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ACCURACY OF THE CORNER COORDINATES OF A BUILDING SURVEYED WITH NINE POINTS IN RTK GNSS METHOD

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Abstract. In this study, measurements were made to compute the coordinates of a building's corner with only one steel tape measure and two GNSS receivers in the field. First, three circle arcs were drawn in the field using a steel tape measure at a distance of 1 meter, 3 meters and 5 meters from the corner of the building, and three points were marked spontaneously on each of these three arcs. A total of nine points were obtained and the coordinates of these nine points were determined by using RTK GNSS technique. The coordinates of the corner of the building (K1) were computed by using the coordinates of nine points on 1 meter, 3 meter and 5 meter circle arcs. In this calculation process, the coordinates of the building corner are obtained by taking the average of the values by using nine points on the three circle arcs. When the building corner coordinates obtained with the total station and the coordinates obtained by marking nine points on the arcs were compared, the maximum and minimum differences were found in the range of 5–6 centimetre. Considering that it is advantageous in terms of time, this new method takes completely about 85 minutes for all of the points.

Keywords: GNSS, corner of building, accuracy, total station.

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1. Introduction

Today, determining the coordinates of the building corners is one of the important subjects of measurement. The latest developments in satellite technology include the modernization of the GPS and GLONASS system, the launch of the Galileo and BeiDou satellite system, and the creation of CORS networks. In this study, a repetitive application was carried out on different days on how to determine the coordinates of the building corner if we only have two RTK GNSS compatible receivers and a steel strip meter in the field (Hofmann-Wellenhof et al., 2008). While the coordinates of the building corners can be determined by photogrammetry and LIDAR techniques, the biggest problem encountered is that the roof of the building prevents this situation. This method, which is proposed as an alternative in this study, has been examined in terms of accuracy and time. The determination of the building corners' coordinates has been the subject of several papers recently (Krzyżek, 2014, 2015a, 2015b, 2015c, 2017; Luo et al., 2018; Sveinung et al., 2021; Pedley, 2012; Jekeli, 2001; Hong et al., 2005; Groves, 2013; Pırtı & Yucel, 2023). The purpose of this article is to carry out a study on how to compute the coordinates of the building corners if we only have two GNSS receivers and a steel tape meter. The primary goal of this study is to determine whether the alternative method (marking the three points on a circular curve distant from 1, 3 and 5 meters from the building edge/corner) is effective for the execution of building edge/corner surveys.

2. Description of experiment

Four tests were carried out in two days in the Davutpasa Campus of Yildiz Technical University in Istanbul to study the impacts of building corners that surveying with RTK-GNSS. A pair of Topcon Hiper VR receivers (Static (Horizontal = 3 mm + 0.4 ppm, Vertical = 5 mm + 0.5 ppm)), (RTK (Horizontal = 5 mm+0.5 ppm, Vertical = 10 mm + 0.8 ppm)) were used for GNSS surveying, Figure 1 (URL 1). Two reference sites (R1 and R2) were placed in the study area for this purpose (clear-line of sight, Figures 2 and 3). The coordinates of the two reference stations were determined by using static GNSS surveys. The two points' static measurements were obtained for at least 1.5 hours of observation time (27 May 2022). For data processing and network changes, the Topcon Magnet TOOLS v. 7.3.0 Software was used. During the adjustment computation, the ITRF 2014 Epoch 2022.4 coordinates of ISKI CORS/

PALA point were fixed (Figure 2, Table 1). The coordinates and standard deviations of two reference stations are shown in Table 1 (R1 and R2). Furthermore, K1 point was marked on the corner of the building in the study area (a building, approximately 4–5 m tall) (Figure 2). For static survey, the data-receiving and processing rates were set to 30 seconds, and the cut-off elevation mask angle was set to 10 degrees. In order to ensure the independence of the coordinate results, the four RTK GNSS surveys were carried out at different times of two days (Table 2). During the testing process, 19 to 25 GNSS satellites were observed, with their distribution being generally "normal" and the Position Dilution of Precision (PDOP) for a static survey ranged between 0.92 and 1.27.

Figure 1. Topcon Hiper VR GNSS receiver

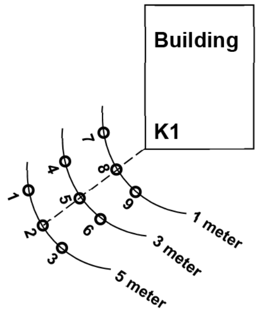

Figure 4. Illustration of the alternative method to determine the coordinates of the building corner

For the proposed alternative method, arcs were marked with the help of a steel tape measure at a distance of 1 meter, 3 meters and 5 meters from the K1 corner point (Figures 3 and 4). Three spontaneous points are marked on these arcs. The coordinates of these selected nine points on three arcs were surveyed by using the RTK GNSS (GPS/GLONASS/Galileo/BeiDou) technique at different times and in the different satellite configurations on two days. Figure 5 shows two triangles that explain graphically for computing the coordinates of point K1.

In the 12K1 triangle; no. 1, firstly the cosine theorem and then the sinus theorem are applied.

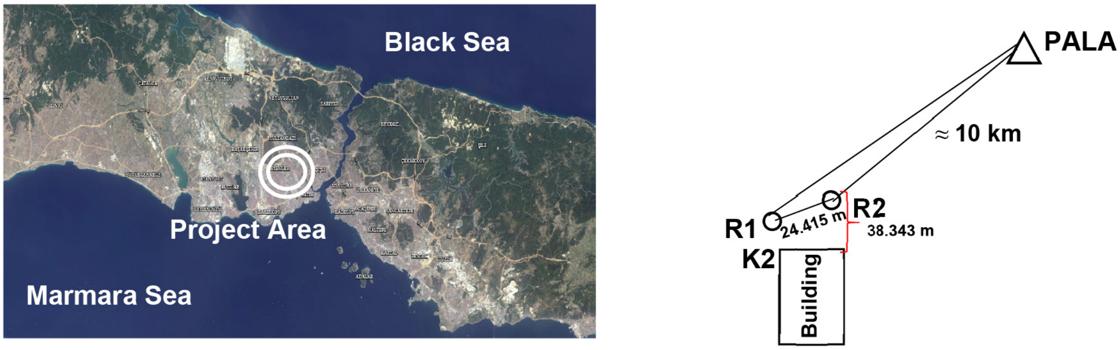

Figure 2. Project area and GNSS network

Figure 3. The reference points (R1, R2) and the corners of building (K1 point in the study area) (source: Pırtı & Yucel, 2022)

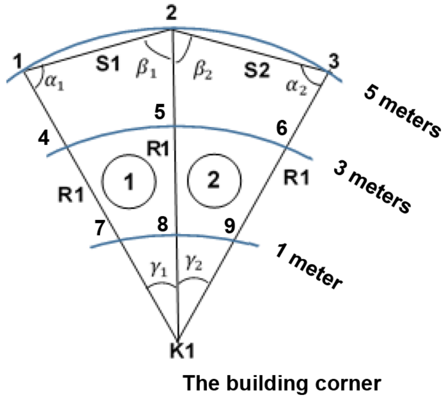

Figure 5. Graphical scheme created for computing the building corner (K1 station) coordinates

$$S_1^2 = R_1^2 + R_1^2 - 2R_1R_1 \operatorname{Cos}\gamma_1; \tag{1}$$

$$S_1^2 = 2R_1^2\left(1 - \operatorname{Cos}\gamma_1\right); \tag{2}$$

$$\operatorname{Cos}\gamma_1 = 1 - \frac{S_1^2}{2R_1^2}; \tag{3}$$

$$\frac{S_1}{\sin\gamma_1} = \frac{R_1}{\sin\alpha_1} = \frac{R_1}{\sin\beta_1}; \tag{4}$$

$$\alpha_1 + \beta_1 + \gamma_1 = 200\,grad; \tag{5}$$

$$t_{1K1} = t_{12} + \alpha_1; \tag{6}$$

$$Y_{K1} = Y_1 + \overline{1K1}\left(R_1\right)\,\sin t_{1K1}; \tag{7}$$

$$X_{K1} = X_1 + \overline{1K1}\left(R_1\right)\,\cos t_{1K1}. \tag{8}$$

The equations given above were applied in the 23K1 triangle and the coordinates of the K1 point were calculated by averaging all values. All these operations were applied within the 1, 2, 3; 4, 5, 6 and 7, 8, 9 points and the coordinates of the K1 point were calculated by taking the average (Table 1).

Figure 6 shows the comparison of all nine points by using RTK GNSS (GPS/GLONASS/Galileo/BeiDou) measurements with each other. Standard deviation values were calculated between 5 mm and 17 mm, and mean values between 7 mm and 31 mm for all RTK GNSS surveys on two days. Four repetitive RTK GNSS measurements of nine points took approximately 85 minutes. The most important and critical situation in this study is to precisely measure the coordinates of three selected points on the arc (Table 2). The coordinates of the building corner point (K1) are calculated by the intersection of these three selected points on the arcs (Figure 7).

Table 2. Coordinates of the marked nine points observed by using R2 reference point on the three arcs (1, 3 and 5 meter distances) at different times of the two days

Point	Y	X	h	Distance from K1
29 May 2022 (10:00–10:20 hours)				
1	406383,426	4543779,344	112,596	1 m
2	406384,967	4543779,430	112,575	
3	406386,958	4543778,839	112,527	
4	406385,908	4543777,121	112,534	3 m
5	406384,994	4543777,437	112,550	
6	406383,924	4543777,405	112,670	
7	406385,082	4543775,282	112,576	5 m
8	406384,483	4543775,467	112,589	
9	406383,950	4543775,340	112,568	
29 May 2022 (14:00–14:25 hours)				
1	406383,445	4543779,356	112,588	1 m
2	406384,964	4543779,444	112,589	
3	406386,955	4543778,860	112,541	
4	406385,901	4543777,155	112,551	3 m
5	406384,988	4543777,433	112,554	
6	406383,916	4543777,406	112,695	
7	406385,065	4543775,313	112,582	5 m
8	406384,464	4543775,465	112,568	
9	406383,937	4543775,325	112,571	

Table 1. Coordinates of station K1 calculated from three points on three arcs selected as auxiliary

Point	Day–Time	Y	X	Explanations	Time period
K1	29 May 2022 (10:00–10:20 hours)	406384,474	4543774,488	5 m	1
K1	29 May 2022 (10:00–10:20 hours)	406384,547	4543774,471	3 m	2
K1	29 May 2022 (10:00–10:20 hours)	406384,571	4543774,445	1 m	3
K1	29 May 2022 (14:00–14:25 hours)	406384,492	4543774,493	5 m	4
K1	29 May 2022 (14:00–14:25 hours)	406384,554	4543774,475	3 m	5
K1	29 May 2022 (14:00–14:25 hours)	406384,555	4543774,479	1 m	6
K1	30 May 2022 (11:00–11:20 hours)	406384,517	4543774,491	5 m	7
K1	30 May 2022 (11:00–11:20 hours)	406384,399	4543774,491	3 m	8
K1	30 May 2022 (11:00–11:20 hours)	406384,571	4543774,467	1 m	9
K1	30 May 2022 (15:00–15:20 hours)	406384,437	4543774,495	5 m	10
K1	30 May 2022 (15:00–15:20 hours)	406384,549	4543774,506	3 m	11
K1	30 May 2022 (15:00–15:20 hours)	406384,488	4543774,478	1 m	12

End of Table 2

Point	Y	X	h	Distance from K1
30 May 2022 (11:00–11:20 hours)				
1	406383,428	4543779,372	112,590	1 m
2	406384,957	4543779,436	112,588	
3	406386,934	4543778,857	112,546	
4	406385,887	4543777,160	112,552	3 m
5	406384,974	4543777,456	112,558	
6	406383,899	4543777,418	112,682	
7	406385,065	4543775,300	112,591	5 m
8	406384,469	4543775,482	112,590	
9	406383,956	4543775,344	112,581	
30 May 2022 (15:00–15:20 hours)				
1	406385,067	4543775,341	112,583	1 m
2	406384,469	4543775,494	112,590	
3	406383,940	4543775,362	112,564	
4	406385,901	4543777,155	112,558	3 m
5	406384,982	4543777,475	112,553	
6	406383,908	4543777,437	112,678	
7	406383,419	4543779,362	112,590	5 m
8	406384,951	4543779,456	112,597	
9	406386,934	4543778,865	112,535	

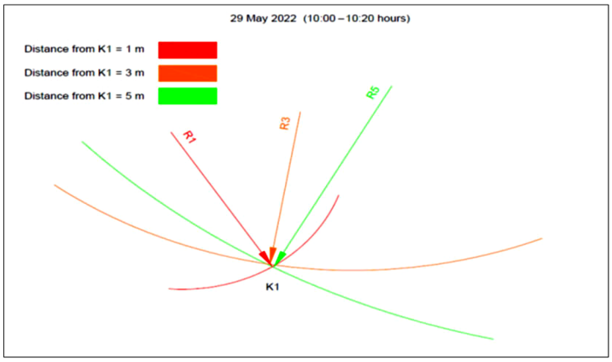

Figure 7. Computation scheme

3. Total station measurements and comparisons

By comparing RTK GNSS data with coordinates obtained from terrestrial measurements, one may ascertain the data's correctness. A complete station was used to measure the angles and distances between the sites in order to compare the outcomes of RTK GNSS techniques. For the total station surveys, the R1 and R2 reference points were used as control points (Figure 2). By setting the reference point PALA (ISKI-CORS), reference stations R1 and R2 coordinates were calculated using the static GNSS data (measurement durations of about 90 minutes). As mentioned before, R1 and R2 stations were used to examine the corner point (K1). The coordinates of the station were ascertained by observing the horizontal directions, zenith angles, horizontal distances, and slope distances using the Topcon GTS-701 (angle accuracy: 2", distance measure-

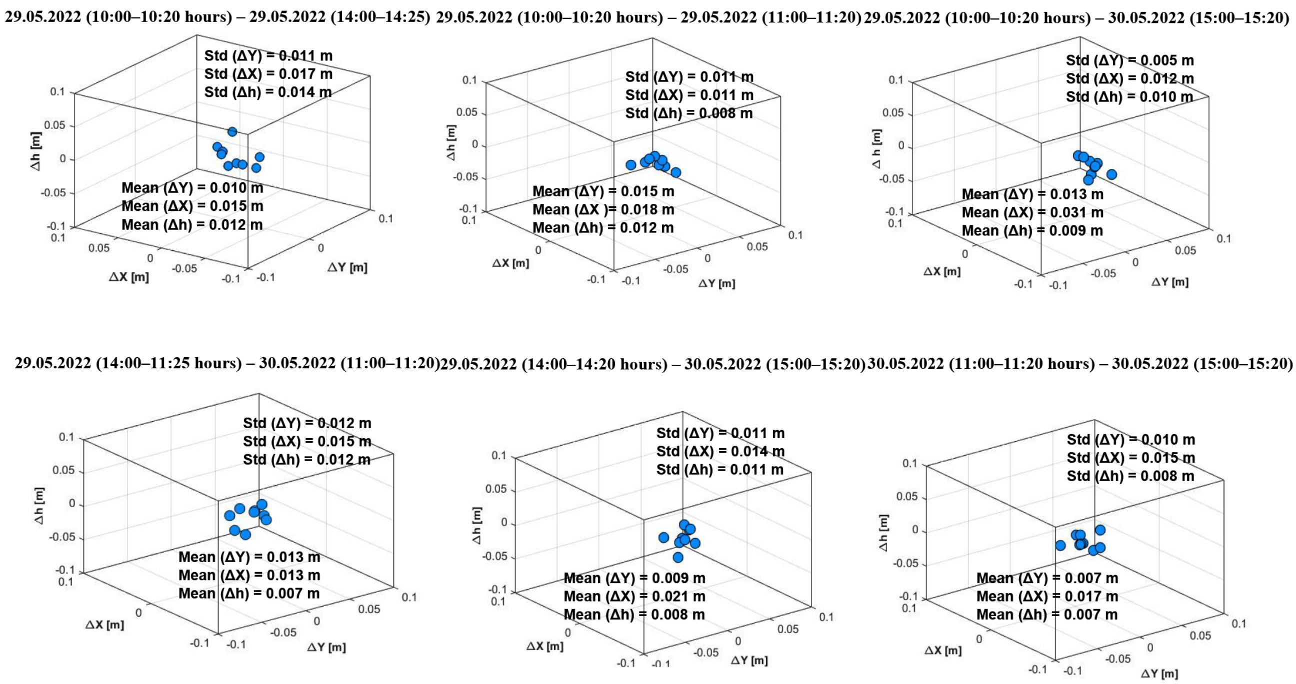

Figure 6. The coordinate differences, standard deviation and mean values among all of the RTK GNSS survey results on two days

ment accuracy: 2 mm + 2 ppm). The coordinate values of station K1 from total station surveys are shown in Table 3 (using R1 and R2 reference locations).

Table 3. Coordinate values of K1 point by using total station

Total station			
Point	Y (m)	X (m)	Height (m)
K1	406384,494	4543774,464	112,601

As explained before, the time interval in which the coordinates of the three points on the arc were determined most precisely was accepted as the highest number of satellites and the lowest PDOP value. For the calculated coordinates of the K1 point, the maximum difference is 9.5 cm, the minimum difference is 0.2 cm in the Y direction, and the maximum difference of 4.2 cm; the minimum difference is 0.3 cm in the X direction. The difference in the Y direction is large because the building extends in the east-west direction. Also, in the satellite configuration, it is the best time periods (Period 1, 4, 7 and 12), see Table 2. Precise results were obtained in the computations performed with the points on the arc, which is 5 meters away from the corner of the building. By using the horizontal coordinates of the three points in this twelve time periods, the building corner point (K1) coordinates at a distance of 1 meter, 3 meters and 5 meters approached the horizontal coordinates found by using Total station with a difference between 3 mm and 95 mm.

The differences in the horizontal coordinate values of the K1 point between the RTK GNSS and total station survey findings were, at most, 5–6 cm and, at least, 2–3 cm (Figure 8). With a standard deviation of less than 6 cm and a mean of less than 5 cm, the coordinates (Easting, Northing) of the K1 point were generally satisfactory (Figure 8).

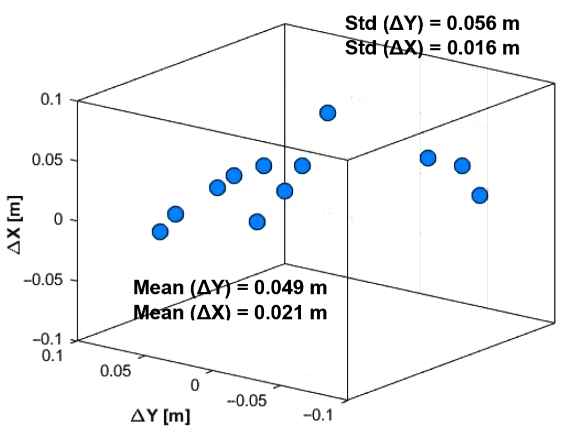

Figure 8. Compare all of the coordinates of the building corner (K1) point in two days by using nine stations on three arcs

All of the results also show that buildings were harmful to RTK GNSS positioning, as they frequently blocked the signals of the low-medium satellites and affect radio signals. Thus, even with the presence of good satellite windows, signal blockage due to buildings could be considered as the main problem affecting use of RTK GNSS in the buildings areas. In the Easting, Northing, and Coordinate directions, the average standard deviations of the four tests of the building's corner (K1 point) are shown in Figure 8. The corner point's easting and northing coordinates were generally acceptable, with standard deviation and mean values of less than 5–6 cm. Given the dynamics of these four tests, as well as the changing geometry of satellites at the corner of the building environment on two days, the results clearly show that the alternative method is a stable system, and the cm level of accuracy is typically attainable under a variety of operational settings (Figure 8).

4. Conclusions

Simply said, the alternative approach cannot be used in all situation or at any moment with the same degree of accuracy. Put differently, surveyors continue to have serious concerns about quality assurance. The results of the testing indicate that the alternative method's accuracy, precision, and performance are significantly impacted by the building. Buildings interfere with GNSS signals by reflecting, attenuating, and blocking them. The investigation's findings indicate that the alternative method's horizontal accuracy is between 5 and 6 cm. These findings demonstrate that another approach is workable, efficient, and successful for placement and other uses in the building's corner that don't lead to unfavourable circumstances. Additionally, this strategy reduces the number of ground control points needed for survey applications. The paper presents many comparisons that demonstrate the high degree of compatibility between the accuracy of the complete station survey and the alternative technique. This alternate approach takes roughly 85 minutes to complete all of the points, considering its time-saving benefits. Based on the research findings, it seems that the novel approach of creating corners using RTK GNSS can reach the 2–6 cm precision needed for most topographic-geodetic applications.

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References

Groves, P. D. (2013). *Principles of GNSS, inertial, and multi-sensor integrated navigation systems* (2nd ed.). Artech House.

Hofmann-Wellenhof, B., Lichtenegger, H., & Wasle, E. (2008). *GNSS – Global Navigation Satellite Systems: GPS, GLONASS, Galileo & more*. Springer-Verlag.

Hong, S., Lee, M. H., Chun, H.-H., Kwon, S.-H., & Speyer, J. L. (2005). Observability of error states in GPS/INS integration.

IEEE Transactions on Vehicular Technology, *54*(2), 731–743. https://doi.org/10.1109/TVT.2004.841540

Jekeli, C. (2001). *Inertial navigation systems with geodetic applications*. Walter de Gruyter. https://doi.org/10.1515/9783110800234

Krzyżek, R. (2014). Reliability analysis of the results of RTN GNSS surveys of building structures using indirect methods of measurement. *Geodesy and Cartography*, *63*(2), 161–181. https://doi.org/10.2478/geocart-2014-0012

Krzyżek, R. (2015a). Algorithm for modeling coordinates of corners of buildings determined with RTN GNSS technology using vector translation method. *Artificial Satellites Journal of Planetary Geodesy*, *50*(3), 115–125. https://doi.org/10.1515/arsa-2015-0009

Krzyżek, R. (2015b). Mathematical analysis of the algorithms used in modernized methods of building measurements with RTN GNSS technology. *Boletim de Ciências Geodésicas*, *21*(4), 848–866. https://doi.org/10.1590/S1982-21702015000400050

Krzyżek, R. (2015c). Modernization of the method of line-line intersection using RTN GNSS technology for determining the position of corners of buildings. *Artificial Satellites Journal of Planetary Geodesy*, *50*(1), 41–57. https://doi.org/10.1515/arsa-2015-0004

Krzyżek, R. (2017). Evaluating the accuracy of determining coordinates of a corner of a building measured in the RTN GNSS mode, having applied the innovative algorithm of vector translation. *Reports on Geodesy and Geoinformatics*, *103*(1), 10–21. https://doi.org/10.1515/rgg-2017-0002

Luo, X., Schaufler, S., Carrera, M., & Celebi, I. (2018). *High-precision RTK positioning with calibration-free tilt compensation* [Paper presentation]. In FIG Congress 2018, Istanbul, Turkey.

Pedley, M. (2012). e-Compass: Build and calibrate a tilt-compensating electronic compass. *Circuit Cellar*, *265*, 16–23.

Pırtı, A., & Yücel, M. A. (2023). Evaluating the accuracy of determining coordinates of corners of the building surveyed in tilt technology. *KSCE Journal of Civil Engineering*, *27*(6), 2629–2636. https://doi.org/10.1007/s12205-023-3309-5

Sveinung, T. K., Jakob, B. K., & Stewart, G. R. (2021). *Accuracy of Tilt-compensated GNSS sensors using Network-RTK* [Bachelor's thesis, Norwegian University of Science and Technology]. Norwegian Research Information Repository. https://hdl.handle.net/11250/2782315

Topcon. (2022). *HiPer VR*. https://www.topconpositioning.com/solutions/technology/infrastructure-products/gnss-bases-and-rovers

Wolf, P. R., & Ghilani, C. D. (2008). *Elementary surveying: An introduction to geomatics* (12th ed.). Prentice Hall.