Intercontinental Geoinformation Days

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Improvement of SPP NMEA output using correction projection method

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Keywords
DGNNS
Accuracy
NMEA
Low-cost GNSS receiver

ABSTRACT

Differential Global Navigation Satellite Systems (DGNSS) positioning is a relative technique used for meter level accuracy requirements that needs an extra communication link between the base and the rover in real-time. For the offline user, the technique can be also used by considering the raw data for both receivers. In the last decade, smartphones with GNSS hardware enormously boomed. In this study, the DGNSS method for low-cost receivers, DGNSS Correction Projection (DGNSS-CP) algorithm was developed and applied for the low-cost, u-blox M8P single-frequency GNSS receiver. The results were analyzed with in-house software developed in MATLAB environment. Detailed analysis of the results outlined that the DGNSS-CP algorithm produced identical results with the position correction in short distance uses. The differential correction in coordinate space (DGNSS-CP) can be applied successfully to all smartphone users.

1. INTRODUCTION

Global Navigation Satellite Systems (GNSS), the satellite-based positioning systems, provide positioning requirements of the worldwide users in different accuracy levels. Single Point Positioning (SPP), usually called a navigation solution in real-time positioning, is an essential processing method of GNSS using pseudorange data of the receiver. This method can be also used in the meter-level accuracy requirements of users in the field of geodesy and GIS.

Improvement of the results with the other augmentation systems such as DGNSS, Local Area Differential GNSS (LADGNSS), Wide Area Differential GNSS (WADGNSS), Satellite Based Augmentation Systems (SBAS), European Geostationary Overlay Service (EGNOS) has been widely used in the literature (Ashkenazi et al. 1998; Enge et al. 1996; Krasuski et al. 2020; Specht et al. 2019; Tabti et al. 2020). Some of these systems require extra communication methods and hardware. These systems also need transferring a common data format (e.g. Radio Technical Commission for Maritime Service (RTCM)) and the computation is performed with corrected observation. In some applications, SPP solutions at National Marine Electronics Association (NMEA) data format are corrected via the Correction Projection Method (Park et al. 2013; Weng et al. 2020; Yoon et al. 2016). The method is widely used compared to the others, as it can be used without GNSS raw data.

The aim of this study was to improve the SPP performance by using the DGNSS Correction Projection method with the implementation of design matrices.

2. METHOD

2.1. NMEA 0183 Protocol

Most low-cost GNSS receivers transmit basic location information and satellite information to the users in the NMEA 0183 protocol, although they do not record GNSS raw data (pseudoranges). Examples of GGA, GSA, and GSV data types are given in Table 1.

Table 1. NMEA 0183 Messages

Data Type	Message
GGA	$GPGGA,113330.00,4048.57208,N,02921.67575,E,1,07,1.37,17.7,M,37.8,M,,*6E
GSA	$GPGSA,A,3,06,32,02,12,19,24,25,,,,,,2.60,1.37,2.22*0E
GSV	$GPGSV,3,1,09,02,41,128,46,06,36,079,45,12,66,325,48,15,07,198,32*79

Position information in a SPP solution is provided via GGA message. The satellite ID and Dilution of Precision (DOP) existing in this solution are included in the GSA

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Cite this study

Sogukkuyu F, Saka M.H (2021). Improvement of SPP NMEA output using correction projection method. 2nd Intercontinental Geoinformation Days (IGD), 40-43, Mersin, Turkey

message. Besides, the elevation and azimuth angles between the satellites and the GNSS receiver are transmitted through the GSV message.

2.2. DGNSS Correction Projection Algorithm

DGNSS, a relative positioning technique, contains two GNSS receivers, one of which is established at the known point. The distance ($\hat{d}^i_{RS}$) between the known point (x_{RS}, y_{RS}, z_{RS}) and satellite i (x^i, y^i, z^i) is estimated by the following equation,

$$\hat{d}^i_{RS} = \sqrt{(x_{RS} - x^i)^2 + \left(y_{RS} - y^i\right)^2 + (z_{RS} - z^i)^2} \tag{1}$$

Pseudorange correction (PRC^i) is generated at the known point and then sent to the user receiver, as follows;

$$PRC^i = \hat{d}^i_{RS} - \rho^i_{RS} \tag{2}$$

where ρ^i_{RS} is the measured pseudorange for each satellite.

To calculate the design matrix H, the position information of the satellites and GNSS receiver is required. There are two methods for calculating the positions of the satellites. In the first method, satellite position information (x^i, y^i, z^i) is computed using the algorithm for ephemeris determination in IS-GPS-200 using the broadcast navigation message collected by the GNSS receiver at the reference station. Then, H design matrix defines as,

$$H = \begin{bmatrix} \frac{x_R - x^1}{\rho_0^1} & \frac{y_R - y^1}{\rho_0^1} & \frac{z_R - z^1}{\rho_0^1} & 1 \\ \frac{x_R - x^2}{\rho_0^2} & \frac{y_R - y^2}{\rho_0^2} & \frac{z_R - z^2}{\rho_0^2} & 1 \\ \vdots & \vdots & \vdots & \vdots \\ \frac{x_R - x^n}{\rho_0^n} & \frac{y_R - y^n}{\rho_0^n} & \frac{z_R - z^n}{\rho_0^n} & 1 \end{bmatrix} \tag{3}$$

where x_R, y_R, and z_R denote approximate coordinates of the receiver in the Earth-centered Earth-Fixed (ECEF) system, ρ_0^i is the geometric range between satellite i and receiver, and n is the number of satellites.

In the second method, the design matrix H is established from the parameters of the local topocentric system. The vector line-of-sight (LOS) is achieved by the azimuth (Az) and elevation (El) angles obtained via the GSV sentence, which can be expressed by the following equation;

$$LOS^i_{local} = \begin{bmatrix} \cos(El^i)\sin(Az^i) \\ \cos(El^i)\cos(Az^i) \\ \sin(El^i) \end{bmatrix} \tag{4}$$

LOS^i_{local} is converted to LOS^i_{ecef} by the rotation matrix (R) that is formed by the receiver's latitude and longitude as shown in Equation 5.

$$LOS^i_{ecef} = R(\varphi, \lambda).LOS^i_{local} \tag{5}$$

The design matrix of H is obtained for n number of satellites as;

$$H = \begin{bmatrix} LOS^1_{ecef} & 1 \\ LOS^2_{ecef} & 1 \\ \vdots & \vdots \\ LOS^n_{ecef} & 1 \end{bmatrix} \tag{6}$$

The position correction (Δx) can be computed from;

$$\Delta x = (H^T H)^{-1} H^T \left(\hat{I} + \hat{T} - \hat{B} + PRC\right) \tag{7}$$

where $\hat{I}$ is an ionospheric delay, $\hat{T}$ is a tropospheric delay, and $\hat{B}$ is the satellite clock offset (Weng et al., 2020).

SPP accuracy can be improved by applying position correction to the stand-alone position (x_0) obtained from the GGA sentence. Then, the DGNSS position is calculated by the following equation;

$$x_{DGNSS} = x_0 + \Delta x \tag{8}$$

2.3. Study Area and Experimental Setup

The study area is Çayırova Campus of Gebze Technical University (Fig. 1). To assess the performance of DGNSS Correction Projection method, the CHC i80 GNSS receiver was established at the reference station and u-blox C94-M8P (Fig. 2) at the rover station. Then, the low-cost u-blox C94-M8P receiver was connected to NovAtel Flexpack 4 antenna. Data collection started at 11:33 UTC on 19 March 2021 and lasted about 75 min with an interval of 1 Hz. The reference and rover receivers collected data at Receiver Independent Exchange (RINEX) and NMEA formats, respectively.

Figure 1. Study Area

Figure 2. u-blox C94-M8P Evaluation Kit

Position correction was applied by performing SPP solution at reference station with satellites used by rover station in SPP solution. In this solution, satellite clock error, ionosphere delay correction and troposphere delay correction were calculated using broadcasting satellite clock error parameters, the Klobuchar model, and the Saastamoinen model (Klobuchar 1987; Saastamoinen 1972).

3. RESULTS

For the processing of the collected data, an in-house MATLAB program was developed. The program performs the common SPP solution for L1 frequency data using broadcast messages with standard atmospheric models. Besides, the data from the rover receiver at NMEA 0183 format is handled by a sub-program.

The processing results are shown in Table 2 and Fig. 3 where the mean error, standard deviation (STD) and root mean square error (RMSE) for the north, east, and up components was estimated from the solution of the rover station.

Table 2. Summary of Statistical Results

		Mean (m)	STD (m)	RMSE (m)
Stand-Alone	E	0.69	0.60	0.91
	N	1.61	0.70	1.75
	U	-3.03	2.47	3.91
DGNNS-CP with NMEA	E	0.19	0.65	0.68
	N	0.12	0.75	0.76
	U	1.40	2.26	2.66
DGNNS-CP with Eph	E	0.19	0.65	0.68
	N	0.12	0.75	0.75
	U	1.40	2.26	2.66

It was observed that RMSE values obtained from DGNSS-CP solutions were smaller than those of the stand-alone solution for all three components. However, no significant differences were found between the DGNSS-CP solutions and the stand-alone solution in terms of the standard deviation values. As it can be seen from Fig. 3 and Table 2 that the DGNNS and DGNSS-CP methods give similar results for short distances, as it is the case in this study (~200 m). Results revealed that that the construction of the design matrix *H* with ECEF coordinates instead of local coordinates did not contribute to solution.

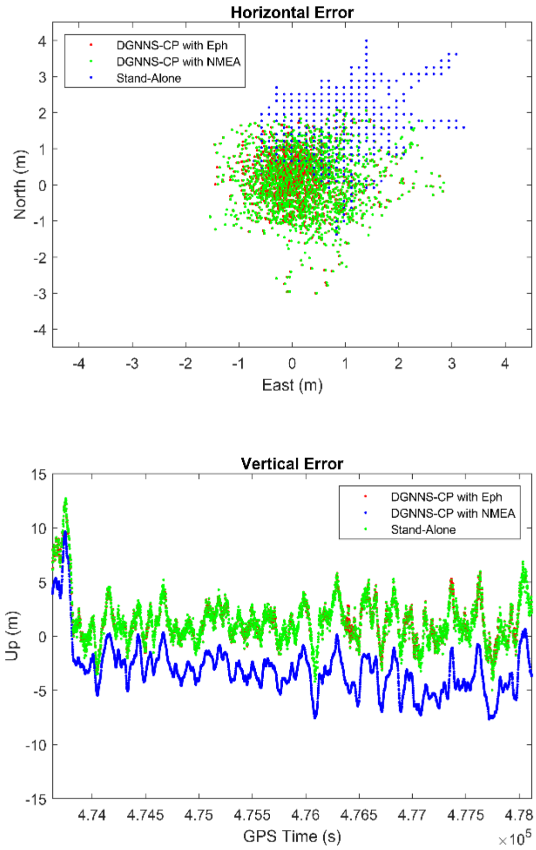

Figure 3. Positioning errors estimated for DGNNS-CP and SPP methods

4. CONCLUSION

The results obtained from the DGNSS-CP were compared with the SPP solution of a low-cost GNSS receiver. The test demonstrated that DGNSS-CP methods provided positioning within meter-level accuracy for horizontal components. In the analysis of North, East, and Up components, it was seen that the performances of the correction methods were identical. Since the navigation message did not contribute to the solution of DGNSS-CP method, the use of DGNSS-CP method with NMEA is found sufficient for the estimation of the positions with low-cost GNSS receivers. In future studies, the performance of DGNSS-CP method will be investigated for longer distances and data from the International GNSS Service (IGS) precise products.

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