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Evaluating the Accuracy of Determining Coordinates of Corners of the Building Surveyed in Tilt Technology

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ABSTRACT

Integrated Inertial Measurement Unit (IMU) and electronic compass; small, sturdy form factor; supports all communications, satellites, and constellations (Revolutionary 9 axis IMU and ultra-compact 3-axis e-Compass). By integrating a 9-axis IMU with a digital compass, the Topcon Hiper Versatile Global Navigation Satellite System (VR GNSS) receiver can correct for up to 15 degrees of pole tilt. It may be now measured all the way to the edge/corner of a building without requiring an offset. The emerging technology makes up for the fact that plum field surveys can be off by up to 15 degrees. The accuracy of measured building corners is investigated in this study using Topcon Inertial Levelling Technology (TILT) in the IMU and e-Compass. The results of a case study of 5, 10, 15 degree tilt angles show that a 3D positioning accuracy of about 10 cm is achievable even when the pole is tilted.

1. Introduction

The usage of technology in the area of surveying has advanced significantly during the past 20 years. Modern solutions include surveying tools that are used to measure field specifics. New measurement technologies are developed, or current measurement methods are improved, thanks to modern equipment that offers a wide range of options. Especially in the measurements of building edges/corners, the location of the building corners is computed by direct measurement or intersection methods by using total stations. With developments in recent years, measurements can be made with cm accuracy and quickly with RTK GNSS (Real-Time Kinematic Global Navigation Satellite Systems) and CORS (Continuous Operating Reference Stations) techniques. The biggest problem in the use of RTK and CORS techniques for corners of the buildings is the obstruction of the satellite view and not being able to hold the pole exactly to the point on the corner of the building (Jekeli, 2001; Hong et al., 2005; Hofmann-Wellenhof et al., 2008; Pedley, 2012; Groves, 2013; Krzyżek, 2014; Krzyżek, 2015a; Krzyżek, 2015b; Krzyżek, 2015c; Krzyżek, 2017; Luo et al., 2018; Karlsen et al., 2021). Today, as a result of technological developments in measuring instruments, paper reflectors, motorized and reflector-less total stations have come to the fore. In building corner measurements, the use of motorized and reflector-less total stations and paper reflectors is preferred. With the use of unmanned aerial vehicles and aerial LIDAR (Light Detection and Ranging), the coordinates of the corners of a building can be easily calculated as long as there is no roof on the building. Recently, many articles have been performed on the calculation of the location of building corners: Evaluation of the accuracy of locating the corners of constructions utilizing a variety of diverse measuring techniques (Krzyżek, 2017), using real time network GNSS technologies to modernize the technique of line-line junction for calculating the location of structural corners (Krzyżek, 2014; Krzyżek, 2015a; Krzyżek, 2015b; Krzyżek, 2015c), calibration-free tilt correction for RTK positioning and higher accuracy (Luo et al., 2018), accuracy of Tilt-compensated GNSS measurements using network-RTK (Karlsen et al., 2021), tilt sensing using a three-axis accelerometer (Pedley, 2012), inertial navigation systems with implications in geodesy (Jekeli, 2001), observability of GPS/INS integration error states (Hong et al., 2005), GNSS, inertial, and multi-sensor INS fundamentals (Groves, 2013). However, in this study, the Topcon Inertial Leveling Technology (TILT) system used by measuring companies was tested repeatedly with 5°, 10°, 15° angle values o n two different days. The purpose of this work was to ascertain if the actual method (TILT)

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utilized in practice for the execution of building edge/corner surveys was effective or not.

2. Materials and Methods

2.1 IMU TILT Sensor in RTK GNSS

An IMU, short for Inertial Measurement Unit, is a sensor that measures angular rate, force and sometimes magnetic field. It uses information from rotational sensors (gyroscopes), acceleration sensors (accelerometers), magnetic sensors (magnetometer) and GNSS. Using these parameters the IMU tilt sensor can continuously determine its position, rotation and degree of tilt. With this technique, you don't have to level your RTK GNSS receiver every time you're gonna measure a new point. The IMU tilt sensor ensures that regardless of whether the RTK device is not level, it will continue to function properly, it still makes an accurate measurement. So, if you have to measure a lot of points, it's not a difficult calculation that the IMU tilt sensor will save you a lot of time. Also, hard to reach points will be very easy to measure with an IMU tilt sensor in RTK GNSS device, think of the edge of a building, a steep slope or a point under an object, like a car for instance. TILT allows the receiver to compensate for up to 15° of pole tilt by integrating a nine-axis inertial measurement unit (IMU) with an electronic compass. It can be now measured all the way to a building edge without requiring an offset (Fig. 1) (SBG Systems, 2020). IMUs measure the forces of inertia and gravity on a device to figure out how it moves and monitor its space position and direction. INS (Inertial Navigation Systems) serve the similar purpose like an IMU only do not depend on external signals such as GNSS. Only the internal sensors are used to figure out the absolute attitude from a given starting point (Kjerstad, 2021). Alternatively, it can be extended to reach an otherwise inaccessible location. Like many other Topcon innovations, TILT is meant to clarify problems during the measurements and make your work easier, faster, and more effective (Luo et al., 2018; Tersus GNSS, 2023; Topcon, 2023).

In RTK implementation, the pole should be levelled using a circular ball in order to remain upright. In this situation, considering the phase centre offset (PCO) and pole length is the only way to lower the antenna phase centre's (APC) location to the pole tip. (Chen et al., 2020). Most modern RTK GNSS receivers with an IMU tilt sensor in them can tilt up to 60°, but some can only go to 30° or even only 15°. There is always a little compensation when you use the IMU tilt sensor. So if you measure a point at a 30° angle, you'll often have a compensation of about 2 centimetres, if you measure a point at a 60° angle you can find yourself having a compensation of 5 centimetres. So keep in mind that if you're measuring something and holding the pole of RTK GNSS receiver at a 60° angle, you can have a deviation of 5 centimetres. Some of the RTK GNSS receivers you first have to shake to initialize the IMU tilt sensor while others are ready to go the moment you turn on the RTK GPS receiver. The TILT, which compensates for field observations that are out of the vertical plane by up to 15°. TILT has a breakthrough 9-axis IMU (inertial measurement unit) and an ultra-compact 3-axis e-Compass, allowing operators to collect field measurements rapidly and confidently even when placing the receiver into a precise vertical position is difficult or impossible (Fig. 1) (Luo et al., 2018; Tersus GNSS, 2023; Topcon, 2023). This study assessed the accuracy and repeatability of RTK GNSS (TILT) by a comparison of the locations of many different testing stations (K1 and K2 points) determined from RTK GNSS and using the total station.

2.2 Traditional Technique: Total Station Surveying

A total station is an optical measuring instrument that uses

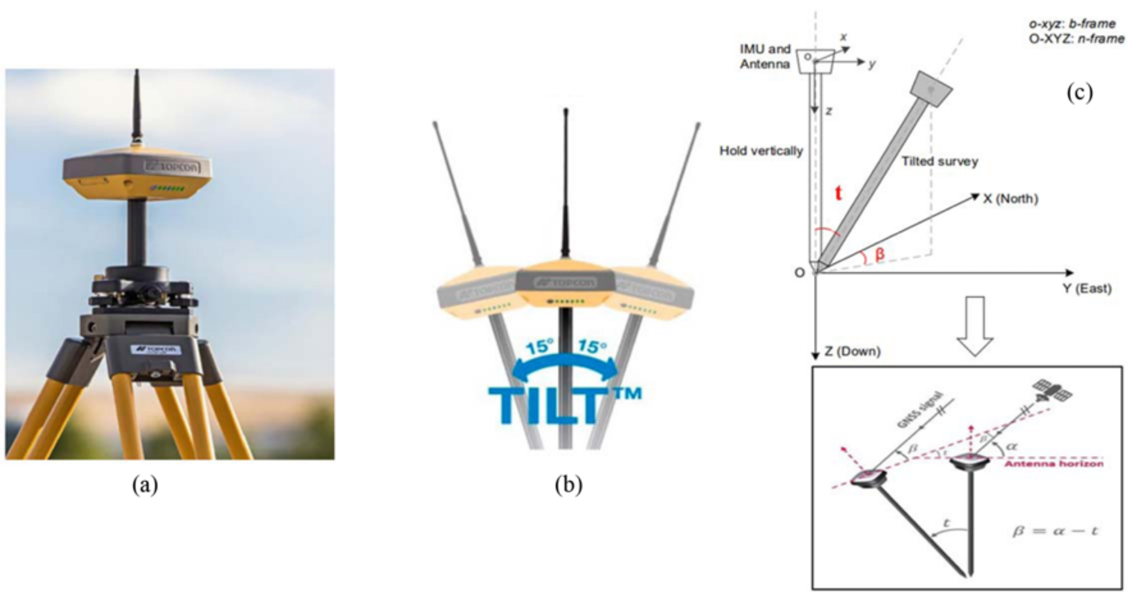

Fig. 1. Topcon Hiper VR GNSS Receiver: (a), Topcon Inertial Levelling Technology (TILT) Schema (b), (Topcon, 2023), The Tilt Angle *t* is Referred to as the Angle between the Vertical Plane and the Pole, Whereas the Horizontal Direction is Described as the Angle between North and the Planar Projection of the Tilted Pole. In Order to Facilitate Analysis, it is Assumed that the IMU Centre Coincides with the APC (c)

technology to measure both distances and angles. It includes a digital theodolite, a microprocessor, and an electronic distance meter (EDM). It also has a Central Processing Unit (CPU), digital data receiver, and storage area, enabling observations to be stored on the instrument (which can be uploaded to a computer for further processing). Reflector-less observations have just lately been included into total stations. They can provide highly simple, safe, and precise measurements if used appropriately and consumers are aware of their limits. The range of these sensors has grown to 1,000 – 1,500 metres for white targets and several hundred metres for natural darker objects. At distances of several hundred meters, it's also difficult to precisely focus the device on its designated destination, and beam divergence may become problematic. Extensive navigating is necessary, which is a downside. Furthermore, considerable clearing of adjoining private properties may also be necessary (Wolf and Ghilani, 2008).

2.3 Description of Experiments

This research investigates two separate studies that were conducted over the course of two days at the Yıldız Technical University Campus in Davutpaşa, Istanbul. For this aim, two GNSS stations (R1 and R2) were chosen in the study site (clear line of sight). Static GNSS surveys were carried out to determine the coordinates of the two reference points (R1 and R2). The static measurements of the R1 and R2 stations were taken for at least 1.5 hours of observation times (1 June 2022). The Topcon Magnet TOOLS v.7.3.0 Software was used for data processing and network adjustments. The ITRF 2014 Epoch 2022.40 coordinates of PALA station (ISKI-CORS) were fixed during the adjustment procedure (Fig. 2, Table 1). Table 1 shows the locations and standard deviations of two reference stations (R1 and R2).

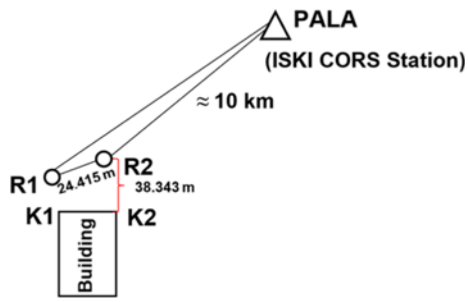

Fig. 2. Study site and GNSS Stations

In addition, K1 and K2 points marked the two corners of the building in the study area (1 store building, about 5 m tall), (Fig. 3). The GNSS equipment used for RTK surveying included a pair of Topcon Hiper VR devices (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)) and (Compensator Tilt Sensor* H: 1.3 mm/°Tilt; Tilt ≤ 10 H: 1.8 mm/°Tilt; Tilt > 10 – *Maximum angle for tilt compensation is 15°), (URL 1). The data-receiving and processing rates were set to 30 seconds, and the cut–off elevation mask angle was set to 10 for static survey. The two RTK surveys were done at various times over the course of the two days, with significant modifications in satellite configuration to assure the impartiality of results (Table 2). The number of observed GNSS satellites and their distribution were typically “normal” during the testing procedure, from 19 to 25 satellites seen and the Position Dilution of Precision (PDOP) ranging between 0.92 and 1.27 for static survey.

Table 1. Standard Deviation and Coordinates of the Three GNSS Stations Using Static Surveys

Point	Grid Northing (m)	Grid Easting (m)	Elevation (m)	Std N (m)	Std E (m)	Std h (m)
PALA	4550678.003	412881.990	170.561	0	0	0
R1	4543784.101	406343.303	113.455	0.002	0.002	0.004
R2	4543760.218	406338.235	113.213	0.002	0.002	0.004

Fig. 3. The Reference Points (R1, R2) and the Corners of Building (K1 and K2 points the project area)

3. Results

In Table 2, RTK GPS/GPS+GLONASS/GNSS surveys between 13 – 15 hours on 26 May 2022 selected TILT angles of 5, 10, 15 degrees were performed by using different satellite configurations (GPS, GPS+GLONASS, GPS+GLONASS+Galileo+Beidou) and R2 reference point to obtain the coordinates of K1 building corner point. The recording interval was selected as 1 sec and the epoch value was chosen as 5 with 5 – 6 GPS, 3 – 4 GLONASS, 4 – 5 Galileo, 10 – 11 Beidou satellites observed in this period. The PDOP values were between 0.8 and 3.1 for this period.

In Table 2, RTK surveys between 10:30-12:35 hours on 1 June 2022 selected TILT angles of 5, 10, 15 degrees were performed by using different satellite configurations (GPS, GPS+GLONASS, GPS+GLONASS+Galileo+Beidou) and R2 reference point to obtain the coordinates of K1 building corner point. The recording interval was selected as 1 sec and the Epoch value was chosen as 5 with 4 – 8 GPS, 3 – 7 GLONASS, 2 – 5 Galileo, 9 – 11 Beidou satellites observed in this period. The PDOP values were between 0.75 and 2.80 for this period.

In Table 3, RTK surveys between 15-17:05 hours on 26 May 2022 selected TILT angles of 5, 10, 15 degrees were performed by using different satellite configurations (GPS, GPS+GLONASS, GPS+GLONASS+Galileo+Beidou) and R2 reference point to obtain the coordinates of K2 building corner point. The recording interval was selected as 1 sec and the Epoch value was chosen as 5 with 4 – 7 GPS, 3 – 5 GLONASS, 4 – 6 Galileo, and 10 – 13 Beidou satellites observed in this period. The PDOP values were between 0.80 and 3.10 for this period.

In Table 3, RTK surveys between 13:30 – 15:40 hours on 1 June 2022 selected TILT angles of 5, 10, 15 degrees were performed by using different satellite configurations (GPS, GPS+GLONASS, GPS+GLONASS+Galileo+Beidou) and R2 reference point to obtain the coordinates of K2 building corner point. The recording interval was selected as 1 sec and the Epoch value was chosen as 5 with 4 – 7 GPS, 3 – 5 GLONASS, 4 – 6 Galileo, 8 – 11 Beidou satellites were observed in this period. The PDOP values were between 0.77 and 3.11 for this period.

GNSS enabled rapid technical advancement in positioning activities. The usage of several constellations is significant because of the rise in the total number of satellites that may be seen, which increases the number of accessible observables and can enhance satellite geometry (Tables 2 and 3). Considering the utilization of GPS/GLONASS/Gaileo/Beidou data, all configurations demonstrated improved location accuracy when all constellations' data was combined (Wolf and Ghiliani, 2008). The GNSS system includes all GPS, GLONASS, Galileo, and BeiDou data and delivers stable RTK positioning with accessibility and dependability. This study assessed the accuracy and repeatability of RTK GNSS (TILT) by using the coordinates of the testing locations (K1 and K2 points) found by RTK GNSS and a total station.

3.1 Accuracy Analysis of RTK-GPS/GNSS (TILT)

In this study, RTK GPS/GPS-GLONASS/GNSS measurements

Table 2. Time Schedule of the RTK GPS/GNSS Measurements for Point (K1) Using Topcon Hiper VR Receiver

Point	Satellites	TILT Angle (degree)	Y	X	h	Epoch
26.05.2022						
K1	GPS	5º	406384.662	4543774.489	112.625	5
K1	GPS	10º	406384.702	4543774.463	112.566	5
K1	GPS	15º	406384.700	4543774.424	112.580	5
K1	GPS+GLONASS	5º	406384.504	4543774.474	112.570	5
K1	GPS+GLONASS	10º	406384.494	4543774.519	112.600	5
K1	GPS+GLONASS	15º	406384.507	4543774.508	112.603	5
K1	GNSS	5º	406384.425	4543774.458	112.616	5
K1	GNSS	10º	406384.378	4543774.684	112.599	5
K1	GNSS	15º	406384.456	4543774.478	112.620	5
01.06.2022						
K1	GPS	5º	406384.517	4543774.458	112.588	5
K1	GPS	10º	406384.500	4543774.460	112.610	5
K1	GPS	15º	406384.535	4543774.464	112.594	5
K1	GPS+GLONASS	5º	406384.469	4543774.515	112.567	5
K1	GPS+GLONASS	10º	406384.480	4543774.496	112.581	5
K1	GPS+GLONASS	15º	406384.469	4543774.513	112.591	5
K1	GNSS	5º	406384.474	4543774.500	112.588	5
K1	GNSS	10º	406384.458	4543774.499	112.585	5
K1	GNSS	15º	406384.440	4543774.465	112.581	5

Epoch: The measurement interval of a GPS7GNSS receiver for coordinate estimation.

Table 3. Time Schedule of the RTK GPS/GNSS Measurements for Point (K2) by Using Topcon Hiper VR Receiver

Point	Satellites	TILT Angle (degree)	Y	X	h	Epoch
26.05.2022						
K2	GPS	5°	406369.764	4543756.225	112.522	5
K2	GPS	10°	406369.761	4543756.254	112.521	5
K2	GPS	15°	406369.735	4543756.289	112.539	5
K2	GPS+GLONASS	5°	406369.762	4543756.277	112.504	5
K2	GPS+GLONASS	10°	406369.799	4543756.252	112.508	5
K2	GPS+GLONASS	15°	406369.825	4543756.180	112.505	5
K2	GNSS	5°	406369.742	4543756.284	112.536	5
K2	GNSS	10°	406369.811	4543756.189	112.531	5
K2	GNSS	15°	406369.830	4543756.149	112.529	5
01.06.2022						
K2	GPS	5°	406369.757	4543756.266	112.537	5
K2	GPS	10°	406369.797	4543756.125	112.541	5
K2	GPS	15°	406369.751	4543756.115	112.368	5
K2	GPS+GLONASS	5°	406369.722	4543756.277	112.483	5
K2	GPS+GLONASS	10°	406369.745	4543756.243	112.498	5
K2	GPS+GLONASS	15°	406369.735	4543756.206	112.498	5
K2	GNSS	5°	406369.753	4543756.159	112.468	5
K2	GNSS	10°	406369.735	4543756.175	112.494	5
K2	GNSS	15°	406369.678	4543756.127	112.454	5

were performed at building corner points K1 and K2 by choosing TILT angles of 5, 10, 15 degrees at different time intervals of the two days. The obtained coordinates were compared and investigated in terms of accuracy. The experiment includes a pair of ground–marked sites (K1 and K2). Note that the surveys were carried out at several hours of the day and with different satellite constellations (Table 2). For RTK GPS/GPS-GLONASS/GNSS surveys, the data acquisition (the act of receiving data) and processing rate (the amount of any raw material or method intermediary that is used in a given amount of time, as well as any output that is made, as a result of using any piece of equipment, reference operation, or controlling device) were set to 1 second and 5 epochs, with a cut-off elevation mask angle of 10 degrees. Using Topcon Hiper VR receivers, the integer ambiguity is corrected between 1 minute and 20 minutes for each location on June 9, 2022. On May 26, 2022, RTK GPS was used to do the first survey. RTK GPS-GLONASS/GNSS was used to do the other surveys on the same day. Figs. 4 and 5 show the coordinate differences among RTK GPS/GPS-GLONASS/GNSS survey results for two points. Figures also show the mean and standard deviation values of the coordinate discrepancy acquired from the first and other surveys. When the results of the RTK surveys are compared, the horizontal coordinates of the locations as independently established by these tests seem comparable, with a few millimetres to twenty centimetres of variation. The height component was, however, less constant across all RTK GPS/GPS-GLONASS/GNSS sessions, varying up to 20 cm at the same places.

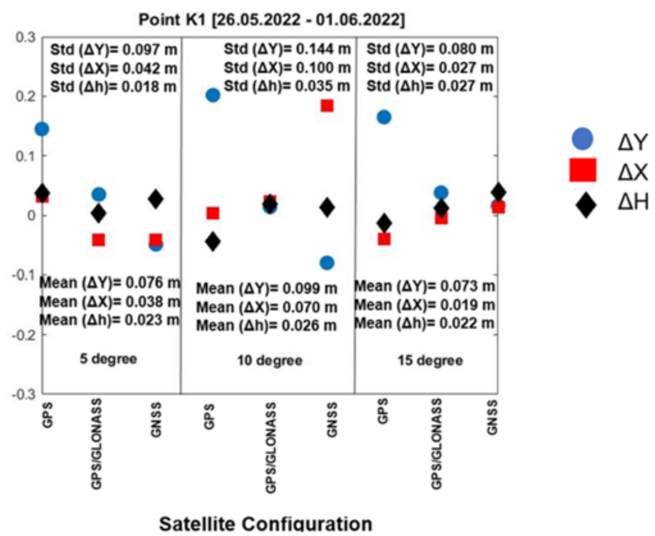

Fig. 4. Comparison of the K1 Coordinates Obtained from RTK GPS/GNSS Surveys on 26 May 2022 and 01 June 2022 by Using R1 Reference Point

Figure 4 shows the coordinate differences between RTK survey results on both days (26 May 2022 – 01.06.2022) for K1 point, located in the corner of the building. The obtained coordinates of the first RTK GPS survey for K1 point are compared with the other five RTK survey results of K1 point. The accuracy (Easting, Northing) of K1 point were enough in general with standard deviation values less than 14.4 cm, mean values less than 8.9 cm.

The height was less consistent, with differences of up to 5 cm at the same point between RTK GPS/GNSS observations. The standard deviation and mean values of height of K1 point were 1.8 – 3.5 cm and 2.2 – 2.6 cm, respectively.

Figure 5 shows the coordinate differences between RTK GPS/GPS-GLONASS/GNSS survey results on both days by using R2 point, K2 located in the corner of the building. The obtained coordinates of the first RTK GPS survey of K2 point are compared with the other five RTK survey results of K2 point. The coordinates (Easting, Northing) of K2 point were good in general with standard deviation values less than 12 cm, mean values less than 8.6 cm. The height component was less consistent, with differences of up to 20 cm at the same point between RTK GPS/GNSS observations. The standard deviation and mean values of height of K2 point were about 2.9 – 6.8 cm and 2.2 – 8.4 cm, respectively.

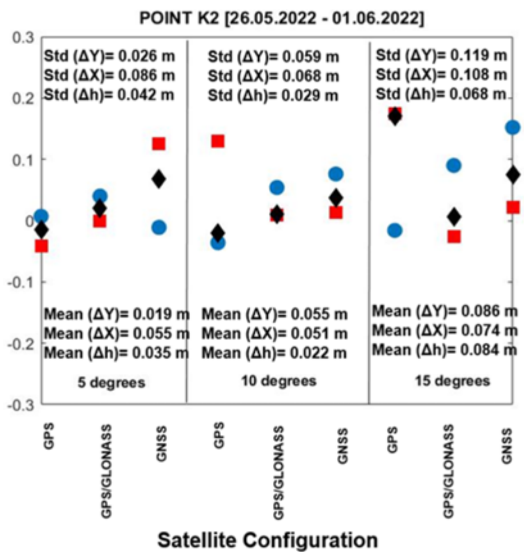

Fig. 5. Comparison of the K2 Coordinates Obtained from RTK GNSS Surveys on 26 May 2022 and 1 June 2022 Using R1 Reference Point

3.2 Total Station Surveys and Comparisons

The accuracy of RTK GPS/GPS-GLONASS/GNSS data may be determined by comparing them to the coordinates derived using terrestrial measurements. The distances and angles between the points were observed by using a total station to compare the results of RTK GPS/GPS-GLONASS/GNSS methods. The R1 and R2 reference stations were taken as control stations for the total station surveys (Fig. 2). R1 and R2 coordinates were computed by using the static GNSS data (measurement periods of roughly 90 minutes) by fixing the reference point PALA (ISKI-CORS). As previously stated, two corner points (K1, K2) were observed from the R1 and R2 points. Topcon GTS-701 (angle accuracy: 2", distance measurement accuracy: 2 mm + 2 ppm) was used to observe the horizontal plane, vertical plane, horizontal distances, and slope distances for calculating the locations of the two stations. Table 3 illustrates the coordinate values of two stations (K1 and K2) obtained from total station

Table 4. Coordinate Values of K1 and K2 Points by Using Total Station

Total Station			
Point	Northing (m)	Easting (m)	Elevation (m)
K1	406384.494	4543774.464	112.601
K2	406369.717	4543756.307	112.696

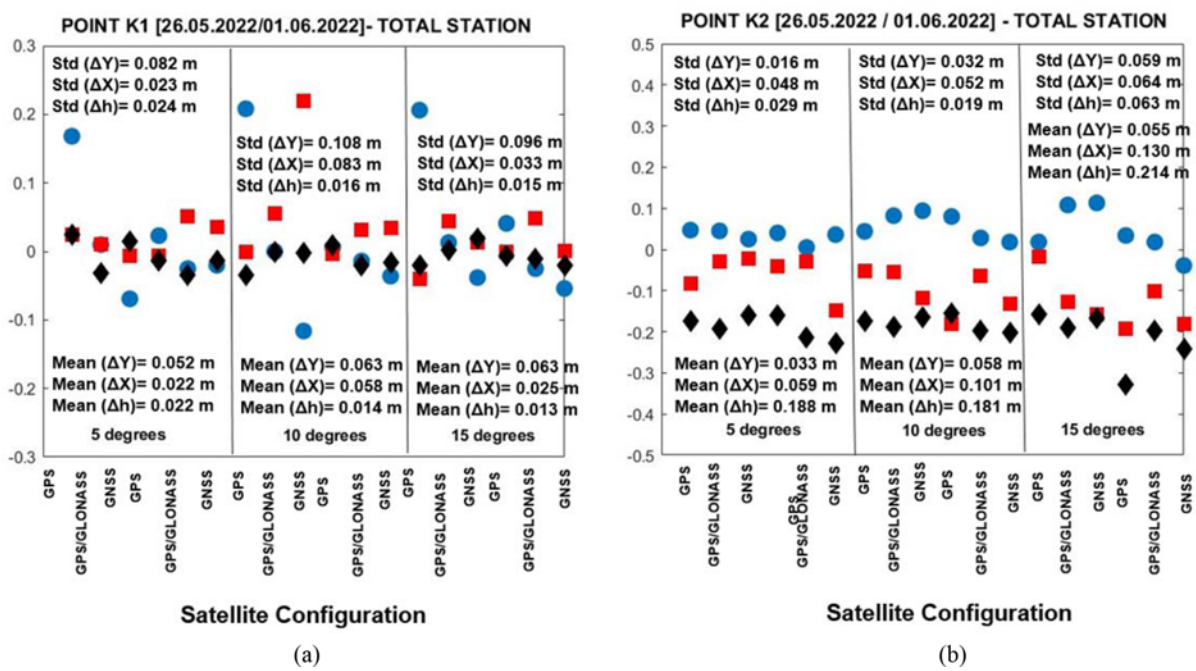

Fig. 6. Comparison of the K1 and K2 Coordinates Obtained from RTK GPS/GNSS Surveys on 26 May 2022 and 1 June 2022 with the Coordinates of Points K1 and K2 Obtained from R1 and R2 Reference Points by Using Total Station

surveys (R1 and R2 reference points).

When the results of the RTK GPS/GPS-GLONASS/GNSS with total station surveys were compared, the discrepancies were (1 – 5 cm) in height values and (1 – 20 cm) in horizontal coordinate values for K1 point (Fig. 6(a)). The coordinates (Easting, Northing) of K1 point were good in general with standard deviation values less than 11 cm, mean values less than 7 cm. The height component was less consistent, with differences of up to 5 cm at the same point between RTK GPS/GNSS observations. The standard deviation and mean values of height of K1 point were 1.8 – 3.5 cm and 2.2 – 2.6 cm, respectively (Fig. 6(a)). When the results of the RTK GPS/GPS-GLONASS/GNSS with total station surveys were compared, it was obtained that the discrepancies were bigger in height (1 – 35 cm) and smaller in horizontal coordinates (1 – 20 cm) for K2 point (Fig. 6(b)). The coordinates (Easting, Northing) of K1 point were good in general with standard deviation values less than 7 cm, mean values less than 13 cm. The height component was less consistent, with differences of up to 20 – 35 cm at the same point between RTK GPS/GNSS observations. The standard deviation and mean values of height of K1 point were 1.9 – 6.3 cm and 18 – 21 cm, respectively (Fig. 6(b)). Moreover, the distance between the corner points (K1 and K2) of the building was measured by using a steel tape and obtained as 23.408 m. The obtained distance between K1 and K2 point was calculated as 23.410 m using total station.

All of the data show that structures are harmful to RTK positioning because they typically block signals from low-to-medium orbit satellites and interfere with radio transmissions. Therefore, even in the presence of strong satellite windows, signal blocking owing to buildings may be regarded as the most significant obstacle to the adoption of RTK GPS/GNSS in the building areas. The average standard deviations of the two tests of the corners of the building K1 and K2 point in the Easting, Northing, and Height coordinate directions are shown in Fig. 7.

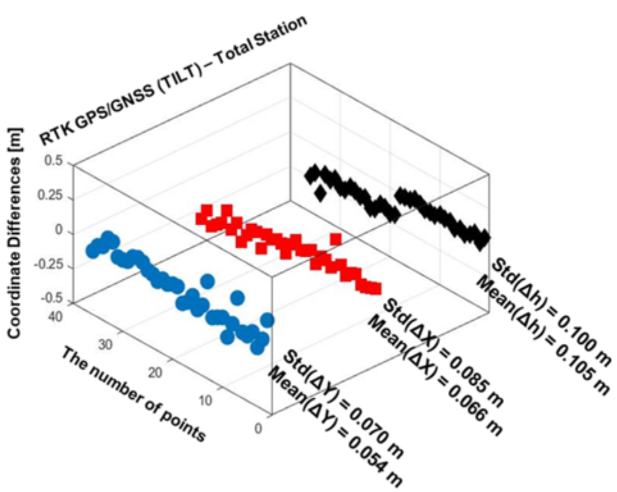

Fig. 7. Compare the Coordinates of the Two Building Corners (K1 and K2) in 26 May 2022 and 1 June 2022 by Using R1 and R2 Reference Points (Topcon Hiper-VR) with the Coordinates of the Two Building Corners (K1 and K2) Using Total Station

With a standard variation of less than 8.5 cm, the coordinates (easting and northing) of all two corner points were sufficient. Height accuracy was less accurate, as predicted, with an average standard deviation of 10 cm. The height components were less consistent, with differences of up to about 50 cm (Fig. 7) between the four RTK sessions using the R2 reference point. Given how these tests moved and how the shape of the satellites at the two corners of the building changed over the course of two days, the results show that the RTK method is a stable system and that the cm level of accuracy can be reached in most operational settings (Fig. 7).

There are now several devices for tilt compensated GNSS receivers; however, this research is confined to Topcon devices. Some receivers have various recommendations for maximum tilt degrees and compensation methods. Statistical significance necessitates a larger sample size. Items in the locality of the receiver may cause disruptions in pseudorange and carrier phase measurements by reflecting some signals before they reach the antenna. Despite the fact that current receivers have many ways for identifying and excluding reflected signals, certain signals may go unnoticed and cause mistakes. Rooftops, for instance, are notoriously poor multipath settings owing to vents and other reflecting surfaces inside the field of view of the antenna. When selecting how much to tilt the GNSS receiver while using tilt-compensated GNSS equipment, it is necessary to take into account the use of tilt-compensated GNSS equipment. In general, a lower tilt angle is desired, although there may be instances when raising the tilt might be advantageous or even mandatory according to local regulations (Luo et al., 2018; Chen et al., 2020).

There are several outstanding issues with this research. We would like to examine the inclination 0, 5, 10, 15 degrees, more types of buildings need to be tested. To develop a more thorough slanted RTK solution, it is necessary to do more research into the aforementioned issues.

4. Conclusions

The TILT method obviously cannot be used in all situations or at all times with the same degree of precision. In other words, quality assurance is still a major concern for surveyors. The trials show that the building has a considerable impact on the accuracy, precision, and performance of the TILT system. Buildings have a detrimental impact on GNSS signals through blocking, attenuation, and reflection. The TILT receiver measured all of the point coordinates with good horizontal and vertical accuracy and precision. According to the results of this investigation, the TILT system has a horizontal accuracy of 8.5 cm and a vertical accuracy of 10.5 cm. These obtained results show that TILT technology is feasible, effective, and efficient for positioning and other applications in the corner of the building which do not create improper conditions. Furthermore, fewer ground control points are needed for survey applications when the Topcon Hiper VR receiver is used. From the comparisons of all methodologies described in this research, it is evident that the accuracy of the TILT approach is relatively comparable to that of the complete station survey. The receiver IMU-based tilt compensation is applicable at 15-degree tilt angles, where a 3D positioning accuracy of about 10 cm is achievable. When employing tilt compensated GNSS equipment, we recommend that you evaluate how much to tilt the GNSS device. While a lower tilt angle is favoured in general, depending on local regulations, raising the tilt may be helpful or even essential in some cases.

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