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Enhancing and Applying the Accuracy of RTK-GNSS Elevations in Earthworks Estimation

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Abstract

Real-Time Kinematic (RTK) as a data acquisition and measurement technique is becoming attractive for many surveying applications in civil engineering. However, RTK's resulting accuracy is still less than the accuracy needed in some engineering works, especially those that rely on measuring the elevations. For this purpose, this paper focuses on enhancing the accuracy of RTK elevations data and assessing the use of the improved elevations in estimating earthworks. Simple Linear Regression (SLR) and Linear Relation (LR) are two models that were developed and used to enhance the accuracy of RTK elevations data. For SLR model, the minimum squares concept was applied in the improvement process. While in LR model, the average of differences between Level and RTK elevations data was used to generate the improved elevations. The Performance evaluation of the studied models was based on a compilation of various statistical parameters and goodness-of-fit measures, the output results of the used models were then compared. The study indicates significant improvements in the RTK elevations data when using the both models.

In general, LR model produced better results in elevations than SLR model. The mean value of differences, absolute mean value of differences and RMSE were improved by about 70 percent, 63 percent and 54 percent respectively when using the SLR model to improve the remaining RTK results. While they were improved by about 73 percent, 70 percent, and 61 percent respectively when using LR model. Test results as they relate to excavation and earthmoving construction sites were discussed and presented. Moreover, the experiences with the enhanced RTK elevations data are useful to researchers or practitioners who need to adapt RTK technology effectively to their applications.

Keywords: RTK-GNSS, Earthwork volume, Simple Linear Regression, and Linear Relation

INTRODUCTION

Earthworks are engineering works that are created by transporting or treating parts of the Earth's surface that include amounts of soil or rocks. The volume of earthworks is important in many types of engineering projects such as calculating the cutting and filling of landfills and clearing land for road engineering, drainage, and construction (Pratomo, et al., 2019). As it well known, the excavation and transportation of materials on such an outline are the most important and costly features of the works, on which gain or loss may rely (Schofield, 2001). Earthworks are represented as the highest cost scheme, and the movement of huge volumes of earthwork is one of the important construction processes (Deakin, 2005). In such these projects, data can be collected using different surveying techniques, for example, level, total station, GNSS, and laser scanning (Zaia, et al., 2017).

Global Navigation Satellite Systems have a significant role in geodesy, cadastral surveying, land surveying, earth science, etc. GNSS positioning can be performed using Single Point Positioning (SPP) without correction process, Differential GPS (DGPS) and Real-time kinematic (RTK) with accuracy enhancement using data from a reference station (El -Rabbany, 2006; Ragheb & Ragab, 2012). As stated in previous studies, RTK-GNSS is a differential positioning technique that can measure the coordinates of unknown points visited by a rover receiver using known coordinates of a reference station occupied by a base receiver (El-

Mowafy, 2000). Simultaneously both receivers make observations of the GNSS signals and a radio data link between the two receivers allow data to be sent from base to rover, where the calculation of coordinates is executed.

There are a lot of applications that use GPS-RTK technology (Morales and Tsubouchi, 2007). As reported, RTK-GNSS techniques reduce the cost up to 50% (El-Mowafy et al., 2006; Sumpter, 1994). According to time expenditure, it was proved that the RTK saved time more than Total Station (Chekole, 2014). On the contrary, conventional surveying methods can be time-consuming and unsafe for workers (Siebert and Teizer, 2014). Another advantage of RTK-GPS that it reduces the mapping process by 30% in normal conditions (Mensah, F. and Duncan, 2006). Additionally, the RTK-GNSS survey presents efficiency since fewer surveyors are required to conduct the survey as it can be completed by only one surveyor (Dedi Atunggal, S.P., Cahyono, B.K. and Matori, 2007). For this reason, RTK is regarded as the best compromise between ease of use and accuracy.

Previous works have studied the accuracy of RTK especially in determining the height of points. Borgelt mentioned that when comparing RTK-GPS system to geometric levelling the error of elevation was limited to 12 cm (Borgelt et al., 1996). Featherstone and Stewart (2001) reported that GPS positioning is weaker in measuring elevation because of the situation of the satellites in the sky (Featherstone and Stewart, 2001). Another study by Aponte assured that the accuracy of RTK is about centimetres (Aponte et al., 2009). As reported by Saghravani, comparing with automatic level, the vertical accuracy of RTK-GNSS in the surveying less than 10 cm with 95% confidence (Saghravani, S. R., Mustapha, S., & Saghravani, 2009). Clark and Lee reported height errors of 4 to 9 cm in their studies with RTK-GNSS to assess the topography (Kizil and Tisor, 2011). RTK-GPS provide real-time corrections and providing accuracy up to centimetre-level (Xu, 2012). GNSS receivers today can continuously provide levels of centimetres of accuracy using technologies such as RTK, DGPS, augmented systems, etc (Manzino, A.M., Dabove, P. and Gogoi, N., 2018).

As stated by the literature, horizontal coordinates of points when using RTK-GNSS are trustable while the elevations accuracy acquired by RTK-GNSS is doubtful. Therefore, the main objective of this study is to improve the elevations accuracy of RTK data which used in the production of earthworks based on the creation and development of two models from Level and RTK data relationship of a part of the land.

2. MATERIALS AND METHODS

2.1 Study area and data sources

The study area was performed in the city of Madinaty, Cairo, Egypt; with an area of about 150 m by 100 m. The observations were carried out on 2 February 2020. The area was divided into 165 points with a distance of approximately 10 m between each two consecutive points, figure 1 illustrates the study area plan. The duration of the RTK-GNSS measurements took about 2 hours. The easting and northing coordinates for 165 points were measured by a sokkia total station. While, the elevation of these 165 points were determined using data of two equipment as follows:

- A Sokkia C330 Automatic Level was used to measure the elevation of points.
- A Sokkia Grx2 GNSS receiver was used to collect GNSS data.
- A Sokkia CX-105 Total Station was used to measure the easting and northing coordinates of points.

Fig. 1: Location of the study area

2.2 Work scheme and Research methodology

Research methodology for improving the accuracy of RTK data by using two SLR and LR models includes data acquisition task, determining the correlation between RTK and Level for a part of the land, and improvement of the remaining RTK data. These steps are further elaborated in the following sub-sections. The work procedures are outlined in figure 2.

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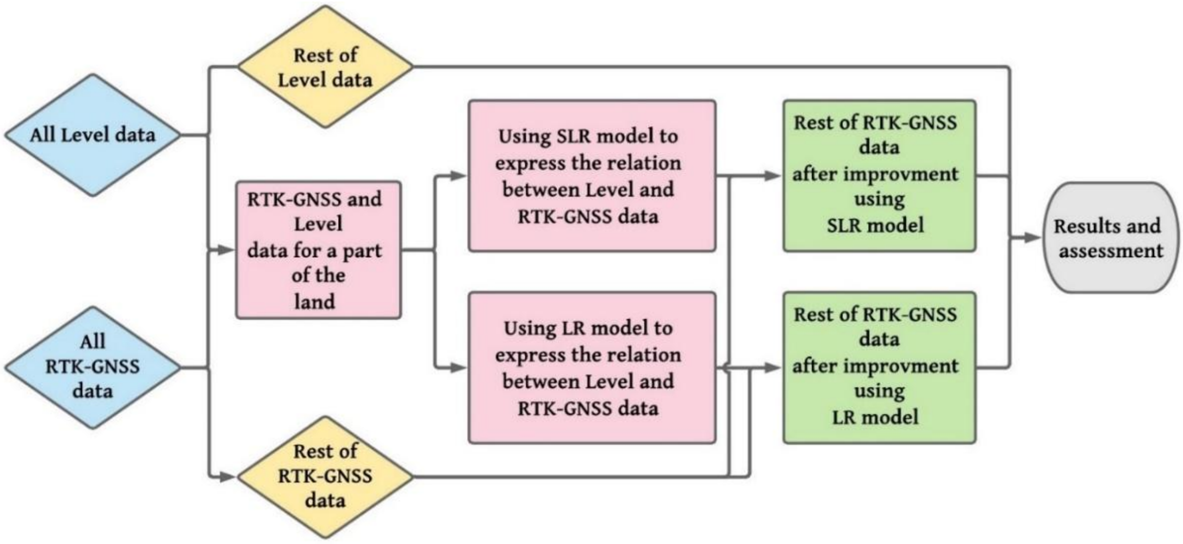

Fig. 2: Work Scheme

2.3 Models used to improve RTK elevations data

SLR and LR are two models that were used to improve RTK-GNSS elevations data. In the SLR model, the improved elevations were created be using simple linear regression. While in the LR model, the average value of differences between elevations from leveling and RTK data for part of the studied area was used in the improvement process.

2.3.1 Simple Linear Regression (SLR) modelling

The minimum squares approach has in the SLR model to find the fixed regression parameters a & b, that were determined from the equations no. 1 & 2 [14].

Where:

$$a = \frac{\Sigma H_{R1} * H_{L1} - n * \bar{H}_{R1} * \bar{H}_{L1}}{\Sigma H^2{}_{R1} - n * \bar{H}_{R1}} \qquad (1)$$

$$b = \bar{H}_{L1} - a * \bar{H}_{R1} \qquad (2)$$

Where: H_{R1} - elevations of RTK data of part of land.
H_{L1} - elevations of Level data for the same part of land.

After that, using equation no. 3, the parameters a & b used to generate the improved elevations of the remaining RTK data.

$$H_I = a * H_{R2} + b \qquad (3)$$

Where: H_I - predicted (improved) elevation for the remaining land.
H_{R2} - elevations of RTK data for the remaining land.

2.3.2 Linear Relation (LR) modelling

LR model consists of two stages, in the first stage the equation no. 4 was used to find the average of the differences between the elevations of points from Level and RTK data for a portion of the studied area.

$$Average = \frac{\Sigma V}{n} \qquad (4)$$

Where,

$$V = H_{R1} - H_{L1} \qquad (5)$$

In the second stage, the improved elevations were generated by using equation no. 6.

$$H_I = H_{R2} - Average \qquad (6)$$

2.3.3 Strategies of selecting the points needed to create the models

The 165-point elevations were calculated using Level and RTK data, see figure 2. These points were divided into two groups; the first group was used to build and develop the model expressing the relation between the Level and the RTK data. While the second group was used to generate the improved elevations and then evaluate the results. Four different cases in order to select a group of points that used to find the relation between the Level and RTK data:

1. Case 1, first 5 points (approximately 3% of all data).
2. Case 2, first 10 points (approximately 6% of all data).
3. Case 3, first 15 points (approximately 9% of all data).
4. Case 4, first 20 points (approximately 12% of all data).

3. RESULTS AND DISCUSSION

At first, the elevations of Level and RTK data were determined for the entire studied area and the differences between them were extracted. Secondly, SLR and LR models expressed the relationship between the Level and RTK data for a part of the area. After that, the two models were used to generate the improved elevations of the remaining RTK data. Finally, to assess the results, the improved elevations of RTK data by the studied models were compared with the corresponding elevations data obtained from Level.

3.1 RTK data accuracy of the entire study area

The RTK-GNSS was conducted by one surveyor and successfully obtained 165 points in around 2 hours. While in about 3 hours by two surveyors, 165 points were collected using the classical survey (Level). After that, the mean value and RMSE of the differences between these two techniques were determined, and their values were 0.050m and ± 0.052m, respectively. According to the results get by Zaia, the mean value and RMSE of differences between the elevations of points from RTK and precise Digital Level were - 0.020m ± 0.063m respectively (Zaia, et al., 2017). By comparing the results with these results, they are close to each other.

3.2 Improving the accuracy of RTK elevations data using SLR model

For the four cases, the parameters a & b, in equations no. 1 & 2, were calculated from points elevations of Level and RTK data for a part of the area, by the minimum squares' method. Figures 3 illustrates the values of parameters a & b in the four cases.

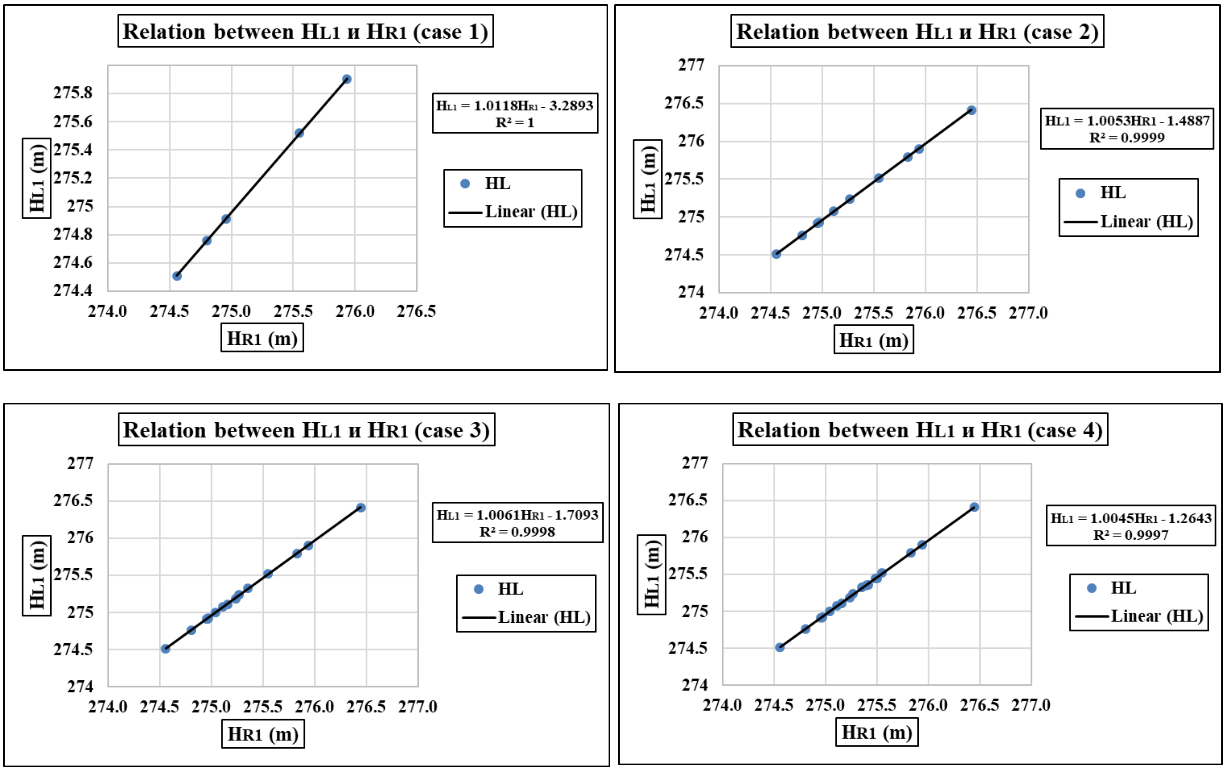

Fig. 3: Relation between elevations of Level data (H_{L1}) and RTK data (H_{R1}) of the part of study area in the four cases

After that, the values of parameters a & b were used in the four cases, using equation no. 3, to generate the improved elevations of remaining RTK data. To evaluate the accuracy of the results, descriptive statistics of differences between elevations from Level data and improved elevations from RTK data were calculated and the results summarized in Figure 4.

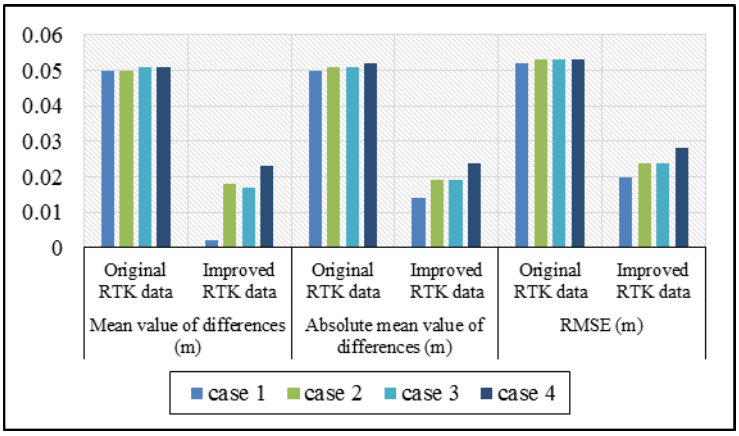

Fig. 4: Descriptive statistics of differences between original/improved (SLR model) elevations obtained by remaining RTK data and corresponding elevations data by Level

The results of Figure 4 showed that, when using SLR model to find the relation, the mean value, the absolute mean value and RMSE of differences were improved in the four cases. In addition, there is no significant difference between the results of the four cases. It was noted that, in case 1; although only five points were used to create the model, the improvement in accuracy was about 61%.

3.3 Improving the accuracy of RTK elevations data using LR model

The average values of the differences between the elevations of points from Level and RTK data for part of studied area was calculated using equation 4 for the four cases. See Table 1.

Table 1: Average values (m) in the four cases

	Case 1	Case 2	Case 3	Case 4
Average values (m)	0.038	0.036	0.036	0.038

After that, the calculated mean values from the four cases were used to generate the improved elevations of remaining RTK data by using equation no. 6. The improved elevations data by RTK were compared with the corresponding elevations data obtained from Level. To evaluate the accuracy of the results, descriptive statistics of differences between elevations data by Level and improved elevations obtained from remaining RTK using LR model, were determined and the results were summarized in figure 5.

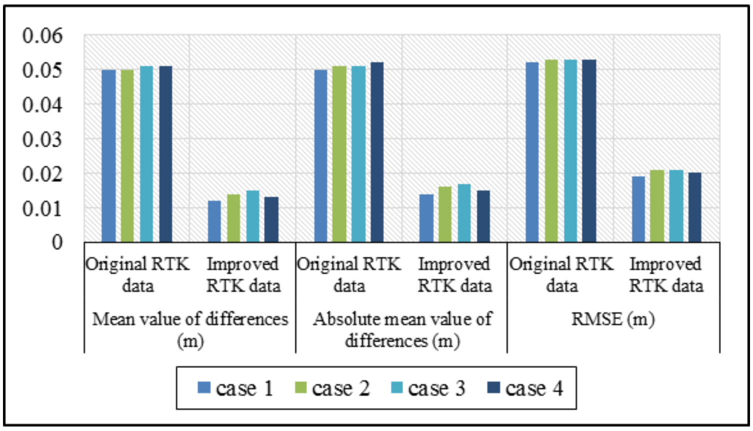

Fig. 5: Descriptive statistics of differences between original/improved (LR model) elevations obtained by remaining RTK data and corresponding elevations data by Level.

The figure results showed that, when using LR model to generate the new elevations from the remaining RTK data; the mean value of differences, the absolute mean value of differences and RMSE were improved in the four cases. In addition, no major differences were noted between the improvements in the four cases. It was noted that, in case 1; although the data used to create the LR model was only about 3%, the result of improving the accuracy of RTK elevations data was about 63%.

3.4 Comparison between SLR and LR models

To compare between the two models, the improvement percentage in the accuracy of RTK elevations data obtained from the two models were computed using equation no. 7 (Awad, 2005), the results were summarized in Table 2.

$$Improvement\ percentage = \left|\frac{O-I}{O}\right|\% \qquad (7)$$

Where: I - Statistics (mean value of differences, absolute mean value of differences and RMSE) of improved elevations extracted by SLR and LR models.
O - Statistics (mean value of differences, absolute mean value of differences and RMSE) of original RTK elevations data.

Table 2: Summary of improvement percentage of the remaining RTK data using SLR and LR models

	Improvement of mean value of differences (%)		**Improvement of absolute mean value of difference (%)**		**Improvement of RMSE (%)**	
	SLR model	**LR model**	**SLR model**	**LR model**	**SLR model**	**LR model**
case; 1	95	76	72	72	61	63
case; 2	65	71	62	68	54	60
case; 3	66	71	63	68	54	60
case; 4	55	74	53	71	47	62

As shown in Table 2, generally, LR model gave results better than SLR model. when using SLR model to improve the remaining RTK data, the mean value of differences, the absolute mean value of differences and RMSE were improved by about 70%, 63%, and 54% respectively. While When using LR model to improve the remaining RTK data, the mean value of differences, the absolute mean value of differences and RMSE were improved by about 73%, 70%, and 61% respectively. In case 1, although only 5 points were used to create the models, the best results were achieved. This is because of the fact that when the points used to create the model represent all study area points, the better the results.

3.5 Applications of SLR and LR models for earthworks enhancement

There are many important applications for the use of elevations in various engineering works. The improved elevations obtained from the first case (5 points) based on the SLR and LR models were used in this part. Initially, the contour lines were drawn for the RTK elevations before and after the improvement, and compared with the decree from the level elevations using "Surfer version 10" program, see figures 6 and 7. After that, to compute the earthwork volumes, the quantities of cutting of the studied area were calculated for Level, RTK, improved RTK by SLR and improved RTK by LR models. Where, the assumed comparison datum of computed quantities was selected to be 273 meters (less than the lowest level in the acquisition data). In addition, the percentage of improvement in cutting volume from SLR and LR models by equations 8 and 9 respectively. Table 3 illustrates the quantities of cutting and the improvement percentage using Civil 3D version 2015 program.

$$Improvement\ percentage\ from\ SLR\ model\ = \left|\frac{(V_R - V_L) - (V_{SLR} - V_L)}{V_R - V_L}\right| \% \qquad (8)$$

$$Improvement\ percentage\ from\ LR\ model\ = \left|\frac{(V_R - V_L) - (V_{LR} - V_L)}{V_R - V_L}\right| \% \qquad (9)$$

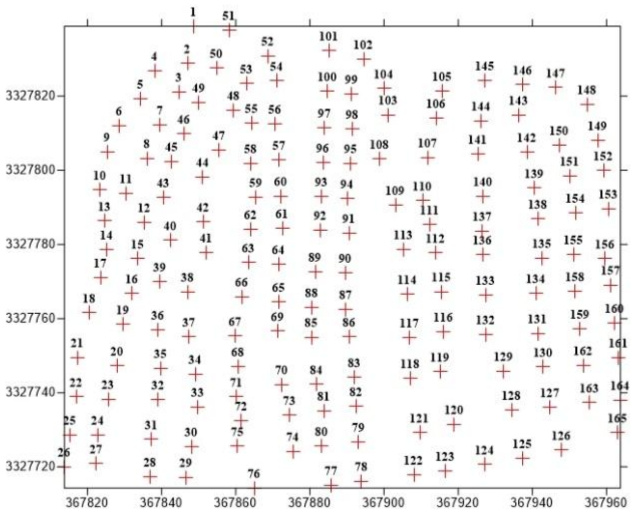

Fig. 6: Post map illustrates the positions and numbers of points.

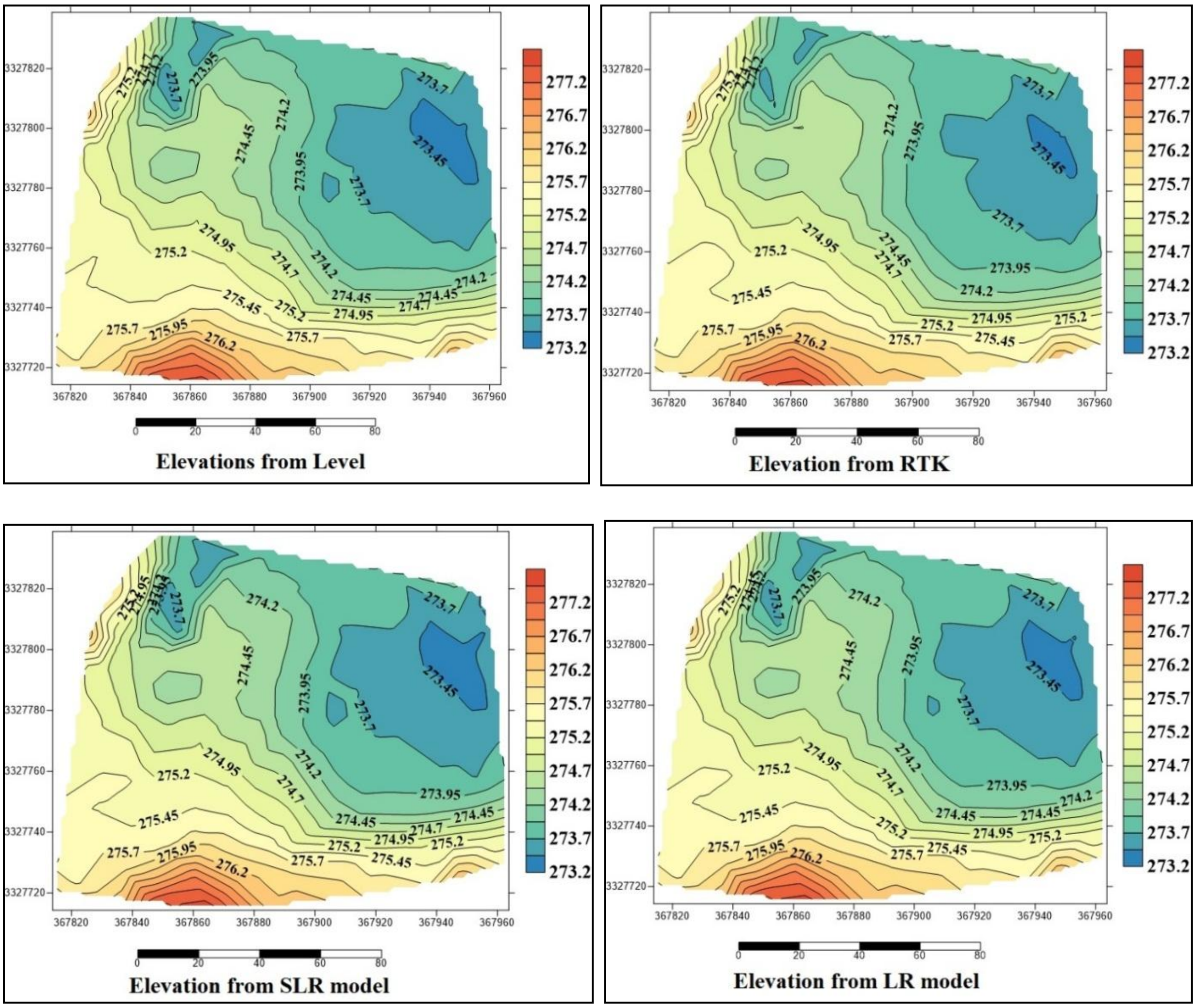

Fig. 7: Contour lines from Level, RTK, and improved RTK data.

Table 3: Summary of quantities of cutting and the improvement percentage based on SLR and LR models

Data acquisition instruments	The used improvement method	Cutting Volume (m^3)	Difference regarding to Level computations (m^3)	Improvement %
Level	-	24984.78	-	-
RTK-GNSS	-	25763.65	778.87	-
	SLR model	25036.77	51.99	93
	LR model	25190.2	205.42	74

Figure 7 showed that, there is an enhancement in the contour lines obtained from the improved elevations based on SLR and LR models compared with the contour lines obtained from the original RTK data. Table 3 also illustrated that, the calculated volume of cutting based on the elevations extracted by the original RTK data is greater than the volume of cutting extracted by the improved elevations based on SLR and LR models by 726.88 and 573.45 m^3 respectively.

4. CONCLUSION

RTK-GNSS is an efficient and effective technology for providing point positioning data in various surveying applications due to its ease of use. The goal of this study is to enhance the RTK-GNSS elevations data as one of the essential means of determining the quantities of earthworks. The concept of this enhancement is to create and evaluate two models using Level and RTK-GNSS data from some selected points to improve the remaining RTK-GNSS data. SLR and LR are two studied models that were used to improve the elevations of RTK data. The results of this study showed that the accuracy of RTK-GNSS elevations was improved by 54% for the SLR model and 61% for the LR model. This improvement was reflected in the output results of the calculated earthworks, as the calculated volume was improved by 93% for the SLR model and 74% for the LR model compared with the calculated volume from original RTK elevations. Overall, the LR model has delivered better results than the SLR model, besides the ease of creating and applying. This article also has revealed that it is not necessary to use the data of many points to construct the models, but only using fewer points of about 3% of the measured data is appropriate, bearing in mind that the selected points should represent remaining points. It is worth noting that the RTK-GNSS data used in this study was collected in a short (several hours) time. Further researches are required to provide a better evaluation by using different times, environments, and conditions.

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