Deriving Appropriate Digital Elevation Model (DEM) from Airborne LIDAR Data and Evaluating the Horizontal Highway Geometry for Transportation Planning

Nursu TUNALIOĞLU, Metin SOYCAN, Kutalmış GÜMÜŞ and Taylan ÖCALAN, Turkey

Key words: Engineering Survey; Laser Scanning; Positioning; Remote Sensing

SUMMARY

Nowadays, highway transportation planning has become a significant problem due to the increased transportation need. Considering the problem as a whole, it is existed intricate subject by the help of constrictions of the land use areas, planning the transportation networks due to the residential areas because of irregular urbanization, penetrated closely of the urban and rural areas. In addition, in many countries, highway transportation is supported by the fast mounting automotive industry. Nonetheless, by not supported integrated models between the transportation systems causes the problem has been continuously increased.

Since a network planning is needed for a large area, a fast and accurate model should be prepared to show the existing situations. A highway is a main road intended for travel by the public between important destinations, and its design varies widely. So, once find out a model for evaluating the design elements of horizontal highway geometry in accurate form, the model could be used for other evaluations.

In this case study, the method presents the efficient, rapid and actual solutions for exposing the horizontal geometry with its profile to where the surveying area for network planning is required. The method is based on getting data of an existing highway by means of LIDAR data and subsequent processing of this information. The important stage is to determine the appropriate interpolation model for having digital elevation models. Then, all the horizontal components of the highway elements were found via the airborne LIDAR data. The LIDAR data is used to collecting the field data with high resolution, on a definite section of a two lane urban highway. The data taken in the highway are used to define the geometric components of the highway, such as horizontal curve radius, alignments etc. are estimated by means of a developed calculation algorithm.

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1. INTRODUCTION

One of the basic requirements for analyzing the transportation problems/planning is to find out the accurate field data in sufficient and efficient way to adapt the computer-based problem solving systems. Map is required which shows constructed and used highways and/or link roads existent plans for planning all kind of transportation plans and analyzing the transportation networks. The scope of transportation planning or analyzing could be separated into many subcategories such as analyzing a preferred alternative way for highway projects, improving connectivity between transportation modes or/ and optimize highway system operations while recognizing the constraints on highway expansion identified through the regional transportation planning process. Furthermore, it is needed for to provide lane continuity and balance, increase safety along and across the corridor, correct roadway deficiencies along existent roads to meet current design standards to provide a safer, more efficient, and more reliable transportation system.

Terrain information is used both to construct and evaluate alternative routes and to create final design plans that optimize alignments and grades for the selected alternative (Veneziano et al., 2002). Geometric definition of the highway alignment is the important part of the determination of the traffic safety and having up-to-date highway inventory. In addition, to represent the highway geometry rapidly, effectively and accurately helps planning the future transportation networks. All transportation agencies maintain some type of roadway inventory, which is used for a variety of purposes. Maintaining up-to-date information about roadways is essential for design, planning, maintenance, and rehabilitation purposes (Shamayleh and Khattak, 2003).

For an existing highway, the main point is how to define the geometry in fasten and accurate way for above quoted purposes. In this context, airborne LIDAR data was used to obtain the field data for exposing the current situation of region in this study. The significant part of the study is to derive the appropriate digital elevation model from airborne LIDAR data.

LIDAR is an active remote sensing system, integrated with GPS, INS/ IMU, and uses laser beams to perform three-dimensional accurate data (Shrestha et al., 1999). These data furnish X, Y and Z data. An aerial platform (usually an airplane) has a laser ranging system mounted onboard, along with other equipment including a precision GPS receiver and accurate Inertial Navigation System (INS) to orient the platform (Shrestha et al., 1999). In the aerial part of the system consists of a navigation system integrated with GPS, and IMU system to control and measure the direction of airborne platform (Wehr and Lohr, 1999). The airborne LIDAR survey, also called Airborne Laser Terrain Mapping (ALTM) technology, is a cost-effective, efficient method for creating high-resolution digital terrain models (DTM) and contours for transportation and environmental applications (Uddin, 2002).

A process of deriving digital elevation models from airborne LIDAR dataset follows this introduction with its subtitle as a brief explanation of used methods for deriving digital elevation models and their comparison. The next section presents exposing highway routes for all kind of transportation related applications by first, obtaining horizontal route and then obtaining profile of the highway from derived appropriate digital elevation model based on airborne LIDAR data. The last part of the study is conclusions.

2. DERIVING DIGITAL ELEVATION MODELS USING LIDAR DATA

The airborne LIDAR data points used in this case study are 1,929,925 which all have x, y, z topographic values. The significant stage is the process of the LIDAR data in appropriate way for obtaining appropriate digital elevation model about the study region. The aerial imagery and LIDAR data were taken from the WADGA via the internet.

2.1 Used Methods for Deriving Digital Elevation Model

The representation of the three dimensional x, y, z coordinated surface data obtained with the help of LIDAR measurement systems can be conducted in the form of point cloud (Reutebuch et al., 2003), triangulated irregular network and grid (Kraus and Pfeifer, 2001). Gridding is one of the most simple and easiest methods that can be used in forming various products such as digital elevation model, digital terrain model, contour lines, shadow and embossed maps, hillside and slope maps. The most important advantage of this method is the very easy organization and simple storage opportunities of grid elevations with the help of interpolation (Hugentobler, 2004; Liu et al., 2007).
The various methods can be used for interpolation of elevation such as, Inverse Distance, Kriging, Minimum Curvature, Nearest or Natural Neighbor, and Radial Basis Functions, Triangulation, Moving Average, Local or Global Polynomial while, in this study, we use three method which are Kriging, Modified Shepard's Method and Triangulation with Linear Interpolation.

2.2 Comparison of the Methods for Appropriate Digital Elevation Models

We decide to use three models, Kriging, Modified Shepard's and Triangulation with Linear Interpolation methods, into cited methods above, due to prior experiments about derivations. The other methods, inverse distance to a power with weighting power two, minimum curvature and natural neighbor methods present nearly same values with selected three methods, which could not be used for taking into consideration as decision criteria. View of derived elevation models are represented in Figure 1 as shaded relief maps and the results about interpolation process for derived digital elevation models are represented in Figure 2 by histograms and statistical values of residuals as minimum and maximum values, range of them, standard errors, average deviations and standard deviations. In the processing stage, 100,000 normal distributed points from the LIDAR dataset were selected for comparing the reliability of the derived digital elevation models as control points. Digital elevation models were derived by the rest of 1,829,925 points. The results were obtained by residuals of them.

As mentioned in the graphic, the standard deviations of the methods, calculated using differences between estimated values and real values of each points, for Kriging, Modified Shepard's Method and Triangulation with Linear Interpolation Methods according to this case study area, are determined as 0.1038, 0.0948 and 0.1204 respectively. Due to achieving appropriate digital elevation model, control points selected from the LIDAR dataset and base points derived digital elevation models are compared in view of values of standard deviations calculated from differences of heights. The standard deviations of methods based on control points are determined with 0.1776, 0.2060 and 0.1878, respectively. As considered all results for this study area, evaluated results are so close to each other to make a certain decision for obtaining more accurate digital elevation model, which would help for evaluating vertical profile section of the highway's horizontal route. Therefore, profile section of the highway is drawn with using three digital elevation models.

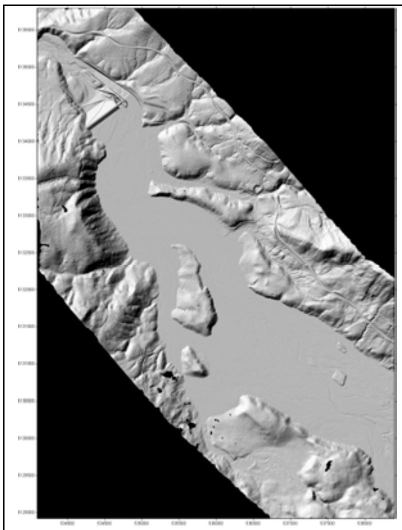
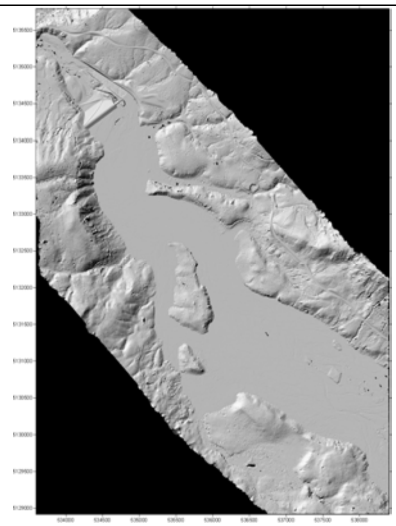
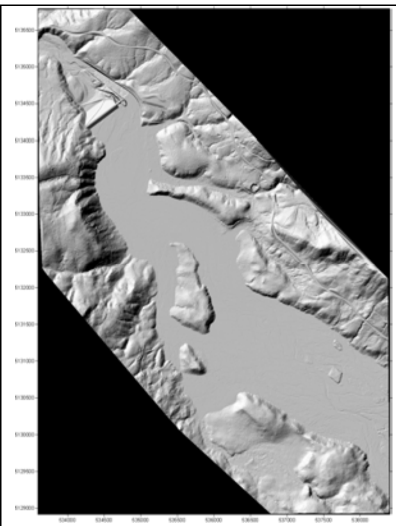
		
Kriging	Modified Shepard' s Method	Triangulation with Linear Interpolation

Figure 1. View of study area with different interpolation methods

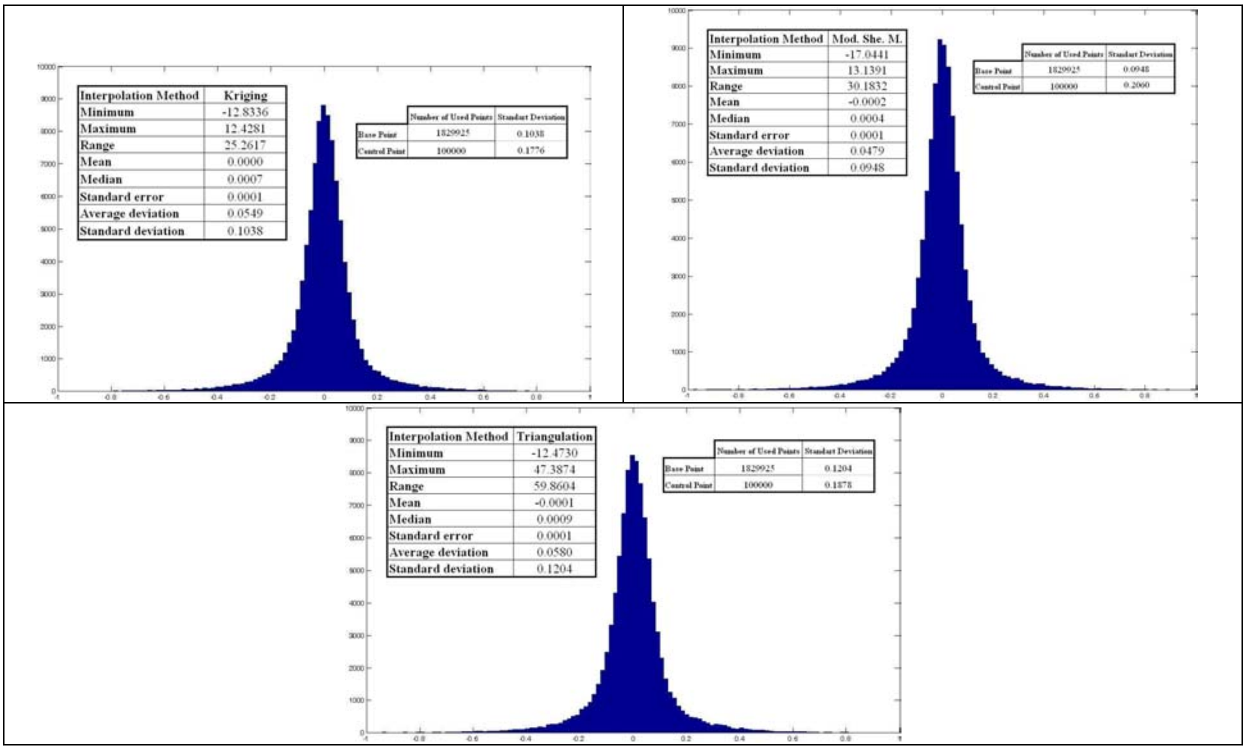


Figure 2. Histograms and statistical results of three methods

3. DATA ANALYSIS FOR TRANSPORTATION PLANNING – A CASE STUDY

The aerial imagery and LIDAR data were taken from the WADGA via the internet. Aerial image was in Geo-tiff format with a spatial resolution of 1 meters while the LIDAR data were in ASCII comma delimited text format with 1,929,925 data points and an accuracy of 3 m resolution. The selected highway corridor for the case study is approximately 2 km longs; two-lane, undivided rural highway. Figure 3 shows the study environment for the case study, which had chosen in rural region.

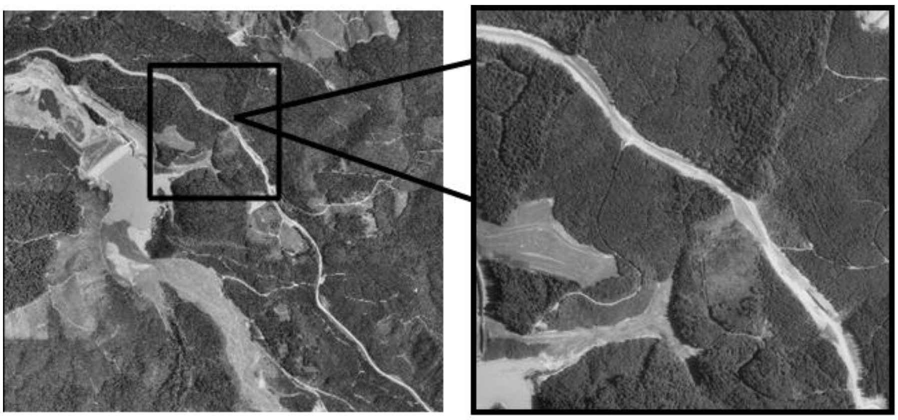


Figure 3. Study corridor map (3D design environment)

3.1 Horizontal Alignment

Two types of data were taken separately as horizontal and vertical. First data group was found from the imagery for having the horizontal highway corridor as traffic lines. The traffic lines were drawn from the selected highway corridor to have the point's information as x, y data. It was seen that the platform wide is 10 m. We found the roadway data as x, y coordinates for axis, inner and outer lines.

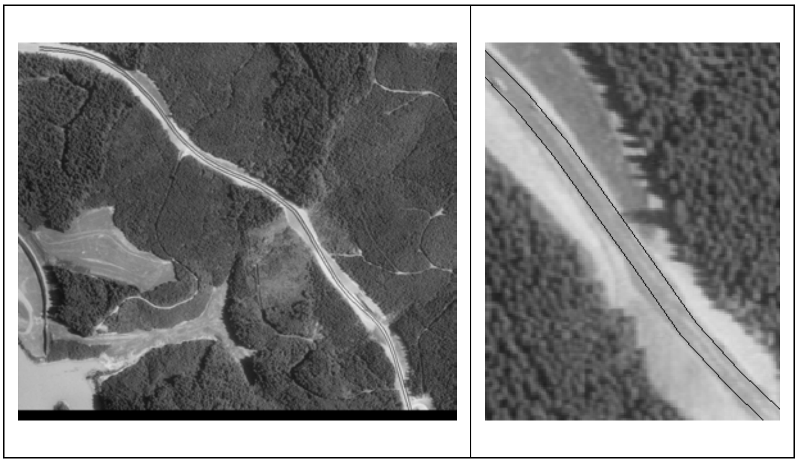
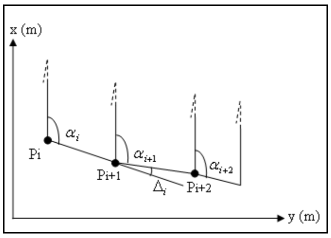


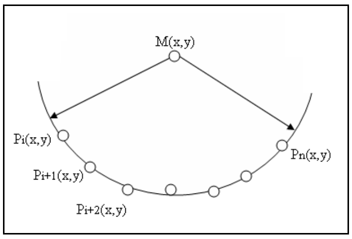
Figure 4. a. Horizontal alignment b. Roadway plan view with lanes

3.2 Definition of the alignment points and curve radius

For having paths exactly parallel to the highway centerline, parallel lines were drawn from the ortho photo. End and start points of lines were taken as knots to determine the horizontal and vertical geometric elements of the existing highway. Exactly matched width for each lane is totally 5.0 m. The horizontal alignment was processed into two parts as straight line and circular curves. To take into consideration of the straight lines' points, each point's deflection angles were calculated. The differences between the angles for each point are the decision criteria for the point's numbers of all straight lines. When the absolute values of the angles started to increase or decrease, we stopped taking the straight-line points then this point. If the deflection angle is bigger than the next one, the last point and previous ones are chosen as the alignment points. That chosen points are taken into consideration of the regression analyze. For each point, the calculation of the angle was done for estimation the alignments through the axis points. The approach for determining the alignment points is illustrated in Figure 5a. As shown in Figure 5a, firstly all of the azimuths are calculated thinking of that here are the points of intersection.
The linear regression analyze was used to estimate the straight lines only for the straighten parts of the highway. For the circular curve parts, the remained points between two straight lines were used to calculate the radius. The axis points of the horizontal alignment were calculated from the inner and outer lines points.



(a)



(b)

$$\alpha_i = \arctan((y_{i+1} - y_i)/(x_{i+1} - x_i))$$

$$\Delta_i = \alpha_i - \alpha_{i+1}$$

$$R^2 = (xi - xm)^2 + (yi - ym)^2$$

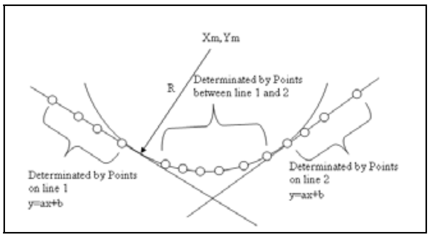
$$\begin{bmatrix} x_i & y_i & 1 \\ x_{i+1} & y_{i+1} & 1 \\ x_{i+2} & y_{i+2} & 1 \\ .... & .... & ... \\ x_n & y_n & 1 \end{bmatrix} * \begin{bmatrix} a \\ b \\ c \end{bmatrix} = \begin{bmatrix} -x_i^2 - y_i^2 \\ -x_{i+1}^2 - y_{i+1}^2 \\ -x_{i+2}^2 - y_{i+2}^2 \\ .... \\ -x_n^2 - y_n^2 \end{bmatrix}$$

where a, b and c is denoted as;

$$a = 2 \times xm$$

$$b = 2 \times ym$$

$$c = xm^2 + ym^2 - R^2$$



(c)

Figure 5. Evaluating horizontal highway geometry and its subsequent processes with equations

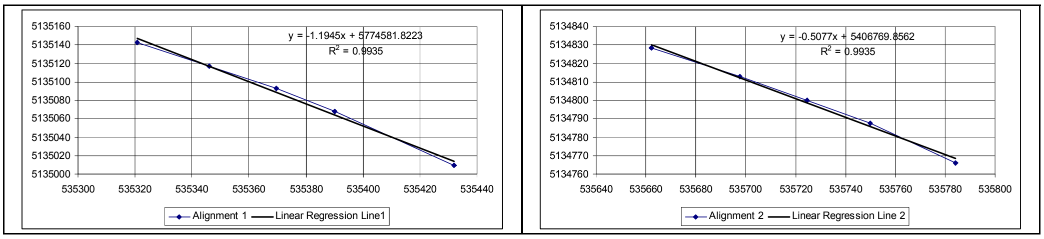


Figure 6. Horizontal alignment for two consecutive straight lines

		Central coordinates of the circle	
Curve#	*Curve radius (m)*	*Xm*	*Ym*
1	415.3793	5134849.9441	535026.7594
2	495.8551	5135291.4618	535838.9057
3	308.1766	5134493.4919	535639.7346
4	530.4561	5134770.1738	536446.7384
5	308.3094	5134124.3347	535914.7954

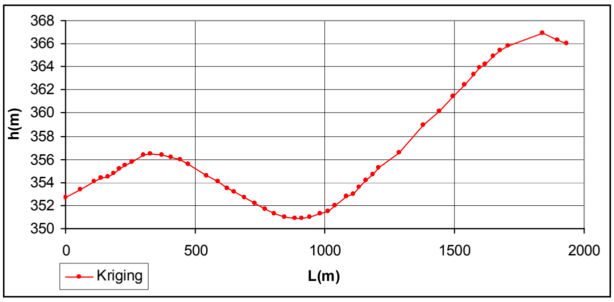
Table 1. Curve radius of highway found via given equations in Figure 5

Because of the data accuracy (horizontal coordinates), the radius are found nearly integer numbers. The values could be rounded to the nearest integer numbers. The results given in Table 1, show that the two-dimensional evaluations found via the ortho photo give acceptable radius values without knowing any prior information about the existing highway.

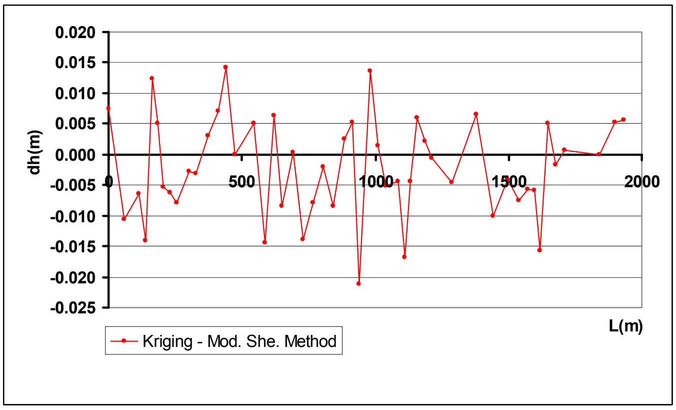
Figure 7. Two Dimensional horizontal route of the existing highway

3.3 Vertical Alignment

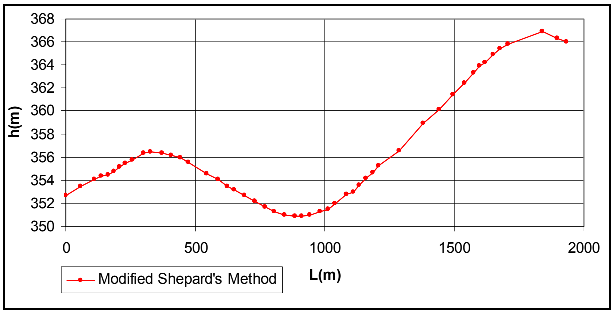
The last process of exposing the highway route is to evaluate the vertical section of it by using derived appropriate digital elevation models for more accurate and fast way in transportation planning analyses. The axis points x, y of the highway obtained by the help of orthophoto is overlaid to the digital elevation model. Three of the digital elevation models are used because of obtained model accuracy. Obtained profiles illustrated in Figure 8 give acceptable results to be informed about the transportation network analyses.



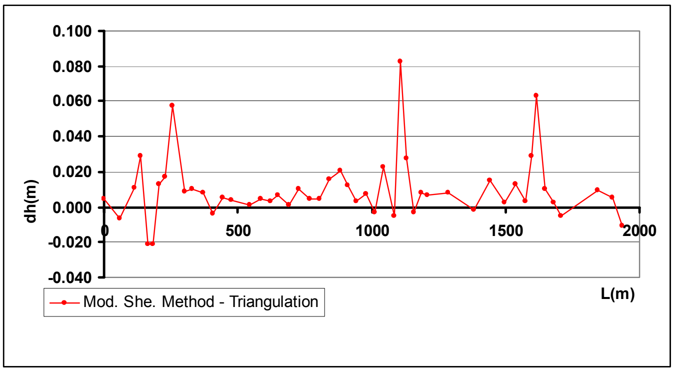
(a) Highway profile obtained from Kriging Method



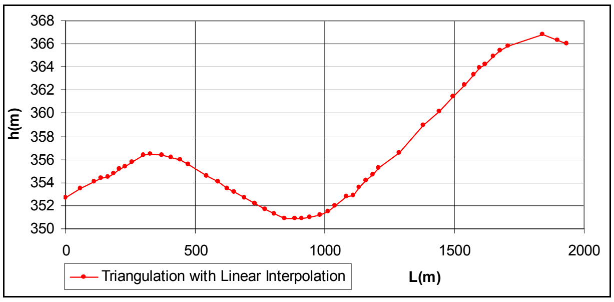
(d) Heights's differences between Kriging and Mod. She. M.



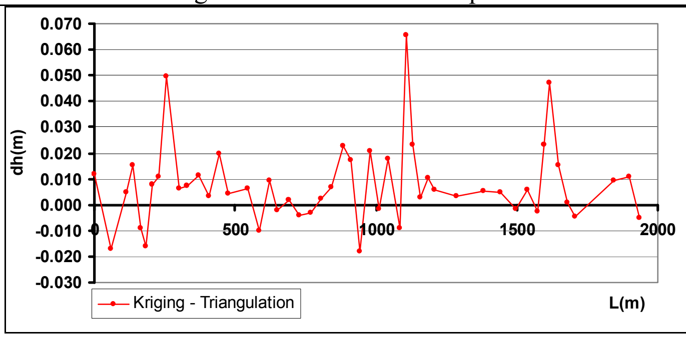
(b) Highway profile obtained from Modified Sheprd's Method



(e) Heights's differences between Mod. She. M. and Triangulation with Linear Interpolation



(c) Highway profile obtained from Triangulation with Linear Interpolation



(f) Heights's differences between Kriging and Triangulation with Linear Interpolation

Figure 8. Profile sections via different digital elevation models and differences between them

4. CONCLUSION

An evaluation method on traffic safety and other transportation applications for obtaining horizontal and vertical geometry of an existing highway has been exposed. The main advantage of this method is to give the efficient, fast and acceptable results by terms of the accuracy of the terrain model. The horizontal and vertical geometric elements of the existing highway have been obtained by airborne LIDAR dataset without knowing any prior information about the roadway, and subsequent processing of this information for defining the all-geometric elements. These results show that the elevation models obtained with the LIDAR measurement system has a significant advantage incomparable to other methods in terms of accuracy, time, economy and applicability. In this case study, Kriging, Modified Shepard's and Triangulation with Linear Interpolation methods could be used to derived appropriate digital elevation models. Results about the study and highway profiles were illustrated in Figure 8. According to obtained elevation models, maximum and minimum height's differences between gridding methods of Kriging and Modified Shepard's Method were found 0.014 m and -0.021 m, respectively. In the same way, maximum and minimum height's differences between gridding methods of Modified Shepard's Method and Triangulation with Linear Interpolation were found 0.082 m and -0.021 m, respectively and, maximum and minimum differences between Kriging and Triangulation with Linear Interpolation method were 0.065 m and -0.018 m, respectively. Due to the results determined in the case study, these three gridding methods could be used for deriving appropriate digital elevation models for exposing highway geometry.

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BIOGRAPHICAL NOTES

Nursu Tunalıoğlu currently is studying for her PhD thesis at the Graduate School of Science and Engineering of the University of Yildiz Technical. Her research interests are highway design, 3D terrain models, airborne LIDAR Technology. She graduated in 2005 as Master of Science in Surveying from the same university and the research topic was multilevel intersections and link roads. Now, she is currently working as a research assistant in Yildiz Technical University in Division of Surveying Technique.

Metin Soycan has been an Associate Professor of Geodesy and Photogrammetry Engineering at Yildiz Technical University since January '09. He received a Ph.D. in GPS/Leveling and Determination of Precise Geoids’ from the same university in 2002. His research focuses on satellite based positioning system, GNSS, deriving digital terrain model, LIDAR data with a particular processing.

Kutalmış Gümüş, studied Geodesy and Photogrammetry at University of Selçuk 1999-2003 and graduated in 2008 with a degree of Master of Science at the Yildiz Technical University. His research topic in his thesis was terrestrial laser scanning technology. His study areas are terrestrial surveys, terrestrial laser scanning system with processing the data. He is a research assistant in Yildiz Technical University and works about his PhD thesis.

Taylan Öcalan, graduated in 2005 with a degree of MSc at the Graduate School of Science and Engineering of Yildiz Technical University and the topic of his thesis was the investigation of relative point positioning accuracy based on permanent GPS stations. He works GNSS and related subjects in his PhD thesis. His study areas are Global Navigation Satellite Systems, terrestrial surveys. He has worked as a research assistant in Yildiz Technical University since 2004.

CONTACTS

Nursu Tunalıoğlu
Yildiz Technical University, Faculty of Civil Engineering, Department of Geodesy and Photogrammetry
34210 İstanbul
TURKEY
Tel. +90 212 383 5321
Fax. + 90 212 383 5102
Email: ntunali@yildiz.edu.tr

Metin Soycan
Yildiz Technical University, Faculty of Civil Engineering, Department of Geodesy and Photogrammetry
34210 İstanbul
TURKEY
Tel. +90 212 383 5307
Fax. + 90 212 383 5102
Email: soycan@yildiz.edu.tr

Kutalmış Gümüş
Yildiz Technical University, Faculty of Civil Engineering, Department of Geodesy and Photogrammetry
34210 İstanbul
TURKEY
Tel. +90 212 383 5320
Fax. + 90 212 383 5102
Email: kgumus@yildiz.edu.tr

Taylan Öcalan
Yildiz Technical University, Faculty of Civil Engineering, Department of Geodesy and Photogrammetry
34210 İstanbul
TURKEY
Tel. +90 212 383 5302
Fax. + 90 212 383 5102
Email: tocalan@yildiz.edu.tr