Assimilation of Break line and LiDAR Data within ESRI's Terrain Data Structure (TDS) for creating a Multi-Resolution Terrain Model

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Building a digital terrain model (DTM) from LiDAR data can successfully be performed using a few techniques, but the quality of the resulted model and the way the terrain information is handled during the processing phase remain a challenge. A new framework for creating a DTM from LiDAR data within ArcGIS ® utilizes the new ESRI data structure known as Terrain Data Set (TDS). This article presents a method utilized within the TDS framework to produce a multi-resolution DTM from LiDAR data that incorporates the terrain break lines. The created multi-resolution terrain models allow for explicit, scale-invariant visualization and analysis of the topography in the study area. Creation of terrain models this way allows for efficient storage and management of the terrain information in the geodatabase.

Introduction and background

The latest developments in geospatial engineering allowed for the collection of vast data for accurate topographic mapping purposes. These include air- and space-borne imagery, LiDAR data, sonar data, terrestrial 3D laser scanning data, etc. LiDAR is a topographic data acquisition technology that uses pulses of laser to map the terrain surface. The LiDAR scanner is commonly carried in an aircraft along with units of an Inertial Navigation System (INS) and Global Positioning System (GPS). It works by processing the return time for each returned laser pulse to calculate the distances and further produce three-dimensional positional information for a cloud of points in the mapped area. The LiDAR system has demonstrated its ability to map different types of terrain surfaces including bare ground surface, urban areas, rural areas, or canopy. LiDAR systems can also be used to capture reflectance data in addition to their ability to collect three-dimensional point data (Ali, 2009). Raw LiDAR data are generally stored in generic ASCII files ".xyz or .txt", but now the industry file format-of-choice for the exchange and delivery of LiDAR data is the Log ASCII Standard (LAS) file format ".las", which is more compact and has higher processing performance.

Building a digital representation of the terrain from LiDAR data can successfully be performed using a few commercial software systems. A digital representation can be a raster grid or a Triangular Irregular Network (TIN) model. When building a digital representation of topography from LiDAR data, a few terms can be used to describe the resulted digital model. These include Digital Elevation Model (DEM), Digital Surface Model (DSM), and Digital Terrain Model (DTM). The DEM is any digital representation of terrain. The DSM is a first surface view of the earth's surface. The DTM is a representation of the bare earth surface, which is obtained by removing all of manmade features inherent to a DSM by exposing the underlying terrain.

The digital elevation model (DEM) is a grid-based representation of the spot heights of the terrain surface. This model is the simplest and most common form of digital representation of the terrain. The DEM has a data structure similar to that of a digital imagery, and the cell size or the resolution of a DEM is very critical parameter in identifying the faithfulness of depicting the terrain surface. High-resolution DEM is always desirable, but is more crucial when a rugged terrain is modeled. The irregularly spaced points of the TIN model can provide a more faithful representation of the terrain surface with more points in rugged terrain areas and less points in relatively flat areas. The TIN model suits visualization purposes because of the continuous nature the triangular facets of the model add to the digital representation (Ali and Mehrabian, 2008). In a TIN model, the sample points are simply connected by lines to form triangles, which are represented by planes, which give continuous representation of the terrain surface. Creating a TIN, despite its simplicity requires decisions about how to pick the sample points from the original data set, and further how to triangulate it. When it comes to triangulating the sample points, a few triangulation methods are available for producing a TIN model (Ali, 2004). Among the existing triangulation methods that are in use is the Delaunay Triangulation (DT), which is very common and popular for its rigorous structure although it produces triangles that are not hierarchical (Fowler and Little, 1979).

Breaklines represent significant topographic changes in the terrain slope and they can be natural (hydrographic features, water bodies, etc) or manmade (roads, overpasses, etc). Break lines data are essential not only for terrain modeling, but also for base mapping and GIS operations. A vigorous LiDAR-based terrain model would have break lines integrated in it. When LiDAR data is used to build a terrain model, breaklines will complement the LiDAR mass points by representing the topographic breaks in the terrain model. Compiling of breaklines is a major component of any terrain modeling project and it can be a time consuming and therefore very costly. Traditionally breaklines are acquired from orthophotos using photogrammteric techniques. Some techniques also have been developed to extract breaklines from LiDAR data (Brugelmann, 2000; Briese, 2004; Yokoyama and Chikatsu, 2006). A robust method for acquiring breaklines has emerged recently, and it fuses orthophotos and LiDAR data.

Methodology

The general procedure for building a DTM from LiDAR data by utilizing methods other than the ESRI ® data structure known as Terrain Data Set (TDS) starts by reading-in the LiDAR mass points files for all tiles necessary for the study area, merging of the tiles to create a continuous non-overlapping data coverage, and interpolating the mass points into a raster grid-based terrain model. In these methods, before breaklines data can be integrated into the DTM, the raster terrain model needs to be converted into a TIN model before a final DTM can be built. The main challenges of these methods include: (a) the interpolation process is very time consuming if the processors don't crash before finishing the process, (b) the process of converting raster model into a TIN model is also time consuming, and (c) every time a breakline feature is integrated into the TIN model, the TIN model needs to be updated and therefore this processing phase becomes the most time-consuming and most processors either freeze or crash before the processing is complete. Unlike these methods, the TDS method incorporates the LiDAR and breaklines data into a geodatabase before a TIN-based terrain model is created, and then a raster DTM that integrates breaklines can be extracted at the application appropriate resolution. The general workflow for the TDS method is illustrated in Figure 1 below.

The TDS method, which was released by ESRI with ArcGIS 9.2 was used to build the DTM from LiDAR data with the breaklines integrated in it. The TDS resides inside feature datasets in ESRI geo-databases, which may include break lines features that can participate in the TDS; enabling for robust terrain surface modeling. One of the primary benefits of creating terrain surface using TDS is the ability to manage vector-based terrain information in the geo-database. Size limits for terrains is two gigabytes in personal geo-databases (pGDB) and one terabyte in file geo-database (fGDB). Size limits for a TIN model is 15 to 20 million nodes with 32 bit processing. Size limits for raster grids is about 4x4 million cells. TDS has participating feature classes and rules that are similar to those of topology used with vector GIS. The workflow for creating a TDS-based terrain model that integrates breaklines within ArcGIS are as follows:

(a) Creation of a file-based geodatabase,
(b) Creation of feature classes for the breaklines,
(c) Importing of the breaklines into the file geodatabase as feature classes,
(d) Building of the terrain, and
(e) Extraction of the raster-based model from the terrain model.

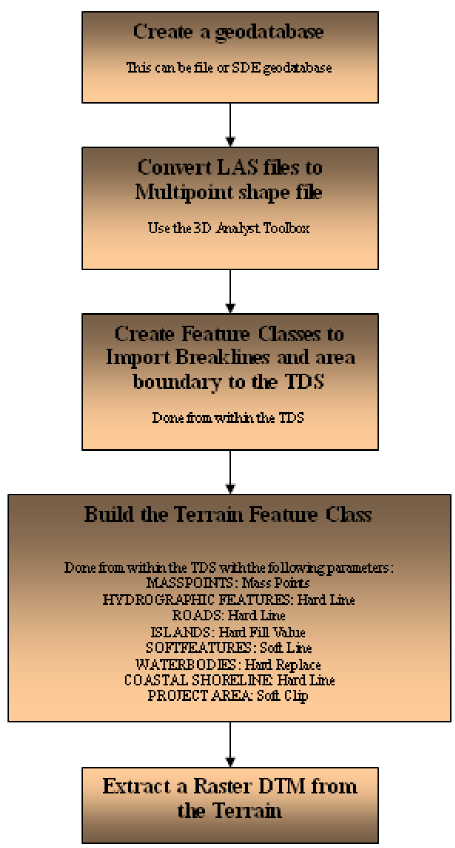

Figure 1: The workflow for building a DTM from LiDAR and Breaklines data using ArcGIS 9.2 TDS method

Study area and data description

The study area is a 2.82x2.82 miles section located east of the Town of Bayshore Garden in southwest Manatee County, Florida (Figure 1). The LiDAR dataset were produced in 2005 for the Southwest Florida Water Management District (SWFWMD) as part of the Manatee/Little Manatee LiDAR Survey project, which consists of approximately 176 square miles. The Southwest Florida Water management District uses topographic information to support regulatory, land management and acquisition, planning, engineering, and habitat restoration projects. The data set comprised of 3-D bare earth mass points delivered in the LAS file format based upon the District's 5,000' x 5,000' grid structure. The LiDAR point cloud was collected using a Leica LS-50 LiDAR system integrated with an inertial measuring unit (IMU) and a dual frequency GPS receiver. Positional accuracy is 0.75-ft root mean square (RMSE), which satisfies the National Standard for Spatial Data Accuracy (NSSDA) standard for 2-foot contours (scale of 1:12,000). Bare earth LiDAR masspoint data display a vertical accuracy of 0.3-feet root mean square (RMSE) in open and unobscured areas with standard reflective quality. Projected Coordinate System is North American Datum (NAD) of 1983; State Plane System of Florida West and the Vertical datum is the North American Vertical Datum (NAVD) of 1988. The breaklines data for the study area was produced by fusing orthophotos and LiDAR data using photogrammetric techniques. Breaklines data layers available for the study area include: hydrographic features, roads, overpasses, islands, waterbodies, and soft features. Breaklines data has average vertical accuracy of 0.65-ft, which is lower than that of the LiDAR data.

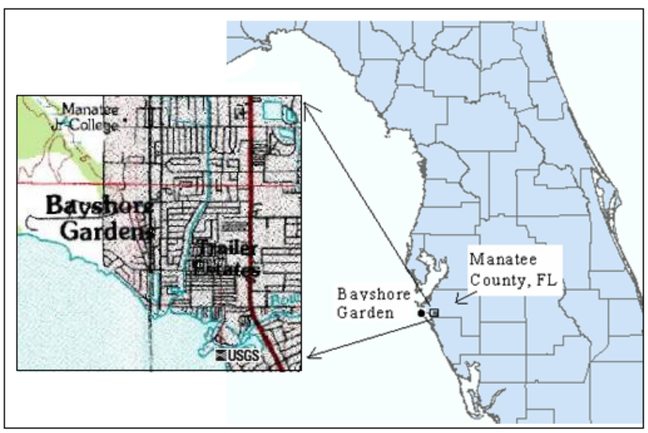

Figure 1: Study area

Results and Analysis

Normally, two factors influence the decision on the appropriate number of multi-resolution terrain representations in an area: the scale range and the shape of the terrain. Having this in mind and knowing that the study area is generally flat, a two-resolution terrain model was built at 1:12,000 and 1:18,000 scales respectively using the pyramids function of the TDS method (Figure 2). The quality of the TDM is determined by the value of the vertical residuals, which is relative to the accuracy of the source data including LiDAR and break line data used to create the TDS. For example, if the LiDAR data has a known vertical accuracy of a value say; x feet, then the absolute accuracy of the first multi-resolution layer will be equal to nx feet, where n is a real number that is larger than 1 (Ali, 2009).

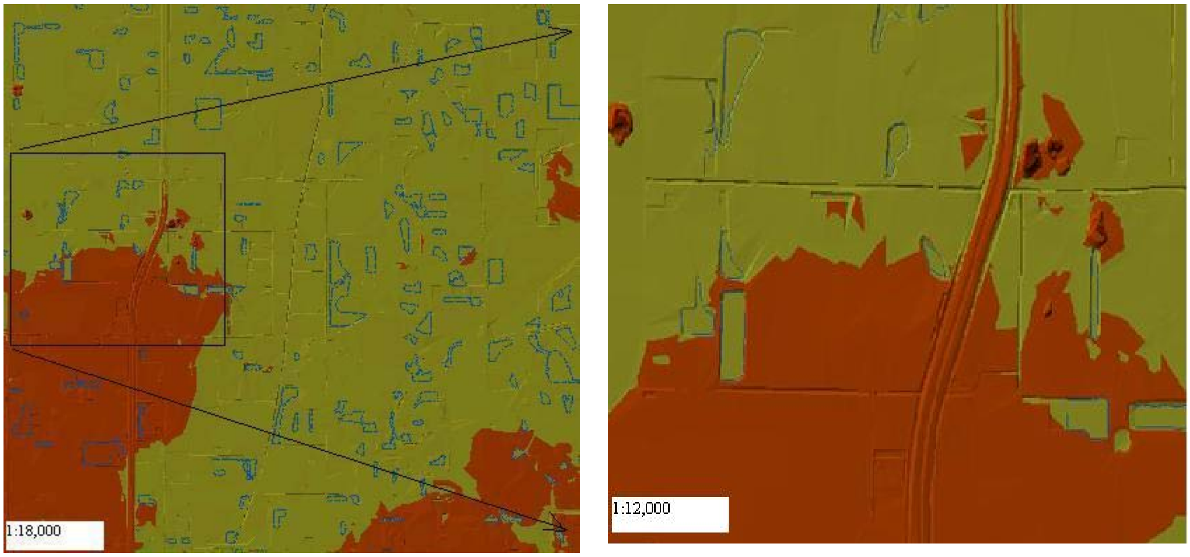

Figure 2: The two-resolution terrain model created for the study area

Accuracy testing guidelines of the Spatial Data Transfer Standard (SDTS) states that “accuracy testing by an independent source of higher accuracy is the preferred test for accuracy. Vertical accuracy shall be tested by comparing the elevations in the dataset with elevations of the same points as determined from an independent source of higher accuracy. A minimum of 20 checkpoints shall be tested, distributed to reflect the geographic area of interest and the distribution of error in the dataset”. This standard uses the Root Mean Square Error ($RMSE_z$) of the elevations of the checkpoints. To compute the vertical accuracy of the two-resolution DTM, 20 check points were used of which 12 were part of the LiDAR data acquisition control network, but eight more points were located using differential GPS (DGPS) utilizing a Topocon® Hiperlite+ GPS (base + rover). The $RMSE_z$ values obtained for the original and the two-resolution DTMs produced in this study using the checkpoints were 1.23-ft and 1.44-feet respectively. These are within the limits of the $RMSE_z$ values identified in the National Standard for Spatial Data Accuracy (NSSDA) given their corresponding scales (FGDC, 1998).

Conclusion

The new framework for creating a DTM from LiDAR data within ArcGIS®, which utilizes the ESRI data structure known as Terrain Data Set (TDS) was used to create a multi-resolution terrain model that integrates breaklines and LiDAR data. The two-resolution terrain model built herein, which conforms to the mapping standards, offers explicit, scale-invariant visualization and analysis in the study area. Multi-resolution terrain models created using the TDS method allow for efficient storage and management of the terrain information in the geodatabase. Editing and updating of the terrain model when adding or deleting a breakline data layer, is therefore straightforward and inexpensive process.

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