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# Testing RTK GPS Horizontal Positioning Accuracy within an Urban Area

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## Research Article

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**Abbreviations:** GPS: Global Positioning System; PDOP: Position Dilution of Precision; RMSE: Root Mean Square Error; RTK: Real Time Kinematic

**ABSTRACT**

Today, advanced GPS receivers are improving the accuracy of positioning information, but in critical locations such as urban areas, the satellite availability is limited due to the signal blocking problem, which degrades the required accuracy.

The objective of this article is to evaluate the horizontal positioning accuracy of a Real Time Kinematic Global Positioning System (RTK-GPS) available at the surveying engineering program laboratory in the civil engineering department at King Saud University, using RTK technique.

To accomplish this task, a reference network of eleven control points within King Saud university compass area was established in an almost limited open area to work as an accuracy testing reference.

The GPS was used to determine the horizontal positions of the eleven test points. Results show that a horizontal positional root mean squares error of 11 mm can be obtained using the Leica SR 530 RTK-GPS.

## INTRODUCTION

Surveying engineering deals mainly with field measurements including distances, directions and height. It is well known that measurements and observations are usually accompanied with errors that deteriorate accuracy. Surveying engineers have been interested in accuracy since the early history of their profession. Even since the use of tape, they were interested in the material it is manufactured with and its variations when interact with the weather conditions so they can determine the ultimate accuracy they can obtain.

There are various positioning survey techniques, however, the latest geodetic GPS receivers are improving the accuracy of positioning information, but in critical locations such as urban areas, the satellite availability is difficult due to the signal blocking problem, multipath etc. which degrade the required accuracy.

The RTK technique is becoming widespread and is now commonly preferred GPS positioning technique. It is an advanced form of relative GPS carrier phase surveying in which the reference station transmits its measurement data to the rover that compute in turn a vector baseline from the reference station to the rover position.

RTK GPS is, however only suitable for environments with reasonably good GPS tracking conditions and with continuously reliable base station to rover communication [1].

Considering these limitations, the objective of this article is to evaluate the horizontal positioning accuracy of the GPS instrument available at the laboratories of the civil engineering department at King Saud University: Leica SR530 L1/L2 Base and Rover RTK Survey GPS. Leica, manufacturer of this instrument, claims to achieve 10 mm positioning accuracy while performing RTK (Leica Geosystem). This claim will be tested in a small open area within King Saud University (KSU) campus in this project.

The results of the study can be used as an indication of whether RTK GPS can be used for surveying in such a site to achieve cm horizontal positioning accuracy as claimed by the manufacturer.

## GLOBAL POSITIONING SYSTEM (GPS)

GPS is a highly accurate navigation system using signals from satellites to determine a location on the Earth's surface, irrespective of weather conditions. It is based on GPS satellites high above the Earth which transmit signals containing the time and location of the satellite. Any ground-based receiver which receives signals from four or more GPS satellites can use navigation equations to calculate its location on the Earth's surface. GPS was originally developed for military use but since the 1990s has been open for civilian use and is now used in such common applications as mobile phones, car navigation systems, and of course surveying and mapping [2,3].

## METHODS OF GPS MEASUREMENT THAT ARE UTILIZED BY SURVEYORS

### Static GPS Baseline

Static GPS is used for determining accurate coordinates for survey points by simultaneously recording GPS observations over a known and unknown survey point for at least 20 minutes. The data is then processed in the office to provide coordinates with an accuracy of better than 5mm depending on the duration of the observations and satellite availability at the time of the measurements [4].

### Real Time Kinematic (RTK) Observations

This is where one receiver remains in one position over a point of precisely known ground coordinates, called the Base Station – and another receiver moves between positions to be determined– the Rover Station. The position of the Rover can be computed and stored within a few seconds, using a radio link to provide a coordinate correction. This last mode is the one that this research will focus on. In the coming section some research done in assessing horizontal position accuracy and the obtained results would be outlined.

## LITERATURE REVIEW

During the last two decades, considerable research about the accuracy of RTK-GPS has been carried out. Some of the research done is summarized and results achieved are given in the following section.

Chekole tested a network of control points to compare accuracy and time expenditure by TS and GPS. The accuracy of the RTK measurements on the network was found to be less than 9 mm in horizontal and they reach 2.2 cm in vertical coordinates [5].

In order to check the compatibility of the RTK method with that of total station method, Ahmed, 2012 tested RTK and total station measurements on an existing network [6]. The objective of the test was to assess the RTK achievable accuracy, to check the repeatability of the results under different satellite configurations and to evaluate RTK performance in urban area. In the test, accuracy and repeatability assessment of the RTK was carried out by comparing the coordinates of points with that of independently precisely determined using a total station. According to the result, the difference between the coordinates of total station and RTK was 2 cm for the horizontal and 3 cm for the vertical coordinates.

Ehsani et al. surveyed a 50 ha area with RTK-GPS. The base station and four reference points were established over the highest point in the survey area Corrected GPS signals are transmitted in real time from a base receiver at a known location to one or more rover receivers [7]. Results from RTK GPS method gave a horizontal coordinate accuracy of 1 cm by compensating for atmospheric delay, orbital errors and other variables in GPS geometry.

Lin, performed accuracy test between GPS RTK and total station. The results showed that a positional accuracy of 14 mm has been achieved using GPS RTK while using total station it was possible to determine 16 mm positional accuracy [8].

Jonsson et al. carried out RTK measurements to test accuracy of different GPS instruments (Leica, Topcon and Trimble). A network of nine control points was established using total station [9]. Then, the authors performed RTK measurement on the same network and compared results with different instrument. Results obtained from RTK measurement have shown a horizontal and vertical accuracy of 10 mm and 2 cm respectively.

Veersema A conducted a case study survey to investigate the use of the RTK technique for boundary surveys [10]. Both a Nikon DTM821 Total Station and a Leica SR530 RTK field unit and base station with a radio link survey were conducted in Inverell, northern New South Wales and the site chosen for the survey consisted of six lots comprising about 10 hectares located on the town's outskirts [11].

The differences in distances between the RTK and the Total Station surveys range from 13 mm to 57 mm, with a standard deviation of 14 mm. When comparing the Easting and Northing coordinates for each point obtained by each method some interesting trends were discovered. The easting differences were almost all negative values, suggesting that the RTK derived coordinates were further east than the Total Station derived coordinates by an average of 22 mm. The differences in the northing coordinates also showed a trend in that the RTK derived coordinates were almost all South of the Total Station derived coordinates as a large majority of the difference values were positive by an average of 16 mm. Position vector error was 34.4 mm.

A. El-Mowafy tested RTK-GPS positioning accuracy in construction work achieving positional accuracy of 1-3 cm (15 mm RMSE in position) [12].

## STUDY AREA

Locating a suitable area for conducting horizontal positional accuracy of RTK-GPS involves considering the following:

- Test area should be free of construction or any causative for sudden changes in its terrain (flood, drilling or dump).
- No obstruction above 15° elevation to avoid signal blockage.
- No reflecting surfaces (metal structures, fences or water surfaces) to avoid multipath.
- No nearby electrical installations to avoid signal disturbances.

Riyadh, capital of kingdom of Saudi Arabia, lies in the center of Arabian Peninsula on latitude 34° - 38′ north and longitude 46° – 43′ east approximately 600 meters above Mean Sea Level in Eastern Najd, a region largely dominated by a rocky plateau landscape, in the center of the Arabian Peninsula **(Figure 1)** [13].


**Figure 1.** Riyadh geographical location. King Saud University (KSU) campus whose Google map is shown in **Figure 2** lies in the north part of Riyadh.


**Figure 2.** King Saud University (KSU) campus.

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KSU campus is really busy with construction being carried out at various sites [14]. Considerable time has been spent to select an isolated area **(Figure 2)** where there are neither construction nor moving vehicles to obstruct satellite signals.


**Figure 3.** Test area within KSU campus, bounded by red line.

## METHODOLOGY

The test steps start by constructing a network of horizontal control points that will work as test points whose horizontal positions will be determined by the RTK-GPS approach to determine its horizontal positioning accuracy **(Figure 3)**.

**Establishing Reference Network**

After selecting the test area which is the most suitable within the KSU campus for satellite visibility, test points were marked with nails for sustainability reason. These points form an eleven traverse points **(Figure 4)**.

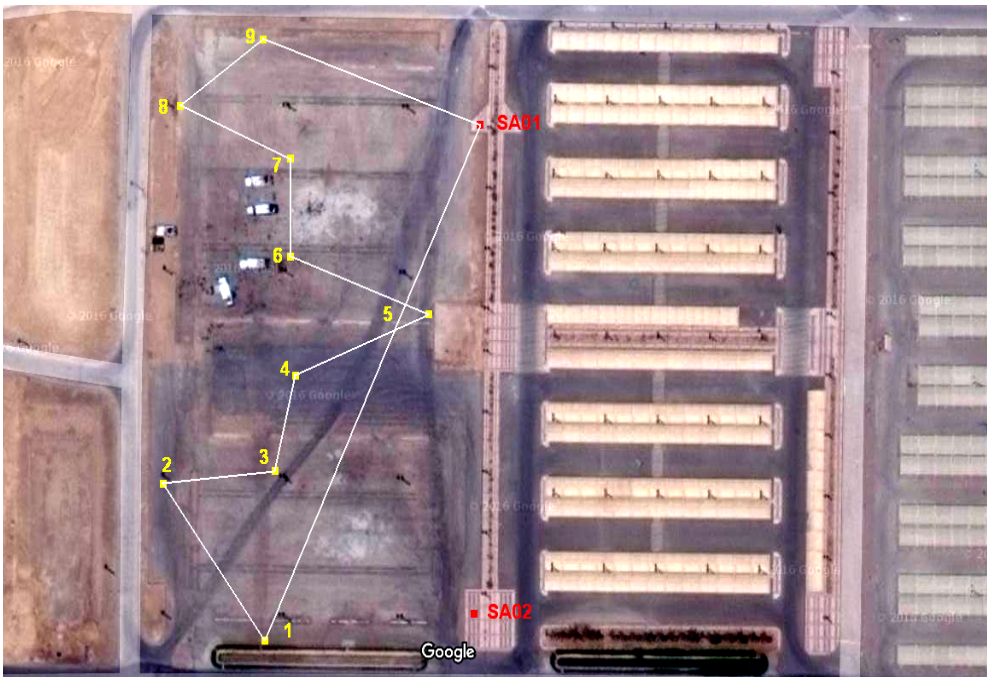


**Figure 4.** Traverse reference test network.

Coordinates of two points SA01 and SA02 **(Figure 5)** were measured with static GPS for three hours in order to be used as a baseline for the network traverse. These two points were corrected with the existing control point AM2 (local control point for the college of engineering), SA01 was used as one of the net traverse points.

To calculate the network points coordinate with high accuracy, measurements have been taken in two faces with three

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rounds each using Leica 1101 Total Station to eliminate instrumental errors such as line of sight errors, tilting axis errors and vertical index errors.

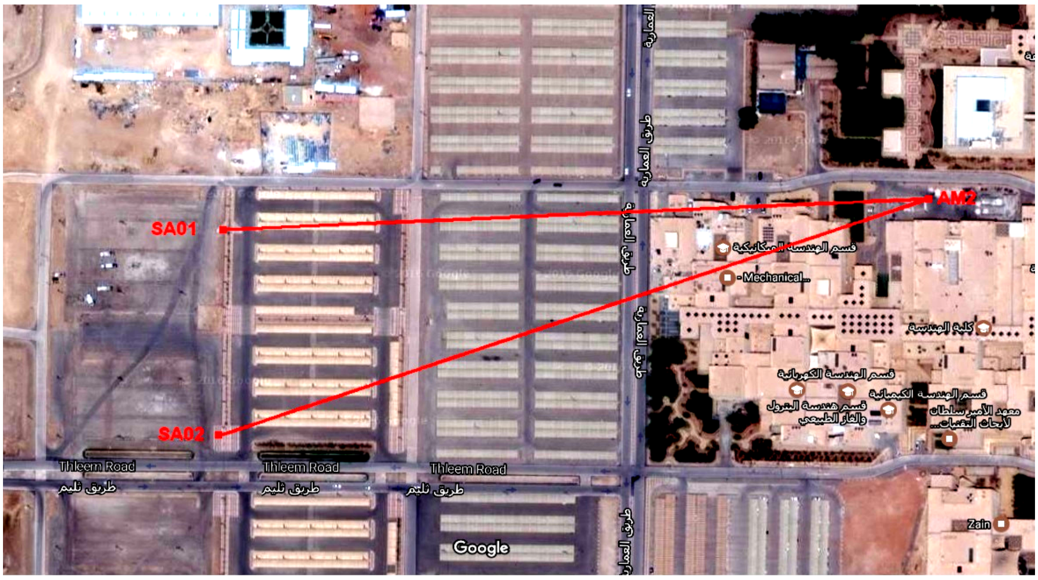


**Figure 5.** Selected stations SA01 and SA02 linked to control AM2.

After observing the interior angles for the traverse and lengths of its sides the coordinates of the traverse points were determined using closed traverse formulas and errors conditions.

The traverse interior angles closing error can be calculated using the following relation: Theoretical sum of interior angles of traverse – sum of observed traverse interior angles.

Theoretically, the sum of the interior angles of a closed traverse is given as [15]:

$(n - 2) \times 180°$

Where, n=number of sides, or angles of the traverse.

The closure observation error of the traverse = $(n - 2) \times 180° - \Sigma$ observed interior angles. For the current case, the polygon is 10-sided (n=10) and therefor, the theoretical sum of its interior angels = $(10-2) \times 180° = 1440$.

The actual closing error will determine if it is acceptable according to the standard permitted errors table and which degree is it.

**Table 1.** Standard permitted errors table.

| Degree Of Traverse | Angular Error | Relative Error Distance To Perimeter | Suitable Type Of Work |
|---|---|---|---|
| $1^{st}$ Degree | $2'' \sqrt{n}$ | 1:25000 | Control points and aerial surveying |
| $2^{nd}$ Degree | $10'' \sqrt{n}$ | 1:10000 | Engineering surveying |
| $3^{rd}$ Degree | $30'' \sqrt{n}$ | 1:5000 | Setting out works |

Knowing the error and its degree we can adjust the interior angles error to zero **(Table 1)**.

**Table 2.** Traverse SA1-9 adjusted interior angles, in degrees.

| Station | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Hz Angle | 60.2433 | 58.2200 | 240.0372 | 143.9583 | 318.3522 | 113.8228 |
| Station | 7 | 8 | 9 | SA1 | Σ | error |
| Hz Angle | 233.5775 | 69.2944 | 121.925 | 80.5692 | 1440 | 0 |

The closure error is distributed equally among the observed traverse angles to get the adjusted angles **(Table 2)**. These were then used to calculate side azimuth of the traverse starting from side SA01 and side SA02.

The finally adjusted coordinates of traverse net control points are given in **Table 3**.

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**Table 3.** Finally adjusted traverse points coordinates (in meters).

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | SA01 |
|---|---|---|---|---|---|---|---|---|---|---|
| X | 3164.819 | 3135.348 | 3172.130 | 3187.169 | 3217.033 | 3174.662 | 3169.987 | 3139.241 | 3158.718 | 3230.685 |
| Y | 5171.068 | 5212.793 | 5215.016 | 5245.173 | 5260.688 | 5271.409 | 5298.976 | 5314.506 | 5332.354 | 5177.553 |

**Planning for GPS Observation**

Before data collection planning was carried out to observe theoretical satellite availability. Most GPS software has the ability to provide a theoretical estimate of the satellite availability at a given location and time **(Table 4).** Data collection is hence planned to be done at times when there is optimum satellite availability and when the satellites are at appropriate configuration to produce an acceptable (lower) PDOP value.

Using Satellite Availability program the suitable dates and intervals for Observations was selected from the charts shown below as given for both stations SA01 and SA02 **(Table 5)**:

**Figures 6-8** show observation date plan for the two stations SA01 and Sa02, respectively.

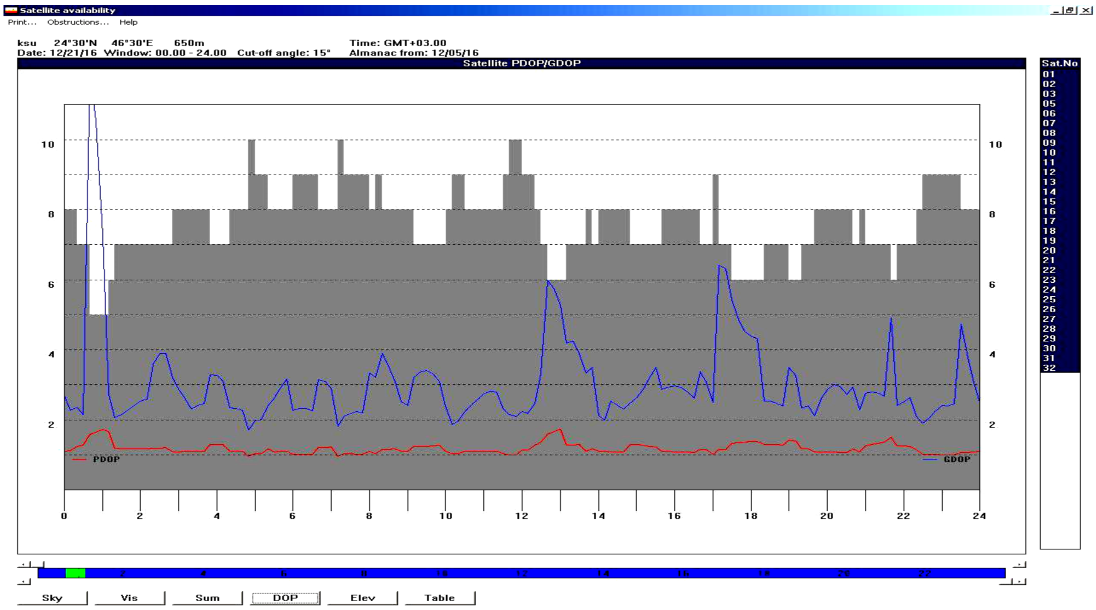


**Figure 6.** SA01 observation date plan.

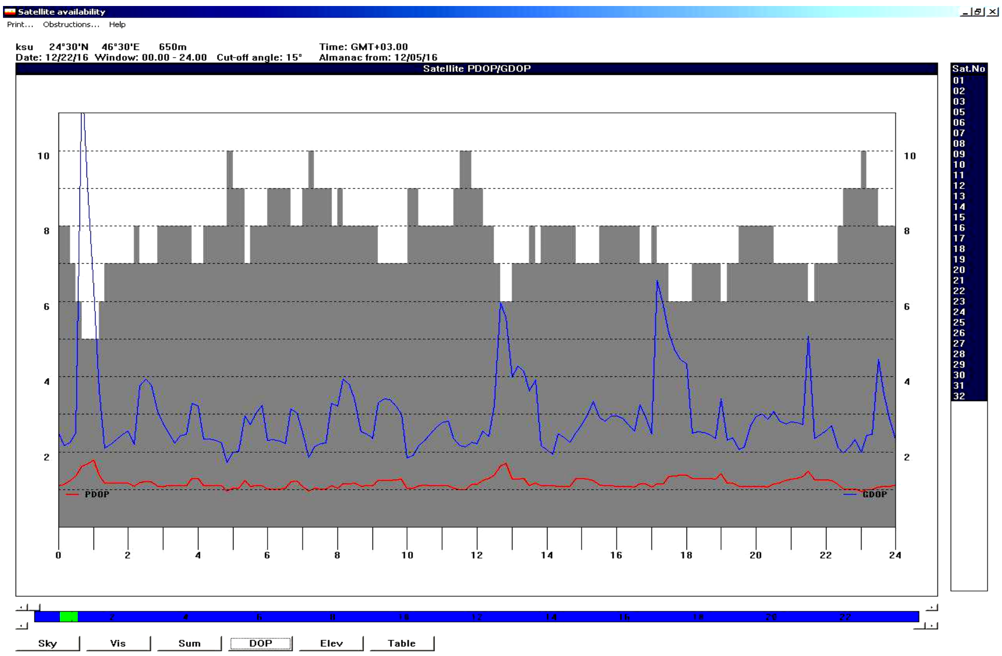


**Figure 7.** SA02 observation date plan.

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**Table 4.** GPS observations specifications.

| Point | GDOP | PDOP | Period | Interval | Number of visible satellites |
|---|---|---|---|---|---|
| SA01 | Max 3.3 | Max 1.8 | 3 hours | 8.35 – 11.48 | 10 |
| SA02 | Max 3.9 | Max 1.5 | 3 hours | 7.43 – 10.45 | 10 |

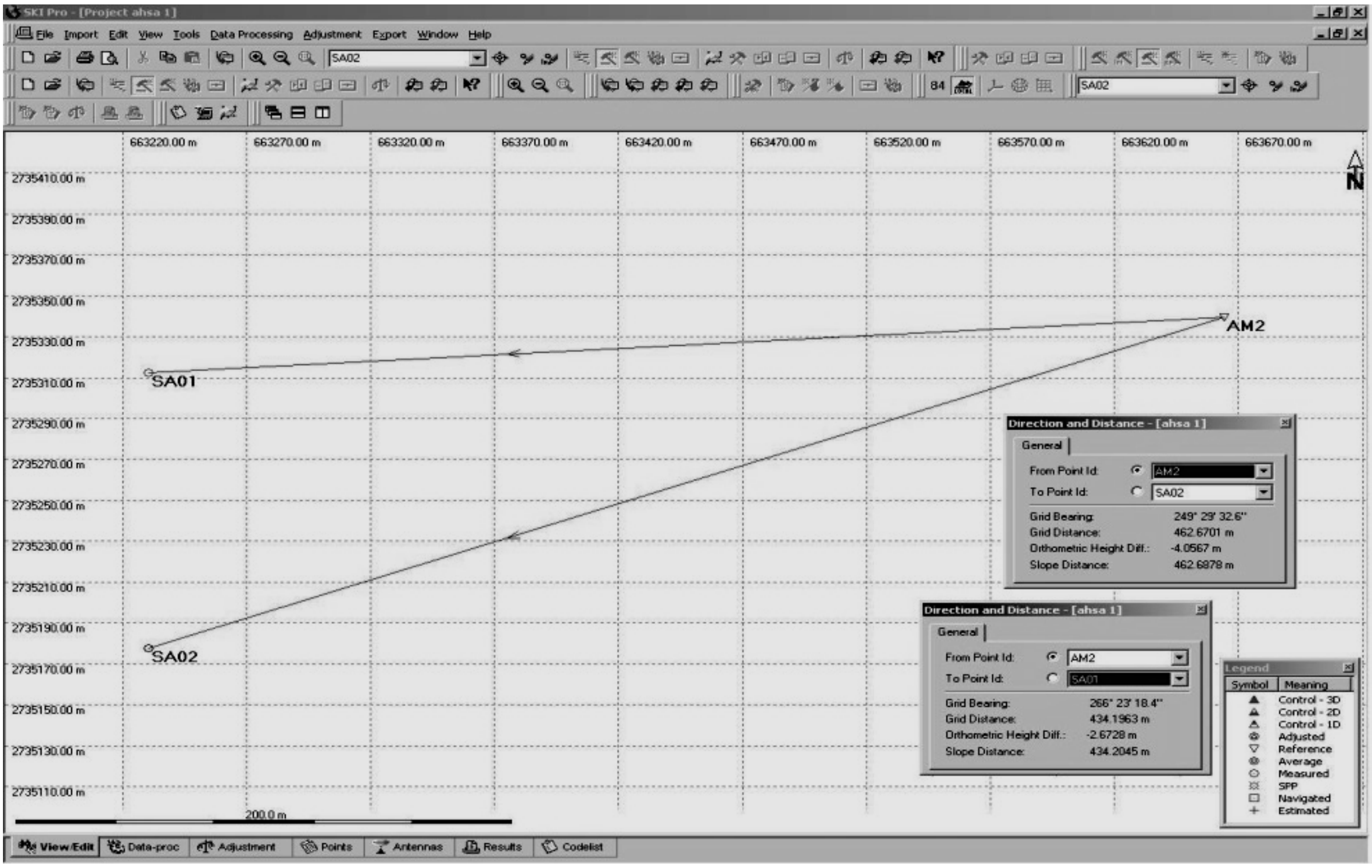


**Figure 8.** Direction and distance of SA01 and SA02 link to control AM2.

**Table 5.** Control points coordinates (m).

| Point | X coordinate | Y coordinate | Distance to AM2 |
|---|---|---|---|
| SA01 | 663230.7000 | 2735312.2901 | 434.1963 m |
| SA02 | 663230.6853 | 2735177.5530 | 462.6701 m |

## TEST RESULTS AND DISCUSSION

RTK-GPS test results: minimum, maximum and root mean square errors in X and Y directions, together with RMSE in horizontal position are given in **Table 6**.

**Table 6.** RTK-GPS minimum, maximum and RMSE in X and Y directions and RMSE in horizontal position (mm).

| Minimum | | Maximum | | RMSE | | |
|---|---|---|---|---|---|---|
| dX | dY | dX | dY | $\sigma_X$ | $\sigma_Y$ | $\sigma_P$ |
| 0.6 | 1.0 | 18.1 | 27.7 | 7.9 | 7.4 | 10.8 |

A first glance to **Table 6** shows that for the used instruments GPS planimetric accuracy (11 mm). The magnitude of errors for the coordinates determined by GPS range from 0.6 mm to 18.1 mm with RMSE of 7.9mm in X direction and from 1.0 mm to 27.7 mm with RMSE of 7.4 mm in Y direction. RMSE of horizontal position obtained was 10.8 mm.

Comparison with previous research results **Table 7** shows RMSE of horizontal poisoning obtained by RTK-GPS tests carried out by authors mentioned in the above literature review.

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**Table 7.** RTK-GPS horizontal positioning accuracy (mm) obtained by different authors.

| Reference | Current study | [5] | [8] | [9] | [6] | [7] | [12] |
|---|---|---|---|---|---|---|---|
| RMS Positional accuracy (mm) | 10.8 | 9.0 | 14.0 | 10.0 | 18.0 | 10.0 | 15.0 |

Results obtained in the current test (RMSE horizontal positioning 10.8 mm) compare well with those RMSE positioning accuracy obtained by other researchers that range from 9 mm to 18 mm. It also compares well with what has been claimed by manufacturer.

## CONCLUSION AND RECOMMENDATIONS

The horizontal positioning accuracy of RTK-GPS was tested using 10 reference control point network established for the test and found to be 10.8 mm. This result compares well with results already obtained by other researchers.

Applications which require high accuracy to serve as reference value (X, Y) coordinates, such as control point establishments, RTK- GPS can be fairly used.

RTK- GPS can be used for many tasks within different applications, for example, geodesy, engineering, architectural and mining surveys and documentation of cultural heritage with high accuracy level (up to 11 mm in horizontal positioning).

RTK GPS survey equipment can be an advantage for the builder or land owner. It makes the survey more accurate, decreases the risk of errors and problems, and gives a more professional and guaranteed sense to the survey in the long run.

It is stated in the specifications of accuracy and standards, 2015 in Caltrans Survey Manual (California Department of Transportation, 2015) that all horizontal project control surveys must have a minimum network accuracy of 2 cm. or better which is fulfilled by the RTK-GPS as verified in this study [16].

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