SKY PLOT VISIBILITY BASED ON BEIDOU AND GPS SATELLITES OVER BANGKOK, THAILAND

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ABSTRACT

The Global Navigation Satellite System (GNSS) over the Bangkok region occasionally has spots where its performance could be more consistent and imprecise due to the dust in the sky, the surroundings, and high buildings. As a reason, the area has an impact on satellite signal reception. As a reason, the area has an impact on satellite signal reception. As a reason, the area has an impact on satellite signal reception. It blocks and reflects satellite signals and more than the visibility of GNSS satellites is needed to be useful. We offer a sky visibility analysis based on satellites classification. We provide information on sky visibility estimation for BeiDou and GPS satellites based on direct GNSS receiver measurements. The visibility of BeiDou and GPS satellites is classified by sky plotting techniques. For our proposed analytical evaluation of the visibility satellites over Bangkok on November 8th, 2023, we found that the locations of BeiDou and GPS satellites were at different times and affected the efficiency of analyzing the visibility of sky plots throughout Bangkok, Thailand.

Keywords: Sky visibility, BeiDou satellite, GPS satellite, Sky plot, GNSS

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I. INTRODUCTION

The positioning systems based on the GNSS are now considered an important technology for daily life. Especially this technology is used to determine position such as car navigation systems, transportation systems, and aviation systems. Relying on this system must avoid buildings that may obscure the satellite signal. For example, large urban areas like Bangkok have used this technology because there are surrounding buildings that block or affect the reception of satellite signals. Positioning system services based on GNSS are used daily. GNSS positioning is an important technology such as car navigation and real-time monitoring of Sanitation vehicles in cities. However, GNSS positioning performance in a big city could be more satisfactory due to the surrounding buildings blocking or interfering with some satellite signals. Therefore, this affects the positioning error in these areas for upper a hundred meters (An et al., 2020, pp. 1-13; Dabove & Pietra, 2019, pp. 1-17; Garcez et al., 2019, pp. 1-15; Geng et al., 2019, pp. 977-991; Hamza et al., 2023, pp. 1-19). GNSS positioning is a popular approach for improving this urban GNSS positioning performance in which GNSS system analysis like GPS, BeiDou Galileo, GLONASS, IRNSS, and QZSS satellites are used to analyze and predict the satellites sky plot visibility over Bangkok, Thailand.

For GNSS testing, (Hamza et al., 2020 & 2021, pp. 1-16; Huang et al., 2021, pp. 1-20; Yang & Shim (2013, pp. 199-204), they investigated the GNSS signals and simulated the transmitting path, Carrier-to-Noise ratio (C/No) of satellite signals, planimetric plot, and cumulative loss of continuity. Jia et al. (2022, pp. 1-9) experimented by using a single frequency GNSS receiver for analyzing the GNSS satellites signals. They used the single-epoch attitude for determining method with orthogonal constraints for GNSS. BeiDou and GPS satellites can be divided into different positions based on their presence on the sky visibility are applying by Li et al. (2014, pp. 72-89) presented real-time GNSS seismology using a single receiver. Xu et al. (2020, pp. 1-15) presented method sky visibility estimation based on GNSS satellite visibility: an approach of GNSS-based context awareness and Zhang et al. (2020, pp. 1-21) who used a single-receiver geometry-free approach to stochastic modeling of multi-frequency GNSS observables. We offer an analysis that can provide information on sky visibility predictions for BeiDou and GPS satellites based directly on GNSS receiver measurements. Colagrossi et al. (2020, pp. 1-30) describe the methodologies and the proposed strategies to overcome the mission limitations, while achieving a satisfactory constellation visibility of the sky throughout the mission duration. Cai et al. (2015, pp. 133-143) investigating the quad-constellation precise point positioning (PPP) for position determination and analyzing its positioning performance. A quad-constellation PPP model is developed to simultaneously process the observations from GPS, BeiDou, GLONASS and Galileo satellites systems. Lu and Han (2020, pp. 123-128) proposes using superimposed column method to analyze GNSS receivers' surrounding environments and thus improve GNSS satellite visibility predictions in an efficient and reliable manner. Kenpankho et al. (2021, pp. 2152-2159) applied a multi-frequency GNSS receiver to find real-time GPS receiver bias estimation. Liu et al. (2021, pp. 1-12) found the characteristics of phase bias and GNSS application in multi-frequency and multi-GNSS PPP with ambiguity resolution. Wielgocka et al. (2021, pp. 1-14) found the feasibility of using low-cost dual-frequency GNSS receivers for land surveying. In addition, Mao et al. (2021, pp. 1-13) solved the problem on the delay time from GNSS satellites signals according to a new simplified zenith tropospheric delay model for real-time GNSS applications. For the GNSS performance investigation, Odolinski and Teunissen (2020, pp. 1-17) found the best integer equivariant estimation: performance analysis using real data collected by low-cost, single-and dual-frequency, multi-GNSS receivers for short- to long-baseline real-time kinematic positioning (RTK) positioning. Tu et al. (2021, pp. 345-355) investigated the precision of frequency transfer model suitable for short baseline link based on GPS single-differenced observations with ambiguity resolution. Moreover, Ding et al. (2023, pp. 1-13) investigated the performance analysis of a normal GNSS receiver model under different types of jamming signals.

After studied the research, there was found that one research project used to verify GNSS, which is the examination of BeiDou and GPS satellites over Bangkok Thailand. It was interested in studying the appearance of satellites between BeiDou and GPS over Bangkok Thailand on November 8th, 2023, a day during which there was a severe change in the Earth's magnetic field, in where researchers can determine the GNSS receiver is located, allowing BeiDou and GPS satellite in that GNSS system can be applied. BeiDou and GPS satellites can be divided into different positions based on their presence on the sky visibility are applying by Li et al. (2014, pp. 72-89) who presented the real-time GNSS seismology using a single receiver and Zhang et al. (2020, pp. 1-21) used a single-receiver geometry-free approach to stochastic modeling of multi-frequency GNSS observables. We offer an analysis that can provide information on sky visibility predictions for BeiDou and GPS satellites based directly on GNSS receiver measurements.

The statement of research purpose is inspired using a multi-GNSS receiver application. The visibility of BeiDou and GPS satellites can be classified by sky plot technique. For assessing the sensitivity of our proposed sky plot visibility analysis, we used a multi-GNSS receiver for receiving BeiDou and GPS satellites signals that are in different time periods and effects on the performance on the analysis of sky plot visibility over Bangkok, Thailand.

II. METHODOLOGY

A. Research procedure

According to the research studies and related research information, we studied the visibility of GPS satellites and BeiDou satellites over Bangkok, Thailand. The research processes were procedures step by step: First, the collected observer BeiDou and GPS satellite signal data and classified it by include periods of time are sunrise, noon, sunset, and midnight. Then, we collected BeiDou and GPS satellites positioned signal data using multi frequency.

B. Data collection

In the studies, we collected BeiDou and GPS satellites data from a multi GNSS receiver at SIET KMITL station Bangkok, Thailand, (13.729°N, 100.780°E). We collected BeiDou and GPS satellites data following observed on November 8th, 2023, there are changes Total Electron Content (TEC) in the ionosphere to magnetic field changes in the earth. Satellites data were collected into four time according to the phase of sun periods: sunrise (6:00 o’clock), noon (12:00 o’clock), sunset (18:00 o’clock), and midnight (00:00 o’clock). In this study, the multi GNSS receiver (BG2s GNSS ionospheric monitor model) was the instrument to collect BeiDou and GPS satellites signals data. The BG2s GNSS ionospheric monitor system is supported by Geology and Geophysics, Chinese Academy of Sciences (IGGCAS). The GNSS ionospheric monitor system connection is shown in Figure 1 as the BG2s GNSS ionospheric monitor.

Figure 1 BG2s GNSS ionospheric monitor system.

C. Data analysis

The visibility of the global navigation satellite system is positioning above the sky at the location where the GNSS receiver is installed locating, distinguishing numbers, and signal information of the global navigation satellite system, that can be observations from satellite receivers at that time. All information displayed can only be viewed by using GNSS receiver and assume of the information which are positioning displayed of each satellite above that location. The different heights, strength of the satellite signal transmitted. GPS satellites and BeiDou satellites received from GNSS receivers are using to display the visibility of the global navigation satellite system in the regions around the world. The visibility of the BeiDou and GPS satellites can be created using a simulated sky based on the Earth's elevation line of 0° from the ground up to a perpendicular point of 90° above the area where the global navigation satellite receiver is installed and divided the angles of the directions that angle 0° is north, 90° is east, 180° is south, angle 270° is west, and finally at 360° is north again. The sky plot visibility mask generated from GNSS receiver, BG2s ionospheric monitor, is calculated by the elevation angle and azimuth angle can be expressed as in Equation (1). There are $elev_{Az}$ for the elevation angle of a particular azimuth angle Az, which ranges from 1° to 360°, $elev_R$ for elevation angle 90°, and Az_D for azimuth angle direction of GNSS receiver, BG2s ionospheric monitor, position 360° (Xu et al., 2020, pp. 1-15).

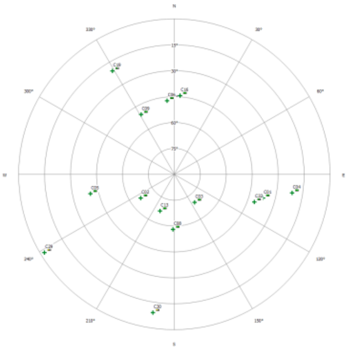
$$\text{Sky plot visibility} = \frac{\sum_{Az=0^\circ}^{360^\circ} elev_{Az}}{elev_R \times Az_D} \quad (1)$$

where $elev_R$ is 90°, and Az_D is 360°

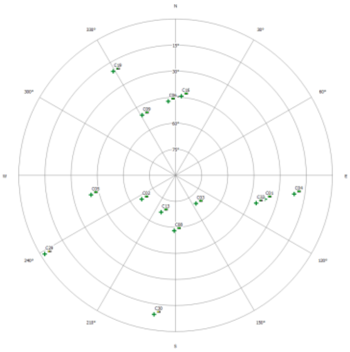
III. RESULTS

This study research collected BeiDou and GPS satellites data as the results, from a multi GNSS receiver at SIET KMITL station over Bangkok, Thailand. We collected BeiDou and GPS satellites data following observed for a day on November 8th, 2023. Satellites data were collected into four time periods at 06:00 o'clock for sunrise, 12:00 o'clock for noon, 18:00 o'clock for sunset, and 00:00 o'clock for midnight according to the phase of sun. According to the Equation 1, the sky plot visibilities of BeiDou and GPS satellites were plotted into four times including for sunrise, noon, sunset, and midnight as shown in Figure 2 which BeiDou and GPS sky plot visibilityes on November 8th, 2023, are shown respectively.

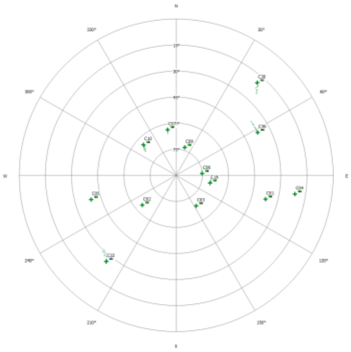
In Figure 2, the result of observed number of satellites were BeiDou and GPS sky plot visibilities over Bangkok, Thailand on November 8th, 2023. There is a comparison of the number of satellites which are displayed by the BG2s satellite receiver in each period which is divided into four time periods: 6:00 a.m., sunrise time, 12:00 p.m., noon time, 6:00 p.m., sunset time, and finally 12:00 a.m., midnight time.



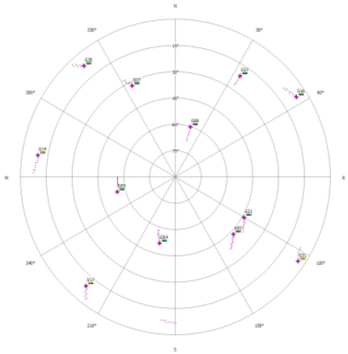
a) BeiDou sky plot visibilities at 06:00 am.



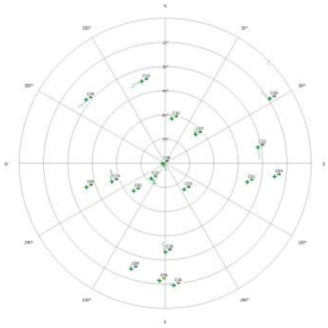
b) GPS sky plot visibilities at 06:00 am.



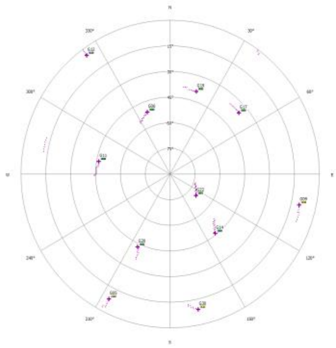
c) BeiDou sky plot visibilities at 12:00 am.



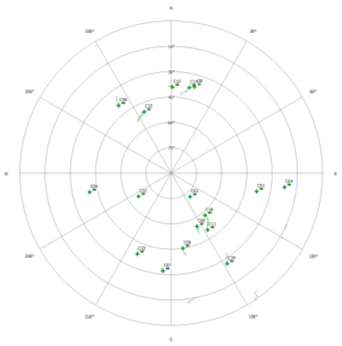
d) GPS sky plot visibilities at 12:00 am.



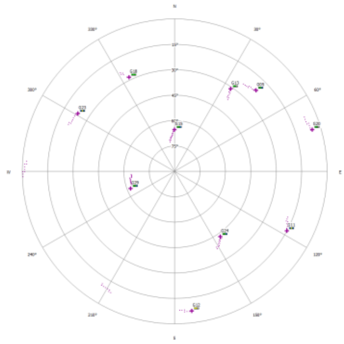
e) BeiDou sky plot visibilities at 18:00 pm.



f) GPS sky plot visibilities at 18:00 pm.



g) BeiDou sky plot visibilities at 00:00 am.



h) GPS sky plot visibilities at 00:00 am.

Figure 2 BeiDou and GPS sky plot visibilities on November 8th, 2023.

The BeiDou satellites visibilities at local time (LT) over Bangkok On November 8th, 2023, show in Table 1. There are 38 BeiDou satellites in the satellite number preceded by a letter indicating "C". There are 38 BeiDou satellites that are visibility on sky plot excluding C15, C17, C18, C20, C21, C23, C27, C31, C33, C34, C35, C37, and C38. There are C1, C2, C3, C4, C5, C6, C9, C10, and C16 that can be received for four periods of time. The BeiDou satellites that can be received all three periods of time are C7, C8, and C13. There are satellites that can received two periods of time which are C8, C19, C22, C24, and C30. Other than that can be received one periods of time as show in Table 1.

Table 1 BeiDou satellites visibilities over Bangkok on November 8th, 2023.

No.	Time (LT)	06:00		12:00		18:00		00:00	
	Satellite	Azimuth	Elevation	Azimuth	Elevation	Azimuth	Elevation	Azimuth	Elevation
1	C1	105°	37°	105°	37°	103°	38°	102°	38°
2	C2	235°	66°	229°	64°	229°	64°	235°	66°
3	C3	144°	70°	147°	69°	144°	70°	141°	72°
4	C4	99°	21°	99°	21°	97°	22°	97°	22°
5	C5	257°	40°	254°	39°	253°	39°	257°	40°
6	C6	352°	47°	73°	73°	184°	18°	154°	51°
7	C7	-	-	348°	63°	46°	64°	185°	32°
8	C8	178°	58°	-	-	266°	89°	12°	36°
9	C9	328°	59°	16°	70°	199°	23°	170°	41°
10	C10	173°	32°	308°	64°	8°	62°	203°	38°
11	C11	-	-	-	-	-	-	141°	50°
12	C12	-	-	-	-	344°	38°	144°	0°
13	C13	200°	67°	-	-	223°	77°	0°	38°
14	C14	-	-	-	-	-	-	7°	38°
15	C15	-	-	-	-	-	-	-	-
16	C16	2°	44°	92°	69°	178°	15°	141°	54°
17	C17	-	-	-	-	-	-	-	-
18	C18	-	-	-	-	-	-	-	-
19	C19	326°	15°	-	-	46°	1°	-	-
20	C20	-	-	-	-	-	-	-	-
21	C21	-	-	-	-	-	-	-	-
22	C22	-	-	219°	26°	87°	32°	-	-
23	C23	-	-	-	-	-	-	-	-
24	C24	-	-	-	-	263°	56°	114°	14°
25	C25	-	-	-	-	-	-	168°	13°

Table 1 (continued) BeiDou satellites visibilities over Bangkok on November 8th, 2023.

No.	Time (LT)	06:00		12:00		18:00		00:00	
	Satellite	Azimuth	Elevation	Azimuth	Elevation	Azimuth	Elevation	Azimuth	Elevation
26	C26	-	-	-	-	182°	41°	-	-
27	C27	-	-	-	-	-	-	-	-
28	C28	-	-	-	-	-	-	322°	34°
29	C29	239°	2°	-	-	-	-	-	-
30	C30	189°	9°	41°	19°	-	-	-	-
31	C31	-	-	-	-	-	-	-	-
32	C32	100°	41°	-	-	-	-	-	-
33	C33	-	-	-	-	-	-	-	-
34	C34	-	-	-	-	-	-	-	-
35	C35	-	-	-	-	-	-	-	-
36	C36	-	-	54°	37°	-	-	-	-
37	C37	-	-	-	-	-	-	-	-
38	C38	-	-	-	-	-	-	-	-

While GPS satellites visibilities at local time (LT) over Bangkok on November 8th, 2023, shown in Table 1, there are 38 GPS satellites in the satellite number preceded by a letter indicating "G". There are 38 GPS satellites that are visibility on sky plot excluding G1, G33, G34, G35, G36, G37, and C38. There are G2, G16, G21, and G31 that can be received at sunrise and noon. There are G3, G9, G14, G17, and G30 which can be received at noon and sunset. There are G5, G11, G12, G20, and G24 which can be received at sunset and midnight. There are G10, G23, G25, and G29 which can be received at sunrise and midnight. Other that can be received for one periods of time as shown in Table 2.

Table 2 GPS satellites visibilities over Bangkok on November 8th, 2023.

No.	Time (LT)	06:00		12:00		18:00		00:00	
	Satellite	Azimuth	Elevation	Azimuth	Elevation	Azimuth	Elevation	Azimuth	Elevation
1	G1	-	-	-	-	-	-	-	-
2	G2	281°	13°	134°	38°	-	-	-	-
3	G3	-	-	180°	7°	36°	2°	-	-
4	G4	-	-	194°	51°	-	-	-	-
5	G5	-	-	-	-	207°	8°	38°	22°
6	G6	-	-	-	-	339°	55°	-	-
7	G7	-	-	331°	27°	-	-	-	-
8	G8	-	-	17°	60°	-	-	-	-
9	G9	-	-	256°	55°	110°	19°	-	-
10	G10	134°	60°	-	-	-	-	268°	0°
11	G11	-	-	-	-	280°	46°	112°	15°
12	G12	-	-	-	-	324°	4°	173°	7°
13	G13	-	-	-	-	-	-	34°	31°
14	G14	-	-	272°	7°	142°	53°	-	-
15	G15	-	-	-	-	-	-	350°	65°
16	G16	198°	16°	51°	6°	-	-	-	-

Table 2 (continued) GPS satellites visibilities over Bangkok on November 8th, 2023.

No.	Time (LT)	06:00		12:00		18:00		00:00	
	Satellite	Azimuth	Elevation	Azimuth	Elevation	Azimuth	Elevation	Azimuth	Elevation
17	G17	-	-	217°	3°	49°	35°	-	-
18	G18	-	-	-	-	-	-	331°	23°
19	G19	-	-	-	-	18°	39°	-	-
20	G20	-	-	-	-	205°	43°	67°	5°
21	G21	272°	17°	120°	40°	-	-	-	-
22	G22	-	-	-	-	129°	74°	-	-
23	G23	142°	21°	-	-	-	-	294°	21°
24	G24	-	-	-	-	286°	12°	145°	38°
25	G25	45°	24°	-	-	-	-	208°	9°
26	G26	192°	44°	-	-	-	-	-	-
27	G27	-	-	33°	21°	-	-	-	-
28	G28	335°	50°	-	-	-	-	-	-
29	G29	102°	3°	-	-	-	-	266°	62°
30	G30	-	-	317°	2°	172°	13°	-	-
31	G31	288°	52°	119°	4°	-	-	-	-
32	G32	24°	41°	-	-	-	-	-	-
33	G33	-	-	-	-	-	-	-	-
34	G34	-	-	-	-	-	-	-	-
35	G35	-	-	-	-	-	-	-	-
36	G36	-	-	-	-	-	-	-	-
37	G37	-	-	-	-	-	-	-	-
38	G38	-	-	-	-	-	-	-	-

IV. CONCLUSION AND DISCUSSION

In conclusion, the study of the visibility of BeiDou and GPS satellites can be classified according to the methods in the sky plotting process. For classifying and pinpointing the visibility of global navigation satellites above the sky, we offer the researchers to used GNSS receivers for detecting several satellites of BeiDou and GPS satellites. In the future, the research team will collect various information to study the impact on GNSS satellite signals of the ionosphere which are caused by change in the Earth's magnetic field and the occurrence of solar activity in seasons.

In discussion, the researchers were able to identify the BeiDou and GPS satellites using a method to simulate the sky over Bangkok, Thailand. The researchers were able to determine the positions of the BeiDou and GPS satellites, in the GNSS navigation satellite system, as well as research from research studies by Li et al. (2014, pp. 72-89) and Zhang et al. (2020, pp. 1-21). BeiDou satellites can be classified into different classes. According to the visual characteristics of the appearance of satellites in the sky using GNSS seismology displayed in real time, it uses a multi-frequency receiver and is a non-geometry method to model the stochasticity of GNSS navigation systems observed with multi-frequency satellite receivers. Sky visibility analysis from GNSS receivers can detect BeiDou and GPS satellites in the sky over Bangkok, Thailand.

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REFERENCES

An, X., Meng, X., & Jiang, W. (2020). Multi-constellation GNSS precise point positioning with multi-frequency raw observations and dual-frequency observations of ionospheric-free linear combination. *Satellite Navigation*, *1*(1), 1-13. doi:10.1186/s43020-020-0009-x.

Cai, C., Gao, Y., Pan, L., & Zhu, J. (2015). Precise point positioning with quad-constellations: GPS, BeiDou, GLONASS and Galileo. *Advances in Space Research*, *56*(1), 133-143. doi:10.1016/j.asr.2015.04.001.

Colagrossi, A., Prinetto, J., Silvestrini, S., & Lavagna, M. (2020). Sky visibility analysis for astrophysical data return maximization in HERMES constellation. *Journal of Astronomical Telescopes, Instruments, and Systems*, *6*(4), 1-30. doi:10.1117/1.JATIS.6.4.048001.

Dabove, P., & Pietra, V. D. (2019). Single-baseline RTK positioning using dual-frequency GNSS receivers inside smartphones. *Sensors*, *19*(19), 1-17. doi:10.3390/s19194302.

Ding, M., Chen, W., & Ding, W. (2023). Performance analysis of a normal GNSS receiver model under different types of jamming signals. *Measurement*, *214*, 1-13. doi:10.1016/j.measurement.2023.112786.

Garcez, C. C., de Lima, D. V., Miranda, R. K., Mendonça, F., da Costa, J. P. C., de Almeida, A. L., & de Sousa, R. T. Jr. (2019). Tensor-based subspace tracking for time-delay estimation in GNSS multi-antenna receivers. *Sensors*, *19*(23), 1-15. doi:10.3390/s19235076.

Geng, J., Guo, J., Chang, H., & Li, X. (2019). Toward global instantaneous decimeter-level positioning using tightly coupled multi-constellation and multi-frequency GNSS. *Journal of Geodesy, 93*, 977-991. doi:10.1007/s00190-018-1219-y.

Hamza, V., Stopar, B., & Sterle, O. (2021). Testing the performance of multi-frequency low-cost GNSS receivers and antennas. *Sensors*, *21*(6), 1-16. doi:10.3390/s21062029.

Hamza, V., Stopar, B., Ambrožič, T., Turk, G., & Sterle, O. (2020). Testing multi-frequency low-cost GNSS receivers for geodetic monitoring purposes. *Sensors*, *20*(16), 1-16. doi:10.3390/s20164375.

Hamza, V., Stopar, B., Sterle, O., & Pavlovčič-Prešeren, P. (2023). Low-cost dual-frequency GNSS receivers and antennas for surveying in urban areas. *Sensors*, *23*(5), 1-19. doi:10.3390/s23052861.

Huang, K. Y., Juang, J. C., Tsai, Y. F., & Lin, C. T. (2021). Efficient FPGA implementation of a dual-frequency GNSS receiver with robust inter-frequency aiding. *Sensors*, *21*(14), 1-20. doi:10.3390/s21144634.

Jia, X., Cheng, G., Ji, Y., Sun, X., & Wu, J. (2022). GNSS single-frequency, single-epoch attitude determination method with orthogonal constraints. *Mathematical Problems in Engineering*, *2022*, 1-9. doi:10.1155/2022/4426987.

Kenpankho, P., Chaichana, A., Trachu, K., Supnithi, P., & Hozumi, K. (2021). Real-time GPS receiver bias estimation. *Advances in Space Research*, *68*(5), 2152-2159. doi:10.1016/j.asr.2021.01.032.

Li, X., Guo, B., Lu, C., Ge, M., Wickert, J., & Schuh, H. (2014). Real-time GNSS seismology using a single receiver. *Geophysical Journal International*, *198*(1), 72-89. doi:10.1093/gji/ggu113.

Liu, T., Chen, H., Chen, Q., Jiang, W., Laurichesse, D., An, X., & Geng, T. (2021). Characteristics of phase bias from CNES and its application in multi-frequency and multi-GNSS precise point positioning with ambiguity resolution. *GPS Solutions, 25*(58), 1-13. doi:10.1007/s10291-021-01100-7.

Lu, Y.-H., & Han, J.-Y. (2020). GNSS satellite visibility analysis based on 3D spatial information in urban areas. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *43*, 123-128. doi:10.5194/isprs-archives-XLIII-B4-2020-123-2020.

Mao, J., Wang, Q., Liang, Y., & Cui, T. (2021). A new simplified zenith tropospheric delay model for real-time GNSS applications. *GPS Solutions*, *25*(43), 1-12. doi:10.1007/s10291-021-01092-4.

Odolinski, R., & Teunissen, P. J. (2020). Best integer equivariant estimation: Performance analysis using real data collected by low-cost, single-and dual-frequency, multi-GNSS receivers for short-to long-baseline RTK positioning. *Journal of Geodesy*, *94*(9), 1-17. doi:10.1007/s00190-020-01423-2.

Tu, R., Zhang, P., Zhang, R., Fan, L., Han, J., Hong, J., Liu, J. & Lu, X. (2021). Precise frequency transfer model suitable for short baseline link based on GPS single-differenced observations with ambiguity resolution. *Acta Geodaetica et Geophysica*, *56*, 345-355. doi:10.1007/s40328-021-00332-w.

Wielgocka, N., Hadas, T., Kaczmarek, A., & Marut, G. (2021). Feasibility of using low-cost dual-frequency GNSS receivers for land surveying. *Sensors*, *21*(6), 1-14. doi:10.3390/s21061956.

Xu, H., Hsu, L. T., Lu, D., & Cai, B. (2020). Sky visibility estimation based on GNSS satellite visibility: An approach of GNSS-based context awareness. *GPS Solutions*, *24*(59), 1-15. doi:10.1007/s10291-020-0973-5.

Yang, C. K., & Shim, D. S. (2013). Analysis of the effect of time delay on the integrated GNSS/INS navigation systems. *TransNav: International Journal on Marine Navigation and Safety of Sea Transportation*, *7*(2), 199-204. doi:10.12716/1001.07.02.06.

Zhang, B., Hou, P., Liu, T., & Yuan, Y. (2020). A single-receiver geometry-free approach to stochastic modeling of multi-frequency GNSS observables. *Journal of Geodesy*, *94*(37), 1-21. doi;10.1007/s00190-020-01366-8.