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Performance Evaluation of Low-Cost Dual-Frequency GNSS Receivers for Precise Positioning in Senegal: Issues and Challenges

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Abstract

The development of this technology has favored the advances noted in recent years in the field of precise positioning. It has also paved the way for a wide range of research into the evaluation of their performance and reliability, their potential use in different fields, the improvement of performance and combined systems, etc. Single-frequency GNSS receivers, which for a long time remained the only category of low-cost GNSS receivers, often limited by their level of accuracy (metric) mainly due to their single-frequency nature, have been joined in the last decade by dual-frequency GNSS receivers developed by certain manufacturers of positioning equipment. These receivers now offer possible alternatives to the relatively expensive conventional (topographic quality) or geodetic receivers and. In this study, the performance of these low-cost dual-frequency receivers was evaluated in static and real-time kinematic GNSS positioning modes. Static positioning was carried out on three points with sessions of 2 h and 4 h over three days with antenna swapping (CHC i50, Leica GS14 and Emlid Reach RS2+). Real-time observations were carried out on eleven (11) points in open, poorly open and not at all open environments, in order to assess not only performance but also receiver sensitivity in environments with a high risk of multipath. The results obtained showed an average agreement of 2 cm in planimetry between the low-cost Emlid RS2+ receiver and the Leica GS14 and CHC i50 receivers. The differences in altimetry are nevertheless greater (sometimes up to decimetres for certain points). Real-time positioning results provided an average convergence of around 1 cm on the E, N and H components with the results from the low-cost Emlid Reach RS2+ and Ublox ZED-F9P receivers and the CHC i50 receiver. Analysis of the results obtained has enabled us to highlight the various issues and challenges associated with this new generation of GNSS receivers, with a view to enhancing their appropriation and optimal integration in the professional and research worlds.

Keywords

Low-Cost GNSS, NRTK, Precise Positioning, Issues, Challenges

1. Introduction

Data collected in the field as part of infrastructure construction projects, mineral resource exploration or exploitation, land development or natural and technological hazard studies must be positioned with great precision, usually in a single reference frame. Precision positioning therefore occupies a central place in topographic science in particular, and geographic science in general.

The evolution of precise positioning instruments and methods has gone from the surveying chain to the differential GPS, via the theodolite and the total station [1]. Initially, the use of dual-frequency GNSS receivers was conditioned by the possibility of a large investment in heavy, expensive equipment, depending on the precision required. With these GNSS receivers of topographic or geodetic quality, various positioning methods have been implemented with different principles, accuracies, advantages and limitations [2]-[4]. More recently, with the development of nanotechnologies, new low-cost dual-frequency receivers have come onto the market, confirming the progress made in precise positioning over the last decade. The relatively high cost of conventional or geodetic dual-frequency receivers has long been one of the main constraints to sufficient availability of such equipment in developing countries such as Senegal, and in projects with insufficient or very limited budgets requiring precise positioning work. However, this new generation of low-cost receivers could, with their proven performance, present positioning stakeholders in Senegal with multiple issues and potential challenges to be met in order to diversify their applications and ensure greater appropriation. The aim of this study is to evaluate the performance of these low-cost dual-frequency receivers, to show the issues linked to their current and future use, and the challenges to be met, particularly in countries like Senegal.

2. Presentation of Tools Used and Performance Evaluation

In this study, we used the following receivers for GNSS observations: CHCNAV i50, Leica GS14, Emlid Reach RS2+ and a low-cost Ublox ZED-F9P GNSS module with a DA910 antenna, whose characteristics are shown in **Table 1**.

Observations made with these receivers were processed with:

- manufacturers' in-house software for real-time calculations;
- the Canadian online PPP calculation tool CSRS-PPP for PPP calculations;
- leica infinity software for post-processing in static differential positioning.

These GNSS observations were used to evaluate the performance of our low-cost receivers, and different positioning scenarios and strategies were adopted:

- Static mode observations were carried out at three points (LM1, LM2 and LM4) using CHC i50, Leica GS14 and Emlid Reach RS2+ receivers (**Figures 1-4**).

Table 1. Characteristics of the GNSS receivers used.

Receivers	Features	Details	Technical specifications	Acquisition costs
CHCNAV i50	-Dual-frequency GNSS receiver - 624 channels - Support for GPS, GLONASS, Galileo, Beidou, QZSS, SBAS	- RTK: Horizontal: 8 mm + 1 ppm Vertical: 15 mm + 1 ppm - Static post-processing: Horizontal: 3 mm + 0.5 ppm Vertical: 5 mm + 0.5 ppm	- Size: 140 mm × 130 mm × 106 mm - Weight: 1.29 kg - Autonomy: 5 h (RTK) to 12 h (static). - UHF antenna port (TNC female)	11,000 € (Package of two receivers + accessories)
Leica GS14	- Dual-frequency GNSS receiver - Number of channels: 120 - Constellations used: GPS (L1, L2, L2C)	- RTK: Horizontal: 8 mm + 1 ppm - Vertical: 15 mm + 1 ppm - Static post-processing: - Horizontal: 3 mm + 0.1 ppm Vertical: 3.5 mm + 0.4 ppm	- Size (diameter × height): 190 mm × 90 mm - Weight: 0.93 kg - Autonomy: up to 6 h in RTK mode up to 10 h in static mode - antenna: UHF GAT2 type QN	16,000 € (Package of two receivers + accessories)
Emlid Reach RS2+	- Low-cost receiver - Number of channels: 184 - Constellations: GPS/QZSS L1C/A, L2C GLONASS L1OF, L2OF, BeiDou B1I, B2I, Galileo E1-B/C, E5b	- RTK: Horizontal: 8 mm + 1 ppm - Vertical: 15 mm + 1 ppm - Static post-processing: - Horizontal: 3 mm + 0.1 ppm Vertical: 3.5 mm + 0.4 ppm	- Size: 126 × 126 × 142 mm - Weight: 0.95 kg - Autonomy: 16 h in RTK mode up to 22 h in static mode - antenna port: LoRa male	2000 €
Ublox ZED-F9P	- Multiband - constellations: GPS, GLONASS, Galileo, Beidou - antenna calibrated by NGS Survey - Phase center error ±1 mm - Noise ≤ 1.5 dB - IP67 protection		- Size: 140 mm × 130 mm × 106 mm - Weight: 0.54 kg - UHF antenna port (TNC female)	600 €

Figure 1. Distribution of the three statically observed points.

Figure 2. Receivers on LM1.

Figure 3. Receiver on LM2.

Figure 4. Receiver on LM4.

Observations were made in 2 h and 4 h sessions over three days, with antennae permutation (see **Figures 2-4**). This permutation was made with morning (4 h) and evening (2 h) observations, with the same periods for each day of observations, in order to maintain practically the same observation conditions. For the three selected points, we have LM1, which is located on a pillar on the terrace of the educational building in a very open environment; LM2, which is located on a pillar on the ground in an equally open environment; and LM4, which is located on a bollard next to the site and less than 2 m from a substation (see **Figures 2-4**). Points LM1 and LM2 are unique in that they don't need to be set up in any way (the GNSS antenna is fixed directly to the marker on the pillar representing the point), thus avoiding any set-up errors when swapping and mounting GNSS antennas. As for LM3, the only point to be marked by a ground marker, particular care was taken in positioning the tripod and setting up in general (centering and shimming) to avoid any misalignment when swapping GNSS antennas.

- Positioning in Network Real Time Kinematic (NRTK) mode on different points with different environments: not at all clear, not very clear and clear (Figure 5 and Figure 6).

Figure 5. Distribution of points observed in NRTK.

Figure 6. Observation of US16 and US17 points in NRTK with Emlid RS2+ and CHC i50 receivers.

This configuration makes it possible to test the sensitivity and performance of receivers used in environments where there may be a high risk of multipath, little multipath or no multipath. To this end, such conditions will make it possible to evaluate receiver sensitivity, performance and reliability under certain environmental conditions.

3. Results and Discussion

The observations made with the different receivers used were processed according to the different scenarios chosen. The data obtained from static positioning observations, processed with the CSRS-PPP tool, were used to assess the level of conformity between the results of the different receivers (**Figure 7**).

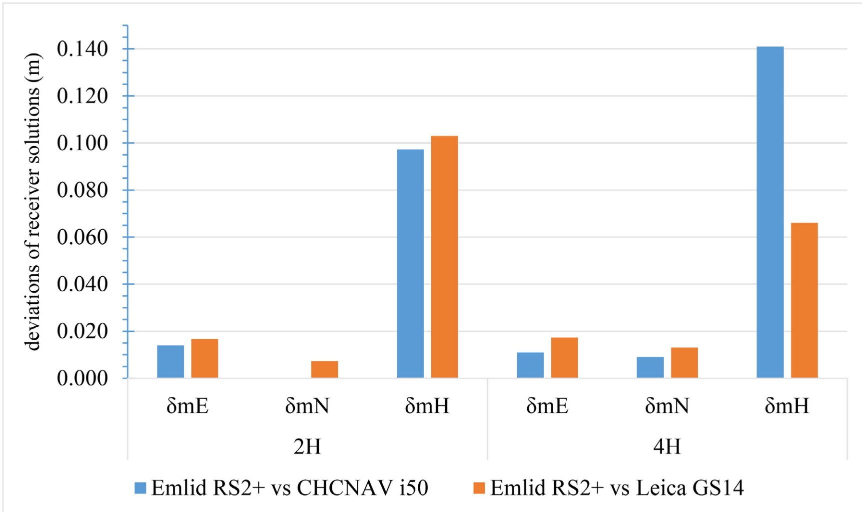

Figure 7. Average PPP spacing (in meters) between Emlid RS2+ and Leica GS14 receivers, and between Emlid RS2+ and CHCNAV i50.

These results (**Figure 7**) show that, on average, the three receivers had planimetric deviations of less than 2 cm. The average altimetry deviations obtained were greater. For the Reach RS2+ and CHC i50 receivers, mean altimeter deviations of 10 cm and 14 cm were obtained for the 4 h and 2 h observations respectively. These relatively large mean altimeter deviations are particularly justified by the 23 cm and 25 cm deviations obtained at point LM1 for 2 h and 4 h of observations respectively. Mean altimeter deviations between the Reach RS2+ and Leica GS14 receivers were estimated at 7 cm and 10 cm respectively for 4 h and 2 h of observations. These significant deviations from the Leica GS14 receiver are also justified by the 29 cm and 19 cm deviations obtained at point LM4 for 2 h and 4 h of observations respectively. Using the calculation reports, we found that the percentage of ambiguity resolution was lower at point LM1 (79% vs. 93% for the CHC i50 receiver) for the 2 h of observations with the Reach RS2+. This could, in fact, contribute to the large discrepancy obtained.

The location of point LM4 in an environment that is not completely clear, with the presence of a substation less than 2 m away, could reduce the performance of some GNSS receivers. The residuals on the phase and pseudo-range measurements of the three receivers remain relatively correlated, even if the residual values recorded with the Reach RS2+ receiver are often higher. This may influence the quality of the results provided (**Figure 8**). The single constellation (GPS) used by the Leica GS14 receiver does not seem to have an impact or create more discrepancies on the results provided by the three receivers.

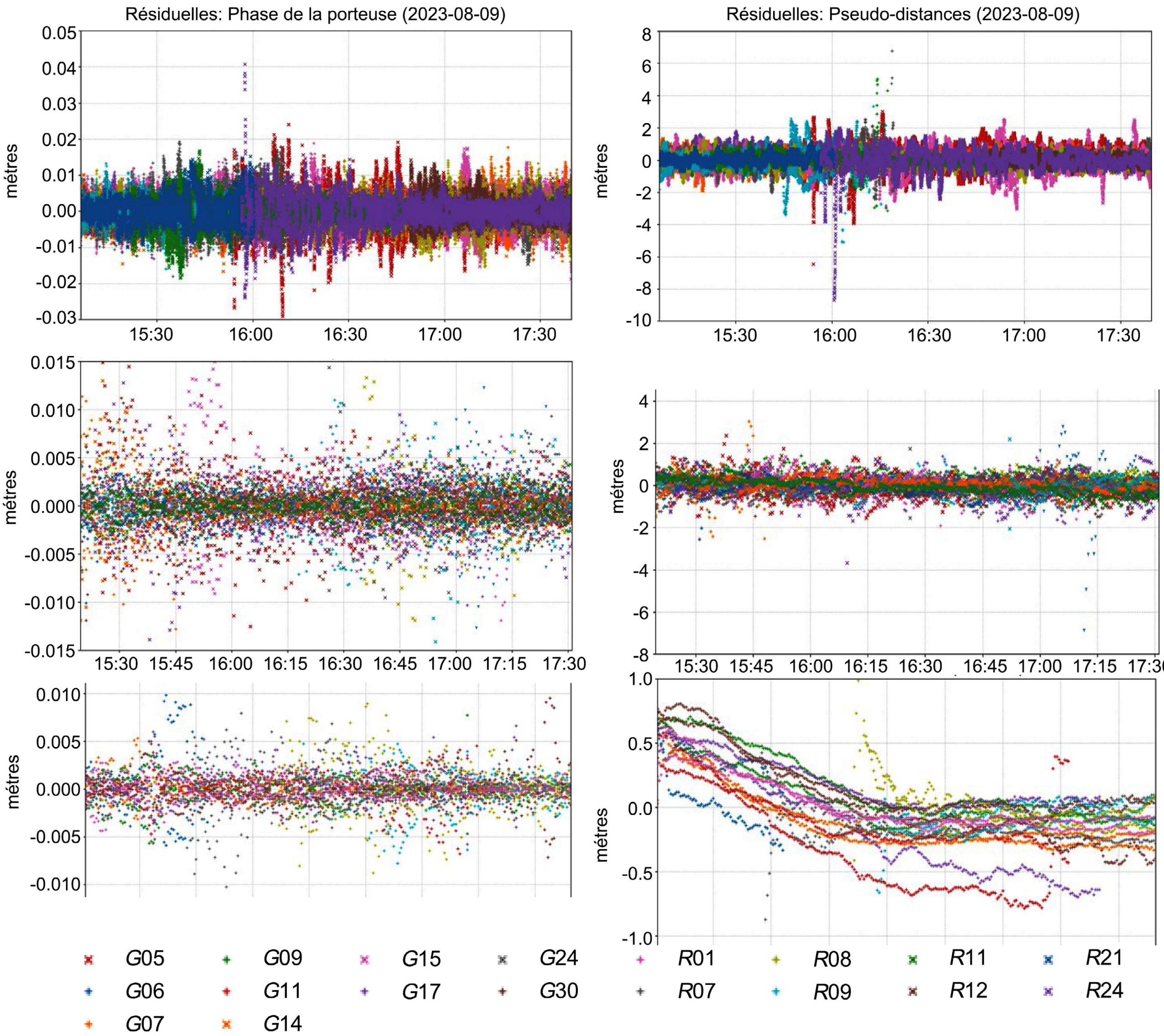

Figure 8. Phase and pseudo-distance residuals at LM1 with Reach RS2+, CHC i50 and Leica GS14 receivers respectively.

It was also noted that the different receivers provided quasi-similar PDOPs (below 1.5, as illustrated by the DOP values in **Figure 9**).

Overall, then, we can see that the three receivers used give relatively convergent planimetry results for both 2 h and 4 h of observations. In altimetry, however, even if the same observation can be made for 4 h of observations, in 2 h, discrepancies in results can occur. It would therefore be more prudent, for altimetry determinations with the RS2+, to keep to observations lasting a minimum of 4 h to ensure the same level of accuracy as with conventional receivers. Tests carried out with network real-time Kinematic (NRTK) surveys using CHC i50 receivers and the Reach RS2+ on different points, which were created following a variation in the environment around the point, produced the deviations below (Table 2).

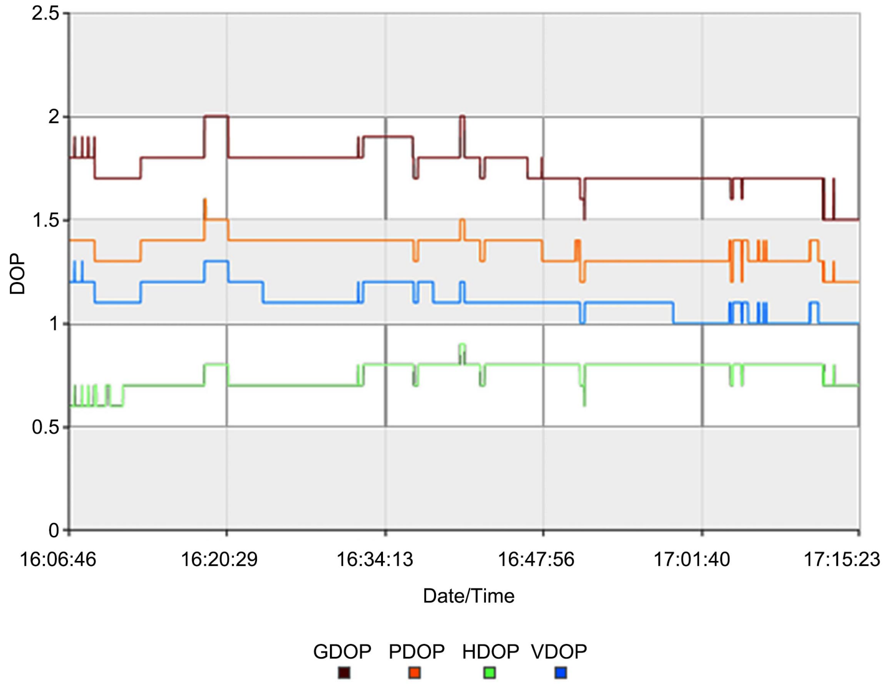

Figure 9. DOP variation at point LM2 with the Reach RS2+ receiver.

Table 2. Differences between coordinates provided by CHC i50 and Reach RS2+ receivers in NRTK surveys.

Points	δE (m)	δN (m)	δH (m)	RMS in planimetry
LM6	0.019	0.01	0.001	0.021
ICU 1	0.005	0.004	0.028	0.006
ICU 2	0.01	0.013	0.003	0.016
ICU 3	0.015	0.013	0.01	0.020
ICU 4	0.000	0.028	0.015	0.028
ICU 5	0.009	0.012	0.016	0.015
USI 6	0.008	0.003	0.039	0.009
USI 7	0.001	0.008	0.003	0.008
ICU 8	0.036	0.008	0.01	0.037
USI 9	0.013	0.002	0.021	0.013
USI 10	**0.049**	**0.082**	**0.116**	**0.096**
Average deviations	0.012	0.01	0.014	0.016

The deviation results presented in **Table 2** show a good level of convergence between the coordinates provided by the two receivers. In fact, we can see average deviations (without the USI10 point) of 1.2 cm, 1 cm and 1.4 cm respectively on the E, N and H components. The smallest deviations were obtained on points US14 with 0 mm on E, US17 and LM6 with 1 mm on E and H components respectively. The largest deviations were obtained on point USI10 with 4.9 cm, 8.2 cm and 11.6 cm respectively on the E, N and H components. These deviations were used to quantify the RMS in planimetry for these two receivers. The calculations revealed an average RMS in planimetry (excluding point USI10, which showed significant deviations) of 17 mm, reflecting the level of convergence of the two receivers in planimetry.

The large discrepancies at USI10, one of the points with a high level of masking (and therefore high multipath potential), can be explained by the point's environment (masked), but also by the numerous resets that were carried out with both receivers, which presented difficulties in fixing ambiguities. Nonetheless, other points, such as USI17 (**Figure 7**), which still had an unclear environment, showed good agreement for both receivers. These results show that the low-cost Emlid Reach RS2+ receiver is capable of providing NRTK results in agreement with those that can be provided by a conventional dual-frequency topographic receiver such as the CHC i50, in the centimetre to millimetre range on all three components (E, N and H). These deviations are also valid for clear, little or no light conditions.

Another GNSS RTK positioning performance evaluation was carried out using a low-cost, Continuously Operating Reference GNSS station. We named this antenna UIDT. The UIDT station was attached in ITRF2020 and used as a permanent base for RTK determination of points LM1, LM2 and LM4, whose coordinates were already known in ITRF2020, taken as reference coordinates and determined with the CHC i50 receiver. A comparison was made between the coordinates obtained from the low-cost permanent base and the reference coordinates (**Table 3**).

Table 3. Differences between coordinates obtained from the low-cost permanent base (DA910 antenna) and reference coordinates.

Points	δE (m)	δN (m)	δH (m)	EMQ in planimetry
LM1	0.003	0.000	0.003	0.003
LM2	0.010	0.002	0.039	0.010
LM4	0.000	0.010	0.103	0.010
Average deviations	0.004	0.004	0.048	0.006

We note a good correlation in planimetry between the RTK coordinates obtained from the low-cost permanent base and the reference coordinates obtained with a PPP topographic-quality receiver, with deviations on average in the millimeter range. The H component shows higher deviations in the centimetre to millimetre range.

These results show that today's low-cost dual-frequency GNSS receivers offer performance levels that enable them to be used in a variety of precise positioning domains. They can be used in RTK/NRTK mode with rover or base, or in static mode. Nevertheless, we have noted with these latest results that performance on the altimeter component is still perfectible for the low-cost DA910 antenna used as a permanent base.

In the face of ever-increasing needs and requirements for precise positioning, low-cost receivers could play a major role in many positioning-related fields. In Senegal, although many advances have been made over the last decade in the use of and access to precise GNSS positioning, the cost of the equipment required still remains a constraint for many players.

4. Issues and Challenges of Using Low-Cost GNSS Receivers for Precise Positioning in Senegal

4.1. Issues

The use of low-cost dual-frequency GNSS receivers could, in view of their performance, facilitate the work involved in many positioning activities. This is justified by the many challenges this will present in many fields.

- Land tenure and land register: the control and management of land resources remains a major concern for the State of Senegal and the local authorities in charge of managing the national domain comprising most of the land in Senegal. The lack of data, linked to the non-exhaustive mapping of land resources, combined with a land register that is more urban than national (with little cadastral data in rural areas), has contributed to the many land-related problems and conflicts that have arisen in Senegal in recent years. With the aim of finding solutions to these shortcomings, the State of Senegal, with the support of the World Bank, set up the Land Registry and Security Project (PROCASEF) in 2021 (for a period of 5 years), one of the main objectives of which is to set up a national land registry across the 136 target communes of the project. To this end, firms have been recruited by the project to carry out delimitation and land survey work in the five clusters grouping the 136 project communes. According to their terms of reference, the accuracy required for positioning (delimitation) work is of the order of 10 cm in rural areas (covering most of the target communes) and 5 cm in urban areas. We can see that, for such specifications, low-cost dual-frequency receivers would be capable of delivering such accuracies in both base-mobile and CORS modes, whether or not combined with topographic-quality receivers. This would result in major cost savings, as more receivers could be acquired, increasing the number of data collection teams in the field and reducing the duration of work. Some surveying firms, land registry offices and local authorities in particular, are often confronted with a shortage (sometimes absence) of suitable equipment for topographic surveys and layouts in the land sector. The accuracy required in this field is often in the centimeter range, sometimes even decimetric in rural areas, making it possible to use low-cost dual-frequency GNSS receivers. The prices of this new generation of receivers, which vary between 400 and 2000 euros (sometimes less), offer a real opportunity for the technical services of territorial collectivities in Senegal (whose budgets are often very limited). These low prices will enable them to have access to reliable data collection equipment for better land control and management, which will help reduce the many land conflicts currently noted in the country and bridge the gap in terms of accessible and reliable land information.

- Strengthen the national geodetic infrastructure by installing low-cost GNSS stations to improve coverage of the national territory. The high cost of conventional permanent GNSS stations (CORS) with geodetic antennas (€60,000 to €215,000) very often limits the deployment and sustainability of active national geodetic networks, particularly in developing countries like Senegal. This situation means that priority installation sites are generally selected on the basis of a number of parameters (geographical location, level of need or use, characteristics of the area, available resources, etc.). Low-cost dual-frequency receivers could therefore be used to complement the active network with installations in rural and peri-urban areas, for example, where many works (land development, agriculture, mining, etc.) require a level of precision in line with the performance of these receivers.

- Topographical monitoring is based on the availability of precise, reliable data over time on a given site or structure: the equipment generally used for estimating geometric deformations in the context of structure monitoring is generally top-of-the-range, with state-of-the-art performance. This implies an expensive investment, particularly if several stations are to be installed, as is required for some structures [5]. In Senegal today, it is rare to find sites or structures with permanent monitoring equipment. However, this is sometimes necessary for better real-time monitoring and the development of real-time warning systems. One of the constraints that may explain this situation is the cost of the equipment to be used. Low-cost single- or dual-frequency GNSS receivers have been used for decades in the field of structure monitoring worldwide, and have proved their worth [6] [7] and [8]. Their adoption by positioning players in Senegal could make it easier to set up CORS networks in certain situations, for better real-time monitoring of monitoring work.

- Topographic or positioning work plays an important role in building and civil engineering. From the early stages of project development, with site survey work, through to project execution and acceptance, a variety of positioning instruments can be used to ensure accuracy in line with the project's technical specifications. Although these specifications may vary from one project to another, different phases of topographic work, such as site surveys, may have virtually the same requirements. For such operations, low-cost receivers remain suitable, with the possibility for some projects of installing a permanent low-cost GNSS base. This will facilitate positioning work at lower cost and reduce expenses or charges relating to project execution. These receivers can also be used in geotechnical studies for precise mapping of sounding points, for example, as well as in geological studies to track the displacement of geological structures [9].

- Agriculture: a key priority for the Senegalese government. At a time when we are talking about food sovereignty and the need to develop agriculture in Senegal, it is becoming important to modernize many farming practices, increase yields and use tools that are suited to large-scale farming. These tools include GNSS receivers, which have given rise to precision farming. Although these receivers have long been used in hydro-agricultural development work, their integration into machinery guidance systems has made a considerable contribution to agricultural work. Unfortunately, their use in Senegal is still relatively limited. However, these low-cost receivers could represent a real opportunity to raise awareness and encourage appropriation by producers and suppliers of agricultural equipment in Senegal, given their relatively low acquisition costs and sometimes modular architecture. Such a situation would make it possible to develop the precision farming system based on low-cost positioning as quickly as possible.

- Environmental management and protection: these are largely based on the location and mapping of areas at risk or potentially at risk, sources of pollution, specific routes, waterways, forests, etc. They may require precise positioning, for example, to ensure that the environment is protected. This may require precise positioning. To achieve such objectives, different tools and methods with varying levels of performance or accuracy can be used. The current performance of these receivers means that they can be used in many studies and projects relating to environmental management and protection, particularly for projects with limited budgets and monitoring sea-level variations [5] [10]-[13].

4.2. Challenges

A number of challenges will need to be met if these receivers are to be more effectively and sustainably adopted by the players involved:

- Training players to enable them to understand and master the devices and tools associated with these receivers, their specific features, the different solutions available on the market, and the manufacture of certain accessories for certain components (housings, GNSS chips, additional ports, etc.). The different categories or models of low-cost receivers available on the market, apart from variable acquisition prices, can be sold as complete receivers with all components integrated, or as receivers with separate components [14]. Faced with this situation, users should be technically well-equipped to make optimal choices according to their needs and available resources.

- Appropriation by the players should involve a guarantee of the precision and quality of low-cost receivers. Professionals, still accustomed to equipment whose purchase price is often correlated with its performance, will need to be made aware of the need for illustrations that will enable them to place their trust in these receivers, which can cost 10 to 20 times less than conventional receivers. This will require not only a thorough evaluation of their performance, but also the dissemination of the results of these evaluations and the advantages of these receivers to professionals, to guarantee the accuracy and reliability of these receivers in various fields (topographic surveying and implementation, auscultation, agriculture, atmospheric sciences, etc.).

- Low-cost receivers available on the market, making them more accessible to professionals. The manufacturing companies of these receivers have not yet sufficiently occupied the market, but this can be explained by the still relatively timid use and appropriation in many fields and in several countries, particularly those in the developing world. Expanding the list of manufacturers and suppliers, particularly in underdeveloped countries, would facilitate access to and availability of these receivers.

- Adaptability to the modernization of GNSS systems means that these low-cost receivers can handle signals from new satellite constellations, integrate new frequencies and maintain or even improve performance.

- Research into the development of new, even more efficient and even less expensive GNSS modules remains a challenge. Evaluating the performance of low-cost single- and dual-frequency multi-constellation receivers in greater depth and diversity, combining them with topographic and geodetic quality receivers in different positioning activities, developing low-cost or mixed CORS networks, improving hardware robustness, reducing their sensitivity to interference and multipath, integrating complementary sensors, integrating machine learning modules with artificial intelligence (AI), etc., would enable more significant advances in precise positioning. would enable more significant advances in precise positioning [15]. The development of open source software for GNSS data processing in the various fields of use of these receivers would enable the development of low-cost data collection and processing systems. For developing countries, these receivers should be a source of inspiration for researchers in the development of low-cost solutions in many fields. This would enable our governments and our private sector (technical services, local collectivities, small and medium-sized businesses, universities, etc.) to better cope with budgetary and economic constraints. The development of new technologies, or the adaptation of existing technologies to our constraints (socio-economic realities), would accelerate the closing of the gap between developing countries and the emerging world.

5. Conclusion

The development of nanotechnologies has revolutionized many fields, including geospatial. Dual-frequency GNSS receivers have long been at the heart of precise satellite positioning. These multi-constellation receivers have long coexisted with low-cost, single-frequency receivers, whose metric accuracy is ill-suited to many precise positioning activities. This is one of the reasons why low-cost dual-frequency receivers have attracted so much interest since they first came onto the market. Even if studies on their performance in various fields are still underway, or avenues of research have yet to be explored, the results of research already carried out show a level of performance that can be deemed satisfactory for many precise positioning activities (topographical surveys and layouts, auscultation, photogrammetry for georeferencing, precision agriculture, environmental studies, etc.). As a result, they are now positioned as genuine alternatives to topographic or geodetic quality receivers in many fields.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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