

APPLICATION OF BREAKLINE AND MANUAL ADDITIONAL POINTS IN TIN MODELING

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ABSTRACT:

The triangular irregular network (TIN) is the most commonly used digital elevation models. However, because there is no boundary information contained in LIDAR data, and the LIDAR dataset contains data gaps where water occurs, TIN modeling will only follow the principles of structure, without using any boundary information. Thus, there will be depiction error in TIN modeling when it comes across some special features. This paper reviews the technique of airborne LiDAR Data Collection and Processing, and the use of LiDAR data for DEM generation, with special focus on method of TIN modeling. Two methods will be used to support TIN modeling, one is integration of the breaklines into TIN modeling, and the other one is integration of manual additional points into TIN modeling. In the experiment, some kinds of features and terrain will be used to analysis the validity and necessity of these methods in supporting TIN modeling.

1. INTRODUCTION

LiDAR is an acronym for Light Detection And Ranging, sometimes also referred to as Laser Altimetry or Airborne Laser Terrain Mapping (ALTM). The LiDAR system basically consists of integration of three technologies, namely, Inertial Navigation System (INS), LASER, and GPS. Advances in airborne LiDAR systems make it possible to acquire high quality terrain data in terms of accuracy and density. Using LiDAR data for DEM generation is becoming a standard practice in spatial related areas.

Digital Elevation Models (DEMs) play an important role in terrain-related applications. Researches on terrain data collection and DEM generation have received great attention. Traditional methods such as field surveying and photogrammetry can yield high-accuracy terrain data, but they are time-consuming and labor-intensive. Moreover, in some situations, for example, in forested areas, it is impossible to use these methods for collecting elevation data. Airborne LiDAR also referred to as Airborne Laser Scanning (ALS), provides an alternative for high-density and high-accuracy three-dimensional terrain point data acquisition. One of the appealing features in the LiDAR output is the direct availability of three dimensional coordinates of points in object space (Habib et al., 2005).LiDAR data have become a major source of digital terrain information (Raber et al., 2007) and has been used in a wide of areas, such as building extraction and 3D urban modeling, hydrological modeling, glacier monitoring, landform or soil classification, river bank or coastal management, and forest management.

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LIDAR dataset contains data gaps where water occurs, TIN modeling will only follow the principles of structure, without using features' boundary information. Thus, there will be depiction error in TIN modeling when it comes across some special features. There are two methods used to support TIN modeling, in the experiment, some kinds of features and terrain are used to analysis the validity and necessity of these methods in supporting TIN modeling.

2. AIRBORNE LIDAR DATA COLLECTION AND PROCESSING

2.1 Data Collection:

LIDAR data collection begins with a well-defined flight plan meeting the project's requirements. The average post-spacing of the points must be at a density to support the level required for a Surface Elevation Model. Changing the flight altitude of the aircraft or the scan angle of the scanner allows for modifying the density of the post-spacing. Urban areas with tall buildings and steep terrain require special consideration to avoid holes in the data. For the kinematic GPS, a base station of known location with a multi-channel GPS must be initialized with the GPS receiver on-board the aircraft. This initialization lock must remain in place during the entire flight. For this reason, very shallow turns are made between flight lines during data acquisition. LIDAR data may be acquired quite rapidly. Since LIDAR is an active illumination system, data can be captured in all 'clear' conditions—day or night. This factor is very useful in taking advantage of good weather conditions and the opportunity to capture data at night in busy air space around airports. As mentioned, most terrain mapping LIDAR systems use a near infrared laser, so pulses hitting standing water are completely absorbed. Upon landing after a mission, the system is de-initialized, and quality assurance of the data begins. Since

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all of the data collected are georeferenced, it can be viewed in-situ using GIS software to verify coverage of the site. Also, to validate the accuracy of the collection, known survey data and a check of the bore site should be completed in-situ. Without proper quality assurance at this phase, the absolute accuracy of the data collected should be suspect.

2.2 Data Processing Workflow

The current workflow for processing the LiDAR data is shown in Figure 1 as sequential tasks optimized to maximize the quality of the final product.

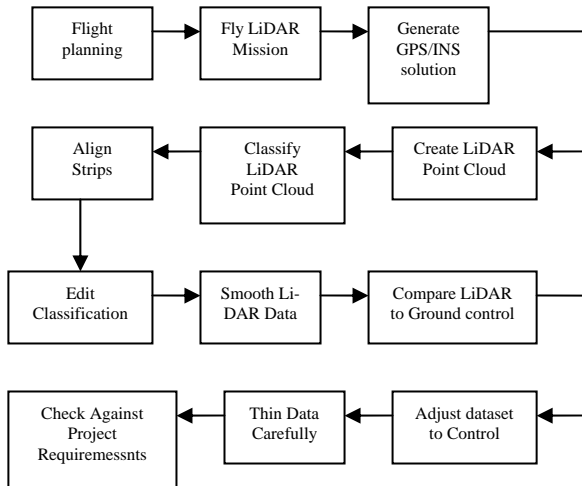


Figure 1. Data Processing Workflow (Eva Paska, 2007)

Datums, Coordinate Systems, and Transformations: To obtain the final product, the process utilizes many software packages during the various procedures. At different stages of the process, coordinate and datum transformations are performed.

Strip Analysis and Alignment: With flying 50% overlap for the design applications, the LiDAR datasets always contain multiple strips even for small jobs. The multiple overlapping strips are analyzed and viewed in GIS software to determine if any vertical discrepancies between the LiDAR strips exist. This procedure is necessary because the data in overlapping areas are used, not discarded.

Classification of LiDAR Points: The point cloud is classified using GIS software with the following classes: ground, vegetation and miscellaneous, water, and bridges. The standard classification routines do a reasonably good job of properly assigning points to the appropriate classification. Note that both the water and the bridges classifications are manually separated. The point classifications are reviewed and edited to correct any noticeable or perceived classification errors.

Smoothing Points: Having the points properly classified. Only the ground classified points are desired in the remainder of the processing to create an existing surface. Smoothing of the points on hard surfaces has a minimal effect on the quality of the end product (Eva Paska, 2007).

Thinning Points: The thinning is performed in GIS software to reduce the size of the files needed to create the end products.

Care must be taken when performing thinning to ensure points necessary to define the surface are not eliminated, otherwise the accuracy will suffer. Thinning can obviously vary depending on the terrain, vegetation, point density and desired outcome which necessitates review of the thinning parameters on a project by project basis.

Adjusting data to the LiDAR control: The remaining points are used to create the TIN which is compared to the LiDAR control points. The analysis of the results enables a comparison between the dataset and the control. Any adjustments to improve the fit to the control are performed and the analysis is run again to ensure the end product meets the required specifications.

3. DEM GENERATING AND MANUAL EDITING

The filtering of off-terrain points from lidar data is a common and necessary step in order to derive a DEM. But a certain filtering method is not able to do the whole job, especially when the terrain is extraordinary complex, so, no automated filter process is 100% accurate. On the other hand, because there is no boundary information for use, the automated model couldn't be exactly accurate to represent the terrain, and the accuracy of DEM will be reduced by a certain degree. To meet the accuracy, manual editing should be taken with the images from high-resolution camera. Different digital elevation models have been developed to represent the terrain surface. The triangular irregular network (TIN) is the most commonly used digital elevation models (Ramirez, 2006). But there is something exceptional when comes across some special features. In this case, TIN creation should incorporate additional information.

3.1 Triangulated Irregular Network

A triangulated irregular network (TIN) is a digital data structure used in a geographic information system (GIS) for the representation of a surface. A TIN is a vector based representation of the physical land surface, made up of irregularly distributed nodes and lines with three dimensional coordinates (x, y, and z) that are arranged in a network of nonoverlapping triangles. An advantage of using a TIN over a DEM in mapping and analysis is that the points of a TIN are distributed variably based on an algorithm that determines which points are most necessary to an accurate representation of the terrain. Data input is therefore flexible and fewer points need to be stored than in a DEM with regularly distributed points. While a TIN may be less suited than a DEM raster for certain kinds of GIS applications, such as analysis of a surface's slope and aspect, TINs have the advantage of being able to portray terrain in three dimensions.

A TIN comprises a triangular network of vertices, known as mass points, with associated coordinates in three dimensions connected by edges to form a triangular tessellation. Three-dimensional visualizations are readily created by rendering of the triangular facets. In regions where there is little variation in surface height, the points may be widely spaced whereas in areas of more intense variation in height the point density is increased. A TIN is typically based on a Delaunay triangulation but its utility will be limited by the selection of input data points: well-chosen points will be located so as to capture significant changes in surface form, such as topographical summits, breaks of slope, ridges, valley floors, pits and cols. Although usually associated with 3-dimensional data (x, y, and z)

and topography, TINs are also useful for the description and analysis of horizontal (x and y) distributions and relationships.

3.2 Rule Of Breakline In Controlling TIN Modeling

Breakline is a feature line or polyline representing a stream channel, ridge or some other feature that you wish to preserve in a TIN. In other words, a breakline is a series of edges that the triangles should conform to. Breaklines can be very useful when trying to eliminate unwanted pits on the interior of a TIN. Breaklines define and control surface behavior in terms of smoothness and continuity. As their name implies, breaklines are linear features. They have a significant effect in terms of describing surface behavior when incorporated in a surface model. Breaklines can describe and enforce a change in the behavior of the surface. Z-values along a breakline can be constant or can vary throughout its length. Two types of breaklines can be employed to describe surface behavior: soft breaklines and hard breaklines. As there is no boundary information contained in LIDAR data, and the LIDAR dataset contains data gaps where water occurs, both soft breaklines and hard breaklines will be very helpful in TIN modeling.

3.2.1 Soft Breakline: Soft breaklines are used to ensure that known z-values along a linear feature are maintained in a TIN. Soft breaklines can also be used to ensure that linear features and polygon edges are maintained in a TIN surface model by enforcing the breakline as TIN edges. However, soft breaklines do not define interruptions in surface smoothness. Here is an example of how the inclusion of a soft breakline can enforce a different surface behavior. Note how the TIN builder has added extra vertices along the breakline to ensure that the line is maintained in the TIN. The z-values for these new nodes have been derived by linear interpolation along the breakline. When the line is enforced as a breakline, the line is maintained in the TIN. Note the z-values of the introduced nodes (see Figure 2). As with all breaklines, soft breaklines can have constant or varying z-values. For example, a section of a constant elevation can be defined as a soft breakline. In contrast, a highway with fluctuating elevation can be incorporated into a TIN surface model as a soft breakline.

3.2.2 Hard breaklines: Hard breaklines define interruptions in surface smoothness. They are probably the most common and easily understood type of a breakline. Hard breaklines are typically used to define streams, ridges, shorelines, building footprints, dams, and other locations of abrupt surface change.

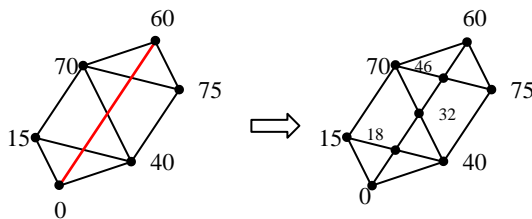


Figure 2. TIN and breakline
(The number means the z-value of discrete points)

3.3 Rule Of Manual Additional Points In Controlling TIN Modeling

Interpolation is one of the core techniques in digital terrain modeling. Interpolation in digital terrain modeling is used to determine the terrain height value of a point by using the known heights of neighbouring points. Two implicit assumptions here are: the terrain surface is continuous and smooth; and there is a high correlation between the neighbouring data points.

The initial LIDAR dataset is irregularly spaced. Regularly spaced Digital Elevation Models (DEMs) may be generated by interpolation between irregularly-spaced mass points that reflect the bare earth elevation where a LIDAR pulse hit the ground. Areas covered by water create natural voids in LIDAR datasets. Other voids are created during processing where LIDAR fails to penetrate dense vegetation. Mass points (points used in defining the tin) plays an important role in TIN modeling as each triangle's surface would be defined by the elevations of the three corner points. There may be something wrong with TIN modeling when come up against voids. Adding some manual points in these areas may do well in TIN modeling. During the modeling newly added points will be used so that the surface can be accurately represented.

The following procedure is the method of integration of manual additional points into TIN modeling:

- 1) Interpolate lattice grids from triangulated surface models;
- 2) Read the lattice grids data into the voids edited, and set a suitable elevation;
- 3) Create TIN with mass point and the newly added points.

4. APPLICATIONS OF BREAKLINE AND MANUAL ADDITIONAL POINTS IN TIN MODELING

4.1 Source Data

The data of this research comes from Leica ALS50-II LIDAR System. Main specifications are contained in the following table.

Specification	Leica ALS50-II
AGL	2000m
AMSL	2050m
FOV	66
Speed	100kts
Pulse Rate	100.1kHz
Scan Rate	26.5Hz
Laser Current	65%
Accuracy	Horizon(0.2-0.27m) Height(0.07-0.14m)

Table 1 Main specifications of Leica ALS50-II LIDAR System

4.2 Application of the two methods

In this portion, several kinds of primary features are researched with breakline and manual additional points in TIN modeling. By comparison, we can see their indispensable function in TIN modeling.

4.2.1 Lake

As mentioned, most terrain mapping LIDAR systems use a near infrared laser, so pulses hitting standing water are completely absorbed. Because the LIDAR dataset contains data gaps where

water occurs, a linear interpolation is performed from points along the shorelines, which leads to an inaccurate representation of the water surface. But not all the points were acquired just on the shorelines. In this case, high and low points will be connected during TIN modeling as a edge of the triangle, and the lake surface will turn out to be a aslant one(see Figure 2 A).

The water edge breakline was used to restrict the effect of bottom elevation points on the TIN to only the area covered by water in the original LIDAR. Some guidance can be obtained by sampling LIDAR elevations near outlet points of the lake. Select appropriate elevations to be coded with the breakline polygons, then create tin with breakline, the new model is shown in Figure 3 B.

Interpolate lattice grids from LiDAR data, and read them into the void area in GIS software. Before modeling, we must fit the points' elevation at a suitable value. Rebuild model with mass point and the newly added point, the new model is shown in Figure 3 C.

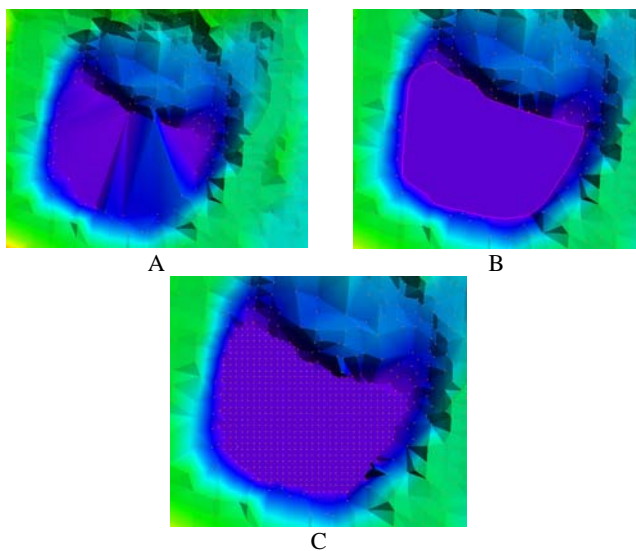


Figure 3 Geometric View of a TIN (A). Geometric View of a TIN Created With breakline (B). Geometric View of a TIN Created With manual additional points (C)

4.2.2 Viaduct

Viaduct should be removed from DEM because that it is not the component of terrain. In certain case, although ground points and non-ground points are classified correctly, there is still something wrong with TIN modeling, and it fails to represent the terrain surface veraciously (see Figure 4 A).

Develop breakline along the edge of road suspended above the terrain, create tin with breakline, the model is shown in Figure 3 C; the model is more approximate to the real terrain.

Because LIDAR points are collected randomly and at an angle, points may appear atop and below viaduct, lattice grids can be interpolated from points collected below viaduct, and read them into the void area in GIS software. Rebuild model with mass point and the newly added point, the model is shown in Figure 4 B.

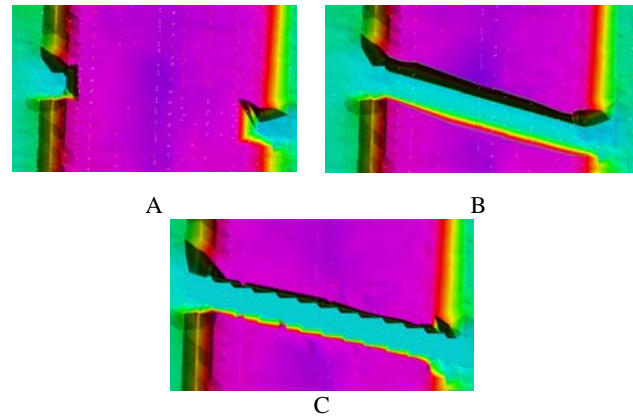


Figure 4 Geometric View of a TIN (A). Geometric View of a TIN Created With breakline (B). Geometric View of a TIN Created With manual additional points (C).

4.2.3 Building

The latest airborne laser scanning technology allows the capture of very dense 3D point clouds from the terrain and surface features, therefore 3D building reconstruction from LiDAR becomes feasible. Building detection or extraction algorithms are used to extract the building boundaries from the laser scanning data. Many researchers are interested in building extraction. There is still room for improvement in automatic building extraction because it is not totally reliable. Here is a TIN model of a building in Figure 5 A, it is very rough and unreliable. In this paper, breakline data is used to avoid the problem. In this example, breakline is the building's boundary digitized from an orthophotograph, and TIN is created using computer software from mass points and three-dimensional (3-D) breaklines. The new model is shown in Figure 5 B.

The LIDAR dataset contains data gaps on a side of a building because that LIDAR points are collected randomly and at an angle. To create an accurate TIN, the void area can be added into some points according to the neighboring points. The new model is shown in Figure 5 C.

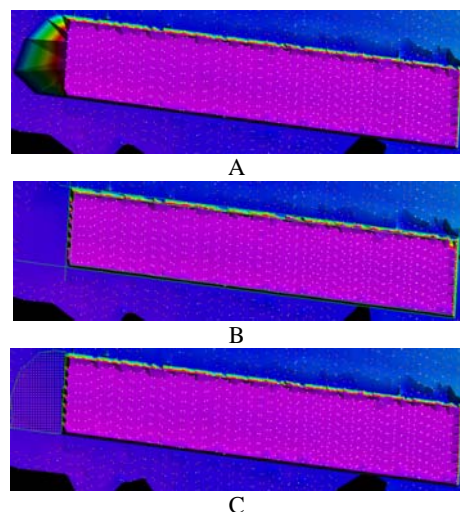


Figure 5 Geometric View of a TIN (A). Geometric View of a TIN Created With breakline (B). Geometric View of a TIN Created With manual additional points (C).

4.2.4 River

In this example, there is something the same with example of Lake. There is also a void area because of water, and then the interpolation and TIN modeling are wrongly executed (see Figure 6 A).

To improve the quality of the TIN, breakline digitized from an orthophotograph is used in TIN modeling(see Figure 6 B).The breakline is three-dimensional(3-D)break lines.3-D breaklines are obtained by assigning z-values to 2-D breaklines using suitable elevation value.

Maybe add points to void areas can help to create an accurate TIN, but, there are numberless void areas in the river, it's time-consuming for us to rectify by this method. So, in this case, the method is not suitable for TIN modeling.

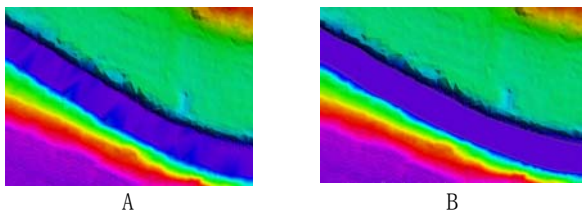


Figure 6 Geometric View of a TIN (A).
Geometric View of a TIN Created With breakline (B).

4.2.5 Ridge

In this example, the density of mass points is high enough to for a tin to represent the ridge.,so it is not suitable to add points manually to mass points in TIN modeling. On the other hand, when incorporate breakline in TIN modeling, there will be some dark triangles in the resulted model, it can't represent the ridge as accurate as the one before (see Figure 7).

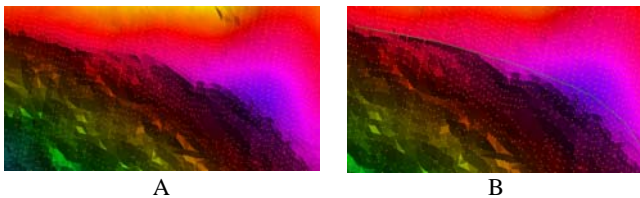


Figure 7 Geometric View of a TIN (A).
Geometric View of a TIN Created With Breakline (B)

5. CONCLUSION

Although DEM generation from LiDAR data has been documented in several papers, due to the specific characteristics of LiDAR data, extensive attention should be paid to issues such as choices of modeling methods. Triangulated Irregular Network (TIN) is a high-effect means expressing the terrain surface in the computer, compared with GRID model, TIN model can use less sampling to approach the terrain surface precisely. The advantages of TIN model in the vertices count can achieve rendering small vertices in terrain visualization. But, there will be depiction error in TIN modeling when it comes across some special features. In this paper, breakline and manual additional points are applied in several kinds of terrain.

The following sentences are the conclusions come from the comparison of the tins created with breakline and manual additional points:

- (1) Extraction and inclusion of critical terrain elements such as breaklines into the generation of a DEM will maintain high level of accuracy.
- (2) LIDAR dataset contains data gaps where water occurs, when interpolation is performed from points along the shorelines, it often leads to an inaccurate representation of the water surface.
- (3) TIN with breakline and manual points can represent terrain better than the tin created only with mass points.
- (4) Because LIDAR points are collected randomly and at an angle, points may appear atop and below viaduct, the points below the viaduct can help develop breaklines so that tin can represent terrain correctly.
- (5) The method adding points to tin is helpful in TIN modeling, but it is only suitable for certain area. In addition, its procedure is very complex and time-consuming.
- (6) The method incorporate breakline in TIN modeling is and helpful for tin to represent terrain, the application of breakline is very flexible.

6. REFERENCES

- Ackermann, F.1999: Airborne laser scanning-present status and future expectations. *ISPRS Journal of Photogrammetry and Remote Sensing* 54(4), 64-67.
- Bjorke, J.T. and Nilsen, S. 2002: Efficient representation of digital terrain models: compression and spatial decorrelation techniques. *Computer and Geosciences* 28,433-445.
- Ahlberg, S., Soderman, U., Elmqvist,M. and Persson, A.2004:On modeling and visualization of high resolution virtual environments using lidar data. *Proceedings of 12th International Conference on Geoinformatics*, Gavle, Sweden, 299-306.
- Ali, T.A.2004: On the selection of an interpolation method for creating a terrain model from LIDAR data. *Proceedings of the American Congress on Surveying and Mapping (ACSM) Conference 2004*, Nashville TN, U.S.A.
- Anderson, E.S., Thompson, J.A. and Austin, R.E.2005a: LiDAR density and linear interpolator effects on elevation estimates. *International Journal of Remote Sensing* 26(18), 3889-3900.
- Barber,C.P. and Shortrudge, A.M.2004: LiDAR-derived Elevation Data for Surface Hydrology Applications. East Lansing, MI, USA: Institute of Water Resource, Michigan State University.
- Briese, C. 2004a: Breakline modeling from airborne laser scanner data, (PhDThesis). Vienna, Austria: Institute of Photogrammetry and Remote Sensing, Vienna University of Technology.
- Brügelmann,R.2000: Automatic breakline detection from airborne laser range data. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences* 33(B3),109-116.

Callow, J.N., van Niel, K.P. and Boggs, G.S. 2007: How does modifying a DEM to reflect known hydrology affect subsequent terrain analysis? *Journal of Hydrology* 332(1-2), 30-39.

Crosilla, F., Visintini, D. and Prearo, G. 2004: A robust method for filtering non-ground measurements from airborne LiDAR data. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences* 35(B3).

Beinat, A., Crosilla, F., Visintini, D., Sepic, F., 2007. Automatic non parametric procedures for terrestrial laser point clouds processing. In: *Proceedings of PIA07 Photogrammetric Image Analysis*, Munich, Germany September 19-21, 2007.