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Automatic Road Extraction from Airborne LiDAR : A Review

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ABSTRACT
LiDAR is the powerful Remote Sensing Technology for the acquisition of 3D information from terrain surface. This paper surveys the state of the art on automated road feature extraction from airborne Light Detection and Ranging (LiDAR) data. It presents a bibliography of nearly 50 references related to this topic. This includes work related to various main approaches used for extracting road from LiDAR data, Feature extraction based on classification and filtering.
***Keywords* –** LIDAR, Road Extraction, Classification, Filtering, Digital Elevation Model

I. INTRODUCTION

Road Extraction from remotely sensed data is very challenging issue and has been approached in many different ways by photogrammetric and digital image processor. [1] Roads have long been important for development and prosperity and are essential for many applications such as urban and rural planning, transportation management, vehicle navigation, emergency response, etc. Often, road database is generated through field surveys with the help of GPS (Global Positioning System) enabled instruments. This approach of road extraction, however, is time consuming and labour intensive. With increase in availability of satellite imagery both in high and low resolutions, automatic road network extraction from satellite imagery has received considerable attention and has been studied extensively since 1970s. Since road region appear as linear segment in low resolution images, earlier research on road extraction focused on extracting road center-line from low resolution images. On the other hand, high resolution satellite images provide an opportunity to extract entire road area, which are particularly useful for vehicle navigation, along with road network. LiDAR (Light Detection and Ranging) has become reliable technique for collection of terrain and non-terrain features from the earth surface. LiDAR system consist of laser scanner, Direct Georeferencing(Direct measurement of the sensor positions X,Y,Z and orientation with respect to ground) ,GPS(Global Positioning System) [2]. Characteristics of LIDAR data include Discrete LIDAR returns, Full waveform LIDAR and LIDAR intensity. Data collection vendors deliver LIDAR data according to user specification (ASCII text file, LAS binary file etc.) [3]. Using this technology we can obtain 3D information very quickly. This paper only focuses on various methods related to road extraction from airborne LIDAR point clouds, and general approaches used for processing of LIDAR data for Road extraction

Paper is divided into 4 sections. Section 2 discusses general algorithms used for road extraction from LIDAR data. Section 3 discusses feature extraction based on classification. Section 4 and 5 shows survey based on filtering and finally section 6 shows summary on surveyed techniques and how road detection works for LIDAR data.

II. RELATED SURVEY BASED ON GENERAL ALGORITHM OF ROAD EXTRACTION.

The road network is an essential geographic information system (GIS) layer in applications such as urban and rural planning, transportation management, vehicle navigation, emergency response, etc. Extraction of curvilinear features, linear features has been a popular research topic in Computer vision and Remote Sensing communities. There are several recent algorithms available that makes the use of Airborne LIDAR data for road feature extraction.

Existing airborne LIDAR technology needs a large amount of work in post processing stage. Most of the existing algorithms use some basic methods, but some of which have no definitive boundaries until they are not used in specific processing procedures. [4] Hu X. et al. (2014) [5] proposed a method which detects road centrelines from airborne LIDAR data which consist of three steps spatial clustering based on multiple features using an adaptive mean shift method to detect center point of roads, Stick Tensor Voting to enhance salient linear features and weighted Hough Transform to extract the arc primitives of road centrelines. They denote their as Mean Shift, Tensor Voting, Hough Transform. They applied their method on two different datasets.

Yuan Wang et al. (2013) [6] developed a method using morphological operation which extracts road from airborne LIDAR data. Firstly, they segmented ground points from raw LIDAR data by morphological operation where selection of window size and elevation threshold were important to prevent over segmentation, then using intensity constraint and local point density and region area constraint, and so on candidate road points were selected from ground points. Thirdly, morphological opening operation and closing operation were used to process the candidate road points segmented from above steps. The opening operation may effectively filter the noise areas, and greatly maintain the road detail. The closing operation may fill the small holes within the road, connecting nearby roads, and smoothing the road boundary, without signification area change. The result shows that the proposed method can automatically extract road from airborne LiDAR data with higher efficiency and precision.

Jiaping Zhao et al. (2012) [7] presented a novel approach to extract road network from LIDAR data. After separating ground and non ground parts, buildings and trees were distinguished in energy minimization framework. They designed structure templates to search roads on ground intensity images; road width and orientation were determined by subsequent voting system. A scene dependant Markov Network was constructed for pruning false positives and infers undetected roads. Li hui-ying (2012) [1] proposed a Hierarchical algorithm for DTM generation to extract terrain point from LIDAR data. They stratified raw point cloud according the height, then judged terrain and non terrain points by connectivity. Road networks were identified by morphological characteristic of the network structure with long continuous strip, intensity information and elevation information.

Peng Jiangui et al. (2011) [8] proposed a method from main road extraction from LIDAR data. Firstly, they applied adaptive TIN (Triangular Irregular Network) for ground and non ground classification. Intensity information was used to find out candidate road points and non-road points. Lastly, they constructed constrained Delaunay TIN candidate road points to improve accuracy of classification and road counters are extracted from road points image. Experimental results show that the method can extract the main road of urban area effectively. Jiaping Zhao et al. (2011) [9] described unsupervised approach for extraction of grid structured urban road from LIDAR data. Ground-height mask was produced by removing elevated objects by depth images, then by mask superimposed intensity image road features are segmented out by EM algorithm. From segmented image they used total least square line fitting approach and developed new Radius- rotating method to detect road intersections. To evaluate the reliability of each road segment they developed a direction based cumulative voting technique.

Cjuoreng Wang et al. (2011) [10] extracted 3D road information from fusion of LIDAR and Arial imagery. After preprocessing both LIDAR data and arial imagery, in order to obtained spectral data and to classify LIDAR data with high accuracy data extraction procedure was employed which extracts the converted pixel values of arial image to LIDAR data. Then improved mean shift algorithm was employed to classify LIDAR data fused with spectrum attribute into groups by kinds of features such as buildings, roads, vegetation etc. Liang Gong et al. (2010) [11] used the same fusion approach and extracted road information from LIDAR intensity and arial photo and applied clustering method for extraction but while fusing spectrum information of arial image large error points were removed but point cloud of road keep down. Yue Zuo et al. (2010) [12] fused LIDAR data with passive imagery and explored the impact of land use on the accuracy of derived road network.

F. Samadzadegan et al (2009) [13] proposed a method which is based on combination of multiple classifiers for achieving best accuracy for extracting road feature. They fused majority voting and selective Naïve Bayes classifiers. Q Zhu et al. (2009) [14] used approach of segmenting data based on edge and region properties and extracted roads by hypothesis testing. They formulated road extraction as minimum cover problem whose approximate solution can be computed efficiently. Poonam Tiwari et al (2009) [15] explored methodology of semiautomatic extraction of urban roads. Their integrated approach of ALS altimetry and high resolution data has been used to extract road and differentiate them from flyovers. They used Object oriented fuzzy rule approach which classifies roads from high resolution satellite images. The results show that an integration of LiDAR data and IKONOS data gives better accuracy for automatic road extraction.

Jiangtao Li et al (2008) [16] developed a novel algorithm to extract road points from massive LIDAR data based on intensity and height information. First the robustness of the sequential algorithm has been verified with real data points then a parallel algorithm has been developed by applying smart area partitioning. The performance of a parallel algorithm showed us a close linear speedup with the use of up to four processors. Poullis C. et al. (2008) [17] presented vision based system for automatic detection and extraction of complex road networks. They proposed an integrated system that merges the power of perceptual grouping theory (Gabor filtering, tensor voting) and optimized segmentation techniques (global optimization using graph-cuts) into a unified framework to address the challenging problems of geospatial feature detection and classification W.A. Harvey et al. (2008) [18] co-registered airborne LIDAR and multispectral source for evaluation and extrapolation of road surface and centreline within a commercial road network extraction system. Incorporating co-registered LIDAR permits direct elevation determination and is less sensitive to occlusions and multi-image matching errors. They described results in detection and delineation of road networks using co-registered LIDAR MSS. This approach improved road network accuracy and completeness in complex urban area.

Yun-Woong Choi et al. (2007) [19] proposed a novel method to extract urban road network from 3D LIDAR data. This method has used height and reflectance of LIDAR data and cluster road point information. Geometric information of road is also used to extract road point group correctly. Simon Clode et al. (2007) [20] presented a method which has been used for detection and vectorization of roads from LIDAR data. The method uses hierarchical classification for technique to classify road and non-road points. The resultant binary classification is then vectorized by convolving a complex-valued disk named the Phase Coded Disk (PCD) with the image to provide three separate pieces of information about the road. The centerline and width of the road are obtained from the resultant magnitude image while the direction is determined from the corresponding phase image, thus completing the vectorized road model.

Kong-Hyun Yun et al. (2006) [21] presented a road boundary extraction technique that combines information from aerial color image and LIDAR data. They have removed shadow effect and extracted road boundary from the image. First, the shadow regions of the aerial color image are precisely located using LIDAR DSM (Digital Surface Model) and solar positions. Second, shadow regions assumed as road are corrected by shadow path reconstruction algorithms. After that, road boundary extraction is implemented by segmentation, edge detection, and edge linking method. Finally, road boundary lines are extracted as vector data by vectorization technique. For the purpose of terrain surface visualization Nizar Abo Akel et al. (2005) [22] used generalization (reducing details while enhancing important features at the same time) and enhancement of topographic objects like dams, roads etc. An algorithm for the extraction of roads is developed and is followed by a generalization algorithm that weights together road networks and filtered LiDAR point clouds. Clode et al. (2004) [23] used hierarchical classification technique followed by DTM generation by successive morphological openings with different structuring element sizes.

III. SURVEY BASED ON CLASSIFICATION

Classification is used to discriminate among the several categories of ground objects such as roads, buildings, vegetation etc. to group into different classes of clusters by applying various pattern recognition algorithms, such as bayes classifiers, k-means, ISODATA by Elberink and Maas, (2000) [24]; Song et al., (2002)[25]; Alharthy and Bethel (2003) [26].

Cheng-Kai Wang et al (2014) [27] demonstrated a study of using dual-wavelength airborne LIDAR data to classify the land cover. Based on major features of the LIDAR data for land cover such as surface height, echo width, and dual wavelength amplitude, a support vector machine was used to classify six types of suburban land cover road and gravel, bare soil, low vegetation, high vegetation, roofs, and water bodies. Jixian Zhang et al. (2013) [28] proposed object based classification method for classifying airborne LIDAR point cloud in urban areas. In the process of classification, the surface growing algorithm is employed to make clustering of the point clouds without outliers, thirteen features of the geometry, radiometry, topology and echo characteristics are calculated, a support vector machine (SVM) is utilized to classify the segments, and connected component analysis for 3D point clouds is proposed to optimize the original classification results.

Nagwa El-Ashmawy et al. (2011) [29] investigated and evaluated different image classification technique for the use of LIDAR intensity data for land cover classification. The two techniques were proposed by them are a) Maximum likelihood classifier used as pixel-based classification technique and b) Image segmentation used as object based classification technique an overall accuracy of 63.5% can be achieved using the pixel-based classification technique. The overall accuracy of the results is improved to 68% using the object based classification technique. M. Salah et al. (2009) [30] presented a work on development of feature extraction from MSS and LIDAR data. They have filtered LIDAR point cloud to generate DTM using linear first order equation then DSM and nDSM were generated. After that a total of 22 uncorrelated feature attributes have been generated from the aerial images, the lidar intensity image, DSM and nDSM. The attributes include those derived from the Grey Level Co-occurrence Matrix (GLCM), Normalized Difference Vegetation Indices(NDVI) and slope. Finally, a SOM was used to detect buildings, trees, roads and grass from the aerial image, LIDAR data and the generated attributes.

A new strategy for automatic terrain extraction was presented by Yu-Chuan Chang et al. (2008) [31] which was based on the sudden elevation changes, occlusion detection, false hypothesis removal based on plane fitting and statistical filtering and then classification of original LIDAR points into ground and non-ground points.A.S. Antonarakis et al. (2008) [32] proposed supervised classification method which is based on the point distribution frequency criteria to differentiate between land cover types. George Sithole et al. (2005) [33] filtered airborne LIDAR point cloud based on smooth segmentation.

IV. SURVEY BASED ON FILTERING

Filtering generally means removing unwanted particles, or finding ground surface from mixture of ground and non ground points To distinguish points located on buildings and tree canopies from those that are expected to be on the ground, order statistics and morphological filters or weighting functions are often applied [3] by Wang et al. (2001) [34]; Tao et al. (2001) [35]; Fraser and Jonas, (2001) [36]; Wack and Wimmer, (2002) [37]. In [37] George Sithole et al (2004) analysed filter performance both qualitatively and quantitatively.

Xiangguo Lin et al (2014) [38] proposed segmentation based filtering method which is composed of three steps ,point cloud segmentation, multiple echo analysis, and iterative judgement based on classic progressive TIN densification method (PTD). Yilong Lu and Xinyuan Lin (2012) [39] studied progressive morphological filtering and its parametric performance in removing unwanted LIDAR measurement. Thomus J. Pingel et al. (2013) [40] applied Simple Morphological Filter (SMRF) for terrain classification. Qi Chen et al. (2007) [41] also used morphological filtering for the same.

One representative sample of the segmentation-based filtering method is presented by Sithole and Vosselman [42]. They partitioned the data into continuous profiles with different orientations. Based on certain criteria, points on a profile are connected as line segments. And by comparing the common points of the line segments from all profiles, the whole segments of the data can be generated.

Roggero [43] proposed the segmentation method by region growing and major elements analysis based on the laser scanning data. Akel [44] interpolated the raw LiDAR data into rasterized grids and constituted a TIN model. Then he carried out the region growing based on the threshold of normal vectors of neighboring triangles in the TIN model. Subsequently the algorithm calculates the normal vectors, edges and height differences of segments and extracts roads from the data. At last, the method iteratively constituted DTM based on the seed points from the extracted roads [43-44].

Tóvári and Pfeifer [45] developed another representative approach based on the region growing. The approach selects a random seed point, and chooses several points from its neighborhood. Then it calculates three parameters: the normal vector of the plane constituted by these points, the distance between the points and the plane, and the distance between the seed point and its neighbor points. Based on these parameters, the method continues the region growing process until no more points can be added in. After the segmentation, iteratively weighted interpolation and grouping are carried out to produce a DTM.

Many segmentation-based filtering methods are implemented in a raster data format which is easy to borrow image processing algorithms. These methods are usually not based on geometrical hypothesis (such as "terrain is continuous.") to describe topographic information. They are using geometry, optics, mathematical statistics and other features to identify point cloud data as larger entities rather than single points. Therefore, they are not influenced significantly by noise and can overcome the problem that wrongly classifies an individual point into a different class than its neighbors from the same segment.

Meng et al. [46] concluded that these filtering algorithms developed in the last decade could also be classified into more subsets including directional scanning, contour-based filters, TIN-based filters, and interpolation-based filters.

V. MORPHOLOGICAL FILTERING

This group of ground filtering method is based on some morphological operators in digital image processing, such as dilation, erosion. An opening operator is a combination of erosion and dilation operations in sequence, while a closing is a combination of dilation and erosion (González et al.[47]). By adopting a certain structure element, also called *window* or *kernel* in different papers, the opening operator can be used for minimum determination of the points, which leads to an approximation of the DTM [8]. In 1993, Lindenberger first applied this method based on a robust time series analysis.

In order to overcome the limitation of window size, Kilian [48] operated the opening process several times based on different window sizes. Each time different weights are assigned to the laser points within the band width with the weight value depending on the size of the window. A large weight would be assigned when a big window is adopted. After all the opening processes, the points with high weight are likely to be terrain points, and the points with low weight are likely to be off-terrain. Once this has been completed, the DEM can be generated by interpolating the weighted points.

The algorithm developed by Masaharu and Ohtsubo [49] consist of two steps. The first step is similar to Kilian's algorithm, which selects the lowest points in a window. Since the window size is relatively small, the whole window might be inside an off-terrain object. In this case, the lowest point in a window is not a terrain point. Therefore, the second step is designed to eliminate these points. The algorithm creates a buffer (has a size bigger than the window) to each selected point, and calculated the average value of all the selected points inside the buffer. If the elevation difference between the point and the average value is over a user given threshold, the point will be removed. To repeat the removal process three to four times, the algorithms can reach a stable group of terrain points which is used to generate the DTM [49].

A filter algorithm proposed by Vosselman [50] is another type of morphological filter, which is closely related to the erosion operator in mathematical morphology. This algorithm identifies a point by the height value differences between this point and all other points (implemented as comparing the altimetry value with its neighbor points).

Wack and Wimmer [51] utilized a hierarchical weighting morphological filter method. They first interpolated a low resolution DEM from the original LiDAR point clouds, and filtered most of the building and thick vegetation by height difference threshold and Laplacian of Gaussian (log) operator, and then calculated the weight function considering the standard deviation of each element. Then the algorithm generates a low resolution DEM based on the weight of the point, and hierarchically generates high resolution DEMs by interpolating low resolution DEMs.

Zhang [52] gradually increased the window size and applied the height difference limitation in his algorithm in order to eliminate points from cars, vegetation and buildings, while keeping the terrain points. The interpolation from unregulated points to rasterized grids will cause the removal of some terrain points. The low outliers may lead to big errors for this algorithm and the consuming time will increase linearly along with increasing of data. Zhang's method effectively removed most of the off-terrain points, but it is based on an assumption that the slope gradient is constant. The method developed by Chen and Peng [53] then overcame this slope restriction.

VI. COMPARISON OF VARIOUS TECHNIQUE

Many researchers had implemented different techniques with combination of various aspects for LIDAR data. Some of them are listed in Table 2.1

Sr. No.	Author/ Year	Technique / Algorithm used	Remarks
1	Hu X. et al. (2014)	Mean Shift Tensor voting Hough Transform (MTH)	Obtained best result as compared to template matching and phase- coded disk
2	Yuan Wang et al. (2013)	Segmentation method using morphological operation	Opening and closing operation maintains noise and small gaps
3	Li hui-ying (2012)	Hierarchical Algorithm for DTM generation and Morphological Operation	Geometry judgment is not very ideal.
4	Peng Jiangui et al. (2011)	Adaptive TIN for ground and non ground classification. Intensity information for candidate road points and non-road points, CD-TIN candidate road points to improve accuracy of classification	Performance is partly influenced by the car parks and city squares.
5	F. Samadza de-gan et al. (2009)	Optimum multiple classifier system	optimum determination of features, type of classification techniques and the potential of other methodologies in classifier fusion
6	Simon Clode et al. (2004)	Detection by hierarchical classification technique vectorization by convolving a complex-valued disk named the Phase Coded Disk (PCD)	Improvements on the detection method to enhance the detection of road intersections and junctions are high priority.
7	Clode et al. (2004)	Hierarchical Algorithm for DTM generation and Morphological Operation	The presence of many car parks and private roads has reduced the achieved correctness value

8	Xianggu o Lin et al (2014)	Segmentation based Filtering and progressive TIN densification method (PTD)	Capable of preserving discontinuities of landscapes and removing the lower parts of large objects attached on the ground surface.
9	Thomus J. Pingel et al. (2013)	Simple Morphological Filter (SMRF) for DTM generation	Serve as a stable base from which more advanced progressive filters can be designed

Extraction of Road from remote images obtained is a complex task. The variables involved in this are LIDAR data of different/various sensors, geographical location. The combination of this various aspects makes the road feature extraction difficult for their performance comparison. Road feature extraction has been implemented by researchers using different techniques with combination of various aspects to compare their accuracies.

VII. HOW ROAD FEATURE EXTRACTION WORKS FOR LIDAR DATA

The past few years was marked by the development of researches that contribute to reach automatic road extraction which is considered as possible solution to prevent human error. Recently, automatic object extraction from LIDAR has attracted grate attention. Based on related survey fig. 1 shows generally used techniques for LIDAR data processing.

6.1 LIDAR data

Raw point clouds of LIDAR returns comes in different format from vendor such ASCII text files for single returns, multiple returns, LAS files, XYZ files for processing. Post- processing software is used to associate

- LIDAR antenna x, y, z positions.
- Antenna roll, pitch, and yaw orientation
- LIDAR range (distance) information into set of latitude, longitude, and altitude (x,y,z) coordinates for each LIDAR return.[2].

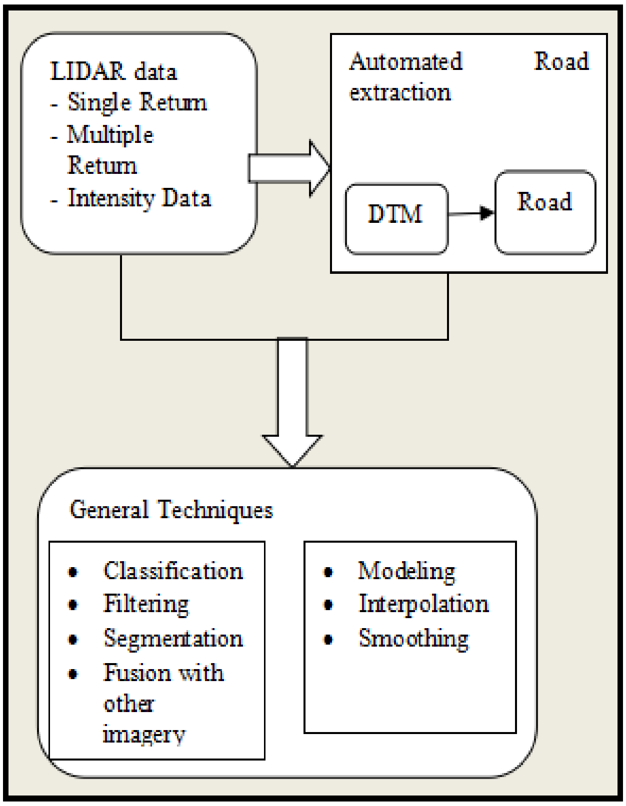

Fig. 1 General Techniques of LIDAR processing

6.2 Road Extraction from DTM

A digital elevation model (DEM) is defined as a file or database containing elevation points over a contiguous area (Miller 2004; Ma 2005) [43][44]. DEMs subdivided into Digital Surface Model (DSM) and Digital Elevation Model (DEM).

- Hierarchical algorithm
- Linear first order equation
- Morphological operations (opening and closing). etc

After classifying ground points, road extraction is performed.

6.3 Classification

The objective of image classification procedures is to automatically categorize all pixels in an image into land cover classes or themes. For classification purpose most of the method uses height and intensity characteristic of LIDAR data. Classification generally performed by well known pattern classification techniques such as

- k-means
- SVM
- Maximum Likelihood classification

- Bayes classifier
- Self Organizing Map
- Surface growing algorithm
- EM classification etc.

Some other filtering techniques are perceptual grouping theory (Gabor filtering, tensor voting).

6.4 Segmentation Based Filters

Segmentation classify group of neighboring points with similar properties. Some of the segmentation techniques used for LIDAR processing is

- Region growing techniques
- optimized segmentation techniques (global optimization using graph-cuts
- thresholdings
- detecting clusters (group of similar feature value)
- geometric properties (height, normal vector, curvature,)

VIII. Conclusion

Recognition of roads is an important GIS layer in significant civilian and military application including navigation or location aware systems and emergency planning systems for evacuation, infrastructure development, and fire response. Author has reviewed the present state and significance of road extraction from the LIDAR data formats. Accurate and up-to-date road network information is essential for urban planning, automated road navigation. Automated methods have the potential to improve the speed and utility for road mapping and are therefore highly desirable. Here several road detection and extraction techniques are theoretically analyzed, it is found that there exist many gaps in the techniques proposed so far. Automated road extraction from LIDAR data is still at its infancy. It yields some erroneous results for filtering point cloud data accurately. With the aim of improving the accuracy for the whole extraction method from LIDAR data, we define two objectives for the related survey.

1. Firstly, this study seeks to develop a new method for extracting road from point clouds.
2. The second objective is, to integrate various algorithms for the proposed method.

So in future work automated a new method for road extraction from LIDAR point cloud is proposed by incorporating various investigated algorithm in the research.

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