Evaluation of RTK-GPS and Total Station for applications in land surveying

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Accuracies of Real-Time Kinematic Global Positioning (RTK-GPS) system and Total Station (TS) were investigated in GIS environment. In geostatistical evaluations, Kriging method was used with spherical, exponential, and Gaussian models. The survey results demonstrated that an area of 3.5 ha or smaller can be best explained with Gaussian model, while the larger areas require a spherical model. A vertical error of 60 cm and a horizontal error of 30 cm can be observed when the survey points outside the construction area are eliminated. The optimum area per survey point was calculated to be 20×20 m² to increase the accuracy. This case study showed that an inaccurate survey can result cost over estimations up to 27%.

1. Introduction

Many agricultural engineering practices require a substantial investment. Therefore, an accurate cost estimate is vital for design and construction of the projects. An inaccurate survey results in a topographic map that does not represent the construction area. Topographic maps have also been used to delineate sub-field management zones (Fraisie *et al* 2001) and site-specific soil management (Franzen *et al* 1998).

The Real-Time Kinematic Global Positioning System (RTK-GPS) is an integral part of topographic surveys. RTK is a technique employed in practices where precision is a must. In RTK, corrected GPS signals are transmitted in real time from a base receiver at a known location to one or more rover receivers. With the recent developments in RTK-based GPS systems, a horizontal accuracy of 1 cm can be achieved by compensating for atmospheric delay, orbital errors and other variables in GPS geometry (Ehsani *et al* 2004).

Satalich and Ricketson (1998) reported that time-dependent systematic errors may affect the vertical accuracy of RTK-GPS systems. Clark and Lee (1998) determined the topography of field size areas using RTK-GPS equipment with elevation errors of 4–9 cm. Wilson *et al* (1998) reported that even small differences in RTK-GPS derived elevation at individual points can result big differences in such parameters as slope gradient and catchment area.

Although successful application of RTK-GPS systems can increase the quality of a topographic survey, there are cases where the accuracy of these systems is questionable. Any blockage from natural or man-made obstacles such as trees and buildings can make use of RTK system limited or impossible. In such cases, Total Stations (TSs) are used. Borgelt *et al* (1996) compared the accuracy of RTK-GPS systems to TS. They reported elevation errors of 12 cm. Precise measurements can be made using TS. However, field conditions do not always allow the instrument's accuracy.

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Therefore, the systems are being used together in land surveys.

Geostatistical methods such as Kriging are used to evaluate the compliance of the topographic maps with second independent survey in terms of time and cost. Even though Kriging does not provide as definitive an answer as a second survey, it is an effective and inexpensive technique (Barton *et al* 1999).

To account for the accuracy of topographic survey data, Kriging, a geostatistical technique, is used to create prediction maps and spatial statistics. Kriging is a different way of thinking about the prediction than is done with deterministic interpolators. In Kriging, a predicted value depends on two factors: a trend and an additional element of variability. For example, there is an upward trend in elevation from a lower elevation to the top of a hill. However, there are likely to be variations because of valleys, streams, knobs and other features (ESRI 2006). May be to account for these variations, Kriging assigns weights to all or a subset of nearby points called ‘nearest neighbours’ (Davis and Culhane 1984). In order to find the weights, information on spatial dependence among the survey points should be known (Dowd 1984). A semi-variogram can be used to express this spatial dependence (Bras and Rodriguez-Iturbe 1985).

The semi-variogram can be expressed as (Barton *et al* 1999):

$$\gamma(d_{ij}) = \frac{1}{2} \text{var}[(z_i - z_j)], \quad (1)$$

where $\gamma(d_{ij})$ is the semi-variogram for the points P_i and P_j with the elevations z_i and z_j , with a lag distance of d . Based on ‘intrinsic hypothesis’ (Delhomme 1983), equation (1) can be written as:

$$\gamma(d_{ij}) = \frac{1}{2N} \sum_1^N [(z_i - z_j)^2], \quad (2)$$

where N is the number of pairs of survey points. As per equation (2), semi-variogram is half the expected value of the squared difference in elevation between two points with lag distance of d . The maximum value of the semi-variogram, called the sill S , is attained at a distance called the range R . The range indicates the average separation needed for the observations z_i and z_j to be considered uncorrelated (Barton *et al* 1999). The best semi-variogram model can be selected observing the root-mean-square values with a trial and error approach for different lag sizes and numbers (ESRI 2006). Sarangi *et al* (2005) and Johnston *et al* (1996) reported that lag size $\times$ the number of lags should be less than one-half of the longest distance in the database. After the lag size and

Figure 1. A typical semi-variogram and its parameters.

Figure 2. Representation of datasets.

number of lags are determined, other semi-variogram model parameters, sill, nugget, range and fitted model type can be optimized observing the smallest root mean square error (RMSE). A typical semi-variogram and its parameters are shown in figure 1.

Common choices for a semi-variogram model include spherical, exponential, and Gaussian (Christakos 1984). Once the optimum parameters for these semi-variogram models are determined, a technique called cross-validation can be used to select preferred semi-variogram (Davis 1987; Barton *et al* 1999).

The focus of this paper is on evaluating the dynamic accuracy of RTK-GPS and TS system in surveying land for agricultural engineering design practices. This goal was achieved through following specific objectives:

- Evaluating the accuracy of data obtained through surveys where RTK-GPS and TS systems were used.

Figure 3. Surface fitting methodology.

Table 1. Cross-validation error statistics.

Survey method	Semi-variogram model	No. of readings	M	RMSE	ASE	MSE	RMSSE
RTK-GPS	Spherical	749	0.00169	0.4144	1.526	0.00043	0.2765
	Exponential	749	0.00204	0.4185	1.781	0.00062	0.2386
	Gaussian	749	0.02854	0.6584	2.045	0.01362	0.3207
RTK-GPS (partial)	Spherical	62	0.06690	0.7904	2.308	0.01510	0.3150
	Exponential	62	0.07835	0.8666	2.730	0.01702	0.2876
	Gaussian	62	0.08864	0.7338	1.271	0.05160	0.5952
Total Station	Spherical	64	0.05103	0.8209	2.207	0.01006	0.3665
	Exponential	64	0.06118	0.8828	2.544	0.01251	0.3387
	Gaussian	64	-0.0064	0.795	1.442	-0.0248	0.5457

M: Mean error; RMSE: Root-mean-square error; ASE: Average standard error; MSE: Mean standardized error; RMSSE: Root-mean-square standardized error.

- Using GIS and geostatistical methods to perform above-mentioned data's quality analysis.
- Investigating the effects of survey data quality on engineering designs.

2. Materials and method

2.1 Test site location and data collection

The 50-ha area, near Lefor, North Dakota, USA was chosen as the test site because there is no natural or man-made obstacles that can block satellite signals. The area was surveyed with a Trimble 5700 RTK-GPS (Trimble Navigation Ltd., Sunnyvale, California) survey system. The base station and four reference points were established over the highest point in the survey area. The distance between the survey points was 15 m. An operation speed of 5–10 km/h was maintained (Renschler *et al* 2002) in RTK-GPS's continuous topo mode. In order to maintain equal distances between the lines of survey points, a hand-held

Garmin GPSmap 76C (Garmin International Inc., Olathe Kansas) GPS unit was used. Referencing the four reference points, a Nikon NPL-350 (Nikon Geotecs Co. Ltd., Tokyo, Japan) Total Station was site-calibrated to survey NW section of the area that covers about 3.5 ha. GPS survey vehicle tracks and hand-held GPS unit were used to collect TS readings as close as possible to the RTK-GPS survey points.

2.2 Data processing

The available topographic datasets were originally stored as point measurement. Each point had northing, easting, and elevation values. Data processing was done to create contour maps that would be used to design diversion channels in Autodesk Land Desktop 2006 (Autodesk, Fremont California) software. Three layers were created for 50 ha area that was surveyed with RTK-GPS system, and 3.5 ha for TS and RTK-GPS systems. Now onwards, these layers will be referred as 'full GPS', 'TS', and 'partial GPS', respectively (figure 2). The partial GPS

Figure 4. Full and partial RTK-GPS contour maps.

Figure 5. Clean water diversion channel layout.

data will enable us to observe the effects of number of survey points on the quality of survey.

The survey data containing northing, easting, and elevations of each point for all three layers was saved as a database file (dbf) in AutoDesk. Then, ArcGIS's Geostatistical Analyst extension was used to perform geostatistical analysis. In

the analysis, a structured process was followed as shown in figure 3.

Finally, to see the effects of survey quality on engineering design, a 189 m clean water diversion channel with 4:1 side slope ratio in all three datasets (layers) was created. Cut/fill calculations were conducted in AutoDesk software.

Figure 6. Clean water diversion channel profile.

3. Results and discussion

The semi-variograms that yielded smallest RMSE for spherical, exponential, Gaussian models, and cross-validation statistics are shown in table 1. Cross-validation gives an idea of 'how well' the model predicts the unknown values in the creation of surface. In cross-validation the model omits a point sequentially, predicts its value using the rest of the data, then compares the predicted and observed values. In a best model, the mean error should be close to zero; the RMS and average standard error should be as small as possible. The smallest RMSE value was obtained for full RTK-GPS survey with spherical model (Goovaerts 2000). The cross-validation table also shows that the size of the area and number of readings can result in a different semi-variogram model. Even though the reading intervals are same for all three surveys, full RTK-GPS survey data is explained by a spherical model while others require a Gaussian model.

Figure 4 shows the difference between partial and full RTK-GPS survey. The partial contour map uses the same survey points in a smaller area causing horizontal error of up to 30 cm, and an RMSE of 0.7904 while the same number for full contour map is 0.4144. The analysis showed that the greater the area with more readings, the better the quality of the map.

It was also found that a smaller number of survey points and a smaller area have significant effects on vertical precision. The clean water diversion

Figure 7. Channel cut volumes for partial, full RTK-GPS and TS maps.

channel profile represents vertical accuracies of three survey data (figures 5 and 6). The TS and partial RTK-GPS maps yielded a similar ground profile because of the same number of survey points and areas, as anticipated. The vertical difference between the full and partial survey at station 5+50 is as high as 60 cm.

Cut volumes of the three channels that were designed over the partial and full RTK-GPS, and TS contour maps were calculated (figure 7). Considering that the full RTK-GPS survey is the most accurate one, the cut errors of 140 and 393 m³ for partial RTK-GPS and TS surveys, respectively, are significant. The flat rate for excavation was

Figure 8. Relationship between number of survey points and cut volume.

\$ 1.2/m³ in North Dakota (ND-NSPMP 2005). Hence, a 393 m³ error in cut volume calculation can cause a \$ 471 cost (27%) difference for a 189 m channel.

In order to further observe the effect of number of survey points on cut volume, different numbers and resulting volumes were calculated (figure 8). Numbers of 33, 62, 80, 100, and 162 were selected for partial survey area. The full survey area initially had 749 survey points yielding a cut volume of 1460 m³. As the number of survey points decreases, the cut volume increases. The cut volume difference between 749 survey points for 50 ha and 100 survey points for 3.5 ha area is negligible. Therefore, 100 survey points per 3.5 ha area, or 20 m distance between readings yield reasonable results.

4. Conclusions

The use of survey data for creating accurate topographic representations has to be done very carefully because it is critical to any agricultural engineering design. The geostatistical analysis was conducted to see if the size of survey area and number of readings have any effect on semi-variogram model. Also, it was the intention to observe the effects of survey accuracy on the quality of engineering design and cost estimations. Different area size and number of readings showed quite different results.

- The comparison of two techniques including RTK-GPS and TS revealed that RTK-GPS based surveys are not only practical and fast but also yield more accurate topographic maps for design purposes. Therefore, an investment in an RTK-GPS system might be worthwhile.

- Even though all surveys were conducted on the same area, 50-ha RTK-GPS survey was explained with a spherical semi-variogram model while others used Gaussian model. Therefore, for a successful survey one should not limit the area to only construction site. A larger area increases the quality of the survey.
- Survey technique, area, and distance between survey points can result in vertical errors up to 60 cm that may yield huge differences between cost estimations and actual costs.
- An optimum reading interval of 20 m between survey points can be used to improve the quality of the work.

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