EXTRACTION OF DIFFERENT BUILDINGS FROM LIDAR DATA

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ABSTRACT

Airborne laser scanning has become an arch technology and which is now widely accepted for 3D data collection. These 3D points represent the terrain surface as well as objects on top of the terrain surface. Airborne LIDAR systems are able to record data through multiple pulses which make the data very accurate. LIDAR data is a relatively new technology for obtaining Digital Surface Models (DSM) of the earth’s surface which can be very useful for detection of different physical features like trees, buildings, roads, etc. in rural and urban areas. In urban areas problem arises due to high density of points and therefore the demarcation between the different physical objects becomes difficult. In the paper LiDAR data of an urban area is used for buildings extraction. Firstly the data is smoothed to remove random error in it and then a new parameter openness is used for the extraction of building from it. Openness is a novel digital image processing technique which expresses degree of dominance or enclosure of a location on a surface. Openness helps in differentiating different types of physical features present in the data. All the results obtained are presented with discussion. The test results show considerable success in extracting buildings from an urban area where buildings and trees are of equal heights. Generation of the results in this project were done with the help of MATLAB TM programming.

KEY WORDS: Automation, LiDAR, Image Processing

INTRODUCTION

LIDAR (Light Detection and Ranging) data offer a high potential for automated building extraction. Buildings consist of regular surfaces that can be extracted from LIDAR data making use of surface properties such as local co-planarity. LIDAR data is a multi-pass data which can be used for different purposes. The development of airborne laser scanning goes back to the 1970s (Jennifer and Jeff 1999). By emitting a laser pulse and precisely measuring the return time to the source the range can be calculated using the value for the speed of light. In the late-80s kinematic GPS provided the necessary centimetre level positioning accuracy required for high performance LIDAR. The systems required ultra-accurate clocks for timing the return and Inertial Measurement Units (IMU) for capturing the orientation of the scanner (Wehr and Lohr 1999). The system is an active system, so the data can be gathered during the day or night. LIDAR data pre-processing is composed of two efforts. First, the data must be filtered for noise, differentially corrected, and assembled into flight lines by return layer. Second, the LIDAR data may undergo further analysis to derive the final grided DEM products using interpolation.

Airborne LIDAR data is a source of high resolution DEMs, such a DEM generated in an urban area can be very well utilized for extraction of non ground features in that area. LIDAR provides three-dimensional digital information about the Earth's surface that is all three coordinate in space. A great number of research reports indicate that the 3D LIDAR data are a highly qualified source for GIS data acquisition. Many applications, such as urban planning, telecommunication and security services ask for 3D city models. Buildings are the objects of highest interest in 3D city modelling. Urban areas are rapidly changing mainly due to human-activities in construction, destruction or extension of topographic elements such as buildings and roads. This leads to requesting a fast data acquisition technique and automatic method for detecting and extracting 3D topographic objects from the data. Airborne laser scanning is a new technology in which several sensors are integrated to obtain 3D coordinates of points on the earth. In this paper a technique for extraction of buildings from high resolution LiDAR data has been presented. An attempt is made by the help of Digital Image Processing techniques to develop an algorithm for automatic extraction of buildings from high resolution LiDAR data.

Overview Of Current Building Extraction Systems

DEM production from laser data is presented in Morgan and Tempeli (2000). The step involve are re-sampling the irregular elevation points obtained by laser scanning into a regular grid then distinguishing terrain and non-terrain segments by morphological filter. Aiming at a vector representation of buildings, the roof faces are obtained
by further segmentation of the building segments into sub-segments. The 3D geometrical properties of each face are obtained based on plane fitting using the least squares technique. In Seresht and Azizi (2000) the authors describe a strategy for automatic building extraction from aerial imagery and digital elevation models. The first step is a coarse recognition of building regions from DEM. Then some filters are applied on the selected regions based on their shape, size and content to enhance the delectability of the buildings. Further recognition is then achieved based on image features that include points, edges, and lines. In Bethel and Elakser the approach utilizes the geometric properties of urban buildings for the reconstruction of the building wire-frames from the LIDAR data. In Zhao and Trinder (2000) buildings were extracted from aerial images and DEM is presented. In this research, a building is modeled as a polyhedron, comprising planes that are connected to form a solid volume. The intersections of adjacent planes are straight lines. The polyhedron has a set of attributes describing its geometry, radiometry, texture, topology, and context. From this model in order to address the complexity of the problem, the system consists of three parts: building detection, building segment extraction and 3D segment matching and building modeling. The detection process starts with segmentation of the DSM (Digital Surface Model) to derive regions of interest (ROI) that have high expectation of representing individual buildings. Texture and shadow information are extracted and used to refine and verify the ROI.

DATA USED

Data used in the project contains 0.67 points per square meter (point spacing: 1.0 - 1.5m). The X coordinates of the data varies from 512023 to 512549 and the Y coordinates varies from 5403120 to 5403500. Features of interest in the data comprised of densely packed buildings with vegetation between them, building with eccentric roof (bottom left corner) and open surfaces.

METHODOLOGY

In this section steps taken to extract buildings are discussed. In the process physical interpretation of LiDAR data was done to know about what can be expected in an urban area. The features of terrain comprised of flat and gable roof of varying heights, trees of varying heights, roads flat (horizontal making angle 0° with surface) with gentle slope and flat (play grounds) or rolling surfaces (slopes).

Interpreting mainly flat and gable roof in the data (DEM). Flat buildings or surfaces are defined as the elevation of block of pixel which are at approximately same height and this type of arrangement of pixel can lead to a flat roof, a flat play ground or a flat road but the elevation of the flat buildings will be relatively greater than other flat surfaces in a DEM and therefore the boundaries of flat roof are elevated as compared to surrounding pixels. Gable roof are defined as the elevation of block of pixel in which elevation of strip of pixels first increases and then decreases or vice versa along a given direction. The line joining the maximum elevation will give axis of the axis of gable roof. While interpreting trees in data (DEM). It is a group of pixels in which elevation of pixels varies irregularly and the boundaries are marked as we cross the boundaries of tree the elevation fall suddenly. The Roads can be interpreted in data (DEM). It is strip of pixels of very slightly varying elevations. The strip is continuous and the elevation of the pixel is near to least elevation in the data. The flat or rolling terrain can be interpreted in data (DEM). It is group of pixels either forming a simple geometric or irregular shape with very less elevations and elevations will have very less variations.

After interpretation of LiDAR data many steps were taken to achieve the desired. Raw LiDAR data obtained consisted of irregular point data therefore data used is firstly converted into a uniform group of pixels (grid) through standard interpolation techniques and then from it Digital Elevation Model (DEM) is generated. DEM (Digital Elevation Model) obtained was then transformed into grey scales. DEM exhibited considerable degree of variability because of the random error present in it to compress the error edge preserving smoothing was applied to theDEM. After smoothing of the data topography of the area was visualized by Openness (Yokoyama, Shirasawa and Pike, 2002) a novel Digital Image Processing parameter. Positive and Negative Openness was computed on the Digital Elevation Model. After this variance of both Positive and Negative openness was computed and then thresholding was done to extract the buildings from the data. The process or algorithm used is also elucidated by the help of a flow chart below.
**Algorithm Used In The Process (Flowchart)**

1. **Raw Data (DEM)**
2. Smoothing of the data by edge preserving smoothness
3. Computation of Positive and Negative openness
4. Interpretation of the Openness
5. Computation of variance of both type of openness
6. Interpretation of Variance
7. Removal of the roads and flat and gently inclined surfaces by histogram on the basis of their height by threshold
8. Applying median filter
9. The final output compose of extracted buildings roofs

**Methods Adopted For The Process**

a) **Edge Preserving Smoothing by Nagao.** For smoothing and removal of random error edge preserving smoothing (Nagao and Matsuyama, 1980) was used. In this procedure variance of eight possible direction (four in first figure A, two horizontal and vertical and two diagonals of the square and rest four in figure B) is computed and mean along the eight directions is also computed and comparison of eight variances is made and the centre pixel value is replaced with the mean of the vector whose variance is least.

**Figure. A**

**Figure. B**
Nagao and Matsuyama, 1980 suggested that image would be smoothed but some minor edges would be lost. To smooth the data five iteration of the same process was done.

b) Calculations of Positive and Negative Openness values from the smoothened LiDAR data. Openness (Yokoyama, Shirasawa and Pike, 2002) is an angular measure of relation between surface reliefs a horizontal distance. Openness values are mapped by grey scale tones. Openness incorporates the terrain line of sight, or view shed, concept and is calculated from multiple zenith and nadir angles – here along eight azimuths. It has two viewer perspective positive values i.e. indicating area above the surface and negative value describes the area below the surface. Openness is new method surface representation which make easier to get the knowledge of the surface. It is a novel method for digital terrain modeling – actually a image processing technique calculated from DEM, used to visualize landscapes. The resulting maps of Openness superficially resemble digital images of shaded relief or slope angles but emphasize dominant surface concavities and convexities. Here the curvature of the earth is neglected. For calculating Openness values some angular relation between the point of location along individual DEM-derived profiles, for both above or below the surface as per the viewer perspective.

Each point on the DEM is defined by \((i_A, j_A, H_A)\). L is the radial limit of calculation which is larger for mountainous region and lower for plain region. The elevation between two adjacent points \(A, B\) is calculated as follows.

![Figure C](image1.png)

**Figure. C**

Surface Openness defined in terms of zenith and nadir angles, calculated along one of eight azimuths within radial limit \(L\) in the above figure. Positive Openness is mean of \(\Phi_L\) along eight sampling directions; Negative Openness is the corresponding mean of eight values of \(\Psi_L\). the angles \(\Phi_L, \Psi_L\) can be positive or negative depending on the topography of central point A. The zenith angle at a DEM grid point along azimuth \(D\) within radial distance \(L\) and nadir angle are given by:

\[
\Phi_L = 90^\circ - \Phi_L
\]

\[
\Psi_L = 90^\circ - \Psi_L
\]

Finally the positive and negative openness value can be calculated by the following expressions.

\[
\Phi_L = \left(0\Phi_L + 45\Phi_L + 90\Phi_L + 135\Phi_L + \ldots + 315\Phi_L\right)/8.
\]

\[
\Psi_L = \left(0\Psi_L + 45\Psi_L + 90\Psi_L + 135\Psi_L + \ldots + 315\Psi_L\right)/8.
\]

Positive Openness corresponds to \(\Phi_L\), Negative Openness corresponds to \(\Psi_L\).

c) Thresholding of data. This technique is used to remove the gray-level trends in an image, to make the gray-level regions more discrete. This technique is used to transform the original image to a binary image. For example, a threshold value or range of value is chosen. The gray-levels greater than that value is set to maximum level and the levels less than that value are set to minimum value. This process is used in scanned text images.

d) Histogram Equalization. In the original image, the gray-levels of the image are too close to each other. And image’s density function is not uniform or near uniform. This means that the probabilities of the gray-levels are not equal. An ideal image’s density function should be uniform, i.e. the probabilities of the gray-levels should be...
equal to each other. If we transform the original histogram to a uniform histogram, new image will be close to ideal. Such a transformation is called histogram equalization. If the original image histogram is transformed to another histogram by using its own distribution function as transformation function, the result image histogram is equalized.

RESULTS

In this section results obtained in the process are presented with discussion. The data of an urban area is used. The data in pictorial form is presented as below in Fig 1 and fig 2. The topography of fig 2 was generated by coding algorithm for Positive and Negative Openness and it is shown below in Fig 3 and 4 respectively. Openness clearly differentiates between the buildings and non building pixels.

Figure 1. Raw data after smoothing.  
Figure 2. Applying Histogram Equalization.

Figure 3.  
Figure 4.

The result obtain clearly indicates the topography of this area. Now computation of Variance is made on both Positive and Negative Openness computed in fig 3 and 4. The results are shown below in the following fig 5 and 6.
Observing the results obtained after applying variance it is clear that the variance image of both type of Openness are identical and therefore Positive openness result is further processed for extraction of buildings. Now thresholding of the above variance image is done and then comparison of this threshold image is done in such a manner that the switch on points are replaced by the raw data and switch off points are not touched the result obtained is shown in fig 7. Roads from the fig 7 are removed by the help of the histogram approximately the road pixels are put to zero on the basis of their lower elevations. Median filter is applied to fig 7 for removal of trees which are not removed in the above processes. The final extracted buildings are shown in fig 8.

**DISCUSSION**

In this section the process of extraction of buildings from LiDAR data is explained in detail. Major steps involved in the extraction of buildings are as follows.
- Interpretation of LiDAR data.
- Removal of random error by edge preserving smoothness.
- Calculation of Positive and Negative openness values and its interpretation.
- Variance calculation of the two openness.

The differences in the two type of roof in the DEM while in the process of extraction of buildings are as follows. Elevation of flat roof was same in every direction within the region of the roof where as in case of the gabble roof the elevation of the gabble roof changes in a particular direction, it first increases and then decreases along a particular direction and it had an axis which had greatest elevation in the roof. Positive and Negative openness were calculated from the DEM of LiDAR data. The openness (Ref. Sec 2.2(b)) of values of gabble and flat roof were approximately same and the openness values over the trees were irregular from this observation the extraction of buildings could be made but separately identification of two type of roofs was not possible as the two type of roof had same openness values (because uniformly inclined and flat surface had same positive and negative openness values). Apart of calculating the openness many other methods were also tried that included thresholding of different type of openness image.

**Interpretation Of Terrain Features Through Openness.**

In flat roof the value of openness is different at edges, at corners and at the surface of the roof. Positive openness is maximum at the corners then at the edges and the openness is least on the surface of the roof on the other hand negative openness value is least at the corners and then maximum on the surface and on the edges it is in between the two.

Positive openness for corners > edges > surface
Negative openness for corners < edges < surface

![Figures show Flat and Gabble roofs in plan in Grid.](image)

The value of openness at the surface(pixels within the boundary) will be close to 90° for both positive and negative openness calculated at the edge the value of the openness will be greater than 90° as the angle will be greater than 90° for three vectors and for rest five vectors the value is approximately 90° and for the corner five vectors have value greater than 90° and three vectors have angle close to 90° so the order follows and for negative openness value there is no difference in the surface values but for the edges five vector close to 90° and rest three were less than 90° and but for the corners three vectors were close to 90° and rest five were less than 90° so the reverse order follows in this case. The value of Positive openness at any pixel just outside the boundary of the roof will be less than the openness value at the boundary of the roof and the openness value will be maximum at the boundaries of the roof so the boundaries of the roof look distinct.

In case of the gabble roof the value of openness is different at edges, at corners, at the surface and at the axis of the gabble roof. Positive openness is at corners is greater than the openness calculated at the edges of the gabble roof as the angle greater than 90° in case of edge is three and in the case of corner is five. The value of positive openness...
at the surface will be close to 90° and the value of positive openness value at the axis of gable roof will be close to the openness value at the boundary of the roof. Negative openness value at the boundary of the roof is less than the openness value at any pixel outside the boundary the value negative openness but the value of positive openness value at the boundary of the roof is more than the positive openness value at any pixel outside the boundary of the surface. The Negative openness at the surface of the roof is same as the Positive openness value. Comparing the negative openness value to positive openness value at the axis of the roof the value of positive openness value is greater than the negative openness value at the axis of the roof.

Openness values of the trees do not show any regular behavior as the value changes irregularly but the boundaries of the trees can be identified by the sudden change in elevation difference at the boundaries which will lead to higher positive openness values and lower negative openness values at the boundaries. Openness calculated on smoothed data (from raw data), the flat areas like playground and roads have same positive and negative openness throughout which means the roads and play ground are flat or inclined.

After the interpretation made for raw data and openness, it gives direction that the buildings can be extracted from the data. As the openness on the buildings and flat surfaces show a less change in their openness values as compared to the openness calculated for the trees. Now on the openness data variance is calculated as a result of this method the variance calculated over the trees was more and the variance over the buildings and the flat area was less. Through this observation the flat areas and the buildings can be easily extracted from the raw data by thresholding the previous output so that only the flat areas and buildings are retained and the trees are cleared from the image, after thresholding only buildings and flat areas are replaced by the raw data after smoothing and rest of the part is untouched. From the above process this is concluded that the areas having uniform openness are retained and the areas having non uniform openness are removed from the image till now. The flat areas like play ground and roads can be separated from this image on the basis of their elevations now in the new output only buildings are present and the flat areas like play grounds and roads are absent, to remove the irregularity present in the image median filter is applied which further reduces the non uniformity in the output. The final output contains only buildings and rest of the features of the terrain are removed.

CONCLUSIONS

In this paper a novel method for automatic extraction of buildings from high-resolution LIDAR data in densely built-up areas is presented. A new image-processing technique was used to generate angular measure of surface form which was helpful in finding the measure of dominance and enclosure of the surface. Values of Openness which are expressed in grey scale can be used for extraction of topographic features like buildings from high resolution DEMs. The data was comprised of different size of buildings, trees, roads and sloping area. The study is successful in reduction of scene complexity (in urban area) by a hierarchical segmentation of LIDAR DEM. The algorithm was successful in removing most of non-ground, non-building features from the data. Large and medium size building were successfully obtained in the result. The result obtained in this study can be used for future research work in the same direction. Future work will include the implementation of the modules still missing, but also in the assessment of quality parameters for the results. Preliminary results using geometric constraints generated manually, based on visual inspection, show that using our method it is feasible to generate high-quality building models from LIDAR data alone.

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REFERENCES


