Determinability of the Changes in the East-West and the North-South Directions with GNSS Technique

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Key words: GNSS, Reference Point, Object Point

SUMMARY

Nowadays, GNSS(Global Navigation Satellite Systems) techniques are widely used to determine positions of geodetic points. Geodetic networks which have high accuracy can be established with these techniques.

In this study, the success of GNSS technique has been investigated for determining of the changes in direction of coordinate axes. For this purpose, a geodetic network which has 8 points has been established in Selcuk University Campus area, 7 of these points are reference points and one of which is object point. A mechanism that allows virtual shifting at 1cm intervals on the object point was developed. During the measurement, GNSS receiver set up on the mechanism at the object point was shifted to 1 cm intervals and GNSS observations were carried out for 2 hours on each point while receivers at the reference points were continuously carrying out observations. Shiftings on the mechanism at the object point were performed in the east-west and the north-south directions. The coordinates of reference points have been calculated based on CORS-Tr (Continuously Operating Reference Stations-Turkey) network, the coordinates of object point have been calculated based on reference points. Leica Geo Office (LGO) v7.0 software has been used in calculations. When the mechanism placed on object point, the north direction was used to determine shiftings in the north-south direction, thus performed shiftings occurred on X axis. In order to determine the changes in the east-west direction, when the mechanism placed on object point the east direction was used and performed shiftings occurred on Y axis. Virtual shifting amounts on the mechanism were compared with x and y coordinate differences which were obtained from GNSS measurements carried out successively on the mechanism.

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1. INTRODUCTION

Nowadays, GPS (**G**lobal **P**ositioning **S**ystem), GLONASS (**GLO**bal'naya **NA**vigatsionnaya **S**putnikovaya **S**istema (Global Navigation Satellite System)), GALILEO, BEIDOU and other independent positioning systems, which are developed by different countries, become indispensable tools to determine point positions. GNSS techniques provide three-dimensional cartesian coordinates (X, Y, Z) of geodetic points in WGS-84 (World Geodetic System-1984) datum to users. Transformation to a geodetic coordinate system with respect to a reference ellipsoid is also possible. Three-dimensional positioning accuracy can be achieved centimeter level with the GNSS technique, which allows to measure in all weather conditions (Li et al. 2015). Compared to classical techniques, GNSS techniques improve measurement accuracy, productivity and monitoring capacity (Wang et al. 2015). Absolute or relative positioning methods can be preferred when using these systems to determine position of geodetic points. Relative positioning methods are commonly used in geodetic applications. Geodetic networks, which have high accuracy can be established by using these methods.

No requirement of visibility between geodetic points in GNSS networks established by using GNSS provides flexibility in the selection of point locations with respect to classical geodetic networks. Session durations could be reduced to several minutes with rapid static positioning technique which is one of the relative positioning methods (Erol et al., 2004). However, with regard to GNSS positioning technique it should be noted that the longer the length of sessions, the better the solution; 12 h of observations will give reasonable accuracies in the horizontal and the vertical with the error in vertical component being about twice that of the horizontal component (Ogundare, 2016).

In this study, the success of the static positioning technique with GNSS in determining the positional changes in direction of the coordinate axes has been investigated. For this purpose, an 8-point microgeodetic network, 7 of which are the reference points and 1 of which is the object point, has been established in Selcuk University Campus area. The points used in the network were constructed in the form of pillars for forced-centering.

A mechanism that allows virtual shifting at 1 cm intervals on the object point has been developed. During the measurement, GNSS receiver set up on the mechanism at the object point was shifted to 1 cm intervals and GNSS observations were carried out for 2 hours on each point while receivers at the reference points were continuously carrying out observations. The shiftings on the object point were made in the north-south and the east-west directions. Virtual shifting amounts on the mechanism were compared with x and y coordinate differences which were obtained from GNSS measurements carried out successively on the mechanism.

2. STATIC RELATIVE POSITIONING

The GNSS technique has been a widely used method since the end of the 1980s. The GNSS including the US's Global Positioning System (GPS), Russia's GLONASS, EU's Galileo and China Beidou (also called COMPASS) as well as several regional navigation satellite systems, can be characterized as a highly precise, continuous, all-weather and near-real-time microwave (L-band) technique with signals through the Earth's atmosphere. These characteristics of GNSS imply more and wider applications and potentials (Jin et al., 2014). These application areas are positioning, navigation and timing, precise orbit determination, intelligent transport systems, terrestrial reference frame, real-time active control networks (RTK-CORS), monitoring of plate movements, crustal deformation, deformation measurements (dam, bridge, viaduct, etc.), location-based services and cadastral, photogrammetric, hydrographic measurements.

While point coordinates can be determined by using post process with GNSS technique at the beginning, in recent times these coordinates can be also determined in real time. With post process, the point coordinates can be determined by different methods. These methods are static positioning, rapid static positioning and pseudokinematic positioning. In applications requiring high accuracy, such as deformation measurements, tectonic plate movements, monitoring of large engineering constructions, the static positioning method are preferred because of the high accuracy (Table 1).

Table 1. Accuracies for relative positioning (Hofmann-Wellenhof et al., 2008)

Mode	Horizontal accuracy
Static	5 mm + 0.5 ppm
Kinematic	5 cm + 5 ppm

With the static positioning method, base vectors between stations can be calculated by using more than one receiver. Session durations of 1-2 hours are usually suggested for static positioning for civil engineering applications while for regional and global geophysical studies session durations should be 10 to 24 hours (Hastaoglu and Sanli, 2011; Stewart and Rizos, 2002). Higher accuracy can be achieved with increased session durations.

3. APPLICATION

3.1 Study Area

In this study the success of the static positioning technique with GNSS in determining the positional changes in direction of the coordinate axes has been investigated. For this purpose, an 8-point microgeodetic network, 7 of which are the reference points and 1 of which is the object point, has been established in Selcuk University Campus area. The distance of the object point to the reference points changes from ~121 m to 1.6 km. The coordinates of the reference points in the established network were calculated based on the points of Tusaga-Active (Cors-TR) network. The Cors-TR is a network that enables both real-time and post-process positioning, and consists of 146 points covering the whole of Turkey. It has been operating since 2009. In application, the coordinates of the reference points were calculated based on the Cors-TR stations around the study area. The points AKHR, BEYS, CIHA, HALP, KAMN, KAPN, KLUU, KNY1, YUN1 were used in calculations. The distance to the study area of these points changes from ~17 to 162 km (Figure 1).

Figure 1. Microgeodetic network (a) and Cors-TR stations used in application(b)

The SLCK-TUTGA point was used as the object point in the microgeodetic network established in the study area. A mechanism that allows virtual shiftings at 1 cm intervals in the direction of the coordinate axes was placed on the SLCK-TUTGA point, and measurements at the SLCK-TUTGA point were carried out on this mechanism (Figure 2).

Figure 2. SLCK-TUTGA point

3.2 Introduction of Mechanism

A mechanism was developed to determine virtual position changes at 1 cm intervals (Figure 3). CNC (Computer Numerical Control) lathes have been used in the manufacture of the mechanism.

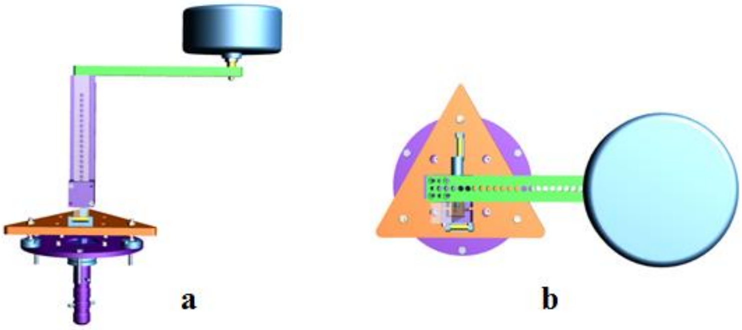

Figure 3. The view of mechanism from side (a) and top (b)

With the help of the mechanism, it is possible to make virtual position changes in horizontal and vertical directions with 1 cm intervals. The 1 cm interval points on the mechanism are used to shift the GNSS receiver horizontally (Figure 4a). The GNSS receiver can be set up on each of these points. Whichever direction the mechanism is directed, the position changes occur in that direction. When it is desired to make virtual position changes in the vertical direction, 1 cm interval points shown in the side view of mechanism are used (Figure 4b).

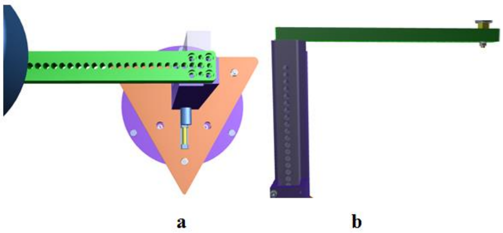

Figure 4. Points used for virtual position changes horizontally (a) and vertically (b)

There are two plate levels perpendicularly positioned to each other on a triangular table on which is placed the mechanism (Figure 5). These levels are set using the screws on the corners of the table, thereby ensuring verticalization of the GNSS receiver.

Figure 5. Plate levels on the triangular table

The mechanism can be directed to the desired direction and mounted using four screws on the forced-centering element of the pillar (Figure 6).

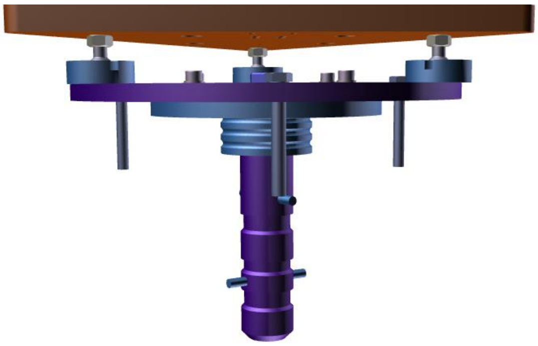

Figure 6. Forced-centering element and triangular table

Once the mechanism is mounted on the pillar and the plate levels are set, system becomes ready for measurements.

3.3 Measurements Carried Out in Study Area and Evaluation

In order to investigate the determinability of the virtual position changes in the north-south direction in the microgeodetic network designed at the Selcuk University campus area, the mechanism was primarily directed to the north on the SLCK-TUTGA point. During the measurement, GNSS receiver set up on the mechanism at the object point was shifted to 1 cm intervals and GNSS observations were carried out for 2 hours on each point while receivers at the reference points were continuously carrying out observations. Afterwards, in order to investigate the determinability of the virtual position changes in the east-west direction, the mechanism was directed to east and the same measurement plan was applied. The data record interval was taken as 5 seconds. Four Javad and four Topcon GNSS receivers were used for carrying out measurements.

While determining virtual position changes in the north-south and the east-west directions coordinates of used reference points calculated based on Cors-TR stations shown in figure 1, by using 10-hours observations per day between July 26 and 28 2016, 8-hours observations per day between October 28 and 31 2016, respectively. Coordinates at the object point were calculated based on these reference points.

Leica Geo Office v7.0 (LGO v7.0) software was used in evaluation of the observations. In the baseline solutions, IGS (International Geodetic Survey) final orbits were used. GPS / GLONASS observations were evaluated together with the elevation mask of 10^{o}. When determining the coordinates of reference points, the data record interval was taken as 30 seconds, and when determining the coordinates of the points on the mechanism, the data record interval was taken as 5 seconds.

Projection coordinates (TM: Transversal Mercator (x, y)) were used in the comparison of the coordinates obtained from data evaluated. Coordinate differences (dx, dy) between 1 cm interval points on the mechanism;

$$dx = x_{i+1} - x_i \qquad dy = y_{i+1} - y_i \tag{1}$$

root mean squares (rms) of these coordinate differences (m_{dx}, m_{dy});

$$m_{dx} = \sqrt{m_{x_i}^2 + m_{x_{i+1}}^2} \quad , \quad m_{dy} = \sqrt{m_{y_i}^2 + m_{y_{i+1}}^2} \tag{2}$$

were calculated by equations (1)-(2). Where m_{x_i}, m_{y_i}, $m_{x_{i+1}}$ ve $m_{y_{i+1}}$ represent rms of coordinates. Coordinate differences and rms of these differences were obtained from 1 cm interval consecutive points. These are given in table 2 and 3, in the north-south and the east-west directions, respectively.

Table 2. Coordinate differences and root mean squares in the north-south direction

Points	**dx (mm)**	**dy (mm)**	**m_{dx}(mm)**	**m_{dy} (mm)**
0 - 1	12.2	-0.2	±3.8	±2.9
1 - 2	9.1	0.4	±3.5	±2.9
2 - 3	9.8	0.2	±3.1	±2.7
3 - 4	11.7	-1.1	±3.1	±2.8
4 - 5	11.0	0.1	±3.7	±3.2
5 - 6	11.4	0.5	±3.8	±3.2
6 - 7	7.2	-0.4	±3.2	±2.7
7 - 8	8.7	-2.0	±3.3	±2.8
8 - 9	11.0	0.6	±3.5	±3.0
9 - 10	9.9	-0.9	±3.0	±2.8

Table 3. Coordinate differences and root mean squares in the east-west direction

Points	**dx (mm)**	**dy (mm)**	**m_{dx}(mm)**	**m_{dy} (mm)**
0 - 1	0.7	9.2	±2.1	±1.8
1 - 2	0.0	11.6	±2.1	±1.8
2 - 3	0.0	8.7	±2.1	±2.0
3 - 4	-1.1	9.8	±2.1	±1.9
4 - 5	1.2	10.2	±2.2	±1.8
5 - 6	2.9	7.0	±2.1	±1.9
6 - 7	3.4	9.6	±2.1	±1.8
7 - 8	-0.2	9.0	±1.9	±1.8
8 - 9	0.3	8.2	±1.9	±1.8
9 - 10	0.8	9.9	±1.8	±1.6

The mechanism was directed to the north and to the east in the north-south and the east-west directions, respectively. For this reason, the x-coordinate differences in the north-south direction and the y-coordinate differences in the east-west direction were calculated and differences (d) between these differences and real value (1 cm) were calculated and shown in table 4 and 5, respectively. It was examined whether the d values are significant or not.

Table 4. Significance test for d values in the north-south direction

d (mm)	**m_{dx} (mm)**	**Test Value t**	**Result T_{table}=1.96**
2.2	±3.8	0.58	$t<T_{table}$ Differences are not significant.
-0.9	±3.5	0.25	
-0.2	±3.1	0.06	
1.7	±3.1	0.55	
1.0	±3.7	0.27	
1.4	±3.8	0.37	
-2.8	±3.2	0.88	
-1.3	±3.3	0.39	
1.0	±3.5	0.29	
-0.1	±3.0	0.03	

Table 5. Significance test for d values in the east-west direction

d (mm)	**m_{dx} (mm)**	**Test Value t**	**Result T_{table}=1.96**
-0.8	±1.8	0.43	$t<T_{table}$ Differences are not significant.
1.6	±1.8	0.90	
-1.3	±2.0	0.65	
-0.2	±1.9	0.10	
0.2	±1.8	0.11	
-3.0	±1.9	1.57	
-0.4	±1.8	0.22	
-1.0	±1.8	0.57	
-1.8	±1.8	1.02	
-0.1	±1.6	0.06	

Test value;

$$t = \frac{|d|}{m_{dx}} \tag{3}$$

was calculated by equation (3). The d values calculated for the north-south and the east-west directions are also shown in figure 7.

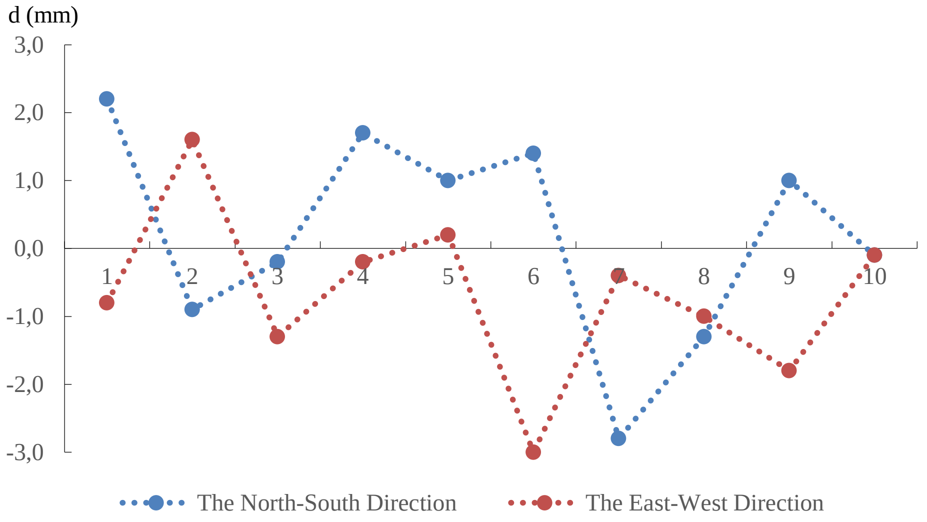

Figure 7. The differences between GNSS and the real value

4. CONCLUSIONS

GNSS techniques, as well as classical terrestrial techniques, can be widely used today in determining point positions. The use of GNSS techniques is easier, faster and more economical than terrestrial techniques.

With the help of the mechanism designed in this study, the point positions were virtually changed in the direction of the coordinate axes and the determinability of these changes was investigated. Coordinates of consecutive points were determined by the static relative positioning on the mechanism and the calculated position changes were compared with real value on the mechanism.

When table 2 and 3 are examined, it is seen that the 1 cm coordinate changes in the north-south direction change from 0.72 to 1.22 cm and in the east - west direction these changes change from 0.70 to 1.16 cm. When Table 4 and Table 5 are examined, it can be seen that differences between these values and real value change from -0.28 to +0.22 cm for the north-south direction and -0.30 - +0.16 cm for the east-west direction. When significance test results of d values are examined, it is considered that these differences are not significant and reasons of these are measurement errors at the 95% probability level. The rms for the differences are ± 3.0 - ± 3.8 mm in the north-south direction and ± 1.6 - ± 2.0 mm in the east-west direction. If it is assumed that the statistical value is 1.96, it can be seen that coordinate changes higher than 5.8 mm in the north-south direction and 3.1 mm in the east-west direction can be determined with this system. It is considered that d values and rms may vary depending on the number of reference points used, the distance of the object point to the reference points, and session durations.

5. ACKNOWLEDGEMENTS

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