# Performance Evaluation of Different GNSS Positioning Modes

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**ABSTRACT**

This paper gives a comparison of different GPS positioning modes using RTKLIB which is free and open-source software. The modes tested in this work are Single point positioning **(**SPP), precise point positioning (PPP), Satellite-based augmentation system **(**SBAS), Differential GPS (DGPS), and Real-Time Kinematic (RTK). The data for tests were obtained from NetR9 receivers, these types of receivers are multi-frequencies and multi-constellation receivers that provide carrier and phase measurements. The SPP mode is the very simplest mode, it can be used for applications where accuracy is not less than 5m, and it can be improved to achieve 1m by using SBAS corrections but only in the coverage area of the system. The DGPS can also provide 1m accuracy using a second receiver as a base station which can increase the cost of the operation. For applications that need very high accuracy, RTK and PPP can be used to reach centimeter-level accuracy. RTK needs a base station in addition to the rover receiver used for the positioning; PPP uses precise orbital and clock solutions which are not available in real time for all users.



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## 1. INTRODUCTION

Global Navigation Satellite Systems (GNSS) are essential tools in all areas of our daily life where the position is required. Since the implementation of the first satellite-based localization system, the American system GPS, in the 1980s, research in the field of satellite radio-positioning has continued to expand. Precise positioning by GNSS methods has experienced constant expansion which was accelerated in the 2000s and it is now possible to position oneself in real-time with a precision which can reach a few centimeters using the new constellations of satellites (GLONASS, GALILEO, COMPASS, etc.) which was developed to complete the GPS constellation and make the use of such systems even more available and more reliable [1].

In addition to the new constellations, nowadays several networks of ground stations are installed, the purpose of each one is to modulate the spatially correlated errors (ionosphere, troposphere, and ephemeris) on each station before setting up error correction models and disseminating the data necessary for users (corrections and/or observations) so that they can position themselves by double-difference with the expected accuracy following various approaches [2] [3].

The implementation of precise positioning algorithms to meet the requirements of precise positioning applications using consumer receivers is currently one of the main challenges in satellite navigation. The techniques that have revolutionized the world of GNSS positioning are satellite-based augmentation systems (SBAS) [3], Precise Point Positioning (PPP) [4][5], Differential GPS (DGPS) [6], and Real-Time Kinematic Positioning (RTK) [7]. Those modes can be divided into two categories, each of which is divided into several parts depending on the observation mode used.

The first one is the absolute positioning; it corresponds to the standard use of a single static or mobile GPS receiver which measures the pseudo-distances of the code to detect the position of the user instantly [8]. Absolute positioning using phase measurements has become possible; it is the case of PPP technique which requires a single receiver that can determines the position with greater precision (cm) [4].

The second one is the relative positioning; this technique uses two receivers separated by a distance called the baseline which simultaneously tracks the same satellites. Code measurements and/or phase measurements can be used in relative positioning, depending on accuracy requirements. The latter provides the greatest precision. The relative positioning can be performed in real-time mode or post-processing mode. The shorter is the distance between the two receivers, the greater is the similar errors [6]. The relative mode is divided according to the method of observation (the state of the receivers) into several modes, through which can find Static mode, Kinematic mode, and also moving base and rover mode [1].

## 2. DATA ACQUISITION

To evaluate the positioning performances of each positioning mode, datasets from 04 GNSS stations (**ST01** to **ST04**) in addition to one reference station (**REFS**) from 22 September 2019 to 13 November 2019 (day of the year (DOY), from 265 to 317) were selected and utilized for numerical analysis. All of the stations receivers are Trimble receivers which are multi-frequencies and multi-constellations receivers. The following table summarizes the characteristic of this type of receiver [9].

Table 1. Receiver features

| Parameters | Information |
|---|---|
| Number of channels | 440 |
| Constellations | GPS/GLONASS/GALILEO/COMPASS |
| Frequencies | L1/L2/L5 |
| SBAS | WAAS/EGNOS/MSAS |
| Battery capacity | 15 hours |
| Operating temperature | -40°C to +65°C |
| Power range | 9.5V to 28V |
| Data storage rate | Up to 50 Hz |
| Antenna type | Zephyr Geodetic 2 |
| Communications | RS-232/USB/Ethernet/Blutooth |

The receiver we used in our study is compatible with all GNSS constellations. For SBAS and PPP the corrections are only available for GPS, to respect the standards of comparison the same constellation must be used for each positioning mode. In this work only GPS satellites are used in the final solution.

For the PPP mode the satellite orbits and clock offsets are corrected by precise data provided by **MGEX**, which is available at (ftp://cddis.gsfc.nasa.gov/). Two types of data can be downloaded from this web site via FTP protocol. The first one is the "**sp3** file" which provides GPS and GLONASS orbital solutions, the second one is the "**clk** file" which provides station and satellite clock solutions.

For the SBAS solution, The SBAS corrections message used in this work are obtained from the CNES website (ftp://serenad-public.cnes.fr) based on the FTP service, this is an historical site containing SBAS ground stations data, SBAS messages, and raw data in different formats for downloading.

For positioning with DGPS and RTK a reference station with a known coordinate was chosen and the following table summarizes the distance (Base line) between each station used in this work and the reference station:

Table 2. Approximate distance between base and rovers stations

| Stations | Base line (Km) |
|---|---|
| ST01 | 75 |
| ST03 | 150 |
| ST04 | 300 |
| ST07 | 750 |

The data was processed by the RTKLib software which is an open-source program package for GNSS positioning. It supports standard and precise positioning algorithms with multi-constellation (GPS, GLONASS, Galileo, QZSS, BeiDou and SBAS) and multi-frequency (L1, L2 and L5). The data can be processed in various positioning modes with GNSS for both real-time and post-processing: Single, DGPS/DGNSS, Kinematic, Static, Moving-Baseline, Fixed, PPP-Kinematic, PPP-Staticand PPP-Fixed [10].

## 3. DATA QUALITY CHECK

Before starting the data processing and the results comparison the quality check of the collected data is a very interesting step to ensure that any limitation in the positioning quality of each mode is due to the algorithms and strategies of the mode and there are no phenomena that influence the results. Many parameters are investigated in this step; the first one is the number of satellites used in the processing, it is necessary to ensure that at least 5 satellites are visible during the observations [11]. The following figure illustrates the number of GPS satellites visible during the observations from the station **REFS**. We can clearly remark that at least 7 GPS satellites are visible at the same time.

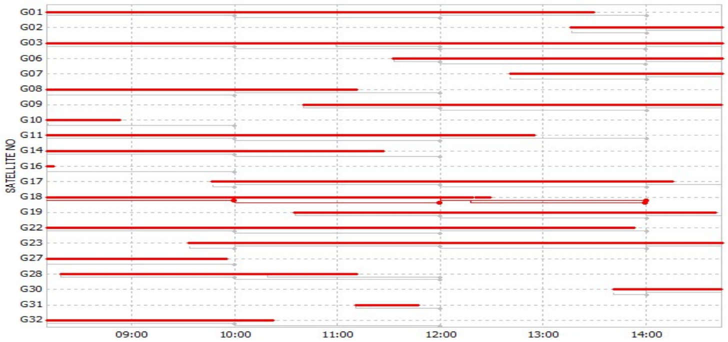


Figure 1. visible GPS satellites used in the solution

The second parameter is the DOP parameter (**Dilution of Precision***)* which is deducted from the matrix of variance and covariance of the unknowns (coordinates and times) of the absolute positioning and it depends on the geometry of the distribution of the satellites [11]. A value between 1 and 5 is considered good, beyond 5 the measurement is no longer considered acceptable.


Figure 2. Dilution of Precision

The last parameter to be checked is the signal-to-noise ratio (SNR). It is the ratio of GPS signal power to the noise floor at the receiver level. The SNR is estimated from the carrier tracking loop outputs and it is different from one GPS frequency to another. The typical SNR value of an ideal GPS receiver ranges from 35 to 45 dB-Hz [12]. The major error that influences the quality of signals is Multipath signals, this phenomenon refers to reflected signals from nearby obstacles one or more times before reaching the receiver antenna [11]. The following figure gives the variation of the multipath error in function to satellite elevation.

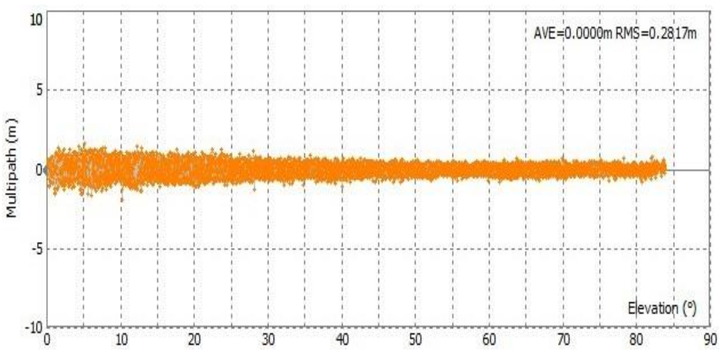


Figure 3. Multipath errors

Figure 3 illustarts the variation of Multipath errors in function of satellites elevation. The elevation is the angle between the vertical plane (horizon) and the line from the receiver directed towards the satellite. We can conclude that the major errors are observed from satellites with elevation less than 15°; an elevation mask is applied in this work to reduce the effect of Multipath. The elevation mask is a filter, which will disallow any signal from a satellite that is below a certain described angle as registered in the satellite's ephemeris. The elevation mask is set to 15° to ward off atmospheric distortion and possible multipath errors due to structural interference.

## 4. EXPERIMENTS AND RESULTS

In this section we will give the results (Position accuracy) of each mode, the same dataset and configuration are used for all modes.

### 4.1. Single point positioning (SPP)

This method is the standard method used for positioning, it is the very simplest method based on the estimation of the pseudo distance between the receiver and each satellite in its visibility. The positions of those satellites are calculated from the broadcasted data (navigation messages) [1][8]. The ionosphere delay is calculated from the Klobuchar model and the Troposphere delay is estimated using the Saastamoinen model [1]. The following figures give the variation of the errors (Easting, Northing, and Up) for station ST01

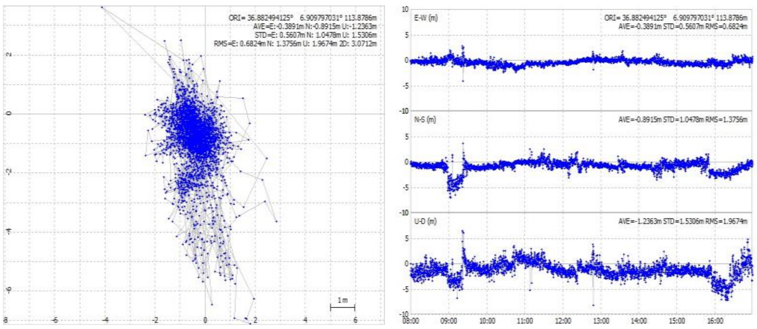

Figure 4. Easting, Northing and Up errors in SPP mode

The following figure summarizes the RMS of the solution obtained for the four stations.

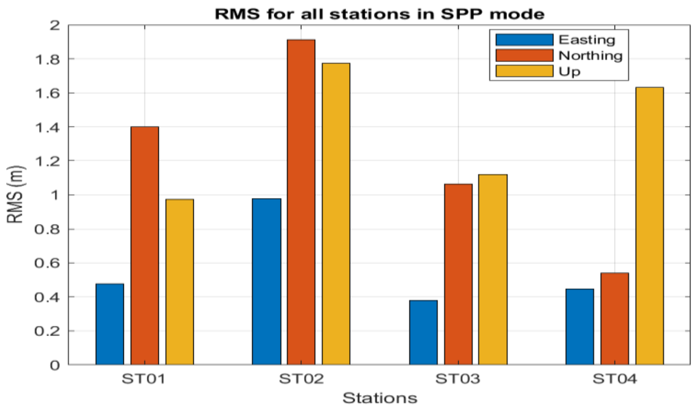


Figure 5. RMS in SPP mode for all stations

### 4.2. Satellite based augmentation system (SBAS)

Spatial augmentation systems consist of terrestrial relay stations and geostationary satellites designed to receive signals from GPS and GLONASS satellites and transmit corrected time and distance measurements, thereby greatly increasing the accuracy of the measurements. The special feature of these systems is that the frequency band and the modulation of the data link signals are identical to those of the GPS signals. In addition, the SBAS signal is broadcast by geostationary satellites covering very large areas [2]. Three groups are currently active: EGNOS for Europe, WAAS for the United States, and MSAS for Japan. China's SNAS system falls into this category. India has also undertaken to implement its GAGAN system pending a larger IRNSS system. The following figure is the variation of the error for station ST01 which is located in the coverage area of the EGNOS system [3].

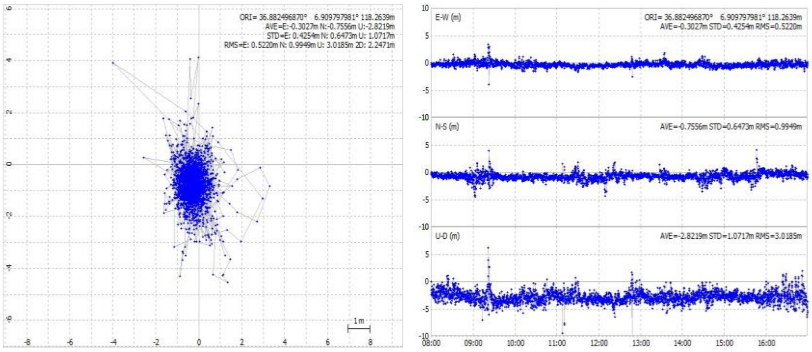

Figure 6. Easting, Northing and Up errors in SBAS mode

The following figure is the error variance of a station located out of the coverage area. We can observe the degradation in the solution compared to the previous station. This can be explained by the inefficacity of the corrections transmitted by SBAS satellite when the receivers are in the edge or out of the coverage area.

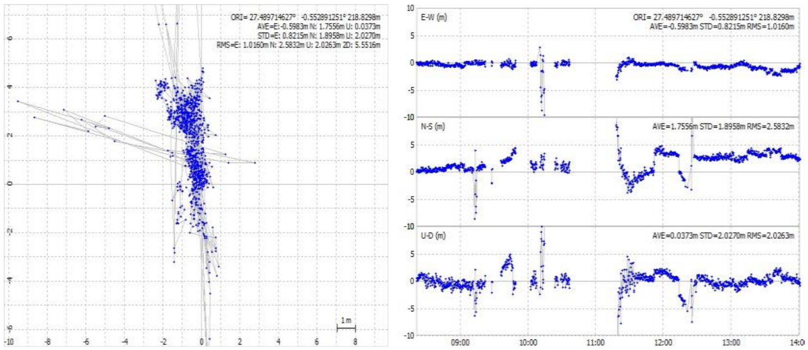

Figure 7. Errors in SBAS mode for a station out of the coverage area

For figure 7, the receiver is placed in a station located just in the edge of the coverage area on the SBAS system (EGNOS) the acquisition of the correction information is not guaranteed in this area, the gaps in the data are because of the inexistence of the correction in this time

The following figure summarizes the RMS of the SBAS solution obtained for the four stations

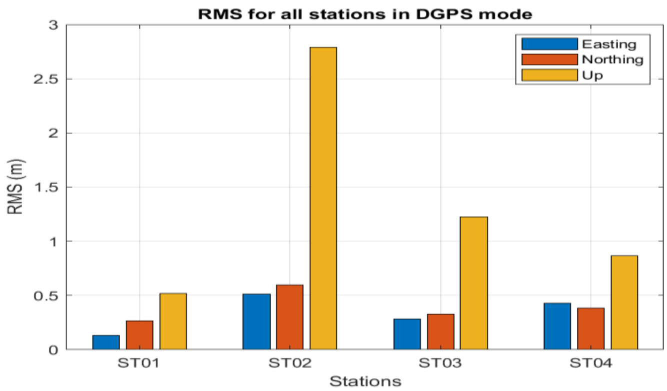

Figure 8. RMS in SBAS mode for all stations

### 4.3. Precise point positioning (PPP)

Nowadays, very precise orbit and satellite clock data are currently available by the IGS (International GNSS Service). The availability of these precise products has enabled the development of a new method of precise absolute positioning which is the PPP. GNSS positioning in PPP mode is a method based on the use of phase observers and zero-difference code. The fact that there is no differentiation, errors must be modeled accurately [4]. This type of positioning is based on the use of phase and code observations on the two LI and L2 frequencies, the ephemerides of the satellites (precise orbits), the rotation parameters of the earth as well as the error of the satellite clock, in order to determine the coordinates of the station, the error correction of the receiver clock [5].

PPP employs zero-difference (ZD) measurement equations like the single point positioning. Precise satellite ephemeris and clock are downloaded from IGS web site as SP3 and CLK files. Receiver antenna phase errors in the image of phase center offset (PCO) and phase center variation (PCV) are corrected using ANTEX file provided also by the international GNSS service. The following figure is the solution obtained from station ST01.

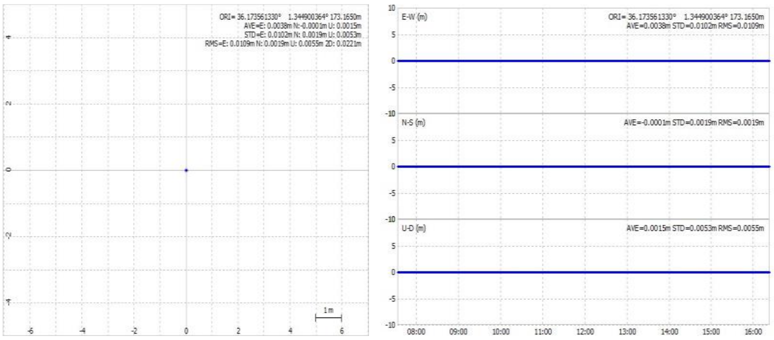

Figure 9. Easting, Northing and Up errors in PPP mode

The following figure is a zoom of the previous figure:

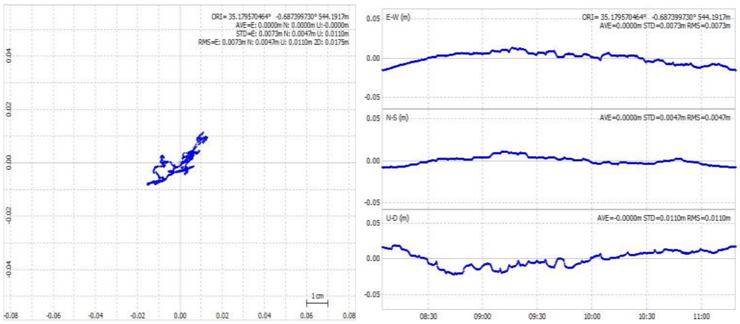

Figure 10. Zoom on Figure 9

The following figure summarizes the RMS of the PPP solution obtained for the four stations

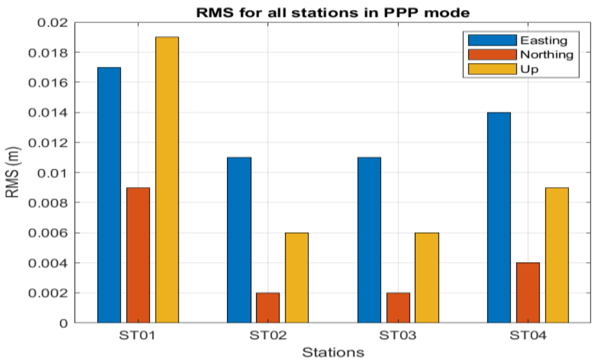

Figure 11. RMS in PPP mode for all stations

### 4.4. Differential GPS (DGPS)

Differential GPS, or DGPS, was designed to circumvent the Selective Availability SA error. It uses a network of fixed reference stations that transmits the difference between the positions calculated from the satellites' signals and their known real positions. The ground network is implemented by the users who resell the corrections. The DGPS offer a resolution in the order of 1m. This technology is widely used in both land and sea navigation. Accuracy varies with distance, when the receiver is very close to the reference, and therefore eliminated by the differential. The range of the reference bases can reach 300km, thus providing for the positioning needs for coastal navigation [6]. The following figure is the results obtained from a station near the reference station ST01 (75 Km is the distance between **ST01** and the reference station (**REFS)**), the results obtained is well improved.

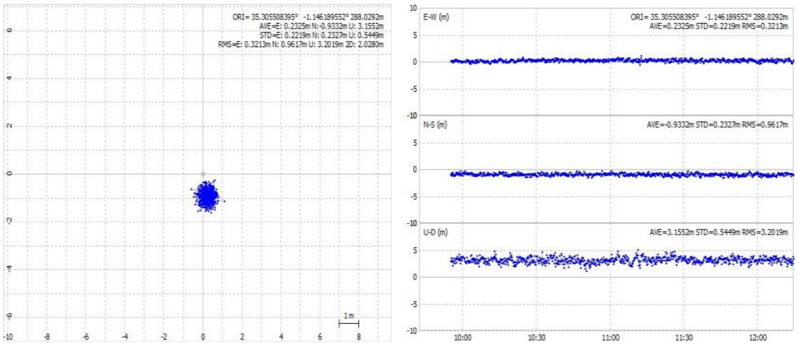

Figure 12. Easting, Northing and Up errors in DGPS mode (75 Km line-base)

The following figure is the solution obtained from station far than the reference station

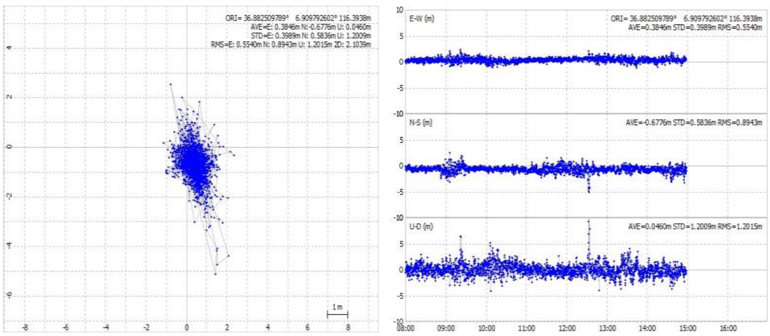

Figure 13. Easting, Northing and Up errors in DGPS mode (>300 Km line-base)

The following figure summarizes the RMS of the DGPS solution obtained for the four stations

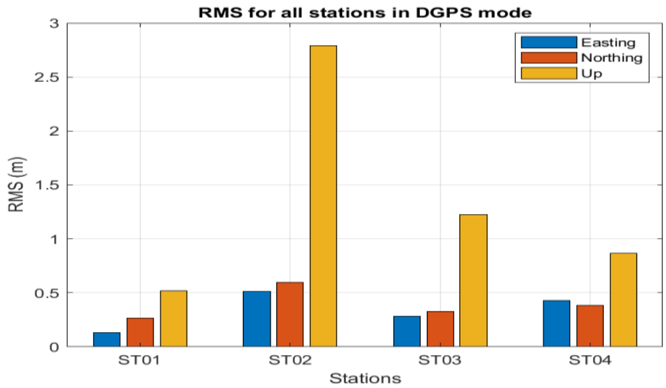


Figure 14. RMS in DGPS mode for all stations

### 4.5. Real Time kinematic (RTK)

RTK uses the same principle of differential correction as DGPS. A base whose position is known transmits the corrections. Its advantage comes from the phase difference used for the correction, the difference between the moment when a signal is transmitted from the satellite and the moment when it is recorded by the receiver. While DGPS uses the code, RTK uses the phase of the signal carrier thus providing proportionally greater precision. This improvement comes at a price; the receiver must not be more than 100km from the base. The solution is then to have its corrective base which sends the corrections by radio link to the mobile. The resolution of phase measurement is a few millimeters. In practice, the positioning uncertainty is of the order of a few centimeters [7]. The same thing as the DGPS, the following results are from ST01 with a base-line equal to 75Km. To fix the ambiguity we used the “continuous” option**.** the results are well improved compared to the results obtained from station far from the reference station.

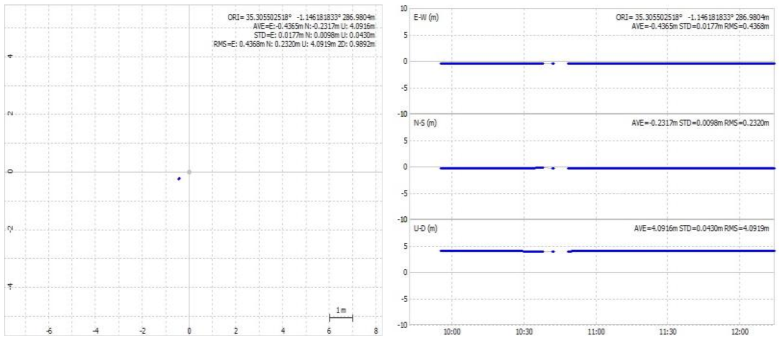
Figure 15. Easting, Northing and Up errors in RTK mode (75 Km line-base)

For figure 15, the gaps in the solution between 10:40 and 10:50 explain that the receiver can’t fix the ambiguity using correction from the base station.

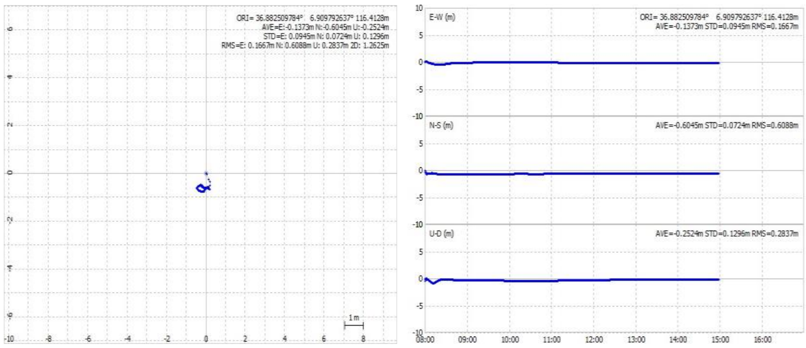
Figure 16. Easting, Northing and Up errors in RTK mode (>300 Km line-base)

The following figure summarizes the RMS of the DGPS solution obtained for the four stations

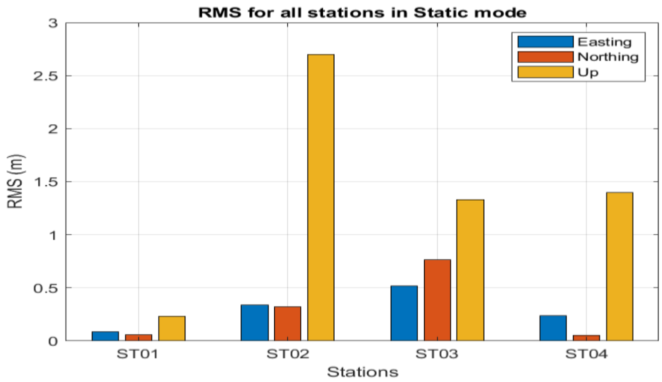

Figure 17. RMS in DGPS mode for all stations

## 5. RESULTS ANALYSIS AND COMPARISON

The position accuracy change from one mode to another depending on various condition, each one has their advantage and inconvenient. The position accuracy can change in the same mode using different constraints like the elevation mask and SNR ratio. Those positioning modes can be classified into many categories depending on the strategies followed by each one in the data processing. The first one is absolute positioning, in this category only one receiver are used to calculate the solution, it is the case of SPP, PPP and SBAS modes. The second one is the differential or relative positioning mode where two receivers are required, the first receiver is used as a reference station with a known position, and another is rover whose position is unknown determined with reference to the base station, in this category we find the DGPS and RTK mode. The modes evaluated in this work can also be divided into two categories based on the parameter of measurement. The SPP, DGPS and SBAS are code based measurements and the PPP and RTK are phase based measurements.

From the previous results, we can clearly remark that Precise Point Positioning is the best positioning technique with centimeter level accuracy but real time PPP until now is still a development project which is not free and not available for all users. SBAS can be used for positioning where accurate required is in the order on 1m but only in the coverage area. SPP can also be used for navigation where accurate positioning is not needed. The SPP, PPP and SBAS are absolute techniques, the cost of logistics and operation are lower in comparison to differential solution DGPS and RTK when a second receiver is needed as a reference station. The DGPS is a good solution when using Low-cost receivers with only code solution, an accuracy of 1m can be obtained when the base-rover distance is less than 300Km. The RTK is phase based solution, the position accuracy in this mode is less then 10cm can be obtained when the base-rover distance is less than 100Km.

The following figure and table summarize the major difference between all modes evaluated in this work.

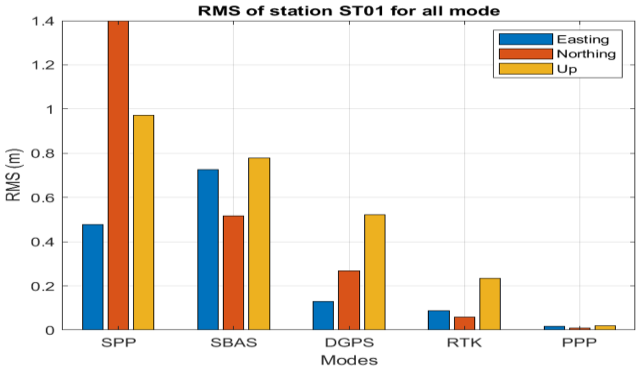


Figure 18. Comparison between all modes for station ST01

Table 3. Comparison between different GNSS positioning modes

| Mode | Measurements | Type | Accuracy | Coverage | Cost | Availablity |
|---|---|---|---|---|---|---|
| **SPP** | Carrier | Absolute | >5m | Global | Low-cost | Real-Time |
| **SBAS** | Carrier | Absolute | <1m | Satellite coverage | Low-cost | Real-Time |
| **DGPS** | Carrier | Relative | <1m | 300 Km | Medium-cost | Real-Time |
| **RTK** | Phase | Relative | <1cm | 100 Km | High-cost | Real-Time |
| **PPP** | Phase | Absolute | <1cm | Global | Low-cost | Delayed |

## 6. CONCLUSION:

In this research, the most important positioning modes were analyzed using RTKLIB software in order to evaluate each mode's accuracy, advantage and inconvenience. Different options in RTKPOST were tested in order to improve the quality of the solution. Starting with the single point positioning mode, the performance of this mode was improved by applying an elevation mask and SNR filter in the aim to remove most multipath and ionosphere errors, the advantage of this mode came from its simplicity with a final solution less than 5m in the best situations. For the SBAS mode, the precision of positioning increased after using corrections transmitted from geo-satellites, the position accuracy in this mode is less than 1m but only in the coverage area of the system which limits the number of users. For the Precise point positioning technique (PPP), the accuracy of the solution obtained can achieve the centimeter level when using precise orbit/clock products by IGS. All the previous sited methods are absolute techniques, they need only one receiver. The DGPS and RTK are relative positioning modes, a reference station with known coordinates is needed. The DGPS is code based technique, with a precision of less than 1m when the distance from the base station is less than 300Km. On the other side, the RTK is a code and phase technique, the use of the phase increase the position accuracy to achieve the centimeter level in real time when the distance between base and rover station is not greater than 100Km.

## REFERENCES

[1] E. D. Kaplan, C. J. Hegarty *Understanding GPS Principles and Applications*, 2nd ed. Norwood, ARTECH HOUSE, 2006

[2] D. Weng, W. Chen, “SBAS enhancement using an independent monitor station in a local area” *GPS Solutions*, vol. 23, no. 12, pp. 2–9, 2019

[3] B. Beldjilali, S. Kahlouche, “Assessment of EGNOS performance for civil aviation flight phase in the edge coverage area in the edge coverage are” *International Journal of Aviation, Aeronautics, and Aerospace*, vol. 7, no. 3, pp. 1–25, 2020

[4] Q. Guo, "Precision comparison and analysis of four online free PPP services in static positioning and tropospheric delay estimation" *GPS Solutions*, vol. 19, no. 4, pp. 537–544, 2015
[5] T. Liu, *et al.*, "Multi-GNSS precise point positioning (MGPPP) using raw observations" *Journal of Geodes,y* vol 91, pp 253–268, 2017
[6] R. Prasad, M. Ruggieri *Applied Satellite Navigation Using GPS, GALILEO, and Augmentation Systems* 1st ed, British Library, ARTECH HOUSE, 2005.
[7] G. Dardanelli, "NRTK, PPP or Static, That Is the Question. Testing Different Positioning Solutions for GNSS Survey" *remote sensing,* vol 13, pp 1–19, 2021
[8] B. Beldjilali, B. Benadda, "Real time software based L1 C/A GPS receiver" 2017 Seminar on Detection Systems Architectures and Technologies (DAT), 2017
[9] Trimble "NetR9 GNSS Reference Receiver User Guide" Trimble guide, Version 4.15, 2010.
[10] T. Takasu "RTKLIB Manual" Version 2.4.2, 2013.
[11] J. S. Subirana, J.M. Juan Zornoza and M. H. Pajares, "GNSS DATA PROCESSING Volume I: Fundamentals and Algorithms" European Space Agency, 2013
[12] B. Andria, A. Penina, K. M. Larson , "Scientific Utility of the Signal-to-Noise Ratio (SNR) Reported by Geodetic GPS Receivers," Proceedings of the 20th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS 2007), Fort Worth, TX, pp. 1999-2010. 2007

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