Military Technical College

Kobry El-Kobbah,

Cairo, Egypt

11th International Conference on Civil and Architecture Engineering

ICCAE-11-2016

The effect of elevation-based stochastic modeling on PPP convergence period

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Abstract

The major limitation of precise point positioning (PPP) is that it requires a long convergence time about 30 min for that the solution reaches the steady state. Pseudorange multipath and noise have a large impact that weakens the performance of the PPP solution to converge rapidly. By mitigating this impact, improved PPP performance in the convergence will be obtained. The stochastic modelling based on the elevation angle of the satellite is used to mitigate the multipath and noise in pseudorange observations. A set of 522 daily observation files from 75 IGS stations within one week is used. An improvement in the rate of the convergence for 23.4% of the data is achieved by the elevation weighting scheme against the standard PPP solution with equal weights.

Keywords: precise point positioning, Pseudorange multipath

Introduction

Precise Point Positioning is a brilliant positioning technology that can provide a 3D accuracy of few centimeters because it uses precise orbit and clock products to correct GNSS data from a single receiver. In the PPP approach, observations from a single receiver are used to estimate the receiver position, the ambiguities, the receiver clock offset and the wet tropospheric delay (Zumberge et al. 1997; Kouba and Heroux 2001). PPP serves a wide range of applications such as: precise positioning (Geng et al. 2010), atmospheric water vapor sensing (Douša, 2010), earthquake and tsunami monitoring (Shi et al. 2010), orbit determination of low Earth orbiting satellites (Bock et al. 2003) and precision agriculture (Dixon, 2006). PPP have demonstrated a high ability to become the next-generation positioning technology.

PPP still needs a long initialization period to reach the solution or the ambiguities to the steady state. Great attention has given for reducing this period or the so-called as convergence time to enable PPP in the real-time applications. Seepersad and Bisnath (2013) mitigated the pseudorange multipath and noise by direct multipath corrections generated by the multipath observable and by stochastic modeling based on the same observable for reducing the PPP convergence period. Percentages of 57% and 37% of the used data had been improved in the rate of convergence with the direct method and the stochastic modeling, respectively. Li and Zhang (2013) used of GPS + GLONASS PPP model, the average convergence time was reduced by 45.9 % from 22.9 to 12.4 min in static mode and by 57.9 % from 40.6 to 17.7 min in kinematic mode, respectively. In this study, pseudorange multipath and noise are mitigated among the un-modeled PPP errors. The effects of multipath and noise can be reduced using the stochastic models based on the satellite elevation angle, and the convergence time is thereby improved.

PPP model

PPP uses an epoch-by-epoch sequential least-squares estimation technique that is composed of two parts: (1) the functional model, (2) the stochastic model. PPP functional model is the ionosphere-free linear combination for pseudorange and carrier phase observations, which describes the mathematical relations between GPS observations and unknown parameters. The stochastic model reflects the quality and accuracy of observations and is defined by the variance-covariance (v-c) matrix. This v-c matrix gives information about how each observation can contribute to the PPP solution. If a stochastic model or v-c matrix is accurately described, the unknown parameters will have better solutions.

Elevation-based stochastic modeling

A proper stochastic modeling for GPS observations is a method to mitigate multipath, thus improving PPP convergence time. A cosecant function based on the satellite elevation angle was used as a weighting scheme because there is a correlation between the ground- bounce multipath and the satellite elevation angle as shown in fig. 1. The sigma of unit weight (SUW) was computed from the equation (1). The output values are normalized by the sine of the average elevation angle equaling 37 °.

$$\mathrm{SUW}(\mathrm{elev}) = \sin(\mathrm{elev}) \qquad (1)$$

Fig.1 illustrates the elevation-based weighting scheme at station IRKT (Irkutsk, Russia), for PRN 18, on DOY 49 of 2012. Figure 1.a, b illustrate the elevation-based sigma of unit weight and the elevation angle of the satellite, respectively. Figure 1.c illustrates the values of pseudorange multipath on the L1 frequency.

The PPP convergence for the station JPLM (United States) on DOY 54 of 2012 is illustrated in Fig. 2, when the elevation weights were tested against the equal weights traditional solution for meeting 30 cm 3D position accuracy. The solution by the elevation weights had a convergence time of 2 minute, whereas by the equal weights had 12.2 minute. Within the first 10 minute, the rms of the position was computed to assure the stability of the convergence. The position rms of 58 cm was at the elevation weights and 72 cm at the equal weights.

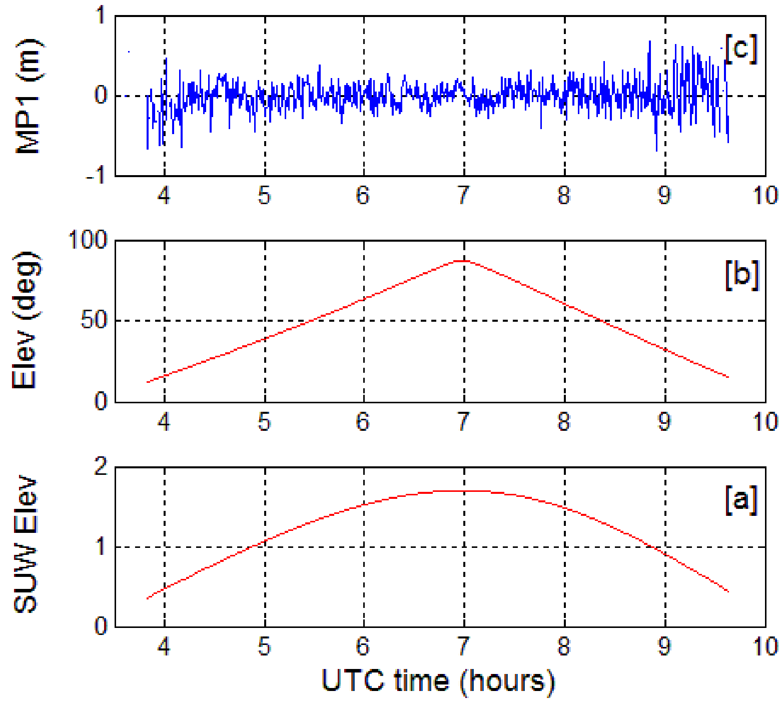

Fig. 1: the elevation-based weighting scheme for pseudorange observations related to PRN 18 at station IRKT on DOY 49 of 2012. Subplots **a** represent the sigma of unit weight based the elevation angle, while Subplots **b**, **c** represents the elevation angle and the pseudorange multipath.

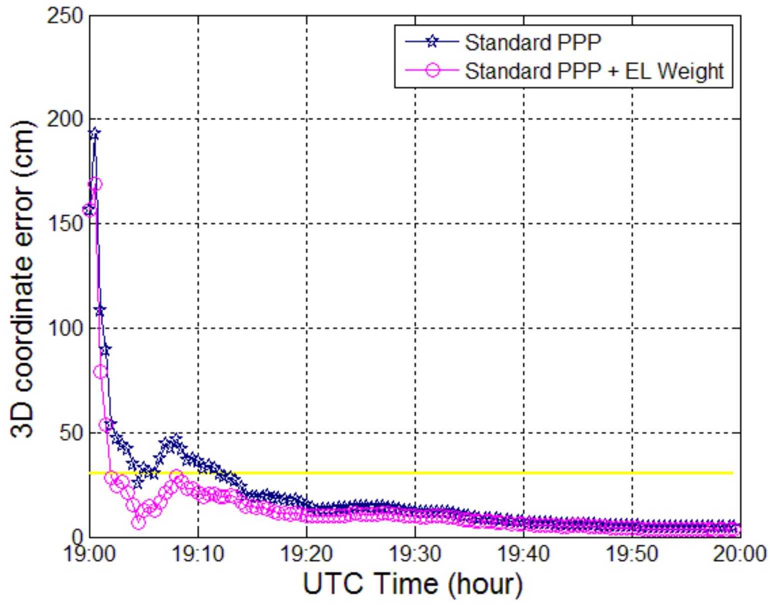

Fig. 2: The convergence time within 2 minutes using the elevation weights at station JPLM on DOY 54 in year of 2012.

To quantify the improvements on the PPP convergence time, the elevation-based stochastic modeling was applied against the traditional PPP solution where all pseudorange observations have the same weight. A 3D position accuracy threshold of 30 cm was selected to examine the improvements on the convergence performance. In Fig. 3, the bar represents the percentage of the data that converged to the previous accuracy threshold. Improvements of 1%, 10 %, 12 % and 9 % are seen against the traditional PPP through the initial 4 time bins. After 10, 20 and 30 minutes were spent, 72 %, 91 % and 95 % of the data converged, respectively. The initial 15 minute is the period where this mitigation technique had significant improvements. As a result, the average convergence time is still 30 minutes.

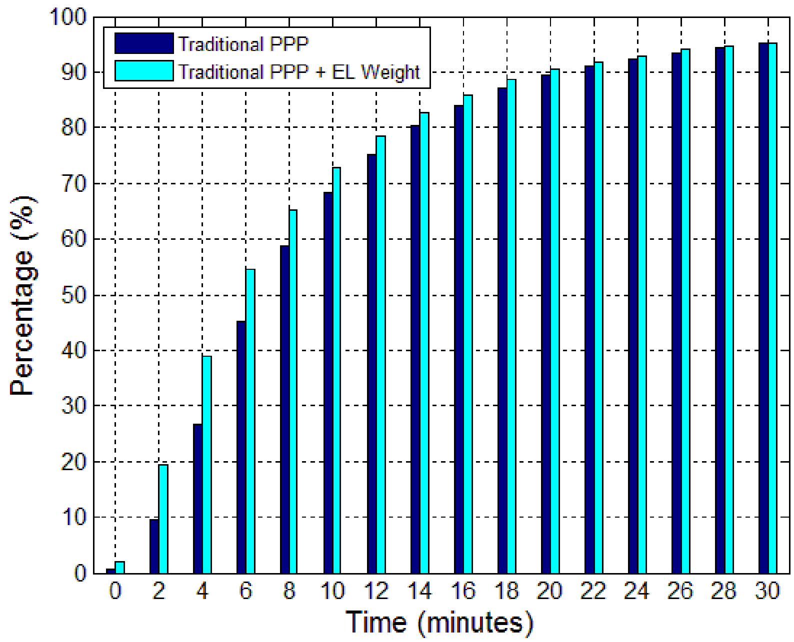

Fig. 3: Improvements in the percentage of the data converged to 30 cm three-dimensional positional accuracy using the elevation weighting technique.

To check the overall quality of the solution by the elevation-based stochastic modelling, the statistical analysis was done for the 3D position error within the first 30 minutes. The mean and standard deviation of the 3D error are computed every 2 minutes. In fig. 4, the bar represents the mean, while the error bar represents the standard deviation. The elevation-based weights initialized with a mean error of 135 ± 112 cm, while the identical weights had a mean error of 158 ± 137 cm. at the 16^{th} minute, the mean error of the elevation-based weights reduced to 15 ± 14 cm. using the elevation weights had the best results against the identical weight through the first 30 minutes except the 10^{th} minute.

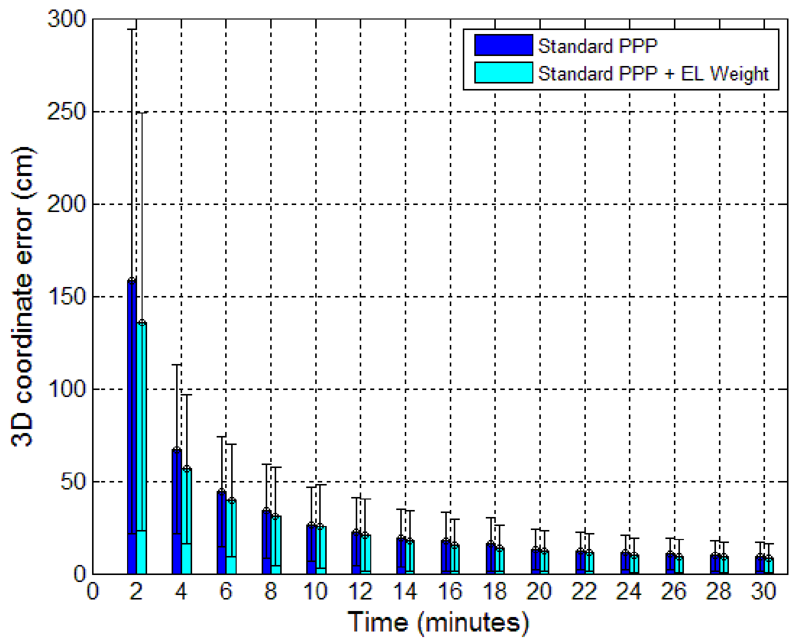

Fig. 4: The mean and standard deviation for 3D position error, computed every 2 minutes for the entire sample size at each method.

Conclusions

Although elevation-based stochastic modelling technique had achieved improvements in PPP convergence period, the average of convergence period was still 30 minutes. A correlation between the multipath and the elevation angle was described well by the cosecant weighting scheme, but this scheme is very approximate and do not provide a realistic stochastic modelling. We suggest mitigating the multipath and noise in PPP functional model and a modification for this scheme to be more realistic.

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