The Gridding Size Effects on Exposing Highway Profile

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Key words: Laser scanning, Positioning, Remote Sensing, Highway

SUMMARY

The length based engineering problems such as highways, railways etc. acquires three-dimensional topographic data to expose the project details. In view of highway transportation planning projects, to expose the existing situation accurately and rapidly has become a significant problem due to the increased transportation need. Therefore, three-dimensional topographic data is a vital element for analyzing the planning problems in all sides. For length-based transportation planning problems, the significant factor is to reach the accurate highway geometry components such as length and elevation information. Especially, planning stages of the transportation networks need existing highways and related roads geometry for modeling and giving decisions about the future works.

The goal of this paper is to find out the usage capacity of different gridding sizes with chosen digital elevation derivative models to expose highway profile geometry, and integrated aerial imagery for horizontal geometry. In this point, airborne LIDAR technology gives efficient, accurate and less time-consuming solutions for generating digital elevation models. This study presents the gridding size effects, which are investigated from generated digital elevation models via airborne LIDAR dataset for exposing highway profile in terms of accuracy and efficiency. In this case study, the three interpolation models, Inverse Distance to a Power (power: 2), Modified Shepard's, and Kriging Methods are used. The generated models' gridding size was computed based on study data area and density of LIDAR data, and then it was changed to provide different digital elevation models. The original airborne LIDAR dataset was divided into two datasets for obtaining checkpoint's dataset and training point dataset, 10 % and 90 % of original data points, respectively with random distribution.

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1. INTRODUCTION

As considered, the length based engineering problems and solutions, need large and corridor based datasets. The lengths and related information are crucial components for highway route analysis, quality control or traffic safety control of existing routes, or a new design routes. Surface terrain information is required to economically locate new or relocate existing transportation facilities (Souleyrette et al., 2002). The important factor at the beginning is to obtain the accurate field data points from the study areas, and then to generate the surface models for constructing or controlling the route or route links. Although there would be several methods to get the accurate field data, the obtaining parameters may change in terms of economy, size of the study area, expected accuracy, time etc. The accuracy of the models is related to study quality, expectations and needs. All data collection methods; remote sensing, photogrammetry or conventional methods, have advantages or disadvantages when they are compared to each other. In recent years, surveyors have used a new method, laser scanning based method, which gives more efficient, accurate, rapid (Veneziano, et al., 2002) and effective solutions for widen study areas (Kraus and Pfeifer, 1998; Means et al., 2000).

The LIDAR (Light detection and ranging technology) is a remotely sensed method, which uses laser beams to get three dimensional topographic data metrics from the ground or somewhere, where the laser beam send and reflect (Baltsavias, 1999). 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). 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). The use of LIDAR for terrain data collection and DEM generation is the most effective way (Forlani and Nardinocchi, 2007) and is becoming a standard practice in spatial science community (Hodgson and Bresnahan, 2004). In use, there are two types of laser ranging method, airborne LIDAR and terrestrial laser scanning. This study is interested in airborne LIDAR dataset.

Terrain information is used to both 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).

The significant second step is to produce the digital elevation models that used as a base map for the other stages of the study. Digital Elevation Models (DEMs) play an important role in terrain-related applications, the success of which refers, among other things to accuracy. Of the many factors that affect the accuracy of DEMs, the accuracy, density and distribution of the source data, the interpolation algorithm, and the DEM resolution or grid size are the main factors (Gong *et al.*, 2000**;** Kienzle, 2004; Li *et al.*, 2005; Fisher and Tate, 2006; Liu, 2008).

This study includes an integrated data use, LIDAR and aerial imagery to obtain highway up-to date information. The used dataset was taken the same without any reduction on control point density, and the grid size was changed continuously to have lower errors from DEMs. The horizontal geometric details were obtained from aerial imagery, and vertical geometric detail was calculated from chosen DEM.

2. METHODOLOGY

2.1 Study Environment and Data

In this study, two different data types, aerial imagery and bare earth airborne LIDAR data were used. The aerial imagery and LIDAR data were taken from the WADGA (Washington State Geospatial Data Archive) via the internet from the southeast region of Elk Rock, Washington State, United States. Aerial image was in Geo-tiff format with a spatial resolution of 1 meter while the LIDAR data were in ASCII comma delimited text format with 664286 data points and an accuracy of 3 m resolution. We use approximately 2,5 km longs from the selected highway corridor for the case study. Figure 1 represents the study environment and 3-dimensional view of region for the case study.

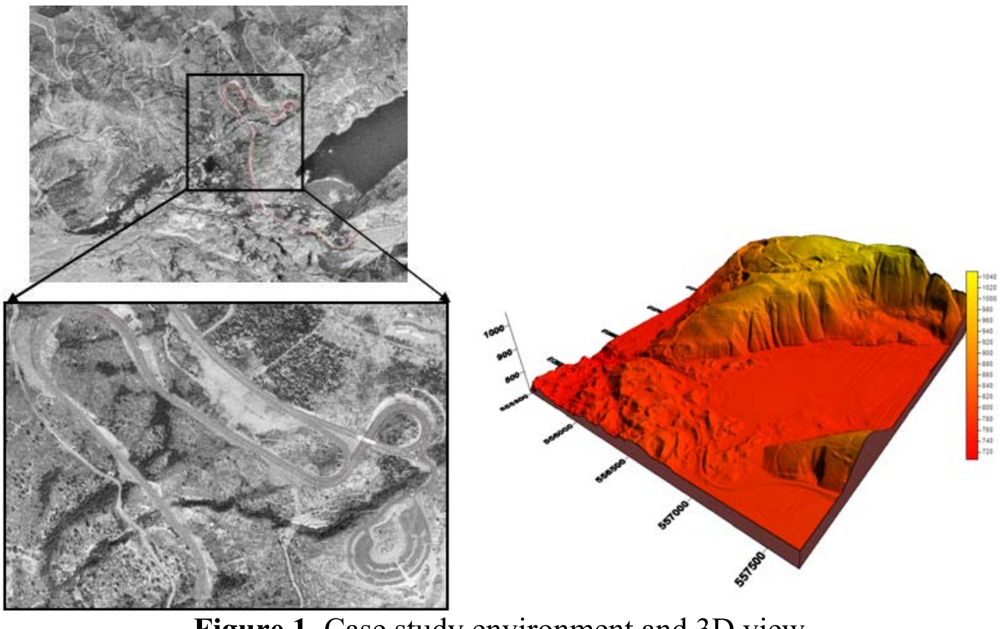


Figure 1. Case study environment and 3D view

The data used in this case study was obtained from WAGDA open data sources via internet. In the selected area, 3 dimensional LIDAR datasets, is limited to 2206.54 m difference through the x dimension and 2512 m through the y dimension. The total study area is approximately 5.5 ha.

In the study area, the maximum elevation is 1050.40 m, minimum elevation is 705.90 m, mean elevation 844.77 m and median elevation is 823.72 m. The elevation distribution histograms for the data (include checkpoints and control points used in interpolation and controlling stage) can be seen in Figure 2.

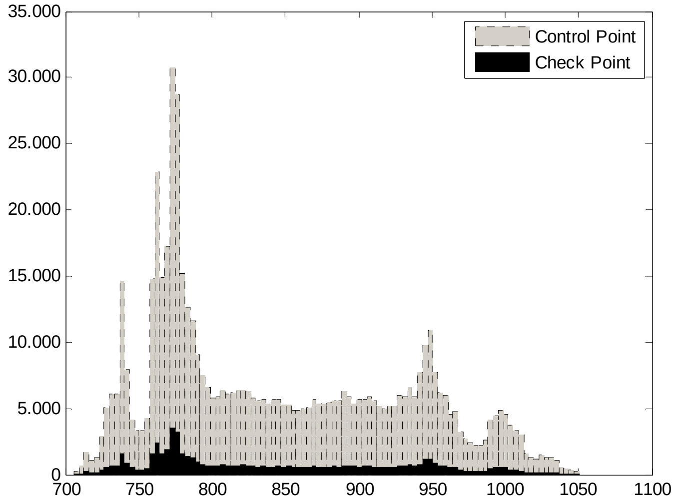


Figure 2. Elevation Histogram of dataset

2.2 Methods

2.2.1 Generating Horizontal Geometry and Adequate DEMs

This study is based on airborne LIDAR data and aerial photography integration, for fast and accurate geometric definition of a highway for future detailed studies such as network planning or traffic safety researches progresses. The represented methodology is about obtaining centerline coordinates of points of a highway by aerial imagery by picking up manually related to horizontal details and profile of the highway by means of airborne LIDAR data and on the subsequent evaluations of digital elevation model for more accurate solutions. As a result of this process, the highway vertical detail, defined by the help of subsequent computations of LIDAR data, is obtained. The points obtained by the manual selection on aerial imagery correspond to the highway centerline can be seen in Figure 3.

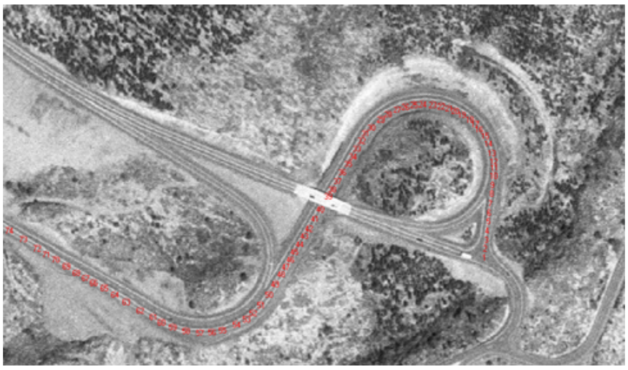


Figure 3. Highway centerline

Because of the large data density and need of exploring the adequate grid sizes, the main object of the study is to have an opinion about the data density, which is suitable for generating digital elevation models for producing a base map for this kind of studies. Beside this, we investigate the grid size effects on these re-generated datasets formed by reducing and increasing grid size intervals. In this concept, to control the quality of the produced datasets, a sub-dataset, which was used as control points dataset, was separated from the original dataset. The separation was done from randomly distributed LIDAR data points and taken 10 % of the original LIDAR points. The rest of the original LIDAR data points were left for training data points. The reason for separating training data as 90% and test data as 10% of the original dataset is to ensure the high density of the training dataset and provision of enough test dataset checkpoints. In this test dataset, a total of 66429 points, 10 % of original data (664286) was used as control points to assess the accuracy and usage capacity of each generated DEMs. The training dataset was included 597857 data points which was used to derivate each DEMs.

The used interpolation methods are Inverse Distance to a power, Modified Shepard's Method and Kriging Method. Each interpolation methods has generated sub DEMs, whose gridding size has been changed to a range of 1 m to 30 m. Generally, to make full use of the data resolution, each grid cell contains one point on average (Yong, H. 2003). The grid size is estimated by;

$$sc = \sqrt{As/ns} \qquad [1]$$

Where, As is the covered area and ns is the number of measured points.

Grid size for the region was evaluated 3 m and then, it was decreased until to 1 m and increased to 8 m with a period of 0.5 m range, and 15 m and 30 m grid interval sizes were generated. The largest grid size on 0.5 m ranged process was chosen as 8 m because of the highway wide related to this study. We prefer to use 0.5 m changing intervals. The reason of this, we try to detect the differences of highway geometry that would correspond to the highway cross section, which could affect the profile values.

The representation of generated DEMs can be seen as shaded relief maps in Figure 4. In representation, we prefer to use the 1 m, 10 m and 30 m grid size intervals.

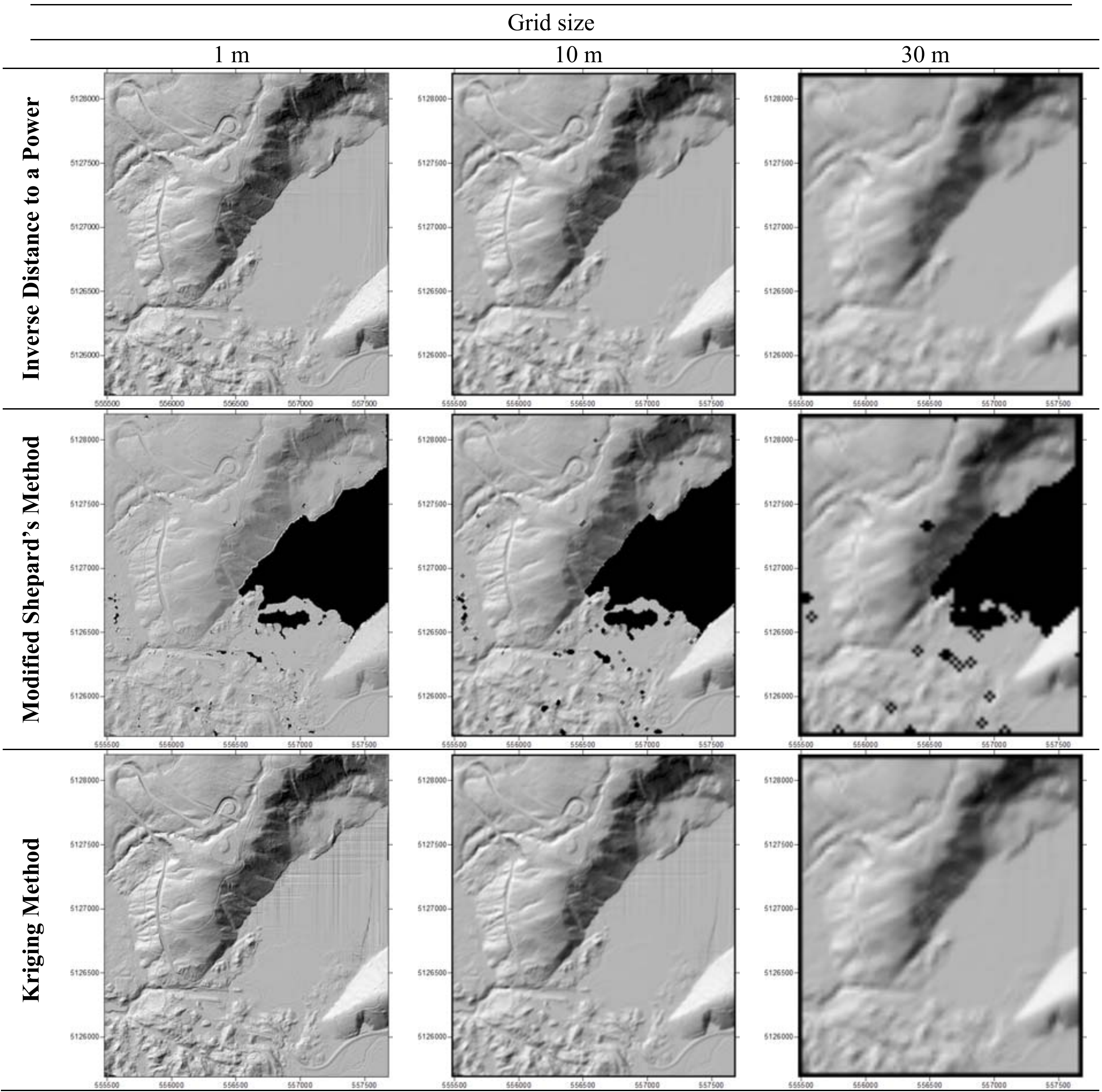
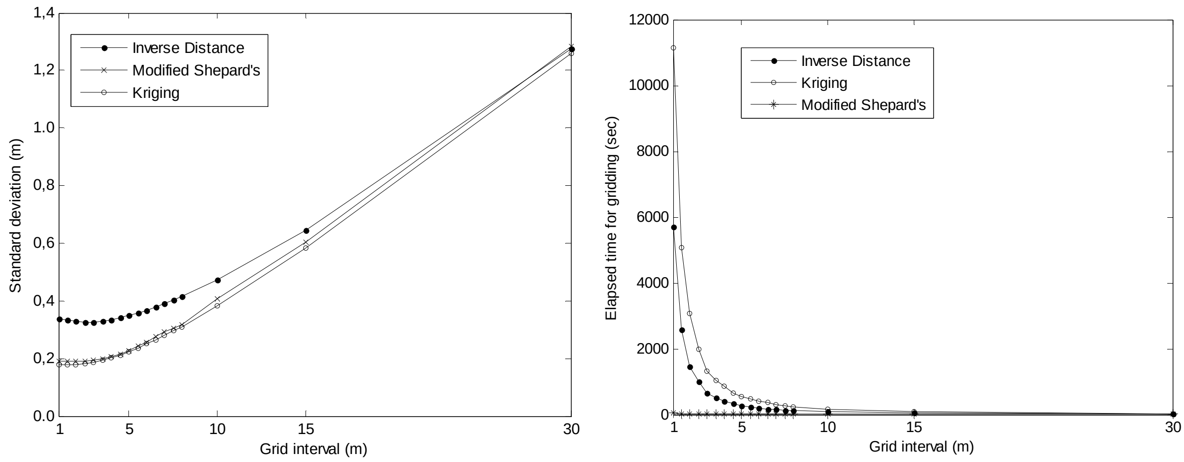


Figure 4. Representation of DEMs as shaded relief maps

Table 1. Statistical Information of DEMs by changing grid intervals

	Inverse Distance				Kriging				Modified Shepard's			
Grid (m)	Minimum (m)	Maximum (m)	Mean (m)	Standart Deviation (m)	Minimum (m)	Maximum (m)	Mean (m)	Standart Deviation (m)	Minimum (m)	Maximum (m)	Mean (m)	Standart Deviation (m)
1	-11.9717	3.6458	-0.0103	0.3397	-12.0404	3.8484	-0.0007	0.1774	-12.0069	5.2981	-0.0003	0.1921
1.5	-12.0060	3.6840	-0.0101	0.3339	-12.0648	3.8490	-0.0007	0.1785	-12.0401	5.0704	-0.0003	0.1913
2	-12.0103	3.6588	-0.0096	0.3277	-12.0571	3.8494	-0.0006	0.1800	-12.0480	5.2303	-0.0003	0.1907
2.5	-12.0034	3.7133	-0.0091	0.3243	-12.0461	3.8460	-0.0003	0.1829	-12.0208	5.0193	-0.0001	0.1914
3	-12.1342	3.6824	-0.0091	0.3243	-12.0587	3.8358	-0.0001	0.1876	-12.0646	4.6857	-0.0002	0.1952
3.5	-11.9722	3.7200	-0.0089	0.3290	-12.0759	3.8469	0.0000	0.1940	-12.0214	4.7681	-0.0002	0.1999
4	-11.9923	3.6609	-0.0083	0.3342	-11.9244	3.8603	0.0002	0.2025	-11.9350	3.8737	-0.0002	0.2069
4.5	-11.9656	3.6630	-0.0084	0.3409	-11.9379	3.8612	0.0002	0.2118	-11.9059	3.8228	-0.0005	0.2166
5	-11.9770	3.8139	-0.0088	0.3483	-12.0427	3.8788	0.0004	0.2229	-12.0960	7.0313	-0.0004	0.2288
5.5	-11.9998	3.6883	-0.0072	0.3575	-12.0680	3.8479	0.0018	0.2366	-12.0409	4.9440	0.0007	0.2424
6	-12.1302	4.4253	-0.0071	0.3683	-12.1526	3.8488	0.0018	0.2498	-12.1622	6.3446	0.0007	0.2548
6.5	-12.2083	4.7830	-0.0069	0.3800	-12.2353	3.8511	0.0020	0.2651	-12.2458	7.7260	0.0007	0.2747
7	-11.8693	4.7243	-0.0073	0.3916	-11.7448	3.9959	0.0021	0.2796	-11.7555	13.8113	0.0004	0.2907
7.5	-12.3235	5.1504	-0.0066	0.4044	-12.2335	3.8195	0.0031	0.2950	-12.2416	8.7254	0.0009	0.3035
8	-12.3237	4.1002	-0.0045	0.4151	-12.4083	3.9459	0.0044	0.3101	-12.4198	6.4477	0.0020	0.3185
10	-12.1825	5.5304	-0.0037	0.4721	-12.5662	3.8802	0.0064	0.3823	-12.7322	22.2406	0.0036	0.4053
15	-12.0709	7.4632	0.0065	0.6445	-12.3743	5.7979	0.0188	0.5852	-12.3915	6.4877	0.0152	0.6053
30	-11.8038	10.7631	0.0685	1.2739	-11.7911	10.6211	0.0907	1.2578	-11.8140	14.6537	0.0902	1.2854

According to statistical computations of DEMs seen in Table 1, Kriging and Modified Shepard' s interpolation methods give the least standard deviation values based on this case study data. The minimum standard deviations are 0.1774 m and 0.1921 m, obtained by Kriging and Modified Shepard's interpolations, respectively. However, the appropriate grid interval size to exact the dataset numbers was computed as 3.04 m, so we chose the 3*3 m grid values for comparing accuracies. The standard deviation of 3*3m grid sizes are 0.3243 m, 0.1876 m and 0.1952 m, obtained by Inverse Distance to a power, Kriging and Modified Shepard's interpolation methods, respectively. The significant changes on standard deviations can be seen clearly in Figure 5a. The drift of the curves on the figure has started to changed from 8 m grid interval DEMs, and the curvature has become rising rapidly to upwards from the 10 m grid size interval. Beside this, we compare the elapsed times for gridding processes to decide the interpolation method and gridding size. This would also make a contribution. The elapsed time for gridding is also important for time-consuming studies. In Figure 5b, the elapsed time for gridding and grid intervals graphic can be seen. The most time-consuming gridding method is Kriging in all changed grid intervals. The others are respectively, Inverse Distance to a power and Modified Shepard' s method. The elapsed time computations were done under the same conditions with the same software and hardware for eliminating computer based effects.



(a) (b)

Figure 5. (a) Change of Standard deviations by grid intervals, **(b)** Elapsed times for gridding process based on grid intervals

Based on the statistical information, the Kriging interpolation that gives the more accurate solutions on standard deviations and Modified Shepard's method, which spend less time for gridding, was chosen for extracting highway profile.

2.2.2 <u>Profile Extraction</u>

For the profile extraction, the manually marked centerline of the highway over the ortho photo of the study region was used. As decided previous subsection of the study, the Kriging and Modified Shepard's interpolations are used. In addition, the appropriate grid size is chosen 8 m. The following figures (Figure 6 (a), (b)) show the vertical geometry of the existing highway. The differences between the profile data points' heights are given in Figure 7.

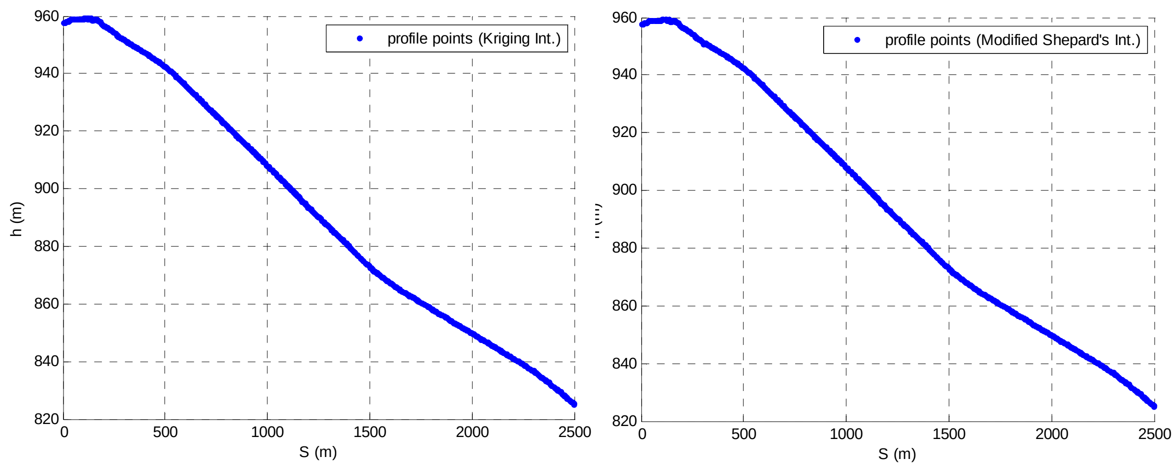


Figure 6. (a) Highway profile obtained by Kriging Int. **(b)** Highway profile obtained by Modified Shepard's Int.

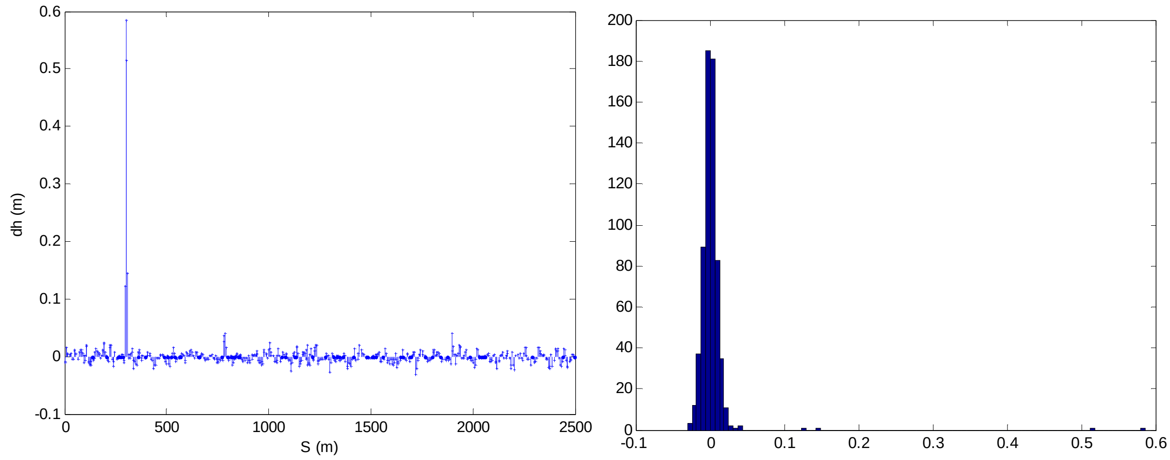


Figure 7. Height differences between Kriging and Mod. Shepard's Int.s and difference histogram

Results about the study and highway profiles were illustrated in Figure 7. According to obtained elevation models, maximum and minimum height's differences between gridding methods of Kriging and Modified Shepard's Method were found 0.5842 m and -0.0318 m, respectively.

3. RESULTS AND CONCLUSION

In this paper, the usage ability of aerial photography and airborne LIDAR data was investigated in the frame of transportation planning and traffic safety controls. In addition, we investigate the gridding size effect on DEM accuracy without any data reduction. DEMs are generated.

As expected, increasing grid size interval influences DEM accuracy: standard deviations are increased as grid sizes are increased (Table 1). As seen in Table 1, the greater grid size gets the bigger standard deviation errors. Between the three interpolation methods, the least standard deviation values for each generated digital elevation models are obtained by the Kriging Interpolation method. Kriging and Modified Shepard's interpolation methods give nearly the same values of standard deviations. The higher values are obtained from Inverse Distance to a power. One can wait that it is nearly a common view that geostatistical interpolation method, Kriging, gives more accurate solutions in generating DEMs. On the other hand, one may think that time could be another decision criteria for choosing the interpolation method. In this point, we recommend that using the Modified Shepard's Method, which is less time consuming in equal conditions. The processing time graphics of the methods can be seen in Figure 5b with grid size.

The adequate gridding size for the dataset was evaluated as 3 m, and sub datasets were produced from 1 m grid resolution to 8 m with 0.5 m increasing rate, and 10 m, 15 m and 30 m. The decision criterion for gridding size was the RMSE values of datasets. We suggested using 8 m resolution. The final product of this study is illustrated in Figure 8. (the 2 dimensional and 3 dimensional views).

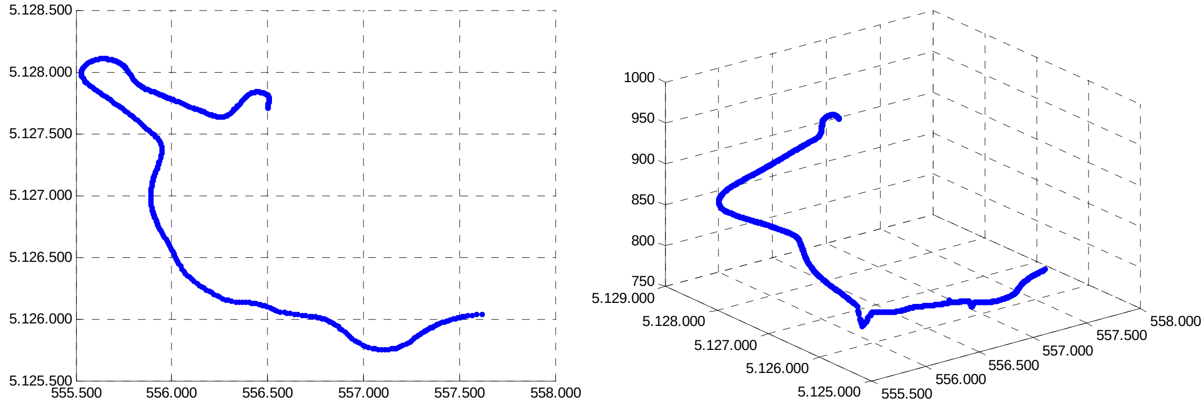


Figure 8. 2D and 3D view of existing highway

LIDAR data based terrain and digital elevation model production has been investigated in several studies. Choosing the modeling procedure, used interpolation models, and grid size selection is crucial for expected accuracy of generated DEMs. Selecting the appropriate gridding size increase the efficiency of data management and storage capacity.

Geometric definition of the highway 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 and related studies.

4. ACKNOWLEDGEMENT

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REFERENCES

Baltsavias, E.P. “Airborne laser scanning: basic relations and formulas”, ISPRS Journal of Photogrammetry & Remote Sensing 54_1999.199–214

Fisher, P. F., Tate, N. J. 2006, “Causes and consequences of error in digital elevation models”, *Progress in Physical Geography*, 30(4), 467-489.

Forlani, G., Nardinocchi, C., 2007, “Adaptive Filtering of Aerial Laser Scanning Data”, ISPRS Workshop on Laser Scanning 2007 and SilviLaser 2007, Espoo, September 12-14, 2007, Finland

Gong, J., Zhilin, L., Zhu, Q., Sui, H.G., Zhou, Y., 2000. “Effect of various factors on the accuracy of DEMs: an intensive experimental investigation”. Photogrammetric Engineering and Remote Sensing 66 (9), 1113–1117.

Hongson, M. E., Bresnahan, P. “Accuracy of Airborne Lidar-Derived Elevation: Empirical Assessment and Error Budget”. *Photogrammetric Engineering & Remote Sensing* **2004**, *70*, 331– 339.

Kienzle, S. 2004. “The effect of DEM raster resolution on first order, second order and compound terrain derivatives”. *Transactions in GIS*, 8(1), 83-111.

Kraus, K., Pfeifer, N. 1998. “Determination of terrain models inwooded areas with airborne laser scanner data. ISPRS, Journal Phtogrammetry and Remote Sensing, Vol:53, pp.193-203.

Li, Z., Zhu, Q., Gold, C. 2005. “Digital Terrain Modeling: Principles and Methodology”. CRC Press, Boca Raton, London, New York, and Washington, D.C.

Means, J.E., Acker, A.A., Fitt, B.J., Renslow, M., Emerson, L., Hendrix, C. 2000. “Predicting forest stand characteristics with airborne scanning Lidar”. Phtotogrammetric engineering & Remote Sensing, Vol.66, No: 11, pp. 1367-1371.

Shamayleh H., Khattak A. 2003. “Utilization of LiDAR Technology for Highway Inventory”. Proceedings of the 2003 Mid-Continent Transportation Research Symposium, Ames, Iowa.

Shrestha, R.L., Carter, W.E., Lee, M., Finer, P., Sartori, M., 1999. “Airborne Laser Swath Mapping: Accuracy Assessment for Surveying and Mapping Applications”. Journal of American Congress on Surveying and Mapping 59 (2), 83– 94.

Souleyrette, R., Hallmark, S., Veneziano, D. 2002. “Comparison of LIDAR and Conventional Mapping Methods for Highway Corridor Studies”. Final Report, October 2002.

Uddin W. 2002. “Evaluation of Airborne LIDAR Digital Terrain Mapping For Highway Corridor Planning and Design”. Pecora 15/Land Satellite Information IV/ISPRS Commission I/FIEOS 2002 Conference Proceedings.

Veneziano D., Hallmark S., Souleyrette R. 2002. “Comparison of LIDAR and Conventional Mapping Methods for Highway Corridor Studies”. Final Report, Centre for Transportation Research and Education, Iowa State University.

Veneziano, D., Souleyrette, R., Hallmark, S. 2002. “Evaluating of Lidar for Highway Planning, Location and Design”. Pecora 15/ Land Satellite Information IV/ ISPRS Commission I/ FIEOS 2002, Conference Proceedings

Wehr A., Lohr U. 1999. “Airborne Laser Scanning—An Introduction and Overview”. ISPRS Journal of Photogrammetry & Remote Sensing 54. 68–82.

Yong, H., 2003, “Automated Extraction of Digital Terrain Models, Roads and Buildings Using Airborne Lidar Data”, Phd Thesis, Department Of Geomatic Engineering, University of Calgary, October 2003

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 areas are highway design, 3D terrain modeling, 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.

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 specialist in Yildiz Technical University since 2004.

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