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RESEARCH ARTICLE

Grid to Ground Solutions in Construction Projects

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ABSTRACT

Nowadays, Global Navigation Satellite System (GNSS) techniques are considered the cornerstones in the field of surveying and civil engineering industry. At present, a plethora of companies is employing GNSS in their daily activities. The engineering construction projects are designed based on ground distances although rapid static works on grid coordinate system, where the distances between points vary from the ground. The established control points should be compatible with the design by converting distances to ground. This study investigates the effect of the scale factor (SF) to reduce the linear distortion when grid is converted to ground. For this purpose, eight different distances from 64.858 m to 887.974 m were taken with rapid static method. The results reveal that whereas the distances are increased, the difference between the grid and ground is proportional, and for the smallest distance, the difference was 54 mm and for the largest was 398 mm. Besides, the grid distances were converted to ground distances using the combined SFs that works as a divider; the average difference was decreased from 175 mm to 45 mm, and the maximum difference was decreased from 398 mm to 85 mm.

Keywords: Global navigation satellite system, total station, grid ground distance, scale factor, conversion

INTRODUCTION

Now in many construction projects, different instruments are used for surveying purposes such as Global Navigation Satellite System (GNSS) and Total Station (TS). GNSS is a multi-constellation satellites that can be utilized to determine the receiver's position on the earth by sending signals from space that contains navigational message to the GNSS receivers. One of the most useful methods in GNSS positioning, for a small distance and in millimeter accuracy, is the rapid static method. It is a relative positioning that uses the carrier phase to determine the coordinates of unknown point (Rover). On the other hand, the other receiver (Base) is occupied on a point with known coordinates which should be tracked the same satellites.[1-3] Details on Rapid static, operational considerations, data transmission, ambiguity resolution, and processing can be found in.[4] The occupation time is planned according to the length of the baseline, the numbers of satellites, the Geometric Dilution of Precision, and the type of the instruments reference[5] stated that the integer ambiguity can be fixed more reliable and faster when the occupation time is adequately long. The accuracy of this method is about 3–5 mm.[1] On the other hand, TS instruments can carry out all the functions that Transits and Theodolites are capable of doing, with more efficiency. In addition to that, they have the ability to observe distances quickly and accurately with the angle and can compute some mathematical calculations by a microprocessor that is fixed in the instrument and display the results in real-time.[2] According to references,[5,6] GNSS works on projected (Grid) coordinates, whereas the TS works on ground coordinates. When these two instruments are combined and used together in a project, linear distortion occurs. This distortion cannot be eliminated, but it can be minimized.[7,8] In this paper, eight different baselines will be taken in different lengths by both GNSS (rapid static method) and TS to present the effect of scale factor (SF) to minimize linear distortion when these types of instruments are combined.

GRID TO GROUND SOLUTIONS

There are three different surfaces of the earth for per project area, as illustrated in Figure 1, the Ground (TS distances), the Ellipsoid, and the Grid (GNSS distances) Plane. Ground distances are distances between objects on the topographic surface of the Earth. It can be measured with chains or calibrated wheels with odometers and are needed whenever an analysis depends on actual distances on the Earth's surface. This can be

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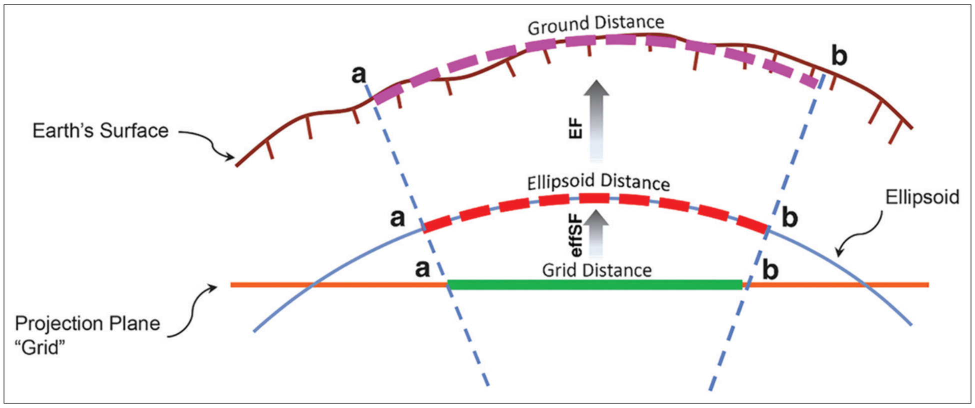

Figure 1: Different types of surfaces

the case for highway construction, hydrology, and meteorology, for example, mappers and surveyors seldom measure ground distances, because most maps are compiled with horizontal or reduced distances.[9] The distance measured by an Electronic Distance Measurement (EDM) is called an EDM distance. In general, they are not straight-line distances, because the light emitted by the instrument is refracted by the Earth's atmosphere. A Euclidean straight-line distance is called a spatial distance. One can attempt to remove the atmosphere's effect on EDM distances by measuring atmospheric temperature, humidity, and pressure.[1] The projected (grid) coordinates are derived from ellipsoidal coordinates in a particular geodetic datum and coordinate reference system after applying a projection like Universal Transverse Mercator projection (UTM).[10]

When points are moved from one surface to another, as shown in Figure 1, the distance between those points varies, resulting in a change in scale owing to the distortion. When intending to depict a curved surface on a plane, it is impossible to do so without introducing some degree of distortion. It indicates that there is a shift in the "real" relationship that exists between points that are situated on the surface of the earth and the representation of that relationship on a plane. Because distortion cannot be completely removed, the most that can be done is to minimize its impact. One of the types of distortions is known as linear distortion which is the difference in distance between a set of projected (map grid) coordinates and the actual horizontal distance between those points (ground), represented by "δ". To transform points from the grid to the ground, first an ellipsoid transformation must be performed, and then, a ground transformation must follow. Each step has its own scale shift.

Scale Factor

The Scale Factor (SF) is the value which specifies the distanced points, such as between a and b on the grid plane (grid distance (Dgrid)) and those matching two locations on the ellipsoid (ellipsoid or geodetic distance (Dellip)). The cause of a scale difference is due to the transformation that occurs from a flat (Grid Plane) to a curved surface (Ellipsoid). Equation (1) calculates the SF at each point:

$$\mathrm{SF} = K_{\circ} + \frac{E_{\circ}^{2}}{2R^{2}} \tag{1}$$

Where:
K: Central meridian's SF
R: Earth's radius
E: Difference between false easting at the central meridian and easting of the point

First, by calculating the grid distance between the two points and then multiplying that result by the effective SF (effSF), it is possible to get the approximate ellipsoidal distance between the two points (a and b). This will yield the value of the approximate ellipsoidal distance. The effective SF (effSF) can be calculated using (2), which is as follows:

$$\mathrm{effSF} = \frac{SF_{a} + 4SF_{ab} + SF_{b}}{6} \tag{2}$$

Where:
SF_a: Stands for SF point a
SF_b: Stands for SF point b
SF_{ab}: Stands for SF point between SF_a and SF_b.

Using Equation (3) the grid distance (Dgrid) can be altered to an ellipsoidal distance (Dellip).

$$\mathrm{Dellip} = \frac{\mathrm{Dgrid}}{\mathrm{effSF}} \tag{3}$$

The scale value that defines the distance between two points on the ellipsoid (geodetic distance, or Dellip) and those same two points on the earth (ground distance, or Dground) is known as the elevation factor (EF). Equation (4) can be used to obtain the EF:

$$\mathrm{EF} = \frac{R}{R+H} \tag{4}$$

Where:
H: Mean ellipsoidal height between a and b

By applying the EF in (5), the ground distance (Dground) can be calculated from the geodetic distance (Dellip)

$$\mathrm{Dground} = \frac{\mathrm{Dellip}}{\mathrm{EF}} \tag{5}$$

The most frequent transformation is that between points on the grid plane and points on the ground. The combination factor (CF) is the scale value that will permit a direct transformation from grid to ground. Equation (6) illustrates how to compute the combination factor by multiplying the SF by the EF:

$$\mathrm{CF} = \mathrm{effSF} \times \mathrm{EF} \quad (6)$$

Using the combination factor, one can determine the ground distance (Dground) from the grid distance (Dgrid), using (7):

$$\mathrm{Dground} = \frac{\mathrm{Dgrid}}{\mathrm{CF}} \quad (7)$$

DATA AND FIELD OBSERVATIONS

Eight points were marked on a satellite image in Iraq-Erbil at latitude 43.993° E and longitude 36.1901°N with different distances. Reconnaissance was done for points to check the intervisibility of points, as shown in Figure 2.

The procedure commenced by measuring coordinates of the eight points using GNSS receiver (Leica GS16) by the rapid static method, because the baselines between base and the rover (at points) were small. Subsequently, the points were measured using TS by the traverse method. Points were randomly distributed to investigate the different distances between GNSS and TS instrument [Figure 3]. Coordinates were measured by rapid static method, starting from point (T1) to (T8) and the occupation time for each point was equal to 15 min. The collected data were processed by Leica infinity software (version 3.0.1) to get the coordinates of the points. On the other hand, the TS (Topcon 255) was used to observe the points by traverse method which started and terminated on T1 which was a common point.

Figure 2: Study area

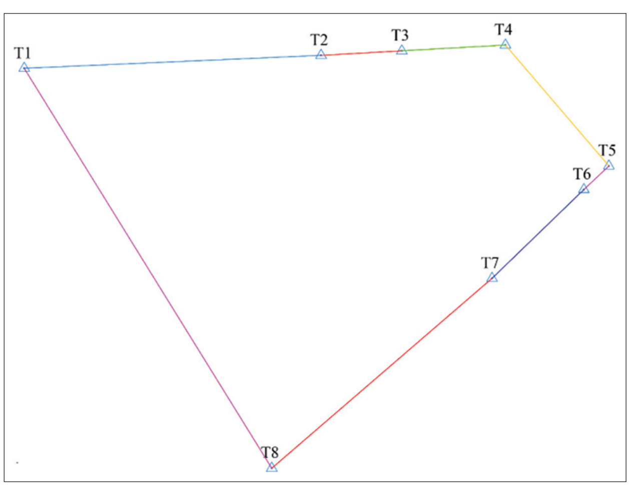

Figure 3: Different distances

RESULTS AND DISCUSSION

The collected raw data by rapid static method were post processed with the selected parameters which were: Cut-off angle was 15°, Ephemeris type was Precise, GNSS types were GPS, GLONASS, GALILLEO, minimum duration for float solution [static] was 5' and sampling rate was 1 s. As illustrated by Table 1, the grid distances (GNSSs) are the smallest, whereas the TS distances are the biggest. In each

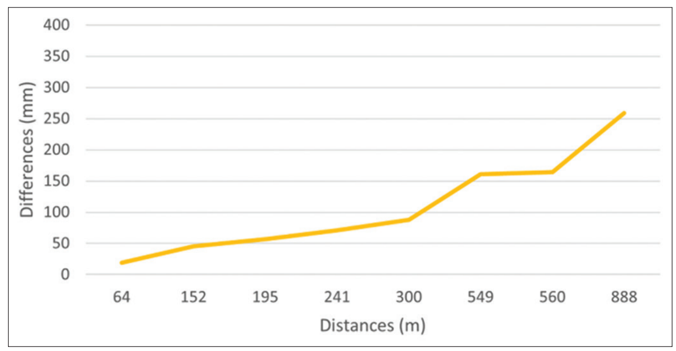

Figure 4: The differences from grid to ellipsoid

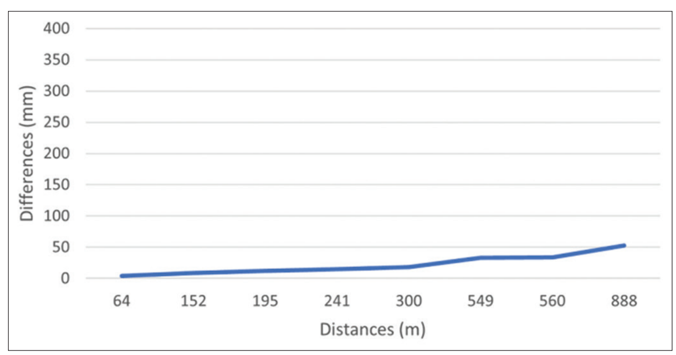

Figure 5: The differences from ellipsoid and ground

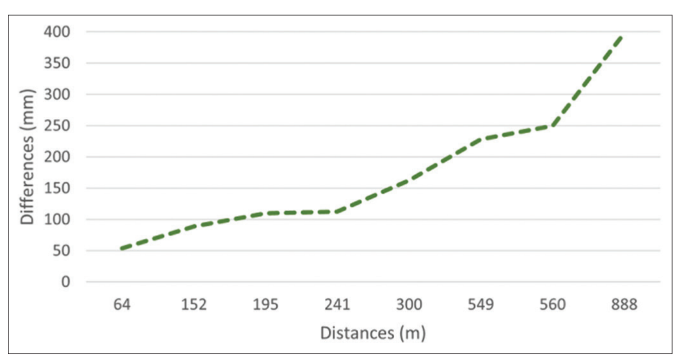

Figure 6: The differences between grid and by total station

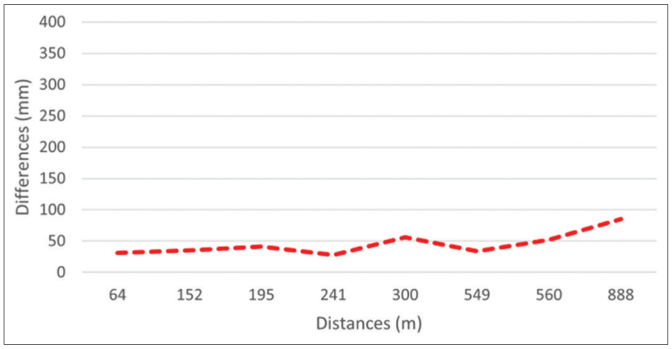

Figure 7: The differences between ground and by total station

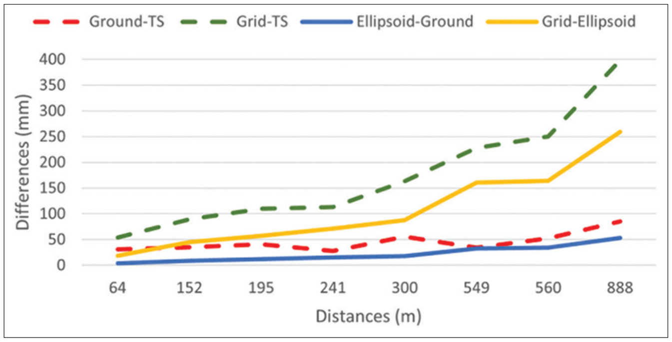

Figure 8: All differences

Table 1: Distances (m)

From–To	Grid	Ellipsoid	Ground	TS
T1–T2	560.730	560.893	560.927	560.979
T2–T3	152.641	152.686	152.695	152.730
T3–T4	195.873	195.930	195.942	195.983
T4–T5	300.378	300.466	300.484	300.541
T5–T6	64.858	64.877	64.881	64.912
T6–T7	241.178	241.249	241.263	241.291
T7–T8	548.874	549.035	549.068	549.102
T8–T1	887.974	888.233	888.287	888.372

Table 2: Differences (m)

From-To	Grid-Ellipsoid	Ellipsoid-Ground	Grid-TS	Ground-TS
T1–T2	0.164	0.034	0.250	0.052
T2–T3	0.045	0.009	0.089	0.035
T3–T4	0.057	0.012	0.110	0.041
T4–T5	0.088	0.018	0.163	0.056
T5–T6	0.019	0.004	0.054	0.031
T6–T7	0.071	0.015	0.113	0.028
T7–T8	0.161	0.033	0.228	0.034
T8–T1	0.259	0.053	0.398	0.085

surface, the distances are increased by a rate close to the TS distances.

From Figures 4-8 and Table 2, it seems obvious that the difference between grid and TS increased proportionally. Due to the impact of the effective SF (effSF), the grid distances were increased considerably by approximately 79% and the maximum difference was 25.9 cm, minimum difference was 4.5 cm, and the average was 10.8 cm. The distances were converted to ground by the EF, and they were slightly increased. The maximum difference was 5.3 cm, minimum difference was 0.9 cm, and the average was 2.2 cm. After applying the combined SF to get the ground distances close to the TS distances, the maximum difference was 8.5 cm and the minimum was 2.8 cm.

CONCLUSION

To sum up, various instruments, such as the GNSS and the TS, are utilized in modern construction projects for surveying. An avoidable linear distortion occurs when both of them are used in a project. This is due to the fact that GNSS works on grid and TS works on ground coordinate system. In this study, to investigate the impact of the SF to reduce linear distortion, GNSS (rapid static method) and TS have been used to determine the accuracy of the factor. Eight different distances were taken, the differences between GNSS and TS distances were increased proportionally. Due to the influence of the effective SF, the grid distances have been significantly increased by about 79%; the maximum difference was 25.9 cm, the minimum difference was 4.5 cm, and the average difference was 10.8 cm. The EF was used to convert the distances to ground; consequently, they have been slightly increased. The greatest difference was 5.3 cm, whereas the smallest difference was 0.9 cm, and the average difference was 2.2 cm. By applying the combined SFs that worked as a divider the grid distances were converted to ground distances, the average difference was reduced from 17.5 cm to 4.5 cm whereas the maximum difference from 39.8 cm to 8.5 cm. It is an indisputable fact that sources of error like the instrumental, personal, and environmental affect the observations. Moreover, if more accurate TS was used with high precision the result might be more accurate.

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