# INFLUENCE OF THE $I_{95}$-INDEX AND LOCAL PARAMETERS ON THE ACCURACY OF GNSS POSITIONING

Assoc. Prof. dr. Greet Deruyter[1]

Prof. dr. Alain De Wulf[1]

Joachim Vercruysse[1]

[1] Ghent University, **Belgium**

## ABSTRACT

Although originally developed for military purposes, Global Navigation Satellite Systems have become indispensable for an ever-growing range of civil and scientific applications such as cartography, cadastral and land information systems, transport systems, precision agriculture, self-driving vehicles, rescue missions, etc.

The accuracy of positioning by means of GNSS, however, is affected by atmospheric distortions of the GNSS signals as well as by the characteristics of the receiver (e.g. number of channels, firmware, etc.), local external influences (e.g. reflective surfaces, obstructions, electromagnetic distortions, etc.), and the system used to correct these distortions (e.g. SBAS, RTK, RTK-network, post-processing, etc.). Hence, to predict the accuracy of the positioning, it is important to understand the degree of robustness of the system (receiver and method) in terms of the degree in which it is affected by ionospheric conditions and local external influences.

For this research the system consisted of a Septentrio ALTUS NR3 GNSS receiver in combination with the Flemish RTK-network FLEPOS, Belgium.

To assess the accuracy and its variations, measurements in varying external circumstances, were performed according to the of ISO 17123-8 standard during the period November 2021 - April 2022.

The results show that the system is very robust for the influence of the $I_{95}$ index and the location specific parameters: proximity of high voltage cables and windmills. However, the distance to the nearest reference station and the number of visible satellites can affect the precision. Further research is necessary to assess the influence of other parameters.

**Keywords:** GNSS, RTK-network, $I_{95}$ index, accuracy, precision, high voltage

## INTRODUCTION

Global Navigation Satellite System (GNSS) is the general term covering all global and regional satellite positioning systems. The global systems are: Global Positioning System or GPS (United States of America), GLObalnaja NAvigatsionnaja Spoetnikovaja Sistema or GLONASS (Russia), Galileo (Europe), and BeiDou Satellite System or BDS, also called COMPAS (China). The main regional systems are: the Indian Regional Navigation Satellite System or IRNSS also called Navigation Indian Constellation or NavIC (India), and the Quasi-Zenith Satellite System or QZSS (Japan). The global systems are based on the concept of trilateration, with the position of the satellites as reference to determine the position of the receiver. All GNSS contain a space-, control-, and user segment. [1] The space segment consists of the satellites transmitting PseudoRandom Noise (PRN) encoded signals which contain the position of the satellite, along with various other information. The control segment consist of monitoring-, master control-, and uplink stations, to resolve satellite anomalies and ascertain and refurbish satellite clock rectifications, the satellite's position, almanac, ephemeris, etc. The user- or receiver segment covers billions of receivers varying from smart watch users to high-end geodetic receivers. [2, 3]

GNSS positioning is independent of weather conditions or day/night limitations, and provides global coverage, however, the accuracy and precision are prone to several disturbance factors. Furthermore, GNSS instruments do not provide a one-size-fits-all solution for geoscientific surveys. Not only a vast number of devices and technologies is available, also a single instrument can provide a range of accuracies, depending on the location and applied method. [2, 4]

In differential surveying, a base receiver is positioned over a known location. By comparing the known and recorded position, and based on the fact that atmospheric distortions are similar for receivers within a distance up to 15 kilometres, the correction to be applied to a second roving receiver can be calculated, either after the survey has been completed or in real time using a short-range radio signal. Real Time Kinematic (RTK) surveys can provide centimetre-level accuracy, and Post Processing Kinematic (PPK) can offer sub-centimetre-level. [4, 5] This could also be obtained with a single receiver using network correction data provided by Continuously Operating Reference Stations (CORS) for Network RTK (NRTK). In NRTK the differential correction is achieved based on an array of CORS surrounding the survey site. The correction data is transmitted to the rover via a mobile phone network [4, 5] or can be downloaded for postprocessing. The CORS used in Flanders, Belgium, is the Flemish Positioning Service (FLEPOS), which supports the simultaneous use of GPS, GLONASS, Galileo, and BDS [6], hence significantly increasing the number of available satellites, thus ensuring more satellites are likely to be observed in challenging environmental settings. Except for the data transmission cost, FLEPOS is free of charge. [4, 7] To receive the correction, a mobile NTRIP (Networked Transport of RTCM via Internet Protocol) or a data-voice-over connection is needed. [8] At this moment FLEPOS deploys 46 CORS of which 34 are FLEPOS CORS and 13 belong to the neighbouring networks, being the other Belgian networks WALCORS (Walloon Region) and GPSBru (Brussels Capital Region) and the Dutch 06-GPS. [8] There are three different possibilities for end-users to receive the FLEPOS corrections: (1) Nearest Reference Station (NRS), (2) Single Reference Station (SRS), and (3) Virtual Reference Station (VRS). When choosing NRS or SRS, the corrections are related to one CORS, producing accurate results for receivers close to that station. For NRS, the most suitable station is chosen based on the location of the receiver. In the case of SRS, the user decides autonomously on the CORS to be used. The VRS possibility uses a network solution. This involves that, similarly to the NRS solution, the position of the user is transmitted to the FLEPOS data centre, which then uses the corrections of the six closest CORS to create a VRS at a maximum distance of 5 kilometres. [8]

At the user end, electromagnetic interference, the satellite constellation, and multipath are important error sources. The Geometric Dilution Of Precision (GDOP) and the Position

DOP (PDOP) are measures to evaluate the continuously changing satellite constellation and as such indicate the quality of the GNSS positioning. DOP values can fluctuate from 1 (ideal) to 50 (extremely bad) and should be less than 6 to ensure a good quality. [9, 10] For the space segment, the ionospheric and tropospheric delays are considered to be the most important error causes. Tropospheric delays are eliminated by using elevation masks together with (N)RTK. However, the ionospheric disturbances are not solved by (N)RTK positioning. The Ionospheric disturbance index $I_{95}$ ($I_{95}$ index) is developed mainly for RTK positioning. For the ionospheric correction models of NRTK, the $I_{95}$ index was developed, which remove the linear part of the differential ionospheric biases. Therefore, the $I_{95L}$ index is an indicator for the non-linearity of the differential ionospheric biases with values are usually lower than the $I_{95}$ index values. [11] In this research only the $I_{95}$ index was available, hence was used as an indicator for ionospheric disturbances. An $I_{95}$ index between 0 and 2 has a negligible effect on the result; between 2 and 4 the influence is minor and an $I_{95}$ index of more than 4 can result in very high deviations or even unusable results. [12]

As mentioned before, the position accuracy depends on the combination of the receiver characteristics, the data acquisition method and external factors. Hence, the aim of this research was to establish the degree of robustness of the combination of a Septentrio ALTUS NR3 GNSS receiver and the VRS solution offered by FLEPOS.

## MATERIALS AND METHODS

The main specifications provided by the manufacturer of the Septentrio Altus NR3 GNSS are summarized in Table 1. The receiver handles signals from all GNSS and is equipped with several patented tools to improve the quality of the measurements of which the most important for this research was the elimination of ionospheric delays (IONO+). [13]

***Table 1: Main characteristics of the Septentrio Altus NR3 GNSS receiver [13]***

| | |
|---|---|
| Satellite tracking channels | 448 |
| Signals | GPS (L1, L2, L5), GLONASS (L1, L2, L3), Galileo1(E1, E5ab, AltBoc), BDS1 (B1, B2)<br>SBAS: EGNOS, WAAS, GAGAN, MSAS, SDCM (L1, L5)<br>NavIC1 (L5), QZSS (L1, L2, L5)<br>L-band1<br>DGNSS and RTK (base and rover)<br>RAIM (Receiver Autonomous Integrity Monitoring) |
| Septentrio's patented GNSS+ technologies | AIM+: anti-jamming and monitoring system against narrow and wideband interference<br>IONO+: advanced scintillation mitigation<br>APME+: multipath estimator for code and phase multipath mitigation<br>LOCK+: superior tracking robustness under heavy mechanical shocks or vibrations |
| RTK performance (baseline < 40km) | Horizontal accuracy 0.6 cm + 0.5 ppm<br>Vertical accuracy 1 cm + 1 ppm |

All measurements were performed with the same instrument using an elevation mask of 15°. The precision was determined according to the procedure defined in the ISO 17123-8. To assess the accuracy, the deviations of the individual measurements from their mean were calculated. In total five different locations were used for the precision assessment, which resulted in ten locations for the accuracy assessment (Figure 1). Table 2 shows the characteristics of each site.

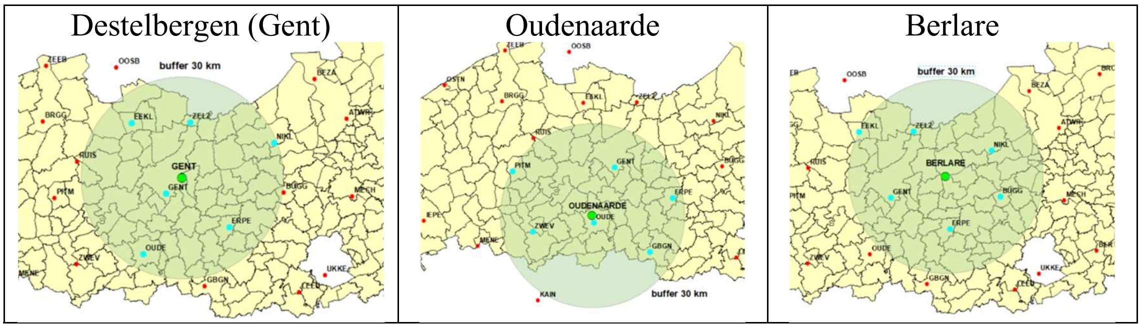


***Figure 1: Location of the survey sites in green; location of the 6 nearest CORS within a maximum distance of 30 km; red location of the other CORS***

***Table 2: Characteristics of the survey sites***

| Location | Number of measurements | ISO 17123-8 procedures | Nearest CORS | Other |
|---|---|---|---|---|
| Destelbergen I | 255 | 21 | ±6.5 km | |
| Destelbergen II | 90 | 5 | ±6.5 km | Distance to high voltage cable (150 kV): 65 m. |
| Oudenaarde | 195 | 39 | ±2.5 km | |
| Berlare I | 105 | 21 | ±16.5 km | Distance to 2 windmills: 300 m. |
| Berlare II | 105 | 21 | ±16.5 km | |

## RESULTS

### *INFLUENCE OF THE LOCATION*

According to the ISO 17123-8 procedure, the precision was determined a total of 57 times on 27 different days and nights between November 11, 2021 and April 15, 2022 in 5 different locations. The results, shown in Table 3, are well within the specifications of the manufacturer and after executing the one-way ANOVA-test for both the horizontal and vertical precision ($p_{hor} = 0.4569$ and $p_{vert} = 0.0583$), it could be concluded that there were no significant differences in precision between the different locations.

***Table 3: Mean precision of the locations determined with IS0 17123-8 (Reference system LB72; $S_x$, $S_y$, $S_{xy}$, $S_z$: the X-direction, Y-direction, horizontal and vertical precisions; range = difference between minimum and maximum precision; N = number of times the ISO 17123-8 was performed)***

| | | $S_x$ (mm) | | $S_y$ (mm) | | $S_z$ (mm) | | $S_{xy}$ (mm) | |
|---|---|---|---|---|---|---|---|---|---|
| Location | N | Mean | Range | Mean | Range | Mean | Range | Mean | Range |
| Destelbergen I | 21 | 4.0 | 4.3 | 5.3 | 4.9 | 9.1 | 8.4 | 6.7 | 4.1 |
| Destelbergen II | 5 | 3.5 | 2.1 | 4.2 | 2.4 | 8.7 | 3.5 | 5.5 | 1.9 |
| Oudenaarde | 19 | 3.3 | 5.3 | 4.3 | 5.4 | 9.4 | 10.0 | 5.4 | 5.3 |
| Berlare I | 6 | 3.4 | 2.2 | 4.0 | 1.2 | 7.8 | 6.0 | 5.3 | 1.9 |
| Berlare II | 6 | 3.4 | 1.0 | 4.0 | 2.0 | 7.0 | 2.1 | 5.0 | 1.3 |

To determine the relation between the accuracy and the location, the differences between the 57 individual coordinates and their corresponding means (ΔXY and ΔZ) were calculated. Again, the one-way ANOVA-test for both the horizontal and vertical differences ($p_{hor}$ = 0.1038 and $p_{vert}$ = 0.8762), revealed no significant differences in accuracy between the different locations.

*RELATION BETWEEN THE PDOP AND THE NUMBER OF AVAILABLE SATELLITES*

The field validation procedure as described in the ISO 17123-8, is based on several measuring series with time intervals to ensure that only the equipment characteristics are evaluated and other influences such as satellite constellation, PDOP, GDOP, ionospheric delays are excluded. Hence, to assess the influence of other parameters on the precision and accuracy, the raw data was further analysed.

Because both FLEPOS and the Altus NR3 GNSS receiver allow simultaneous use of GPS, GLONASS, BDS and Galileo, in normal circumstances the available number of satellites is seldom less than 12, leading to excellent PDOP values. However, even with these high numbers, the PDOP still drops further when more satellites are available. Based on Figure 2, more than 24 satellites induce no further improvement. As the PDOP is directly related to the precision of the position (Figure 3Figure 4), it can be concluded that up to 24 satellites both the horizontal and vertical precision ameliorate with an increasing number of satellites. Figure 3Figure 4 also show a higher sensitivity to the PDOP for the vertical precision. This conclusion is supported by the calculation of the Pearson correlation coefficients (**Fout! Verwijzingsbron niet gevonden.**).

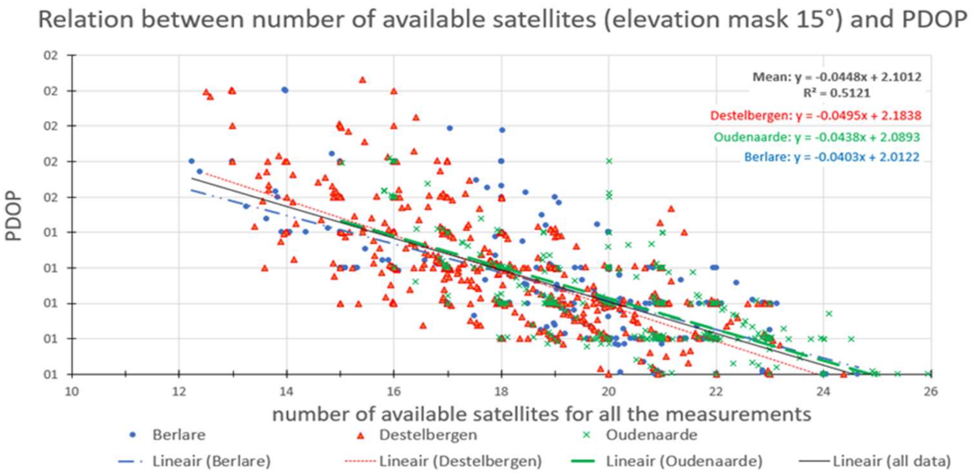


*Figure 2: Negative correlation between the number of available satellites and the PDOP*

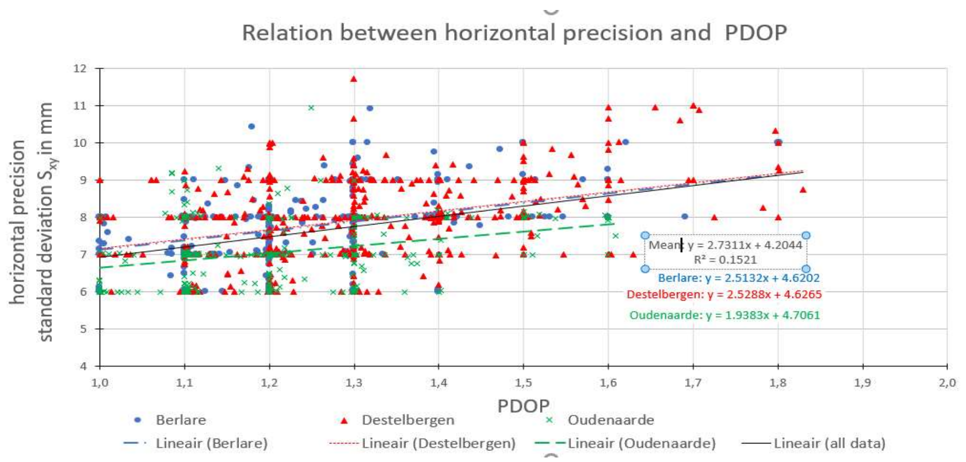


*Figure 3: Relation between the horizontal precision and the PDOP*

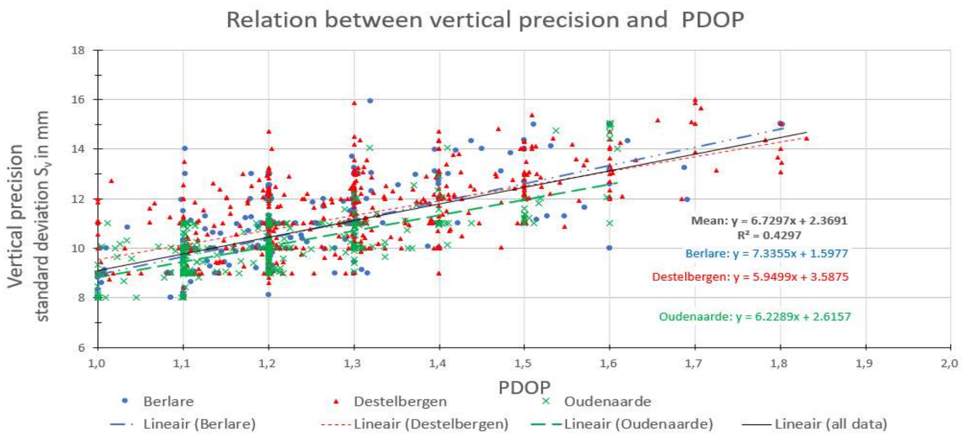


***Figure 4: Relation between the vertical precision and the PDOP***

***Table 4: Pearson correlation coefficients for PDOP***

| Location | PDOP versus number of satellites | PDOP versus horizontal precision | PDOP versus vertical precision | PDOP versus horizontal accuracy | PDOP versus vertical accuracy |
|---|---|---|---|---|---|
| Destelbergen I | -0.7120 | 0.4436 | 0.7086 | -0.0551 | 0.1723 |
| Destelbergen II | -0.6972 | 0.4651 | 0.5989 | -0.0486 | 0.0197 |
| Oudenaarde | -0.7312 | 0.3054 | 0.6912 | 0.0534 | -0.0332 |
| Berlare I | -0.5795 | 0.3168 | 0.6572 | 0.0680 | 0.0959 |
| Berlare II | -0.6884 | 0.4777 | 0.6305 | -0.0733 | 0.0162 |
| Complete dataset | -0.7131 | 0.3845 | 0.6441 | -0.0270 | 0.1243 |

## RELATION BETWEEN THE $I_{95}$ INDEX AND PDOP

For the whole Flemish Region, only one $I_{95}$ index value is registered every hour.

**Fout! Verwijzingsbron niet gevonden.**(A) shows the mean $I_{95}$ values per hour and per season for the period from May 2020 until May 2022. To visualize the night-time better, the daily cycle is repeated, so that in fact 48 hours are shown. Each season exhibits two daily maxima, however the winter and autumn cycles show high peaks around 11-12 a.m., while the other maximum is less outspoken. The values for the summer and spring are generally lower and show less variations. The lowest values appear in the summer.

**Fout! Verwijzingsbron niet gevonden.**(B) shows that the mean $I_{95}$ hourly values for this research period are slightly higher than in **Fout! Verwijzingsbron niet gevonden.**(A), because they are situated further in the 11-year cycle which will reach its maximum in July 2025.

To establish whether the accuracy and the precision are related to the $I_{95}$ index, each interval width of 0.5 of $I_{95}$ values, the deviations between all individual positions and their mean, as well as the mean standard deviations belonging to that interval were calculated. As it was already established that there is no significant difference between the five locations, the data from all locations was evaluated at once.

Calculation of the Pearson correlation coefficients (0.0154 for the horizontal, and -0.0078 for the vertical deviations) indicates no correlation between the $I_{95}$ index and the accuracy. For the precision, the correlation coefficients were 0.0236 for the horizontal, and 0.0634 for the vertical precisions, so also no correlation was found between the $I_{95}$ index and the precision.

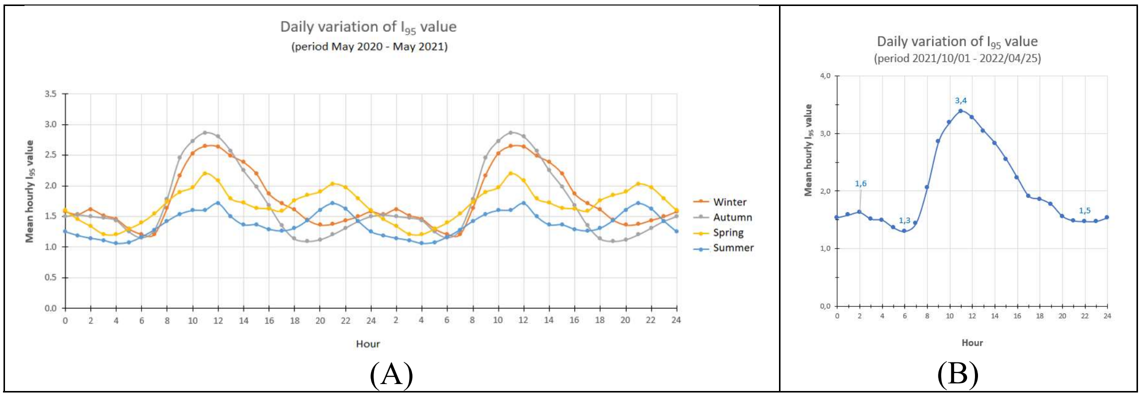


***Figure 5:** (A) Hourly mean $I_{95}$ value per season (period May 2020 – May 2022) and (B) Hourly mean $I_{95}$ value for the research period*

## DISCUSSION

The analysis of the data revealed no influence of the local context on the accuracy and precision of the results, however, this must not be generalized because the high-voltage cables and windmills were possibly too far away from the receivers, to have an influence. Furthermore, for 90% of the measurements 14 or more satellites were available, leading to excellent PDOP values.

No correlation was found between the $I_{95}$ index and the accuracy and precision. However, for 82% of the measurements the $I_{95}$ value was less than or equal to 4 and 20% was less than or equal to 2, leading to very weak possible influences of ionospheric delay. Hence, it is possible that coming closer to the peak of the 11-year cycle, a correlation will be found.

The conclusions are only valid for Septentrio Altus NR3 GNSS-rovers, equipped with the IONO+ tool. Simultaneous measurements should be performed with other receivers not equipped with this tool, to determine which part of the ionospheric distortions are eliminated by the FLEPOS corrections and which part can be attributed to the IONO+ tool.

## CONCLUSION

It can be concluded that the combination Septentrio ALTUS NR3 - NRTK FLEPOS VRS solution complies with, and even performs better than, the manufacturer's specifications.

The combination deployed, uses satellites from all global GNSS, leading to low PDOP values, especially beneficial for the vertical precision, but with no impact on the accuracy.

Finally, the precision and accuracy were not correlated with the $I_{95}$ index, which signifies that the results are not affected by ionospheric disturbances. However, during the measuring campaign ionospheric activity was very low, so it still is possible that higher ionospheric disturbances will affect the results. Also, it could not be determined which part of the elimination of the ionospheric effects can be attributed to the correction provided by FLEPOS and which part is the result of the features of the receiver. Further research is necessary, especially as in the coming years the ionospheric activity will increase, with an expected maximum in the summer of 2025.

## AKNOWLEDGEMENT

The authors want to express their gratitude to Thibault Demey and Thomas Vandenberghe for their efforts in the data acquisition and statistical analysis of the data.

## REFERENCES

[1] "Other Global Navigation Satellite Systems (GNSS)," 2022/06/01, 2022; https://www.gps.gov/systems/gnss/.

[2] A. Kumar, S. Kumar, P. Lal, P. Saikia, P. K. Srivastava, and G. P. Petropoulos, "Introduction to GPS/GNSS technology " *GPS and GNSS Technology in Geosiences*, G. P. Petropoulos and P. K. Srivastava, eds., pp. 3 - 20: Elsevier, 2021.

[3] R. T. Ioannides, T. Pany, and G. Gibbons, "Known Vulnerabilities of Global Navigation Satellite Systems, Status, and Potential Mitigation Techniques," *Proceedings of the Ieee,* vol. 104, no. 6, pp. 1174-1194, Jun, 2016.

[4] M. Schaefer, and A. Pearson, "Accuracy and precision of GNSS in the field " *GPS and GNSS Technology in Geosiences*, G. P. Petropoulos and P. K. Srivastava, eds., pp. 393-414: Elsevier, 2021.

[5] P. Dabove, "The usability of GNSS mass-market receivers for cadastral surveys considering RTK and NRTK techniques," *Geodesy and Geodynamics,* vol. 10, no. 4, pp. 282-289, Jul, 2019.

[6] B. Dierickx, "The Evolution of FLEPOS 3.0," *Gim International-the Worldwide Magazine for Geomatics,* vol. 34, no. 3, pp. 30-31, May-Jun, 2020.

[7] X. X. Li, M. R. Ge, X. L. Dai, X. D. Ren, M. Fritsche, J. Wickert, and H. Schuh, "Accuracy and reliability of multi-GNSS real-time precise positioning: GPS, GLONASS, BeiDou, and Galileo," *Journal of Geodesy,* vol. 89, no. 6, pp. 607-635, Jun, 2015.

[8] D. Vlaanderen. "FLEPOS Centimeternauwkeurige positiebepaling," 2022/06/01, 2022; https://www.vlaanderen.be/digitaal-vlaanderen/onze-oplossingen/flepos-centimeternauwkeurige-positiebepaling.

[9] H. Azami, M. R. Mosavi, and S. Sanei, "Classification of GPS Satellites Using Improved Back Propagation Training Algorithms," *Wireless Personal Communications,* vol. 71, no. 2, pp. 789-803, Jul, 2013.

[10] M. Tahsin, S. Sultana, T. Reza, M. Hossam-E-Haider, and Ieee, "Analysis of DOP and its Preciseness in GNSS Position Estimation," *International Conference on Electrical Engineering and Information Communication Technology*, 2015.

[11] L. Wanninger, "Ionospheric Disturbance Indices for RTK and Network RTK Positioning," in 17th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS 2004), Long Beach, CA, 2004, pp. 2849 - 2854.

[12] M. Pluta, "The Influence of Condition of the Ionosphere on the Accuracy of Real Time Kinematic GPS Measurements," https://bibliotekanauki.pl/articles/385414, 2013].

[13] "Altus NR3 Compact GNSS Rover for Surveying & GIS Applications," *Septentrio_Altus_NR3_LR-1.pdf*, EMEA (HQ), 2020.