroundings of metropolis, such as overhead road, viaduct crossing, large amount of skyscrapers along the two sides of road, heavy and variable transportation and so on. These factors do complicated influence to the GPS signals and wireless communication signals of network RTK together. There is 1858 network RTK position points is obtained altogether along the road. From the concrete check, these points include different kinds of solutions, such as pseudo-range GPS, differential GPS, RTK and so on. The smallest time interval between two data is 1 second. The whole contribution is expressed as the following figure (see Fig.1).



(a) (b)

* blue curve expresses the whole route of network in (a); (b) is the red rectangle zoomed in (a) and blue points in (b) is the network RTK data.

Fig.1 Mobile mapping's network RTK data on Yan'an Road

4. EXPERIMENT AND RESULT ANALYSIS

As we know, network RTK position data's accuracy and reliability are affected by GPS signal and wireless communication network, and mobile mapping platform is always in moving state. Then the actual network RTK data always include differential GPS with different base of the base-network, and single point positioning result. Besides, GPS is always much better on the horizontal plane positioning than the vertical plane. In the filtering experiment, horizontal speed and vertical speed are considered separately. The following figure (see Fig.2) shows the result comparing to the original data (red points show the filtered result, blue points is the original which means filtered).

Fig.2 shows a part of filtered result of network RTK points. From the result, it is easy to know that the filtering work can smooth the error of network RTK. There are 1858 network RTK points and the remains after filtering processing are 1467, 1532 and 1587 points with three different thresholds (see Tab.1). In order to simplify the filtering difference and find the common knowledge in different kind of network RTK data in mobile mapping, the variable thresholds of XYZ are set in the same scale each time. There are five kinds of point solutions in network RTK mode: solid unavailable, pseudo-range, differential GPS, solid RTK and float RTK. In general surveying work, the accuracy is from low to high as the above order. From Tab.1, we find that positioning data filtered are not only marked as pseudo-range point positioning and float differential GPS in network RTK data, but a rather big partition is the class of solid differential positioning result (It is shown more clearly in Tab.1); what is more, each kind of network RTK point maintains a quite steady portion in different given filtering threshold. So it means that the prior knowledge about accuracy of pseudo-range positioning is low, differential GPS and RTK positioning is high is not absolutely reliable in mobile mapping work in dynamic measurement as mobile mapping, and more research should be done in the complicated relationship in GPS dynamic measurement and communication factors in mobile mapping work.

Fig.2 Filtered result of network RTK based on platform dynamic characteristic

	solid solution unavailable	pseudo-range solution	differential GPS solution	solid RTK solution	float RTK solution	Total
original point num and portion of total	10, 0.5%	741, 39.9%	362, 19.5%	388, 20.9%	357, 19.2%	1858
filter remained (Tx,Ty,Tz=5.0)	0, 0%	582, 39.7%	289, 19.7%	328, 22.4%	268, 18.3%	1467
filter remained (Tx,Ty,Tz=7.0)	0, 0%	607, 39.6%	295, 19.2%	349, 22.8%	281, 18.3%	1532
filter remained (Tx,Ty,Tz=10.0)	0, 0%	623, 39.3%	308, 19.4%	360, 22.7%	296, 18.7%	1587

Tab.1 Network RTK filtered result analysis

In the automatic integration work of GPS and DR of mobile mapping, the integration result also shows that filtered result of network RTK can make better solution for mobile mapping's positioning and posing work compared to the original data. Some complicated city area has even obvious improved solution, and the filtering work in the paper also help mobile mapping based on network RTK meet the requirement of 1:2000 scale mapping better than the original network RTK data.

5. CONCLUSION AND PROSPECTS

This paper discussed how to improve the reliability of network RTK in dynamic direct georeferencing positioning of land-based mobile mapping. Based on the dynamic characteristic of Doppler and DGPS 3D speed of the mobile platform, we filtered error data in sequential network RTK data. The experiment is performed based on the mobile mapping's positioning data of Shanghai Yan'an Road, one of the most typical circumstances in metropolis. The analysis shows that network RTK can be used for mobile mapping in metropolis, and filtering method presented in the paper can filter crude part in network RTK data and thus improve the network RTK reliability and accuracy for city mobile mapping.

Land-based mobile mapping has much more potential and revolutionary impetus in improving city's development and management of infrastructure, utility, facility, emergency response, public security and so on. That calls for better development of mobile mapping itself. Network RTK is built in more and more big cities, and it has very distinguished economic and performance advantages compared to the traditional GPS. The next step of our work is to interpolate good points in sequential position data instead of the current filtering in dynamic network RTK application. In that issue, we'll use high accuracy characteristics provided by differential Doppler measurement.

ACKNOWLEDGEMENTS

The paper is substantially supported by National 863 High-tech Project "Complicated Features' Extraction and Analysis from Central Districts in Metropolis", ChangJiang Scholars Program, Ministry of Education, PRC and Tongji University "985" Project Sub-system "Integrated Monitoring for City Spatial Information". The author would like to thank ChangJiang Scholars Dr. Ron., Li and Dr. Hongxing Sun for their substantial help.

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