ANALYSIS OF THE ORIENTATION OF AN EDMI CALIBRATION BASELINE USING ONLINE GNSS PROCESSING SERVICES

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ABSTRACT

This study evaluated the orientation of the electronic distance measuring instruments calibration baseline at the Federal University of Pernambuco, using data from two CHCNAV i50 GNSS receivers. The data were processed through the AUSPOS and IBGE-PPP online services. The calibration baseline comprises seven pillars equipped with forcing center devices. After the field survey, data from all pillars were submitted in RINEX format to the two processing services. However, due to significant sky obstruction from a nearby building, reports were only received for pillars 4 and 6 from both services. Despite this limitation, the study proceeded using the P4-P6 alignment derived from the geodetic coordinates in the reports. Calculations were performed for geodetic azimuths, geodetic distances, and transformations into plane coordinates for both online processing services. Results were then compared with two previous studies that employed total station surveys. The observed plane distance differences were 0.1725m (AUSPOS) and 0.0235m (IBGE-PPP), corresponding to relative linear precisions of 1/518 and 1/3308, respectively. In this context, the IBGE-PPP service provided better precision, though it was still below the levels stated in its reports. The study recommends using its IBGE-PPP results cautiously for tasks requiring relative linear precision up to 1/3308. Additionally, for the pillars 4 and 6, it suggests longer GNSS occupation times (>8 hours) for applications demanding higher precision.

KEYWORDS: *Geodetic engineering, Metrology, Satellite geodesy, Electronic distance meter calibration baseline.*

I. INTRODUCTION

According to Helmert's classical definition given in the nineteenth century, geodesy is the science focused on measuring and portraying the Earth's surface [1]. This encompasses not only the determination of the Earth's external gravity field but also the mapping of the oceans floor [2]. However, since the space age, geodesy has undergone a revolution [3], because it was not until the launch of the first artificial satellite that geodesy could develop a brand new technique [4].
From then on, the general term satellite geodesy was used, to refer to the observational and computational methods used to solve geodetic problems through precise measurements involving artificial satellites [5]. Thus, with the creation of different types of global satellite-based positioning systems by different countries, such as the American GPS (Global Positioning System), the Russian GLONASS (GLObal NAvigation Satellite System, in English), the European Galileo, and the Chinese BeiDou [6], the term Global Navigation Satellite System (GNSS) came to be used to cover each

individual system as well as the combination or augmentation of these systems [7]. In the early 1980s, geodetic surveyors were among the first civilian groups to adopt this technology to establish the coordinates of ground markers in control networks, so that, nowadays, GNSS is dominant for geodetic surveying worldwide [8].

With regard to GNSS positioning techniques, since its introduction by [9], the Precise Point Positioning (PPP) offers an attractive alternative [10]. PPP is an approach that performs precise position determination using a single receiver without a reference station [11]. With precision satellite orbit and clock information, PPP can be used to achieve centimeter-level positioning [12]. As an example, it can be cited PPP applications in geodetic control establishment [13], and in urban environments [14].

GNSS techniques, in general, require users to have professional experience in data processing and analysis. The selection of appropriate software depends on the research purpose and network features [15]. In this way, while scientific software packages are not readily accessible to inexperienced users [16], license fees for commercial software packages are very high, purchases should be considered carefully [17]. However, nowadays, many people prefer GNSS online processing services over traditional methods due to their ease of use, no cost, no licensing requirements, and the fact that they do not require specialized processing knowledge [18].

Several institutions, research centers or organizations have developed free web-based online GNSS processing services and they have started to become a viable alternative to the conventional data processing method [19]. As an example, the IBGE-PPP, provided by the Brazilian Institute of Geography and Statistics - IBGE [20, 21] can be cited. Another example is the AUSPOS, provided by Geoscience Australia, that does not process non-GPS data, and has not a PPP solution, but a network solution [22-24], namely, it makes use of the network of International GNSS Service (IGS) stations.

As seen above, GNSS is widely used in engineering applications. But, to improve positioning quality, it is essential to understand satellite visibility, which refers to the connection between the ground receiver and the satellite, because this connection is a key factor influencing the accuracy of positioning [25], in sense that it depends on the number of satellites visible to the receiver and on their geometry [26]. In environments such as urban areas, surveys often face challenges like poor satellite coverage and reduced position precision due to signal reflections (multipath) caused by obstacles like buildings and vegetation [27]. Thus, as an example, in [28] there is an accuracy investigation of GNSS-PPP method versus relative positioning near and under forest environment.

In geodesy or in navigation, solving the 'direct' problem (determining a position based on a known location, azimuth, and distance) and the 'inverse' problem (finding the azimuth and distance between two known positions) are essential tasks. These operations are comparable to similar processes in plane surveying [29]. This means that, for example, according to the inverse problem, the orientation of two points can be found from their geodetic coordinates (geodetic latitude and geodetic longitude) coming from a GNSS processing result, as well as the geodetic distance between them. Furthermore, from geodetic coordinates, using appropriate transformations, one can also calculate the plane coordinates of these two points and, by adding horizontal angles and distances suitably measured in the field, according to [30] a traverse can be calculated, which includes the azimuthal transport for all alignments.

Mainly for the reasons explained above, in this work, seven pillars with forced centering device, belonging to a calibration baseline of electronic distance measuring instruments (EDMI) in an environment partially covered by a building, were measured with GNSS receivers, had their data processed by two different online processing services (AUSPOS and IBGE-PPP), and, from the results for two pillars, by the inverse problem, the geodetic azimuth and the geodetic distance were calculated, analyzed and compared with each other and with previous works, with the perspective of using them in the orientation of a calibration baseline, which, in turn, can be treated as a traverse.

This work is organized into four sections. The first section, Introduction, provides a brief literature review, highlighting the importance of the problem and the work's hypothesis. The second section, Materials and Methods, details all the materials and methodologies used throughout the study. The third section, Results and Discussion, presents the findings and analyses related to the hypothesis. Finally, the fourth section, Conclusions, includes the study's conclusions along with suggestions for future research.

II. MATERIALS AND METHODS

The pillars chosen to carry out the GNSS field survey belong to the Federal University of Pernambuco (UFPE) calibration baseline, implemented in 1990 by the Spatial Metrology Laboratory of the Department of Cartographic Engineering [31], that has a misalignment, and because of this, it can be treated as a traverse [32]. Figure 1 shows these pillars, which were labeled P1 to P7.

Figure 1. The seven pillars of the calibration baseline [32].

The calibration baseline is approximately two meters away from the east face of the building of the Center for Technology and Geosciences (CTG) of the Federal University of Pernambuco. This building is approximately 180 meters long, has six floors, and is oriented almost in the north/south direction [33].

Figure 2 shows the baseline as well as the position of the CTG building in relation to it. The most forward pillar is pillar 1, and the others come in sequence, towards the bottom of the figure. It is easy to see that, because of the proximity, the building obstructs visibility of practically half of the sky in relation to the base. Due to this considerable obstruction, all the pillars were occupied with GNSS receivers, with the intention of extracting at least the two best results to perform the calculations of the inverse problem, and obtain the orientation of the baseline.

Figure 2. The UFPE calibration baseline is partially obstructed by the CTG building, April, 2024.

Two GNSS receivers, CHCNAV brand, model i50, were used to collect the data of the baseline. The equipment tracks signals of different satellite-based positioning system, such as GPS (in L1, L2, L2C, and L5 frequencies), GLONASS (in L1 and L2 frequencies), Galileo (in E1, E5a, and E5b frequencies), and BeiDou (in B1, B2, and B3 frequencies), and have post-processing static horizontal precision of +/-(3 mm + 0.5 ppm) and post-processing static vertical precision of +/-(5 mm + 0.5 ppm), in which ppm means parts per million [34]. To ensure static positioning and try to achieve this precision, a four-hour tracking was carried out for each pillar. Beyond that, an elevation cut-off angle beyond ten degrees was used in data collection for all pillars. Figure 3 shows the equipment.

Figure 3. The equipment used was this pair of CHCNAV i50 GNSS receivers, April, 2024.

After the field survey, the data from the seven pillars were transferred from the receivers to a computer, and were properly submitted to online processing by AUSPOS and by IBGE-PPP, always using precise ephemeris.

After online submission, only the pillars that received the processing result back by email were selected, in the form of a complete report, with the geodetic coordinates, respective precisions and other information, for both processing services.

Subsequently, the two pillars with the best results, that were the same pillars for AUSPOS and for IBGE-PPP, had their geodetic coordinates selected, transformed to the same reference system, and inputted in the module called inverse geodesy problem of the academic software called AstGeoTop [35], so that the inverse geodesy problem could be solved. Thus, the geodetic azimuth and the geodetic distance were computed for AUSPOS and for IBGE-PPP for the same two pillars, separately, providing a first comparison between them.

With the geodetic coordinates for the two pillars still in hand, another module of the AstGeoTop software, called coordinate transformation [36], was used so that the geodetic coordinates could be transformed into plane coordinates. This was necessary because only in this way could the results for the plane distances for the two processing services be compared with those obtained with total stations published in other works.

III. Results and Discussions

Before processing, the data went through two phases. The first was the analysis of the satellite availability, from the work that was carried out in the field. The field work took place in April 2024, in the following order: pillars 6 and 7 had their data collections carried out on day 3; pillars 4 and 5 on day 9; pillars 2 and 3 on day 10 and pillar 1 on day 11. All pillars were occupied for a time slightly longer than four hours. Thus, figures 4 to 10 show the occupation times for each pillar, as well as the number of satellites available during the period. Furthermore, none of them shows moments when less than twelve satellites were available. However, these figures only show the total number of satellites available, for all systems (GPS, GLONASS, BeiDou and Galileo) that can be tracked by the receivers. Therefore, due to the considerable obstruction existing in the field and a few tracking satellites, a second analysis, complementary to this one, will be made below.

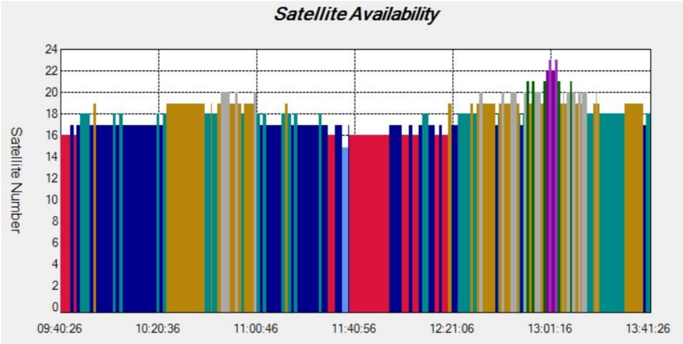

Figure 4. Time of occupation and satellite availability for Pillar 1, on April 11, 2024.

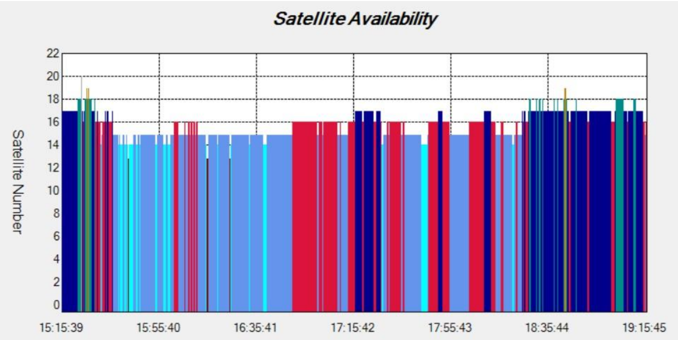

Figure 5. Time of occupation and satellite availability for Pillar 2, on April 10, 2024.

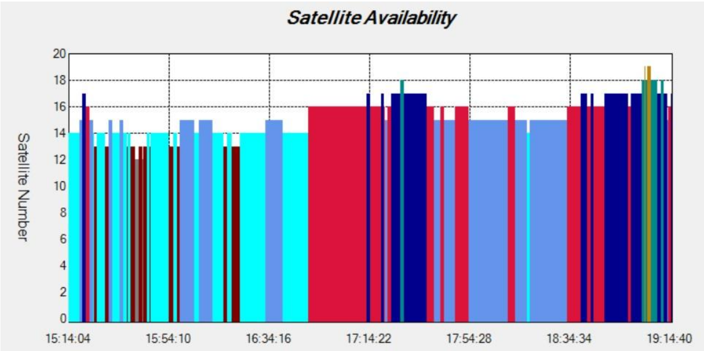

Figure 6. Time of occupation and satellite availability for Pillar 3, on April 10, 2024.

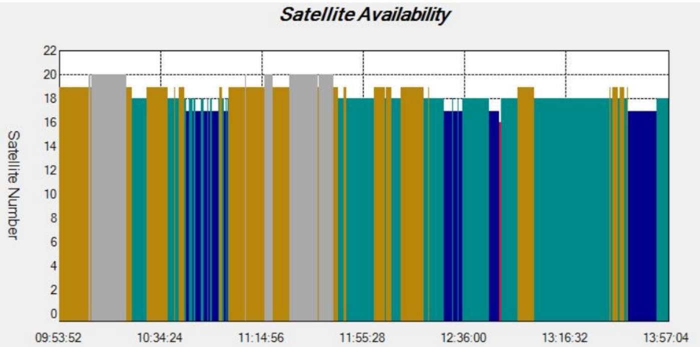

Figure 7. Time of occupation and satellite availability for Pillar 4, on April 9, 2024.

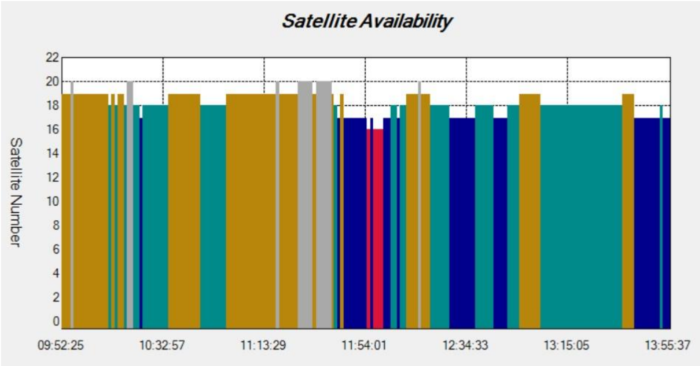

Figure 8. Time of occupation and satellite availability for Pillar 5, on April 9, 2024.

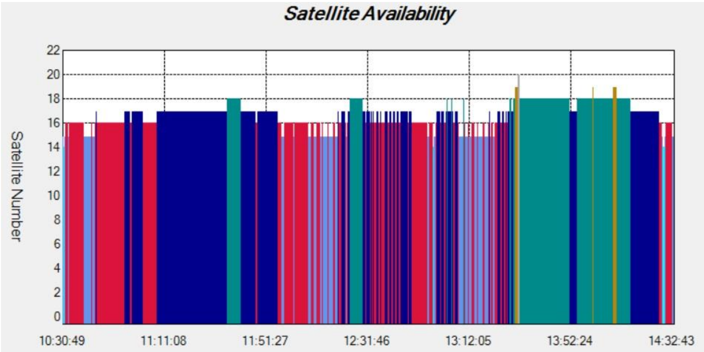

Figure 9. Time of occupation and satellite availability for Pillar 6, on April 3, 2024.

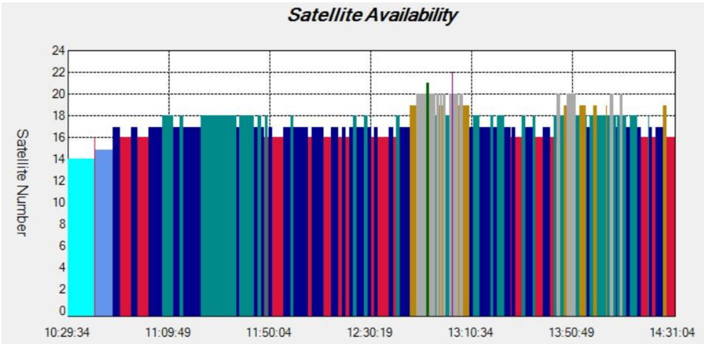

Figure 10. Time of occupation and satellite availability for Pillar 7, on April 3, 2024.

In dense urban environments, buildings and other obstacles block the direct line-of-sight to many satellites [37]. Because of this, the second phase, still before processing, was the analysis of the Signal-to-Noise Ratio (SNR) measurements. SNR is an observable commonly recorded by GNSS receivers [38] that can express the signal quality [39] in a way that according to the correlation between the SNR and multipath effects, the oscillatory variation in the SNR can reflect the influence of the multipath effect [40]. Due to its relevance, figures 11 to 13 show the SNR for all pillars at the surveying time, whose scale is located in the upper right corner, and whose unit is dB-Hz. These same figures show the locations in the sky of the satellites of the four different systems that can be tracked by the equipment in four different colors, as well as the satellite number in relation to its constellation.

Something that can be seen prominently in all the figures (11 to 13) is precisely the absence of satellites on the left side of all of them, that is, there are few satellite signals in practically half of the sky, which directly corresponds to the influence of the obstruction caused by the CTG building. It should also be noted that the few existing values for the SNR (represented by the colored lines) on the left side of all the figures in general are interrupted and are also very low. It can also be noted in all the figures that the highest values for the SNR (the solid red lines) are practically all found on the right side, with the satellites between angles of 30° and 90° above the horizon.

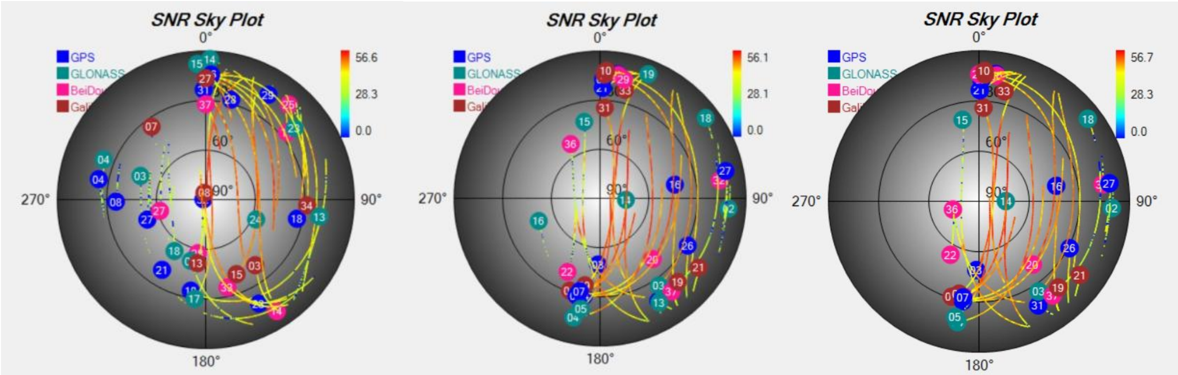

Figure 11. Signal-to-Noise Ratio for Pillar 1 (left), Pillar 2 (middle), and Pillar 3 (right).

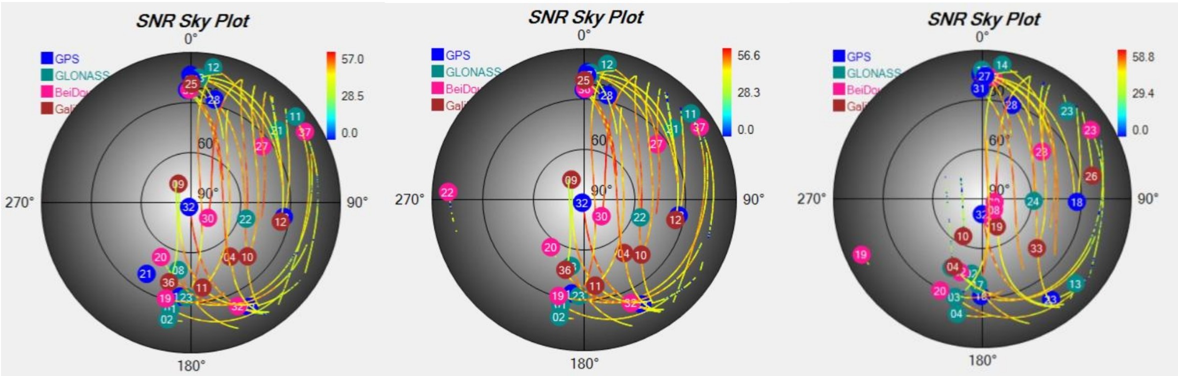

Figure 12. Signal-to-Noise Ratio for Pillar 4 (left), Pillar 5 (middle) and Pillar 6 (right).

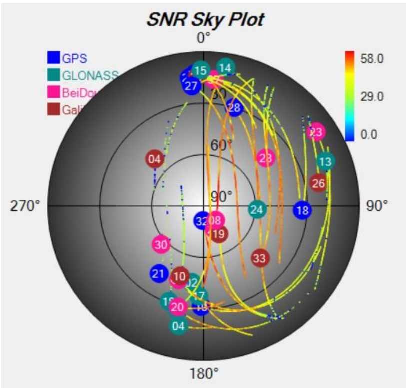

Figure 13. Signal-to-Noise Ratio for Pillar 7.

Furthermore, since AUSPOS only processes data from GPS, something that will probably be relevant in its results will be that, in addition to the great obstruction and the specific location of the highest values for SRN only on the right side of the figures 11 to 13, there is also a shortage of GPS satellites on this same side.

After these preliminary analyses, the next stage was to submit the data, individually for each pillar, in RINEX (Receiver Independent Exchange) format, to the two online processing services. Then, the processing results were received by email. The results that did not fail were received via a full report for each pillar for each processing service, while the results that failed were received without the report, but with a processing failure message.

The processing results submitted to AUSPOS that failed were those relating to pillars P1, P2, P3, P5, and P7, with reports having been received relating to pillars P4 and P6. All reports submitted to IBGE-PPP have been received. Since IBGE-PPP processes data from all satellite systems tracked by the receivers (GPS, GLONASS, BeiDou and Galileo), and AUSPOS processes only GPS signals, and due to the large obstruction in the area, as well as the scarcity of GPS satellites without many signal failures and with good SNR values, it can be assumed that it was mainly due to these facts that processing by AUSPOS was impaired.

Despite this, since at least two pillars are needed to solve the inverse geodesy problem, pillars P4 and P6 were used for this purpose. For this reason, the AUSPOS and IBGE-PPP reports referring to P4 and P6 were analyzed. Since the system in which the IBGE-PPP coordinates are linked to the Geocentric Reference System for South America (SIRGAS2000), and the AUSPOS coordinates to the International Terrestrial Reference Frame (ITRF2020), a transformation was necessary. To this end, the software AstGeoTop, module geodetic systems transformations [41] was used, which transformed the ITRF2020 coordinates obtained by AUSPOS on the survey date to coordinates in SIRGAS2000 on the survey date, thus allowing comparison. From there, the first analysis was in relation to geodetic coordinates and their respective precisions. In this sense, this information can be found in tables 1 and 2.

Table 1. Geodetic coordinates for IBGE-PPP in SIRGAS2000 on the date of survey.

	Geodetic Latitude	sigma	Geodetic Longitude	sigma
P4	-8° 03´ 14,6247”	0,009m	-34° 57´ 15,3280”	0,009m
P6	-8° 03´ 11,7302”	0,009m	-34° 57´ 15,0286”	0,009m

Table 2. Geodetic coordinates for AUSPOS in SIRGAS2000 on the date of survey.

	Geodetic Latitude	Coordinate uncertainty	Geodetic Longitude	Coordinate uncertainty
P4	-8° 03´ 14,62182”	0,099m	-34° 57´ 15,33351”	0,232m
P6	-8° 03´ 11,73483”	0,210m	-34° 57´ 15,02372”	0,503m

In table 1, sigma refers to the standard deviation that represents, in the case of IBGE-PPP, according to the reports, the internal reliability of the processing and not the accuracy of the coordinate.
In table 2, in the case of AUSPOS, according to the reports, coordinate uncertainty is scaled using an empirically derived model which is a function of data span, quality and geographical location, and is expressed in terms of the 95% confidence level.
These uncertainty values will be used later when comparing plane distances, which will be based on total station measurements. However, before reaching this step, it will be necessary to perform calculations for the inverse geodesy problem. Therefore, the next step was to use the AstGeoTop software, inverse geodesy problem module [35], which performed this task. The computations were also performed using an online geodetic calculator from Geoscience Australia [42], and the results were identical to those from AstGeoTop. Table 3 shows the results.

Table 3. Results for the inverse problem of geodesy.

Station	Forward	IBGE-PPP		AUSPOS	
		Geodetic Azimuth	Geodetic Distance	Geodetic Azimuth	Geodetic Distance
P4	P6	5°53`09,840"	89,394m	6°06`16,344"	89,197m

Based on the results in Table 3, it was possible to make the first comparisons between the results of AUSPOS and IBGE-PPP, as shown in Table 4.

Table 4. Differences between geodetic azimuths and geodetic distances.

Geodetic azimuth difference	Geodetic distance difference
0°13`06,504"	0,197m

Analyzing the differences in Table 4, it can be seen that, at this stage, they are proportional to the uncertainties recommended by AUSPOS. However, it is still necessary to compare the results of the two processing services with reference measurements in order to better understand their values. For this reason, the next step was to transform the geodetic coordinates into plane coordinates, so that the plane distance between P4 and P6 could be obtained and thus compared with those measured with total station. To perform this task, the AstGeoTop coordinate transformation module [36] was used. In addition, the Recife campus has a local plane coordinate system (topocentric), which has as its origin the vertex called RECF, whose geodetic coordinates are: Latitude = -8°03'03,46970", Longitude = -34°57'05,45910", and Altitude = 4,217 m; and the plane coordinates are: X = 150.000,00 m, and Y = 250.000,00 m [43]. For this reason, the plane coordinates of pillars 4 and 6 were calculated in this plane system, which results are shown in Table 5.

Table 5. Results for the plane coordinates.

Pillar	AUSPOS		IBGE-PPP	
	X (m)	Y (m)	X (m)	Y (m)
P4	149.697,655	249.657,393	149.697,823	249.657,305
P6	149.707,139	249.746,085	149.706,990	249.746,227

From the results in Table 5, the plane distances could be calculated and compared with those extracted from previous works. Two articles were chosen that could be used in this case [44, 45], whose plane distances were measured with total station, are found in Table 6.

Table 6. Plane distances between P4 and P6.

Alignment	AUSPOS	IBGE-PPP	Garnés, Seixas e Silva (2014) [44]	Ramos Junior, Seixas e Garnés (2024) [45]
P4-P6	89,197m	89,393m	89,369m	89,370m

Since the results of the two previous studies have a difference of only one millimeter, the average value of 89,3695m was used as a reference for comparison. Thus, in relation to the plane distance calculated from AUSPOS, the difference was 0,1725m (or 172,5mm) which corresponds to a relative linear precision of 1/518, while for IBGE-PPP the difference was 0,0235m (or 23,5mm) which corresponds to a relative linear precision of 1/3802.

The difference found for the plane distance in relation to AUSPOS is within the limits predicted for the uncertainties presented in Table 2. The difference in relation to IBGE-PPP exceeded the limit of 9mm shown in Table 1, however, this limit, as the report of this processing service states, is only related to the internal reliability of the processing. This means that, most likely, effects related to the obstruction due to the CTG building may have caused interference, especially related to multipath and loss of satellite signal, which led to the difference of 23,5mm in relation to the reference measurements. An alternative to try to improve this result would be to collect GNSS data over longer periods, such as 8, 10 or even 12 hours.

IV. CONCLUSIONS

This study examined the orientation of the EDMI calibration baseline at the Federal University of Pernambuco, using data collected with two CHCNAV i50 GNSS receivers. The data was processed through two different free online processing services: AUSPOS and IBGE-PPP. The baseline comprises seven pillars (figure 1), and the site where it was installed, as shown in figure 2, includes a building that obstructs almost half of the sky. This obstruction complicates data collection, as GNSS signals can be lost or reflected when obstacles exist between the satellites and the receiver.
This initial limitation was confirmed during data analysis, as shown in figures 11 to 13, which highlight the significant sky obstruction. Consequently, only pillars 4 and 6 produced valid processing reports from the two online services. However, since only two pillars were required to calculate the orientation, the study proceeded.
Thus, the geodetic coordinates for pillars 4 and 6, that were originally in the AUSPOS reference system (ITRF2020), were transformed to SIRGAS2000 to align with the IBGE-PPP system. Subsequently, geodetic azimuths and distances were calculated for each processing service. And then, plane coordinates were derived from the geodetic coordinates to compare plane distances with results from previous works, which had more precise surveys conducted using a total station. The differences in plane distances observed were 0.1725m for AUSPOS and 0.0235m for PPP-IBGE, corresponding to relative linear accuracies of 1/518 and 1/3308, respectively. This comparison between AUSPOS and IBGE-PPP was important because, even with 4 hours of observation, it revealed discrepancies in the coordinates and respective azimuths. This highlights the need for caution when determining these parameters, as calculating a traverse based on these azimuths, for example, could lead to significant differences in the coordinates of the vertices.
In addition to the significant obstruction to signals caused by the CTG building, another point that may have affected the results was the number of GNSS constellations, as AUSPOS only processes GPS data, while IBGE-PPP processes GPS, GLONASS, Galileo and BeiDou data, thus presenting greater redundancy for carrying out computations.
Thus, in this specific case, in view of what was set out in the four previous paragraphs, it can be seen that processing with IBGE-PPP resulted in better precision, however, it did not reach the level of 0,009m indicated in the processing report (table 1). For this reason, it is recommended to use the results of IBGE-PPP processing (geodetic coordinates, table 1), and the corresponding geodetic azimuth (table 3), geodetic distance (table 3) and plane coordinates (table 5) with caution, so that they are used for tasks requiring relative precision of up to 1/3308. If higher precision is required, to try to help mitigate the influence of the great obstruction, it is advisable to conduct a new GNSS field survey as a first option, with occupancy times exceeding 8 hours, to improve precision.

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