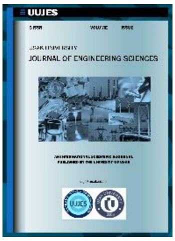

Usak University

Journal of Engineering Sciences

An international e-journal published by the University of Usak

Journal homepage: dergipark.gov.tr/uujes

*Research article*

# COMPARISON OF DIFFERENT BRANDS OF GEODETIC GNSS RECEIVERS ACCORDING TO HORIZONTAL ACCURACIES

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*Received: 31 May 2022* *Revised: 18 June 2022* *Accepted: 21 June 2022* *Online available: 30 June 2022*
*Handling Editor: Jülide Öner*

## Abstract

The accuracy data presented in the technical specifications of the geodetic surveying instruments produced by various companies are controversial. To be able to say anything about the accuracy of these data, they must be obtained under similar conditions, tested by process, adjusting and appropriate statistical methods, and then compared. In this study, Geodetic GNSS receivers produced by different companies were tested according to horizontal accuracies. However, vertical observations were also obtained, only horizontal accuracies were compared. For this purpose, a horizontal control network was established and long-term static sessions were held with the instruments of each company in this network. The data obtained as a result of the sessions were converted into data files in the same format and adjusted separately by processing with the commercial software of one of the instruments. As a result of adjustment, the results obtained from the instruments of each company were compared according to the horizontal accuracy criteria. GNSS receivers used in this research gave nearly the same horizontal accuracy result.

***Keywords:*** *GNSS; Long GNSS Static Session; Comparison of GNSS Receivers; GPS; GLONASS.*

## 1. Introduction

Today, there are measuring instruments belonging to different companies that are used for the same purpose. Looking at the brochures published by the companies that produce them, there are various technical features and accuracy criteria of the tools. The values given in the technical specifications are obtained under laboratory conditions. Therefore, the accuracy of these values, especially the accuracy criteria, should be checked under real

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DOI: https://doi.org/ 10.47137/uujes.1123909

conditions by testing them. The superiority of the accuracy specified in the technical specifications of the measuring instruments produced by different companies but used for the same purposes, can only be determined by tests to be carried out in real measuring environments under the same conditions.

Selecting and buying a GNSS receiver, depending on different needs, is the first step for implementing precision of work.

A GNSS (Global Navigation Satellite System) must be economically viable in order to be used, and, depending on the crop operation, must achieve high values of positioning accuracy. The positioning accuracy of a GNSS is the distance between the position of a point on the Earth's surface determined by this system and the real one (Mariusz Rychlicki et al. 2020).

In this research, GNSS receivers belonging to five companies were controlled in a horizontal control network. For this purpose, four-hour static sessions were held.
First of all, the technical data on the brochures of GNSS instruments were compared. Of course, since this comparison is not an objective comparison, these values do not go beyond giving preliminary information whose accuracy is questionable.

## 2. Brochure Data of GNSS Receivers

In general, when we look at the brochure data of measuring instruments, we see some information as follows. These;

a. Supported GNSS (GPS, GLONASS, Galileo, Beidou etc.)
b. GNSS performance (number of channels, GNSS technology, positioning speed etc.)
c. Measurement Performance and Accuracy (DGPS/RTK/Static)
d. Power
e. Physical characteristics
f. Communication

Table 1 was created by taking the long-term static measurement accuracies only from the brochures of each GNSS receiver, from the measurement performance and accuracy values from these data.

In comparison, only long-term static accuracy criterion was used from these data. When the values in Table 1 taken from the brochure information were compared, the order of the GNSS receivers was as follows, in alphabetical order:

1. Leica Viva GS15, Topcon GR5, Trimble sR8
2. Geomax Zenith25
3. CHC X91+GNSS

It is misleading to try determining their superiority over each other by looking at the brochure information of GNSS receivers. Even the fact that their production times are different makes it clear that catalog information can be misleading. Because this information may change in the model of the same brand that will be produced 1 year later.

**Table 1.** Brochure data of compared GNSS receivers

| | Receiver | Receiver Features | GPS Signals | GLONASS Signals | Receiver sensitivity during long static sessions (High-Precision Static Horizontal) |
|---|---|---|---|---|---|
| **a** | Geomax Zenith25 | 120 channels, (GPS/GLONASS) | L1, L2, L2C | L1, L2 | 3.5 mm + 0.4 ppm (rms) |
| **b** | CHC X91+ GNSS | 220 channels (GPS/GLONASS) | L1C/A, L1C, L2C, L2E, L5 | L1C/A, L1P, L2C/A, L2P, L3 | 3 mm + 0.5 ppm (rms) |
| **c** | Topcon GR5 | 226 channels (GPS/GLONASS) | L1C/A, L1C, L2C | L1C/A, L1P, L2C/A, L2P | 3 mm + 0.1 ppm (rms) |
| **d** | Leica Viva GNSS GS15 | 120 channels | L1, L2, L2C, L5 | L1, L2 | 3 mm + 0.1 ppm (rms) |
| **e** | Trimble R8s | 440 channels | L1C/A, L1C, L2C, L2E, L5 | L1C/A, L1P, L2C/A, L2P, L3 | 3 mm + 0.1 ppm (rms) |

# 3. Methodology

## 3.1. Data Collection

Survey marks with the highest possible positional quality should be chosen in order to obtain and compare the derived solution for accuracy (Catania et al., 2020). To compare the long-term static session accuracy of GNSS receivers produced by different companies, a rectangular network was created in Tuzla, Istanbul (Figure 1). Three of the points in this network (G222H108, G222H127, G222H152) are C2 degree triangulation points (a C2 degree triangulation point is a point, which has high horizontal accuracy in Turkish National GNSS Network), whose coordinates are known in the ITRF96 system (International Terrestrial Reference Frame 1996), which was installed in the form of pillars in the Istanbul GPS Project, which is one of the projects of the Istanbul Metropolitan Municipality, in 2005 (Figure 2). The fourth point is the triangulation point established by us in the form of a pile, and Figure 3.)

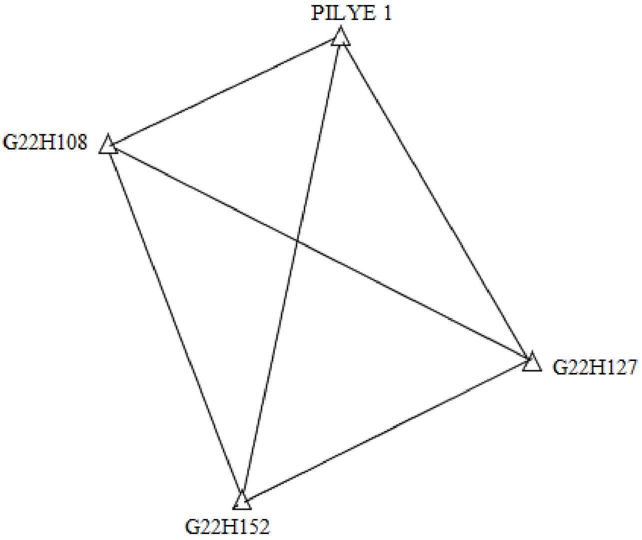

**Fig. 1** Horizontal Test Framework

**Fig. 2** IGNA C2 degree points

**Fig. 3** Established triangulation point (PILYE 1)

IGNA: Istanbul GPS Triangulation Network
Since the sessions were held as a static session for 4 hours, the sessions were held between 08-12 am and 14-18 pm o'clock for two instrument groups during the day. All data were collected from combinations of GPS+GLONASS.

### 3.2. Data Processing and Adjustment

After the static sessions were completed, the raw data obtained from different brands of GNSS instruments were converted into rinex format. The raw data files converted to the Rinex format were resolved as baseline vectors in software used, then processed. Topcon tools software was used for data processing and adjustment. The software uses the following methods in the process of static measurement data according to base lengths.

- VLBL : It is used to solve bases longer than 40km. Triple phases are used in ionosphere and troposphere corrections. "Iono Free" is displayed in the solution type.
- WideLane: It is used to solve the bases between 30km and 40km.
- L1 and L2c: Used on bases between 10km and 30km.
- L1 and L2: Used on bases less than 10km

## 3. Adjustment of GNSS Processed Data by Using Least Square Adjustment Method

After data processing, next step is adjustment of GNSS observations (baseline vectors). Least squares adjustment method has been used in this step. The coordinate accuracies of the points are calculated with the help of the following equations (1).

$n$: Number of measurements
$u$: Number of unknowns
$f$: Degrees of freedom
$\underline{A}$: Coefficient matrix
$\underline{P}$: Weight matrix of observations
$\underline{L}$: Reduced vector of observations
$\underline{v}$: Vector of residuals
$\underline{x}$: Vector of unknowns

$$f = n - u \tag{1}$$

$$\underline{N} = \underline{A}^T \underline{P}\, \underline{A} \tag{2}$$

$$\underline{n} = \underline{A}^T \underline{P}\, \underline{L} \tag{3}$$

$$\underline{Q_{xx}} = \underline{N}^{-1} \tag{4}$$

$$\underline{Q}_{xx} = \begin{bmatrix} q_{x_1x_1} & & & \\ & q_{x_2x_2} & & \\ & & \vdots & \\ & & & q_{x_ix_i} \end{bmatrix} \tag{5}$$

$$\underline{x} = \underline{Q}_{xx}\, \underline{n} \tag{6}$$

The matrix equation for calculating residuals after adjustment, whether the adjustment is weighted or not, is

$$\underline{v} = \underline{A}\, \underline{x} - \underline{L} \tag{7}$$

The standard deviation of unit weight for a weighted adjustment is

$$\sigma_0 = \mp\sqrt{\frac{\underline{v}^T \underline{P}\, \underline{v}}{f}} \tag{8}$$

Standard deviations of the adjusted quantities are

$$\sigma_{x_i} = \mp\sigma_0\sqrt{q_{x_ix_i}} \tag{9}$$

Standard deviations of position of the adjusted points are

$$\sigma = \mp\sqrt{\sigma_{x_i}^2 + \sigma_{y_i}^2 + \sigma_{z_i}^2} \tag{10}$$

### 4.1. Results of Least Squares Adjustment

**Table 2** Fixed point for the adjustment

| Point No | North (m) | East (m) |
|---|---|---|
| **G222H108** | 4534485.198 | 446419.798 |

Table 2 shows the fixed point coordinates used for the adjustment.

Brief of the adjustment:
Method of the adjustment: (Minimum forced, partial trace minimum)
Confidence limit: %95
Adjusted points: 4
Horizontal control points: 1
Number of GNSS vectors: 6

### 4.1.1 Adjustment results for Geomax Zenith25

**Table 3** Adjusted Coordinates and their standard deviations

| Point No | North (m) | East (m) | $\sigma_x$ mm | $\sigma_y$ mm |
|---|---|---|---|---|
| **G222H127** | 4533237.841 | 450499.235 | ±1 | ±1 |
| **G222H152** | 4531437.095 | 448466.770 | ±1 | ±1 |
| **PILYE1** | 4535267.169 | 448574.954 | ±1 | ±1 |

Table 3 shows the adjusted coordinates of unknown points and the standard deviations of them.

**Table 4** Adjusted baseline vector's components and their standard deviations

| GNSS Observations | | | |
|---|---|---|---|
| **Base No** | **dNorth (m)** | **dEast (m)** | **Horizontal $\sigma$ (mm)** |
| **G222H108–G222H127** | -1247.357 | 4079.437 | ±2 |
| **G222H108–G222H152** | -3048.103 | 2046.972 | ±2 |
| **G222H108–PILYE1** | 781.971 | 2155.156 | ±1 |
| **G222H127–G222H152** | -1800.745 | -2032.465 | ±1 |
| **G222H127–PILYE1** | 2029.328 | -1924.281 | ±1 |
| **G222H152–PILYE1** | 3830.075 | 108.184 | ±2 |

Table 4 shows the baseline vector's components and their accuracy of them.

### 4.1.2. Adjustment results for CHC X91+ GNSS

**Table 5** Adjusted Coordinates and their standard deviations

| Point No | North (m) | East (m) | $\sigma_x$ mm | $\sigma_y$ mm |
|---|---|---|---|---|
| **G222H127** | 4533237.840 | 450499.234 | ±1 | ±1 |
| **G222H152** | 4531437.092 | 448466.773 | ±1 | ±1 |
| **PILYE1** | 4535267.166 | 448574.953 | ±1 | ±1 |

Table 5 shows the adjusted coordinates of unknown points and the standard deviations of them.

**Table 6** Adjusted baseline vectors and their standard deviations

| GNSS Observations | | | |
|---|---|---|---|
| **Base No** | **dNorth (m)** | **dEast (m)** | **Horizontal $\sigma$ (mm)** |
| **G222H108–G222H127** | -1247.358 | 4079.437 | ±2 |
| **G222H108–G222H152** | -3048.106 | 2046.976 | ±1 |
| **G222H108–PILYE1** | 781.967 | 2155.154 | ±1 |
| **G222H127–G222H152** | -1800.748 | -2032.461 | ±1 |
| **G222H127–PILYE1** | 2029.326 | -1924.281 | ±1 |
| **G222H152–PILYE1** | 3830.074 | 108.180 | ±1 |

Table 6 shows the baseline vector's components and their accuracy of them.

### 4.1.3. Adjustment results for Topcon GR5

**Table 7** Adjusted Coordinates and their standard deviations

| Point No | North (m) | East (m) | $\sigma_x$ mm | $\sigma_y$ mm |
|---|---|---|---|---|
| **G222H127** | 4533237.839 | 450499.240 | ±1 | ±1 |
| **G222H152** | 4531437.090 | 448466.773 | ±1 | ±1 |
| **PILYE1** | 4535267.169 | 448574.955 | ±1 | ±1 |

Table 7 shows the adjusted coordinates of unknown points and the standard deviations of them.

**Table 8** Adjusted baseline vectors and their standard deviations

| GNSS Observations | | | |
|---|---|---|---|
| **Base No** | **dNorth (m)** | **dEast (m)** | **Horizontal $\sigma$ (mm)** |
| **G222H108–G222H127** | -1247.358 | 4079.442 | ±2 |
| **G222H108–G222H152** | -3048.108 | 2046.975 | ±1 |
| **G222H108–PILYE1** | 781.971 | 2155.157 | ±1 |
| **G222H127–G222H152** | -1800.749 | -2032.467 | ±1 |
| **G222H127–PILYE1** | 2029.329 | -1924.284 | ±1 |
| **G222H152–PILYE1** | 3830.079 | 108.182 | ±1 |

Table 8 shows the baseline vector's components and their accuracy.

### 4.1.4. Adjustment results for Leica Viva GNSS GS15

**Table 9** Adjusted Coordinates and their standard deviations

| Point No | North (m) | East (m) | $\sigma_x$ mm | $\sigma_y$ mm |
|---|---|---|---|---|
| **G222H127** | 4533237.839 | 450499.240 | ±1 | ±1 |
| **G222H152** | 4531437.090 | 448466.773 | ±1 | ±1 |
| **PILYE1** | 4535267.169 | 448574.955 | ±1 | ±1 |

Table 9 shows the adjusted coordinates of unknown points and the standard deviations of them

**Table 10** Adjusted baseline vectors and their standard deviations

| GNSS Observations | | | |
|---|---|---|---|
| **Base No** | **dNorth (m)** | **dEast (m)** | **Horizontal $\sigma$ (mm)** |
| **G222H108–G222H127** | -1247.355 | 4079.440 | ±2 |
| **G222H108–G222H152** | -3048.106 | 2046.972 | ±1 |
| **G222H108–PILYE1** | 781.972 | 2155.154 | ±1 |
| **G222H127–G222H152** | -1800.752 | -2032.469 | ±1 |
| **G222H127–PILYE1** | 2029.327 | -1924.284 | ±1 |
| **G222H152–PILYE1** | 3830.079 | 108.184 | ±1 |

Table 10 shows the baseline vector’s components and their accuracy

### 4.1.5. Adjustment results for Trimble R8s

**Table 11** Adjusted Coordinates and their standard deviations

| Point No | North (m) | East (m) | $\sigma_x$ mm | $\sigma_y$ mm |
|---|---|---|---|---|
| **G222H127** | 4533237.844 | 450499.233 | ±1 | ±1 |
| **G222H152** | 4531437.094 | 448466.775 | ±1 | ±1 |
| **PILYE1** | 4535267.168 | 448574.956 | ±1 | ±1 |

Table 11 shows the adjusted coordinates of unknown points and the standard deviations of them.

Table 12 shows the baseline vector’s components and accuracy of them.

According to standard deviations of unknown points all receivers had the same accuracy. Since the same accuracy criteria are obtained as a result of the adjusting made, GNSS receivers do not have superiority over each other.

**Table 12** Adjusted baseline vectors and their standard deviations

| GNSS Observations | | | |
|---|---|---|---|
| **Base No** | **dNorth (m)** | **dEast (m)** | **Horizontal $\sigma$ (mm)** |
| **G222H108–G222H127** | -1247.353 | 4079.435 | ±2 |
| **G222H108–G222H152** | -3048.104 | 2046.977 | ±2 |
| **G222H108–PILYE1** | 781.969 | 2155.158 | ±1 |
| **G222H127–G222H152** | -1800.751 | -2032.457 | ±1 |
| **G222H127–PILYE1** | 2029.326 | -1924.278 | ±1 |
| **G222H152–PILYE1** | 3830.072 | 108.181 | ±2 |

## 5. Conclusion

According to the accuracy criteria obtained as a result of the application, all of the GNSS receivers gave close results. Considering different software may produce different results in terms of accuracy. This research revealed that all GNSS receivers used gave similar results in long-term static sessions. Although GNSS receivers of different brands are compared in this article, getting more accurate results from such a research depends on the fact that many criteria such as the quality of the materials used in production, the superiority of the software, etc., primarily the production years of the compared GNSS receivers are close to each other.

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