CORS ZWD Augmented PPP for Bridge Displacement Monitoring

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Keywords: troposphere augmentation; displacement monitoring; PPP

SUMMARY

PPP is an optimal method for bridge deflection monitoring, particular in the scenario that Double Difference (DD) method is not available due to the reference station failure. More than 20 minutes has to be taken for a reasonable precision when PPP is used for the bridge monitoring. Instead of estimated the tropospheric delays with position in general PPP method, we take the tropospheric delays derived for the local CORS as a tropospheric correction on the observations. GNSS data gathered on the Severn bridge, UK is used for assessing the tropospheric correction PPP performance. The studies implied that CORS tropospheric correction augmented PPP can effectively shorten the convergence period. Additionally, the PPP precision is also improved by using the local CORS derived troposphere correction.

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1. INTRODUCTION

PPP has been investigated for the bridge monitoring in the past few years. PPP is a viable option for the bridge monitoring in the scenario that DD method is failure. However, PPP displacement monitoring precision is not as good as that of DD. The long time requirement of PPP convergence for a reasonable monitoring precision also limits the PPP practicality in many potential applications. Many previous studies has been investigate the PPP precision improvement, short time converging. Wilgan et al. (2017) assessed the contribution of PPP positioning precision and convergence time using varieties of mapping functions and Zenith Total Delays (ZTDs), which are calculated by the Weather Research Forecasting (WRF) model and local GNSS permanent network stations, respectively. Yao et al. (2018) compared the ZTDs from Global Geodetic Observing System (GGOS) with the ZTD products from IGS stations. The spatial and temporal resolution of GGOS's ZTD, with 2.5◦ × 2◦ grids and 6-hour interval resolutions, improves the real time PPP convenience and positioning precision on the up-component particularly. An external Numerical Weather Model (NWM) WRF, with 9 km × 9 km spatial and 6-hour temporal resolutions, was applied for improving PPP position parameters precision in an experiment that hot air balloon flight from earth surface to the 2 Km altitude (Vaclavovic et al. 2017). Convergence time can be shortened by applying the WRF ZTD constrain in the PPP. Positioning results are also credible while the geometry change suddenly, due to satellite flies in or out of view. These studies confirm that PPP can be augmented by using the external NWM (Alves et al. 2016; Yao et al. 2017). Viable alternative to the external NWM for augmenting the PPP, a global distributed GNSS stations or region CORS are applied to improving the PPP performance(Li et al. 2013; Zhang et al. 2011). Oliveira et al. (2017) modeled the troposphere by the local CORS and investigated the dense and sparse network contributions to the PPP augmentation. The previous studies implied that there is no evident difference between PPP positioning time series augmented by tropospheric corrections, respectively derived by dense and sparse networks.

This paper investigated the ZTD augmentation for the PPP bridge displacement monitoring. the ZTD over the bridge has been modeled by the selected stations from the local CORS. Bridge data are applied for assessing the performance of the ZTD augmented PPP. ZTD at the bridge surveying point is first interpolated from the CORS modeled ZTD, then applied as the PPP correction for the bridge displacement monitoring. in the results' section, DD bridge displacement time series are used as the truth, compared against the PPP time series.

2. EXPERIMENT DESCRIPTION

Blue cycles with yellow dots in auxiliary figure 1 represent the locations of 10 selected UK CORS permanent stations, distributed around the Severn Bridge. The red pentagram represents where the bridge is. Green dot shows the location of reference station, which is 1.416 km far away from the farthest surveying point A at bridge midspan (figure 1). All receiver's cut off angle at each CORS station was set as 5 degree. The sampling rate of receiver is 1 Hz.

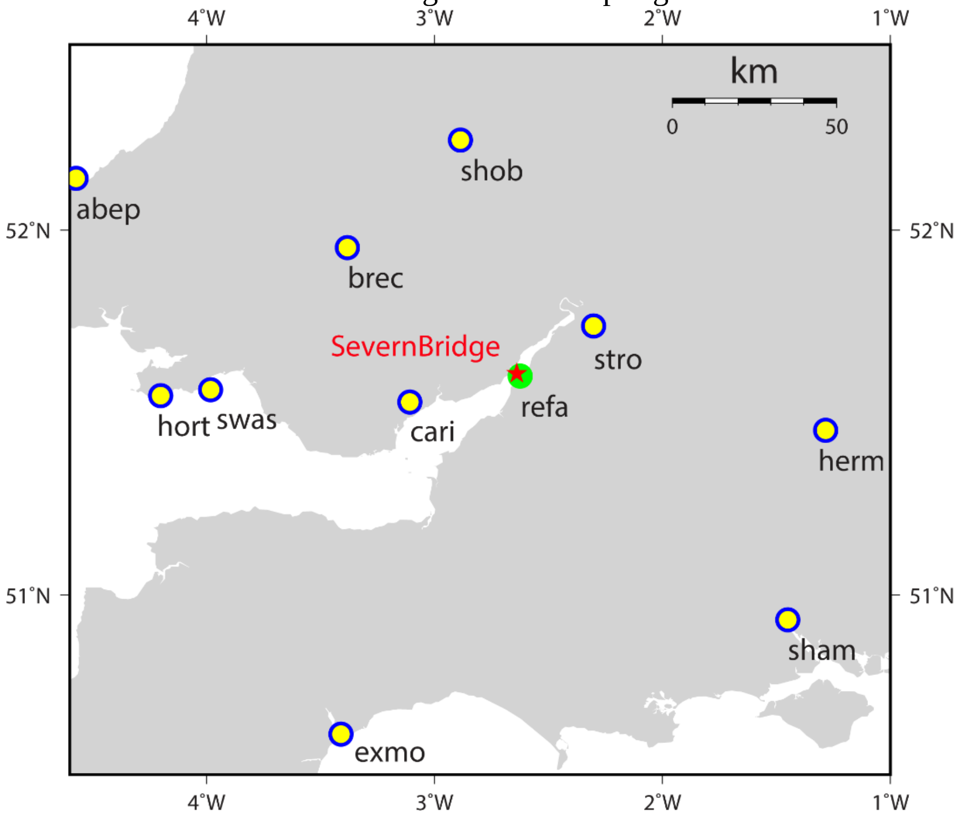

Fig. 1 10 selected UK CORS stations surrounding of bridge (blue cycles with solid yellow dots), location of Severn Bridge (pentagram)

There are 3 Leica 1200 dual frequency GPS receivers mounted on the suspension cable. The raw GPS data was gathered at the rate of 20 Hz. The reference station is equipped with the Leica Viva receiver, which was configured to gathering data at the rate of 10 Hz. Cut off angle was set as 5 degree as well. Datasets between 8:00 to 09:30 11st March 2019 were processed in this study, with all 3 rover stations and reference station continually tracking satellites over one and half hour.

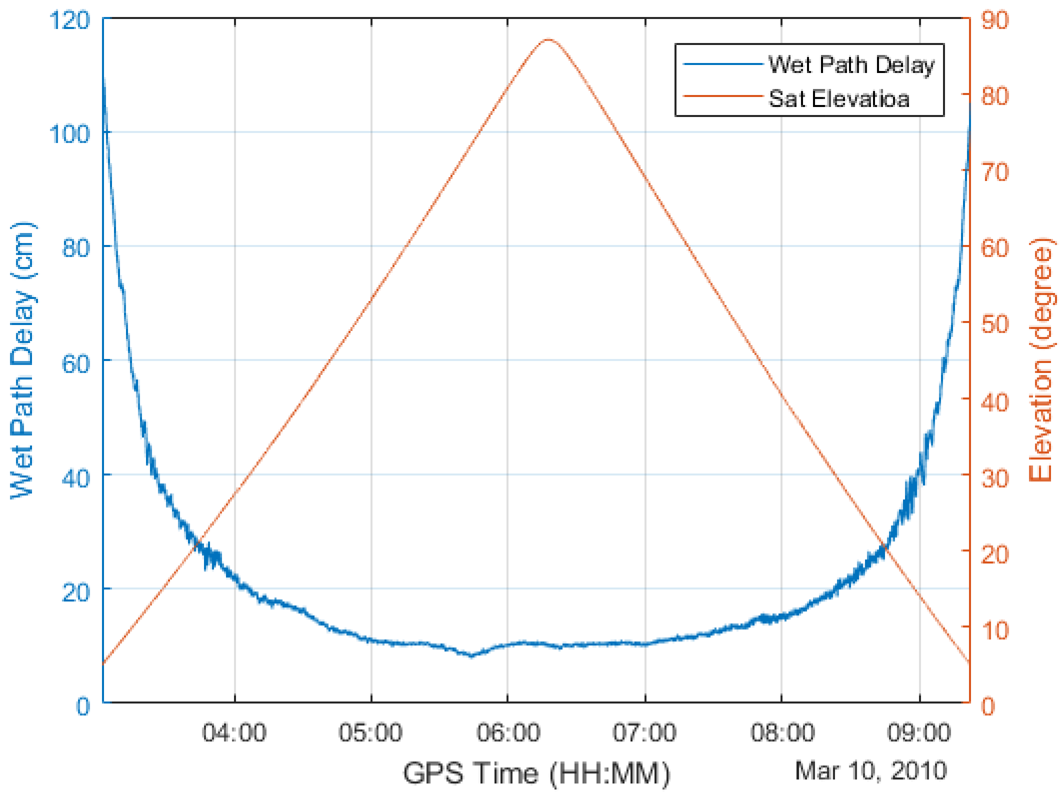

Fig. 2 The changing of wet path delay with GPS PRN 03 satellite elevation varying.

Figure 2 shows the zenith wet delay mapped on the "line-of-sight" between GPS PRN 03 satellite and antenna at UK CORS STRO station. The wet path delay is no more than 20 cm while the satellite elevation is bigger than 30 degree, but increasing significantly with the elevation decreasing from 30 to 5 degree. The maximum wet delay GPS PRN 03 can be up to 113 cm while the elevation is 5 degree. Better GPS constellation geometry can be obtained while the satellites with low elevation employed for PPP data processing, Meanwhile, the bigger noise will challenge the positioning precision. Time varying tropospheric parameters are precisely modeled and employed for investigating the contribution to PPP applied in structure deflection monitoring with different cut off angle configuration.

3. DATA PROCESS AND RESULTS

Figure 3 illustrates the DD deflection time series and the PPP without/with troposphere augment time series at location A, B and C. The cut off angle is set as 05 degree in case of the worse geometry reduce the general PPP positioning performance and precision. The top, middle and bottom panels shows that the augmentation PPP has short convergence time, comparing that general PPP, at locations A, B and C, respectively. There is no specific constant convergence time at these three locations. The augment PPP takes approximate 5 minutes for achieving the deflection monitoring precision requirement at location A, while the general PPP takes more than half an hour. We can also see the convergence time improvement at locations B and C, but is not so distinguished like that of Location A. The correct peaks in PPP time series are also extracted during the convergence time either with or without the troposphere correction at location B. This reflects that the antenna oscillation is not the reason degrading the PPP convergence time.

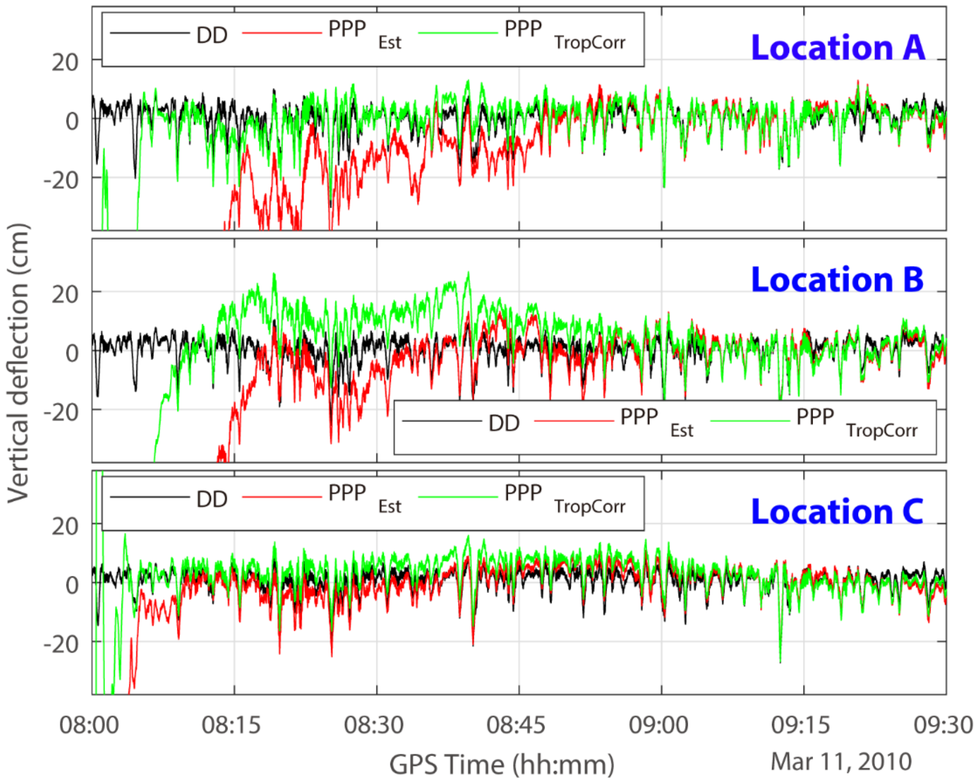

Fig. 3 PPP time series without/with the troposphere augmentation at Location A, B and C. The cut off angle is 5 degree.

We also investigate the positioning precision improvement by employing the augmented PPP in bridge deflection monitoring. So as to avoid the effecion of convergence time on analyzing the PPP deflection monitoring precision, the time series at location A, B and C from 9:00 to 9:30 after one-hour convergence are chosen to calculate the root mean square error and correlation coefficients. DD time series is treated as the truth deflection of bridge. Top 3 panels of figure 4 show that bridge deflection time series' errors at all 3 location individually increasing while the cut off angle is set as 5, 10 and 15 degree, respectively. Green bars in figure 4 top 3 panels did not show the consistence of RMSEs and the individual cut off angles. This proves that the the troposphere correction augmented PPP is not sensortive to positioning precision, but the general PPP is. Bottom 3 panels of figure 4 show the correlation coefficients between PPP and DD deflection time series. Augemented PPP has better than 0.8 correlation coefficient at 5, 10 and 15 cut off angles. PPP correclation coefficient without the tropospheric augmentation can only be up to 0.8 while the elevation is 15 degree. Performance of unaugmented PPP is worse than augmented PPP in the term of either correlation coefficinet or RMSE at 05 degree cut off angle, at which unaugmented PPP has best performance, comparing with that of 10 and 15 degree cut off angle.

The imprōment of position precision due to the gredient correction is not evident. The maximum defferences of RMSE is 3.2 mm at location C when the elevation cut off angle is 15 degree. The relative bigger effection of gradient is on the signal fsrom the satellite elevation below 15 degree. The RMSEs reduce by 2.4 mm and 0.3 mm, respectively, at location B and C when the elevation cut off angle is 5 degree. The RMSE of ZWD correct PPP is even 1.6 mm worse than that of ZWD+Grid correct PPP. The gradient has few milimeter positioning precision effection on the tropospheric augmented PPP.

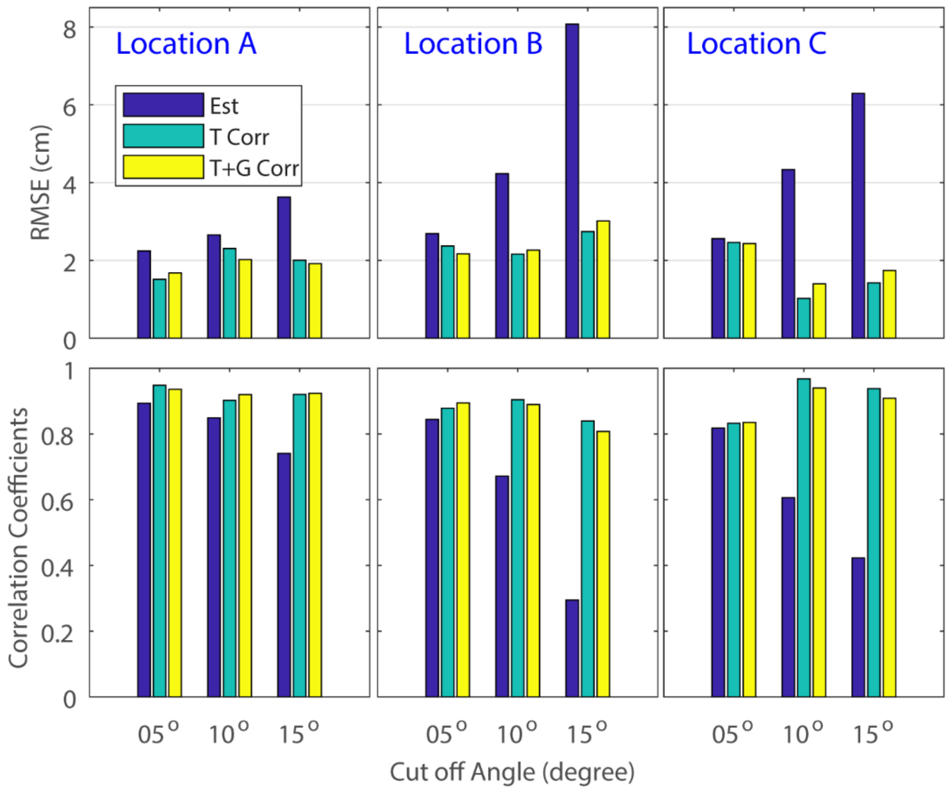

Fig. 4 Root mean square error and correlation coefficients of location A, B and C PPP time series at 05, 10 and 15 degree cut off angle.

4. CONCLUSION

PPP is an alternative method for the structure monitoring when DD is failed due to the reference station is not available. Varieties of errors in PPP procedure have to be eliminated or reduced for the high precision of positioning applied in the structure monitoring. ZTD consists ZHD and ZWD can introduce meters delay on the signal between satellite and terminal receivers' antenna. ZHD can be precise modeled, but the time varying ZWD dependents on the weather situation around the antenna. This paper invests structure monitoring using PPP augmented by the "given" ZWD, which is interpolated at the surveying point from CORS station. ZWD is approximate 10 cm at the zenith direction, can introduce meters delay at the receiver-satellite direction. PPP precision with the ZWD augmentation can be significantly improved, particularly in the scenario that low elevation signal is blocked by obstacles. The gradient effection brings sub-centimeter delay on the signal at the satellite with lower than 15-degree elevation, and only few millimeter effection on the positioning precision. Bridge experiment illustrates that augmented PPP not only shorten the convergence time, but also improves deflection monitoring precision of general PPP applied in structure monitoring.

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BIOGRAPHICAL NOTES

Dr Xu Tang is an associate professor in Nanjing University of Information Science & Technology, Nanjing, China. His research interest covers various aspects of Engineering Surveying, Deformation monitoring, research into GNSS PPP for structure deflection detection, vapor remote sensing using GNSS etc.

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