**ANNOTATED BIBLIOGRAPHY**

**FILTERING**


Presents methods and algorithms for filtering laser scanner data based on elevation values. Classification is based on user defined slope thresholds; Minimum Description Length criterion. Recommends incorporating number of returns and reflectance values to improve filter performance.


Introduces a filtering algorithm based on densifying a Triangular Irregular Network (TIN).


Presents an approach based on a multiple pass classification process on a regular grid. The classification divides laser points in three main classes: ground, low non-ground, and non-ground. The initial estimation is the input for a deformable model algorithm.


Present a progressive morphological filter adaptive to local slope.


Present an automated method to classify LiDAR points as ground or non-ground using an iterative multi-scale algorithm. The method was applied to data representing a heavily forested area with complex terrain.


The authors investigate a despike algorithm that classifies return as ground and non-ground on the basis of the geometry of the surface in the neighborhood of each return. The laser-return is represented as TIN constructed from discrete returns. The despike algorithm can work with first, last, or multiple returns; this paper used only last return. Breaklines can be included in the surface model.


The authors introduce a filtering and interpolation method to classify lidar data points into terrain and off-terrain points. The algorithm is based on linear prediction.

The authors present modification to a previously developed algorithm. In addition, methods are described to derive 3D breaklines from the lidar point cloud.


A review LiDAR filtering methods, interpolation, and issues around resolution and DEM generation.


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A review LiDAR filtering methods and discussion of critical issues for the development and application of LiDAR ground filtering algorithms.


Describes an algorithm to identify and then classify LiDAR points as ground points. A ground surface is approximated using local regression criterion. LiDAR points are classified as ground on the basis of vertical distance from the approximated surface meeting threshold criterion.


A model-based approach is described in which multi-scale gradient of the surface is computed and used to adaptively erode gridded LiDAR data with the multi-scale Hermite transform (MHT).


Describes modifications to an existing slope-based filtering algorithm to overcome limitations on slope thresholds.


A review of LiDAR filtering algorithms.


A review of LiDAR filtering algorithms.

The paper presents an approach to filtering point clouds using scan line segmentation with multiple orientations. The segment-based classification preserves discontinuities in the bare Earth surface but the detection of vegetation in sloped terrain is problematic.


Presents a filtering approach based on the rasterization of data points. The algorithm consists of a hierarchical approach combined with a weighting function. The weighting function considers terrain shape in conjunction with point distribution within a raster element.


Presents a filtering method based on height differences. Acceptable height difference between two points is defined as a function of the distance between the points.


A morphological filtering approach is presented that uses the first return of a LiDAR pulse as a factor in selecting ground points. The assumption is that geomorphology can be predicted from vegetation. The elevation difference between approximated surface of the first and last returns is used as a threshold.


The authors developed a progressive morphological filter that uses variable opening operations and elevation difference thresholds.


The authors compare the elevation threshold with expanding window (ETEW), maximum local slope (MLS), and progressive morphological (PM) filters for removing non-ground points from airborne laser scanning data.

**Filter Enhancement**

The authors combine lidar intensity data and optical images to generate a Hybrid Normalized Difference Vegetation Index (HNDVI). The vegetation mask is used in adapting the window size of a morphological-based filtering algorithm.


Introduces an algorithm that incorporates intensity information and distribution of multiple echoes into an adaptive weight and iterative filtering process.


Demonstrates that intensity values for the same material/surface yields different values and normalization improves results where intensity is used for segmentation or classification.


The authors classified ground and non-ground points in a LIDAR point cloud with statistical measures skewness and kurtosis of the intensity data values.


The authors use the full waveform of backscattered signal to assign a-priori point weights based on echo width.


The authors use image segmentation to classify LiDAR data as terrain, buildings, and vegetation using height differences only. The classification is refined (e.g., classify noise and data gaps) and a final local analysis is preformed on each grid cell to lable raw data points inferred by the classification.


An existing vegetation point removal algorithm is used, adjusting the parameters based on presence of vegetation land cover types. Vegetation is classified from the lidar dataset.

An approach to estimate bald-earth surfaces from LiDAR data by including independently measured breaklines and surface categories derived from statistics on individual LiDAR points, curvature, and slope.


The authors present a new methodology to identify ground points based on vegetation classification derived from LiDAR intensity and Gaussian distribution of LiDAR elevations.

**GENERALIZATION**


Describes application of genetic algorithm to reduce stream channel cross section data for use in 1-D hydraulic flow and sediment transport models. Compares the process to the “standard procedure” used by Barton et al. (2004).


Describes application of genetic algorithm to the decimation of LiDAR and bathymetric data. Compares the process to the automatic point selection procedure developed by Chen and Guevara (1987) and LATTICETIN, an implementation ArcInfo to generate a triangulated irregular network (TIN) from a regularized grid (DEM).


Present an algorithm aimed at reducing the number of points in a TIN. The algorithm is implemented in C+ using ArcObjects and ArcGIS extenstions 3D and Spatial Analyst.


A TIN refinement approach to reduce the number of data points in a surface model is presented that uses a filtered DTM as opposed to the original point cloud. Starting from a few known terrain points new points are added based on certain distances from the triangulated surface.

**INTERPOLATION**


Presents a scalable algorithm for a grid digital elevation model from datasets acquired by LiDAR.

The authors identified common problems in applying regularized spline with tension smoothing (RST) interpolation method on a variety of terrains.


The authors tested inverse weighting (IDW) and regularized spline with tension smoothing (RST).


The authors quantify the effects of topography and data density on DEM accuracy derived from natural neighbor (NN), inverse distance weighted (IDW), triangulated irregular network (TIN), spline, ordinary kriging (OK), and universal kriging (UK).


The authors investigate the application of the spline approximation to smooth surface and reduce noise in lidar-based digital elevation models. Topographic parameters (slope and curvature) are simultaneously computed to extract dune crests.

BREAKLINE DETECTION


Presents an approach of generating b-spline surfaces as an analysis grid to identify breaklines and introduces the idea to use an interpolation scheme to generate smooth breaklines.


Presents case study of terrain feature detection based on slope analysis to identify breaklines. Slope analysis is performed on a regular grid digital terrain model (DTM) to generate breakpoints. An interpolation scheme is applied to generate breakline points. The breakline points are interpolated to create breaklines.

Presents a fully automated procedure for extracting breaklines from LIDAR data using ground return point cloud. Contract the approach to deriving breaklines from regular grids and raster-based operations previously reported semi-automated procedures (Briese 2004a, 2004b).


The authors assess various procedures for automatic extraction of breaklines from an elevation grid.

**DATA QUALITY AND ERROR ASSESSMENT**


The paper explores the effects of terrain morphology, sampling density and interpolation methods for scattered sample data on the accuracy of interpolated heights in grid DEMs. The objective was to identify empirical relationships between interpolation RMSE and variables such as terrain ruggedness, sampling density, and interpolation method.


The paper presents a methodology for modeling error in LiDAR-derived DEMs. The objective was to develop an empirical basis for the selection of point density in order to optimize survey effort.


Evaluates the accuracy of a LiDAR dataset in representing topography along a stream corridor relative to various terrain components and cover types.


The study explored effects of LiDAR point density on DEM accuracy.


The study explored effects of LiDAR point density on DEM accuracy relative to HEC-RAS modeling results.
SOFTWARE AND TOOLS


Describes the LiDAR point cloud filtering algorithm implemented in GRASS, draws comparison with algorithms developed by Axelsson (1999) and implemented in Terrascan, a proprietary software.


Describes the development and capabilities of Tiffs: Toolbox for LiDAR Data Filtering and Forest Studies, a software for processing LiDAR data to extract bare earth and forest structure information.


The authors describe TIN processing using Surfling software.


Describes tools for processing mass points into digital elevation models.


Describes an algorithm that uses elevation information from points within a user-specified search radius and outputs a grid with minimum, maximum, mean, and inverse distance weighted mean of local points, and number of points within the search radius. The DEM products are complementary to outputs of the regularized spline with tension interpolation algorithm.


The authors assess algorithms implemented in various software tools used to classify LiDAR data. Software assessed includes: Terrasolid (TerraScan), TLID, SAGA GIS, Canopy Fuel Estimator (CFE).


The authors describe algorithms and software routines for extracting shoreline features from imagery and LiDAR data. The algorithms are implemented using C++ programming language and available functions in ArcGIS.
FUSION user manual.

The authors describe the application of BCAL Lidar Tools extension.

The software program ALDPAT is described. ALDPAT implements a variety of automated filtering methods (Elevation Threshold with Expand Filter Window (ETEW), Progressive Morphology (PM) Filter, 2D Morphological filters, Maximum Local Slope (MLS), Iterative Polynomial Fitting (IPF), and Adaptive TIN (ATIN)) along with manual point extraction tools.

Describes the development and capabilities of Merrick Advanced Remote Sensing (MARS) software application.

TerraSolid’s TerraScan user guide.

Investigates and compares the accuracy of the Boise Center Aerospace Laboratory LiDAR (BCAL) algorithms and the Multiscale Curvature Classification LiDAE algorithm developed at the Moscow Forestry Sciences Laboratory of the USFS Rocky Mountain Research Station.

SCOP ++ user manual.

ALDPAT user manual.