A PRELIMINARY STUDY ON THE QUALITY OF GNSS RELATIVE POSITIONING FOR A MOVING PLATFORM

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Abstract: Global Navigation Satellite System (GNSS) has been widely used for positioning, navigation and timing applications nowadays. Receivers of different types as well as various platforms have been utilized for assorted purposes. In the case where the positioning accuracy is of a major concern, the relative GNSS positioning becomes the most preferable technique since a majority of error sources can be eliminated by the combinations of simultaneous observations at the base and rover receivers. This technique also enables a continuous positioning solution for a moving platform (e.g. mobile mapping vehicle). On the other hand, the resulting accuracy of a relative GNSS positioning is greatly affected by the baseline length and the geometry constituted by the satellites simultaneously visible to the base and rover receivers. Especially when a platform is in motion, both the above two factors tangle and vary dramatically. This study aims to stress a need of rigorous approach that can be used to explicitly determine the GNSS positing quality along the route of a moving platform. By using the digital surface model (DSM) and line-of-sight (LOS) analysis technique, the satellite visibility condition of a moving receiver as well as its base receiver could be first determined. Then the satellite geometry with respect to a specific base receiver is evaluated and the dilution of precision (DOP) values are finally produced at each single epoch. With the process suggested in this study, the field work of a moving platform can be better planned, and thus a more reliable and efficient spatial data acquisition along the moving route can be achieved.

INTRODUCTION

The U.S. Department of Defense developed the Global Positioning System (GPS) project since 1973 for the purpose of navigation, positioning and time information gathering for military usage. Afterward, GNSS (Global Navigation Satellite System, GNSS) has been developed by countries all over the world with more thorough satellite coverage, higher accuracy, and more possible applications. Continuous positioning for moving platforms is one of the applications provided by GNSS. Lichti (2000) presented preliminary simultaneous positioning by the combination of Inertial Measurement Units (IMU) and GPS, which record the attitude parameters and position parameters, respectively. As accuracy rises with the development of technology, positioning is no longer limited to navigation. Accurate surveying, for example: topography mapping has also made use of the moving positioning technique.

GNSS provides solutions that are unaffected by weather and without the need for a clear line of sight between ground stations. The coordinates of a receiver is solved under the basic principle by the range observations of satellites to the receiver. Thus, both the number of visible satellites, and the geometry constituted by these satellites directly affect the quality of GNSS positioning. In urban areas, topographic obstruction is a major issue which affects positioning quality. An even more complicated relationship between the baseline and satellites for moving platforms could be encountered. This highlights the preliminary planning before actual field surveying. Suitable receiver positions and surveying time would result in better satellite visibility and network geometry. The commonly used commercial software for GNSS analysis only offers single-point positioning quality assessment. The actual obstruction or topography is ignored by using a roughly assumed masking angle to consider the topography effect. However, as the digital terrain information being easily acquired lately, it should be applied on the visibility analysis for a more accurate field work planning.

The most basic GNSS positioning method is single-point positioning. The reception of only four satellite signals would be enough to obtain the necessary coordinates and clock offset of the measurement point. However, single-point positioning accuracy would be effected by satellite orbits error, clocks error, signal propagation error, etc. The relative positioning method could be used to reduce these errors and thus obtain a more precise coordinate measurement for the receiver (Leick, 2004). With both receivers observing the same satellite simultaneously, they will share common clock errors and partially satellite orbital errors. Furthermore, as the distance between the base and rover stations decreases, the ionospheric and tropospheric delays affecting the range measurements will also converge. Consequently, differentiation of range measurements obtained at the rover and base stations can effectively reduce the impact of these errors, leading to an improvement in positioning. (Han et al., 2012)

Receivers of different types as well as various platforms have been utilized for assorted purposes. Both aerial platform and vehicle-based mobile mapping system usually simultaneously receive signals from a ground base station. The relative positioning can then be used to eliminate the single-point positioning errors. For aerial LiDAR, differentiation of range measurements obtained at the GPS receiver placed on the platform and the reference station on the ground together with the attitudes from INS system could be integrated to solve for the coordinates for the points scanned on the ground. (Chen, 2005). Vehicle-based mobile mapping system could also receive signals from ground reference stations to improve the positioning results. But unlike relative positioning, as the platform moves, the range between the reference station also varies, making the baseline length a fluctuate factor.

Besides the varying of baseline, the occlusions and moving path are also changing across time. Fig.1 is an actual experimental positioning result gathered by a moving platform routed through a main road in Taipei City in Taiwan (January, 2012). The route started from an open highway and then entered the crowded urban area. One can easily notice that the positioning results are better at the beginning at the open space on the highway. As occlusions became significant in the urban areas, not only the errors are larger, but also no solution was obtained.

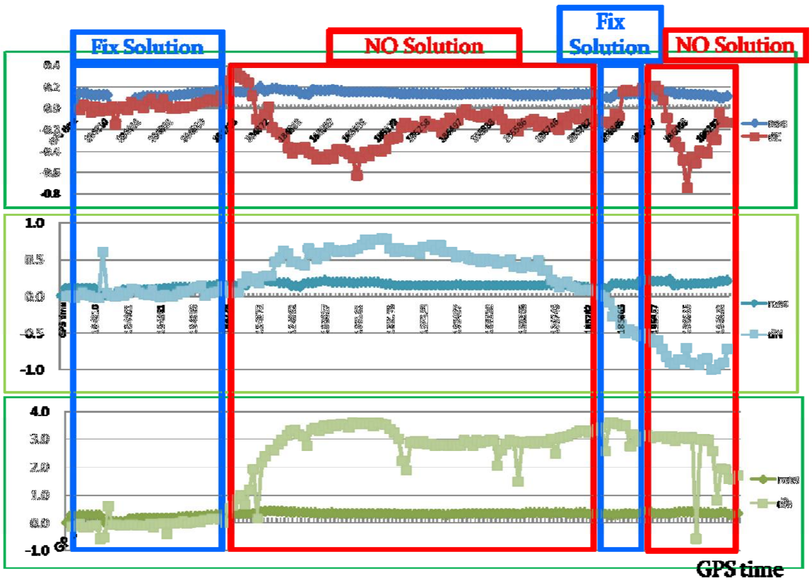

Figure 1: Actual positioning results obtained for a moving platform routed through an urban area (Top: e-direction; Middle: n-direction; Bottom: u-direction)

This study aims to stress a need of rigorous approach that can be used to explicitly determine the GNSS positing quality along the route of a moving platform. By using the digital surface model (DSM) and line-of-sight (LOS) analysis technique, the satellite visibility condition of a moving receiver as well as its base receiver could be first determined. Then the satellite geometry with respect to a specific base receiver is evaluated and the DOP values are finally produced at each single epoch. With the process suggested in this study, the field work of a moving platform can be better planned, and thus a more reliable and efficient spatial data acquisition along the moving route can be achieved.

RELATED RESEARCHES

Occlusions

Many researches have discussed the effect of topography occlusions on the positioning quality of GNSS positioning. Chen et al. (2009) compared the satellite visibility and DOP values between GPS and BeiDou-2/COMPASS. The masking angle was assumed 10° to simulate occlusions for flat areas, and 40° to simulate occlusions for urban areas. However, the masking angle along could not reflect the actual occluded situation.

Zhang et al. (2009) used information including aerial photographs, LIDAR data, cadaster dataset, and building heights in ArcGIS to build a 3D urban model. Then the model was used for satellite visibility analysis. It was proven that the topography and buildings have great influence on the satellite visibility.

Line-of-Sight (LOS) analysis aimed at using existing DTM to determine whether occlusion exists between receivers and points. However, too many sampling points would slow down the computation rate. Han & Li (2010) proposed an adaptive sampling and analysis procedure to increase the computational efficiency while processing high-resolution topographical data.

Relative Positioning

The researches mentioned above discussed the effect of occlusions for single-point precision only. Han et al. (2012) used the adaptive sampling and analysis procedure with DSM to verify the effect of occlusions on relative positioning. DSM datasets of 2-m and 5-m resolution were generated from a LiDAR survey available for a test area. Baselines were formed from three selected site locations and analyzed based on the proposed approach. It was shown that without the consideration of terrain variations, the satellite visibility would be obviously overestimated. The actual visibility and precision would lie between results of 2-m DSM and 5-m DSM.

Moving Platform

Bae et al. (2011) pointed out if more base stations with known coordinates surrounded the unknown point, the positioning accuracy could be improved. Single baseline and multiple baselines were compared in the kinematic positioning. The error variation was more stable for multiple-baselines solutions. The positioning error also increased with longer baselines. Therefore, the variation of baselines would affect the kinematic positioning quality. Later, Ruiz et al. (2009) made a GPS survey of road networks for the positional quality control of maps. A vehicle with GPS receiver was used together with reference stations to survey road networks. The study showed varying precision of the GPS survey along the route. The occlusions should be the main reason for the different accuracy at each point.

The above studies have made explanations of why the baseline would affect the kinematic positioning precision. Also, as the platform moves, the occlusion for each point would differ. This study then aimed at analyzing the effect of occlusions for kinematic positioning precision.

EXPERIMENTS

Two experiments conducted in field were presented to show the results of using masking angle. The first experiment was a comparison of the actual and predicted number of visible satellites and DOP values for single-point positioning. The second experiment was a comparison of the actual and predicted number of visible satellites for kinematic positioning.

Quality evaluation of single-point positioning

The purpose of the experiment is to check the validity of using masking angles to predict the number of visible satellites for topography occlusions. A commercial software was used to predict the number of visible satellites and DOP values per15 minutes. The masking angle was set to be 0, 5, 10, 15 degrees, respectively. Then a comparison could be made with the actual data from in-situ experiment.

Configuration:

- Location: Alishan Weather Station in Chiayi County, Taiwan
- Period：2011.07.13 8:00 a.m. to 2011.07.14 8:00 a.m.(GMT +8)
- Coordinate: 120‘48’47.8E, 23'30'29.42N

Results:

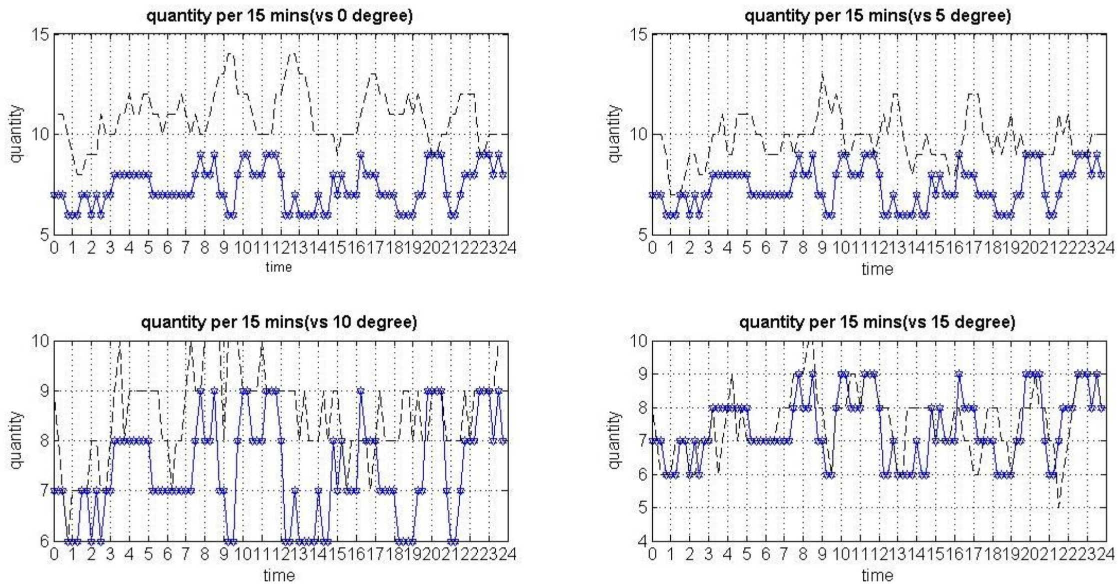

Figure 2: Comparison of the real and predicted quantity of visible satellites
(Blue line: actual; Black dash line: predicted)

One can see from Fig.2 that when the masking angle is set to zero, meaning that no occlusion is considered, the predicted number of satellites is much more than actually received satellites. Since the experiment location is in mountain areas, it is highly occluded, so the masking angle should be set as at least 15 degrees to satisfy the real situation. However, the prediction is not accurate for each epoch. The percentage of successful prediction (PSP) ratio showing whether the prediction for the quantity of satellites and DOP values is over-estimated or under-estimated can be calculated by:

$$PSP \text{ ratio} = \frac{predicted - real}{real} \times 100\% \qquad (1)$$

When the result is overestimated, the percentage calculated will be positive; if the result is underestimated, the percentage will be negative. The precision of the prediction gets better when the percentage approaches zero.

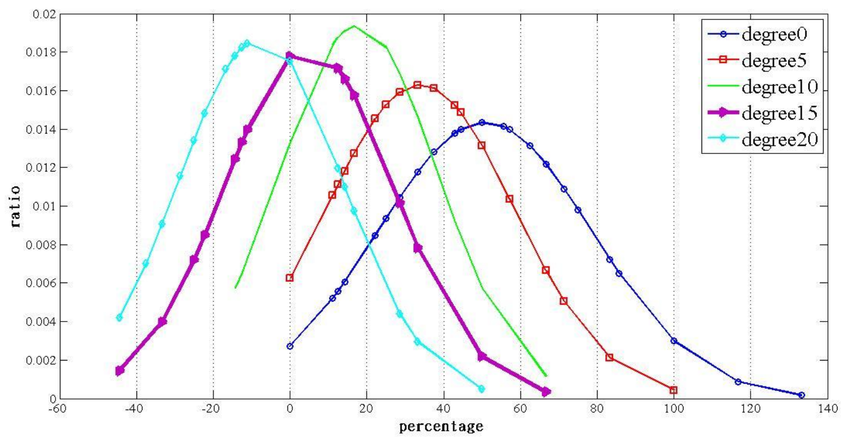

Figure 3: PSP ratios on the numbers of visible satellites under different masking angles.

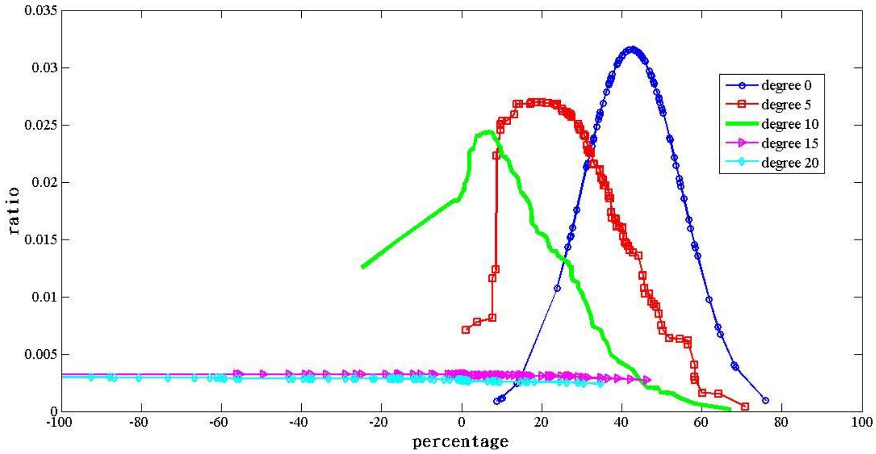

Figure 4: PSP ratios on the DOP values under different masking angles.

It can be observed from Fig. 3 that when the masking is zero, the percentage shows an overestimated result of 50%. When the masking is raised to 20 degrees, the percentage shows an underestimated result of -10%. The optimal masking angle would be 15 degrees to meet the actual situation. However, from the results shown in Fig. 4, the best positioning precision happens when the masking angle is 10 degrees. To sum up, using masking angles to simulate the topography could obtain the number of visible satellites, but the positioning precision could not be evaluated this way. Therefore, the masking angle is not an adequate index for the evaluation of positioning accuracy.

Quality evaluation of kinematic positioning

The purpose of the experiment is to compare the actual number of visible satellites with the estimated number for each point under kinematic positioning.

Configuration:

- Location: Maokong Mountain Area in Taipei, Taiwan
- Period：2012/01/10 approx. 3:00 p.m. to 4:45 p.m.(GMT +8)
- Route: Marked in red in Fig. 5. The left bottom corner:(307800m, 2762900m), the upper right corner: (310900m, 2765700m) (TWD97)

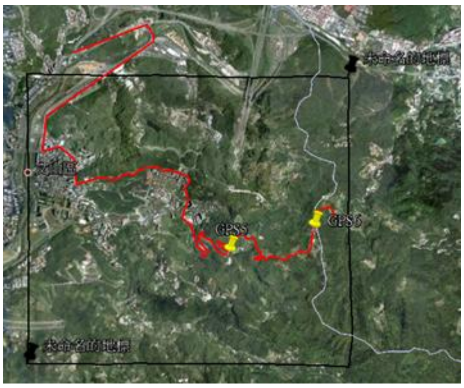

Figure 5: Route of the experiment

Results:

The actually received number of the visible satellites is plotted by the blue line per second in Fig.6. Then using the commercial software with masking angle set to zero, the estimated number is plotted by the red line per minute.

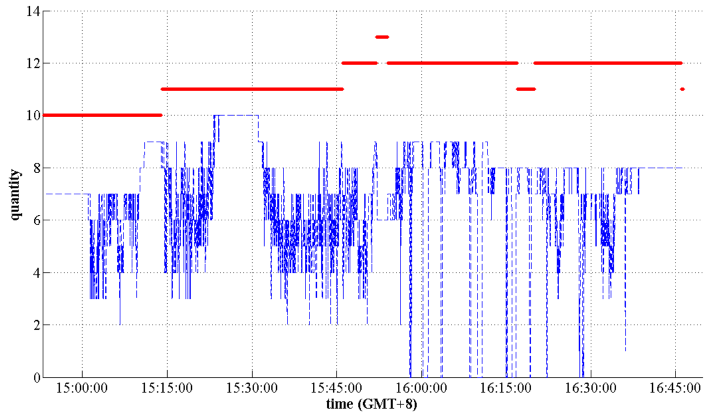

Figure 6: Number of visible satellites by kinematic positioning
(Blue: actually observed; Red: predicted)

It can be seen from Fig. 6 that the actual number of visible satellites varies along the route and does not match the estimated number due to occlusions from topography.

It is proven by these two experiments that although the commercial software is capable of simulating occlusions by masking angles, the actual in-situ situation is quite different. Digital surface model (DSM) should be adapted for a more accurate prediction.

CONCLUSIONS & FUTURE WORK

GNSS has been used on instantaneous positioning for many applications. However, since no commercial software can provide evaluation on kinematic platform positioning yet, a method for evaluation should be established to offer preliminary route planning. For moving platforms, the varying of baselines would also be kinematic. So the factor of baselines should be added to the evaluation to provide an optimal choice of base stations. There are many factors to be considered before planning, for example: DSM, choice of numbers of base stations, route planning…etc. Not only is the computation demand high, but also all the procedures have to be integrated. This study aims to develop a rigorous approach that can be used to explicitly determine the GNSS positing quality along the route of a moving platform. By using the digital surface model (DSM) and line-of-sight (LOS) analysis technique, the satellite visibility condition of a moving receiver as well as its base receiver is first determined. Then the satellite geometry with respect to a specific base receiver is evaluated and the DOP values are finally produced at each single epoch. With the quality indications obtained in this study, the field work of a moving platform can be better planned, and thus a more reliable and efficient spatial data acquisition along the moving route can be achieved. The flowchart of our future work is shown in Fig.7. Hopefully, the results, which could meet a variety of demands, could be presented.

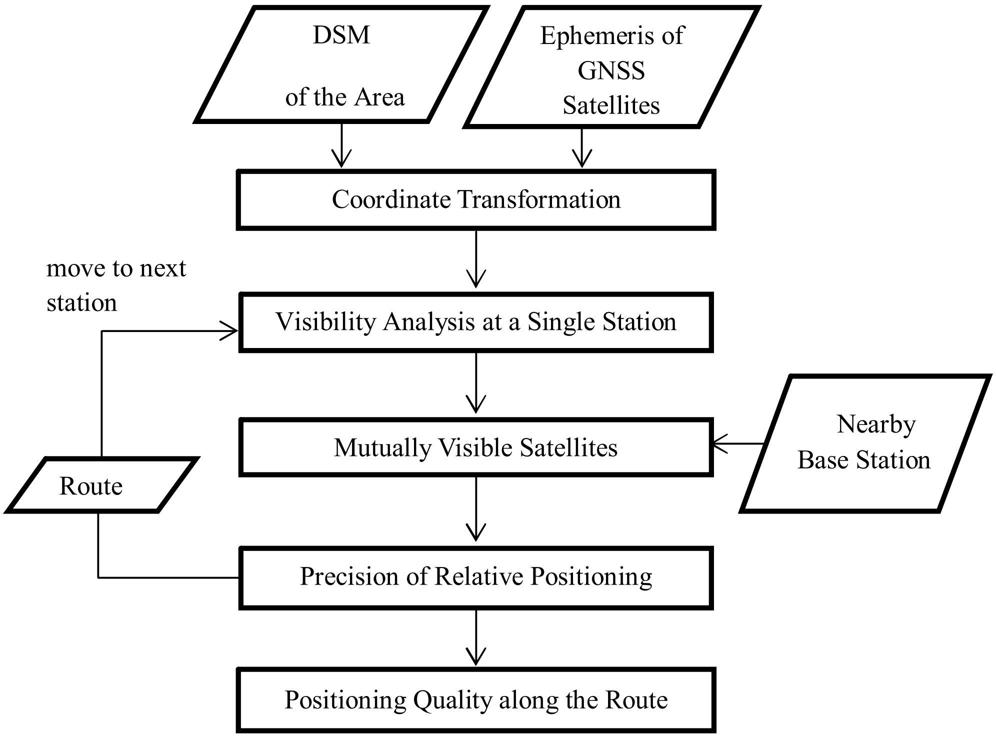

Figure 7: Flowchart of analyzing process

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