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Accuracy of GPS single point positioning solution using IGS precise products

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ABSTRACT

GPS Single Point Positioning (SPP) is the common usage of navigation and meets the meter-level positioning requirements. The error sources including orbital error and satellite clock offset significantly affect the accuracy of the SPP solution. International GNSS Service (IGS) focuses on improvements of orbital and clock products since 1994. In this study, the SPP solution was performed with IGS final precise products using an in-house Matlab program. The ten-days dataset was evaluated with the program. Systematic errors decreasing the accuracy of the SPP solutions were modeled and then removed. Estimating GPS SPP solution was performed by the weighted least squares method for each epoch. It was observed that the accuracy of the solutions was associated with the number of satellites and GDOP values. The results revealed that the positioning accuracy was achieved at a maximum 21 centimeter level for the daily average, and RMSE values of all components were less than 1 meter. It was also clearly seen that the IGS precise products contributed to the accuracy of the GPS-SPP solution.

1. INTRODUCTION

Single point positioning (SPP) is a method that estimates receiver coordinates and clock offset by using the pseudorange measurements. The technique solves the user position at a single epoch with the meter-level positioning accuracy. The accuracy of the results is dependent on many factors, such as satellite clock offset, receiver clock offset, satellite orbital error, ionosphere delay, tropospheric delay, satellite and receiver antenna offsets, multipath, and noise. In addition, the number of visible satellites and satellite geometry plays an important role for positional accuracy (Cai and Gao 2009; Satirapod et al. 2001).

The atmospheric effects resulting from the ionosphere and troposphere are the main sources of error for SPP, and it should be suitably corrected, mitigated, or eliminated. The Saastamoinen tropospheric model is widely used for hydrostatic and wet delays from the zenith directional effect of the troposphere (Saastamoinen 1972). For the slant tropospheric corrections, several types of mapping functions are used. In this study, the tropospheric effect was removed from the data using the UNB3m hybrid model (Leandro et al. 2006). The Ionospheric delay is frequency-dependent; therefore, the effect of the ionosphere is eliminated by ionosphere-free combination in the dual-frequency receivers.

By using dual-frequency receivers and International GNSS Service (IGS) precise products, the daily mean of the positional difference between the SPP solution and the true position was reported to be at 1 meter level for the north, east, and up components (Satirapod et al. 2001). On the other hand, using the single frequency receiver with broadcast ephemeris and ionospheric model, the average error was obtained as about 1m and 2m level for horizontal and vertical components, respectively (Angrisano et al. 2013). In a study conducted by Cai et al. (2014), the accuracy of the vertical component was increased by 10% by the use of GPS and Galileo data together. Also, the triple-constellation combination and quad-constellation use of GLONASS, Galileo, and BeiDou satellite systems together with GPS significantly increased the SPP accuracy (Pan at al. 2017; Kwasniak 2018).

The aim of this study is to investigate the maximum accuracy that can be obtained from GPS SPP solution with IGS precise products using 10-day GPS data collected for ANKR.

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2. METHOD

2.1. Functional and Stochastic Model

In the SPP method, the functional model of the code observation for dual-frequency receivers can be expressed as follows;

$$P_{IF} = \rho + cdt_R - cdT + d_{trop} + \varepsilon_p \quad (1)$$

where, P_{IF} is the ionosphere-free combination of measured pseudorange in meters, dt_R is the receiver clock offset in second, dT is the satellite clock offset from in second, d_{trop} is the tropospheric delay in meters, c is the speed of light in meters per second, ρ is the geometric range between the satellite and the receiver in meters, ε_p is the unmodelled errors such as multipath error, orbital error, and measurement noise in meters. Tropospheric delay (d_{trop}) was corrected using the UNB3m tropospheric model as suggested by Leandro et al. (2006). This model calculates the tropospheric delay using the station's latitude, ellipsoidal height and time (day of year), and the satellite elevation angles.

The adjustment model of the Eq. (1) can be written as follows (Kouba and Héroux 2001);

$$A\delta + l - v = 0 \quad (2)$$

where, A is the design coefficient matrix, δ is the correction vector for unknown parameters, l is the misclosure vector, v is the residual vector of measurements in Eq. (2). Matrix A can be written as follows;

$$\begin{bmatrix} -\dfrac{X^{S(1)} - X_{0,R}}{\rho_{0,R}^{S(1)}} & -\dfrac{Y^{S(1)} - Y_{0,R}}{\rho_{0,R}^{S(1)}} & -\dfrac{Z^{S(1)} - Z_{0,R}}{\rho_{0,R}^{S(1)}} & 1 \\ -\dfrac{X^{S(2)} - X_{0,R}}{\rho_{0,R}^{S(2)}} & -\dfrac{Y^{S(2)} - Y_{0,R}}{\rho_{0,R}^{S(2)}} & -\dfrac{Z^{S(2)} - Z_{0,R}}{\rho_{0,R}^{S(2)}} & 1 \\ \cdots & \cdots & \cdots & \cdots \\ -\dfrac{X^{S(n)} - X_{0,R}}{\rho_{0,R}^{S(n)}} & -\dfrac{Y^{S(n)} - Y_{0,R}}{\rho_{0,R}^{S(n)}} & -\dfrac{Z^{S(n)} - Z_{0,R}}{\rho_{0,R}^{S(n)}} & 1 \end{bmatrix} \quad (3)$$

$$\rho_{0,R}^{S} = \sqrt{(X^S - X_{0,R})^2 + (Y^S - Y_{0,R})^2 + (Z^S - Z_{0,R})^2} \quad (4)$$

where X^S, Y^S, Z^S are the coordinates of satellites, $X_{0,R}, Y_{0,R}, Z_{0,R}$ are the approximate coordinates of the receiver, n shows the number of satellites and $\rho_{0,R}^{S}$ is the geometric range. The weighted least squares method has been applied to solve the adjustment model given in Eq. (2).

$$\delta = (A^T PA)^{-1}(A^T Pl) \quad (5)$$

$$\delta = \begin{bmatrix} \Delta X & \Delta Y & \Delta Z & cdt_R \end{bmatrix}^T \quad (6)$$

where P is the weight matrix of which the diagonal elements are obtained from the elevation angle of the satellites and it can be shown as follows;

$$P_i = (\sin(e_i))^2 / \sigma_0^2 \quad (7)$$

where, e is the satellites elevation angle, σ_0^2 is the *a priori* variance of the ionosphere-free code measurement and the subscript i identifies the satellite number.

2.2. Data and Processing Strategy

For the implementation of the SPP solution, ten-day data of the ANKR station in Ankara in Turkey, one of the IGS stations, was used. The selected data ranged from 12 to 21 July 2020, provided by IGS (available at: https://cddis.nasa.gov/archive/gnss/data/daily/). Precise orbits and clock products are released by IGS. The products of *.eph files, and *.clk files, provided by Center for Orbit Determination in Europe (CODE), were used in the processing stage for daily solutions (available at: https://cddis.nasa.gov/archive/gnss/products). The RINEX data was collected by LEICA GR30 receiver with observation types: C1, P2. Consequently, the Differential Code Bias (DCB) file provided by CODE was used to upscale the C code to the P code in Eq. (8) (Schaer 2012).

$$P1 = C1 + DCB_{P1-C1} \quad (8)$$

where DCB_{P1-C1} is the DCB between C1 and P1 code.

Table1. Processing Strategy of SPP

Parameters	Used in the Study
Processing Mode	Epoch-by-Epoch
Adjustment Model	Weighted Least Square
Satellite Orbit/Clock	Final CODE products
Antenna Phase Center	igs14.atx
Ionosphere	Ionosphere-Free
Troposphere	UNB3m Model
Relativistic Effect	Corrected (Ashby 2003)
Elevation Mask	10°
Sampling Interval	30s
Standard deviation of code measurements	±0.30 m

It should be pointed that all processing stages were carried out by using an in-house software developed on Matlab by the authors. The input files, as outlined in Table 1, are the RINEX observation, satellite orbit and clock, antenna offset, and DCB files. The elevation mask was set to 10°. An epoch-by-epoch solution was performed using the ordinary weighted least squares method. At the processing stage, if there is no data or the Geometric Dilution of Precision (GDOP) value greater than 30, the epoch is skipped, and moved to the next epoch. GDOP is a crucial factor for SPP solution which reflects the numerical condition of matrix A. The accuracy of the SPP result depends primarily on the value of GDOP that is computed from Eq. (9).

$$GDOP = \sqrt{trace((A^T A)^{-1})} \quad (9)$$

Besides, the outlier data were discarded according to the residual of the measurements. Finally, an accuracy comparison was conducted on the SPP results and the true coordinates of the station. The true coordinates of the station were taken from International Earth Rotation and Reference System Service (IERS).

3. RESULT

The purpose of this paper is to improve the SPP positioning performance using the IGS precise products together with modeling of the common systematic error sources. The data were processed epoch-by-epoch and the errors of the north, east, up components, the number of satellites in each epoch, and the GDOP values were estimated (Figure 1). The error of the up component is larger than the other components. It should be outlined that the results were strongly related to the GDOP value and number of visible satellites. The processing results of about 25 epochs were not shown in the Figure1 when the cases of the number of observed satellites less than 5 or GDOP greater than 30.

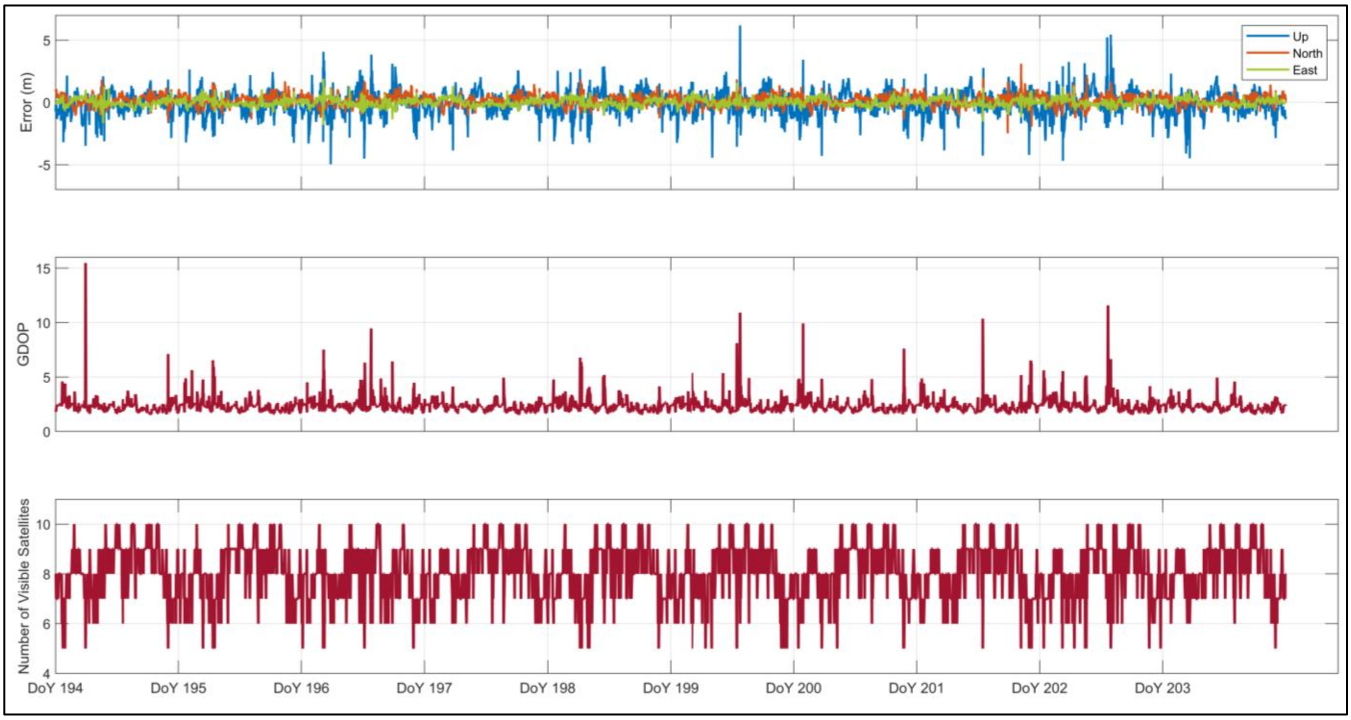

Figure 1. Epoch-by-Epoch Positioning Error, GDOP and Number of Visible Satellites from 13 to 21 July 2020

Table 2 summarizes the daily average error, root mean square error (RMSE), and maximum absolute error for the north, east, and up components that are obtained from the results of the epoch-by-epoch solution for the ANKR station. It was observed that the daily averaged absolute values for all three components were calculated less than 21 cm as shown in Table 2. In particular, the average values of the east component were at the centimeter level.

In addition, more accurate results were calculated for the east component compared to others. The calculated RMSE values were almost at the decimeter level for all three components. Analysis of the result for the error ranges showed that the maximum absolute error of the vertical component was greater than the horizontal components.

Table 2. Statistical Summary of the Processing Results

DoY	Mean (m)			RMSE (m)			Absolute Max. Error (m)		
	N	E	U	N	E	U	N	E	U
194	0.17	-0.02	-0.12	0.43	0.28	0.75	1.82	1.69	3.49
195	0.20	-0.01	-0.18	0.43	0.27	0.80	1.69	1.08	3.24
196	0.21	-0.02	-0.06	0.45	0.30	0.92	1.71	1.91	4.96
197	0.18	-0.01	-0.05	0.40	0.27	0.73	1.48	1.33	3.85
198	0.17	-0.01	0.02	0.42	0.29	0.83	1.80	1.05	3.36
199	0.15	0.02	-0.08	0.42	0.28	0.83	1.85	1.57	6.19
200	0.17	0.01	-0.10	0.41	0.28	0.82	1.39	0.94	4.31
201	0.18	0.01	-0.09	0.44	0.28	0.82	3.12	1.54	4.28
202	0.15	0.02	0.00	0.43	0.28	0.96	2.10	1.30	5.45
203	0.15	0.02	-0.21	0.40	0.27	0.88	1.43	1.06	4.49

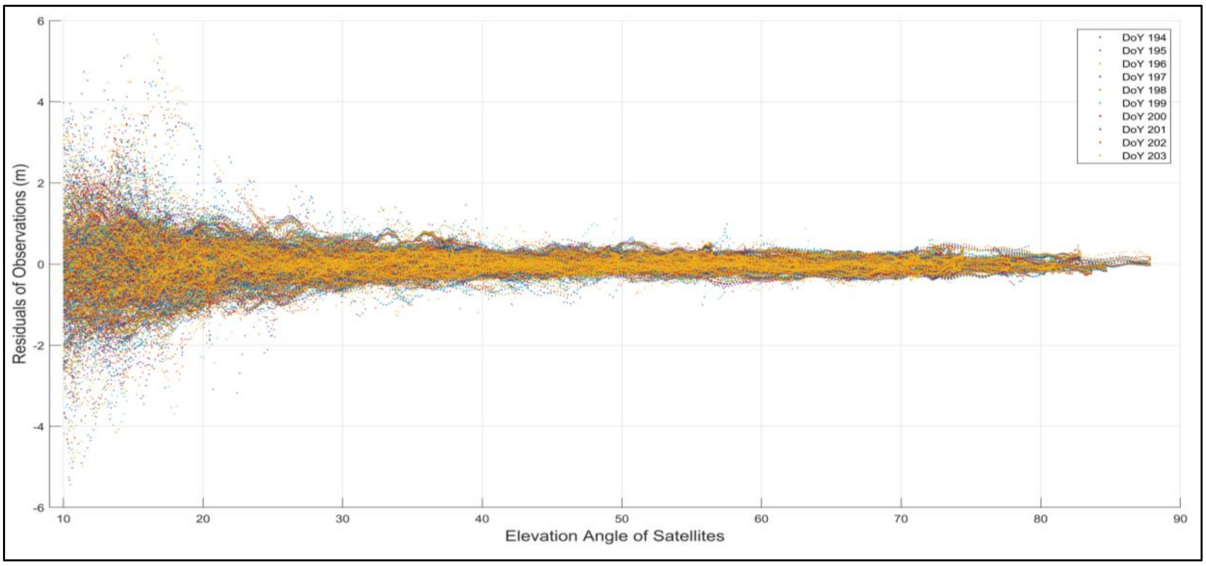

Figure 2. Ionosphere-Free Code Measurement Residual from 13 to 21 July 2020

Figure 2 shows ten-day residuals of the SPP solution with respect to the satellite elevation angle. It can be shown that when the satellite is at low elevation, its residuals get higher. The reason can be explained as the satellites near the user horizon were considerably affected by the multipath and the tropospheric effects.

CONCLUSION

In this study, the performance of GPS SPP was analyzed focusing on the elimination of systematic errors. The test was performed using ten days of observation data of the IGS permanent station called as ANKR. In the processing stage, IGS precise orbit and clock products were utilized. Results produced in this study confirm the effectiveness of the applied strategy, thus improved and comparable results were obtained with the current literature. Daily average coordinate solution was identical to the true positions with a maximum 21 cm error. The RMSE values of all components were at the decimeter level. Furthermore, the up error component was higher than the other two components, as given in Table 2. The results are needed to be clarified using different experiments on different datasets. Improvements of the software will be our priority in future studies to enhance the positional accuracy estimated using the SPP method with other GNSS systems.

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