Airborne LIDAR data based automatic 3D building model

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Abstract - *The fundamental importance of constructing three dimensional building models includes constructing virtual city models, estimating property tax etc.. Conventional methods such as aerial photography, satellite imagery etc. are used for the generation of building models in which, shadows caused by sun is a main difficulty. LIDAR, known as Light Detection And Ranging can be used for the detection of buildings using laser pulses. The Lidar source, which is mounted on an aircraft, emits laser pulses continuously to the earth surface and the reflected light is probed. The pulses first reflect from the top of objects and as laser can penetrate, successive reflections occur and final reflection will be from the ground surface. Thus, by analyzing the reflected pulse, the height and shape of various objects on the earth's surface can be determined. One of the most essential steps in the construction of building model is the creation of Digital Surface Model (DSM). Digital Surface model is the model of earth's surface consisting of buildings, trees, vehicles etc.. Thus, by inspecting the DSM, it is more easier to identify the building models from all other elements such as trees, vehicles, rivers etc.. After the DSM generation, morphological filtering is done for the separation of building points from other terrain points and trees, automobiles etc.. Finally, this filtered DSM is converted into a 3D model for visualization.*

***Key Words*: LIDAR, Point cloud, DSM, 3D model, Morphological opening**

1. INTRODUCTION

For the visualization in GIS (Geographic Information System), estimation of urban population, property tax etc., generation of 3D building model is essential. Lidar is a remote sensing technology that transmits laser lights from the system mounted on an aircraft to measure distance to the Earth by analyzing the reflected light. In Lidar systems, ultraviolet, visible or infrared lights can be used to target wide range of materials, including nonmetallic objects, rocks etc.. Each pulse signal undergoes multiple echoes in which the first return is from the top of trees or vegetation and as laser penetrates the canopy, successive reflections occurs and the last returns are received from the earth. The reflections from an object at a closer distance come faster than from an object at longer distance. Combining both GPS (Global Positioning System) and inertial technology along with laser, the three dimensional set of points in Lidar is created. These three dimensional set (consisting of x, y and z coordinates) reflects the position and elevation of each point. Compared to aerial or satellite images, airborne LIDAR is more efficient for the extraction of building models since they are not influenced by shadow caused by sun and distance.

The Lidar points can be classified into, (a) the points related to bare earth surface (Ground points), and (b) the points related to buildings, trees, vegetation, vehicles etc.. i.e.; points other than ground points (Non-ground points). Hence, the separation of ground and non-ground points is the preliminary step in the 3D building model construction. Several methods were previously proposed for the same. The first and foremost method was the slope based filtering which is introduced by Vosselman [2] for the separation of ground and non-ground points. It is based on the fact that, in the case of ground points, there will not be any abrupt height change. But in the case of dense vegetation, it is difficult to obtain the height difference (though dense vegetation have less height difference) which may produce errors. Sithole [3] modified the slope based filter by using different maximal slope thresholds. In this method, a rough slope map is needed for calculating the local slope threshold. Here also, in the case of dense forest, some points may lie on the same plane, and hence calculation of slope threshold may leads to false detection. So, before separating the ground and non-ground points, DSM (Digital Surface Model) generation is introduced to

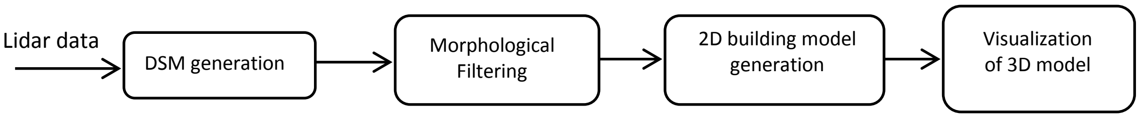

Figure1. Proposed Block diagram for automatic 3D building model

overcome these difficulties. Using high resolution satellite imagery [1], DSM can be effectively derived. It gives high accuracy, but it needs an extra data source other than Lidar. So, here, DSM model is generated with the help of the Lidar point measurements only. After the generation of DSM, filtering is done to obtain the building points. And finally, this filtered DSM is converted into a 3D model.

2. METHODOLOGY

Airborne LIDAR generates irregularly spaced 3D point measurements. So, before the processing of LIDAR data, irregularly spaced 3D data are converted to a regularly spaced 2D data for convenience and ease of computation. The proposed method for 3D building model generation is shown in figure above (Figure 1).

2.1. DSM generation

Before the generation of DSM, the 3D Lidar point data is converted into a 2D array, since it is easier and faster to process a 2D data than processing a 3D data. The algorithm for the conversion of irregularly spaced 3D array to regularly spaced 2D array is given below.

Algorithm for DSM generation:

Step 1: Load the Lidar data which comprises of x, y and z co-ordinates.

Step 2: Obtain the rounded values of x and y co-ordinates.

Step 3: Find the minimum and maximum values corresponding to both x and y co-ordinates (min(x), min(y), max(x) and max(y)).

Step 4: Create a row matrix, say Xi of order 1 x n, such that the values in the row matrix are in the ascending order starting from min(x) to max(x).

Similarly, create another row matrix, say Yi of order 1 x m, such that the values in the row matrix are in the descending order starting from max(y) to min(y).

Step 5: Create a matrix Xd of order m x n, such that each rows of the new matrix are the copies of the row matrix X_i.

$$X_d = \begin{bmatrix} Xi \\ Xi \\ \vdots \\ \vdots \\ Xi \end{bmatrix} \quad (1)$$

Similarly, create another matrix Yd of same order, such that each columns of the new matrix are the copies the row matrix Yi.

$$Y_d = [Yi \quad Yi \quad \dots \quad \dots \quad Yi] \quad (2)$$

Step 6: Finally, create a DSM matrix using Xd and Yd matrices. Each values of the DSM matrix are found out from the corresponding cell values of Xd and Yd matrices. The z value (from the Lidar data) corresponding to the x and y values in Xd and Yd matrix is chosen and is entered into the corresponding cells of DSM matrix.

2.2. Morphological opening based Filtering

Filtering is done to separate the building points from other terrain points. Here morphological opening based filtering is done. It can overcome the disadvantages of the previous filtering techniques such as slope based filtering proposed by Vosselman [2]. In slope based filtering, the ground and non-ground points are identified by comparing slopes between a Lidar point and its neighbours. But here, the commission error (classifies non-ground point as a ground measurement) and omission error (which removes non-ground points mistakenly) was large when this filter is applied to large vegetation having large slope variations. The critical step in designing such a filter is to obtain an optimum threshold such that the omission and commission errors are less. Vosselman [2] demonstrated that good results can be achieved by using slope thresholds from training datasets. However, for better results, training datasets must include all types of ground measurements in a study area which is not always practical.

In morphological opening based filtering, the filtering operation is done with the help of a structuring element.

The effect of the operator is to preserve foreground regions that have a similar shape as that of the structuring element while eliminating all other regions of background pixels. Thus the difficulties of using training dataset in the case of slope based filtering are overcome by morphological filtering.

2.3. 2D building model

The 2D building model will be obtained after performing morphological opening based filtering. This model contains the elevation points (z points) that are related to buildings. Thus, DSM gives 2D building topology which will be converted into a 3D model.

2.4. 3D model

The reverse process of DSM generation is used for the construction of 3D building model. It involves the conversion of a 2D DSM matrix into 3D matrix. That is, the x and y values corresponding to the z values in the DSM matrix is found from the original Lidar data. The following are the steps for the conversion of DSM matrix into a 3D matrix

1. Create a matrix Xx in such a way that the cells are filled with the x values corresponding to the z values in DSM matrix. That is, the first value in the DSM matrix is taken and the corresponding x value is obtained from the original Lidar data. These values are entered in the first cell of the new matrix. Clearly, the new created Xx matrix has same size as that of the DSM matrix.

2. Similarly, create another matrix Yy in such a way that the cells are filled with the y values corresponding to the z values in the DSM matrix.

Thus 3D matrix is obtained which contains elevation values (z values) of the filtered building and the corresponding x and y values. Thus, 3D building model is generated from 3D matrix. Thus, when Lidar points of an area is given, the 3D building model of the buildings present in that area is obtained.

3. RESULTS AND DISCUSSIONS

Lidar data used for simulation are collected from the open topography website (http://opentopo.sdsc.edu/lidar). The Lidar data is collected in .las format. For convenience, the 3D lidar data is converted into 2D data. Simulation is performed using the MATLAB R2012b. The Lidar data and the simulation results are as follows.

After converting into 2D array, DSM is generated from which the ground points and non-ground points are separated. This separation is done using morphological filtering. Finally 2D building model is generated and is converted into 3D model. Figure 2 shows the recent digital map of the area (from Google maps) from where the Lidar data was collected previously. (The digital map is not used in simulation; it is just given for better understanding of the results).

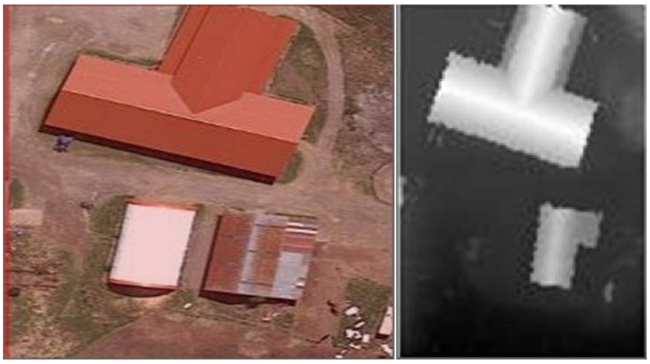

Figure2. (a) Digital map of area from where the Lidar is collected, (b) the corresponding DSM model generated.

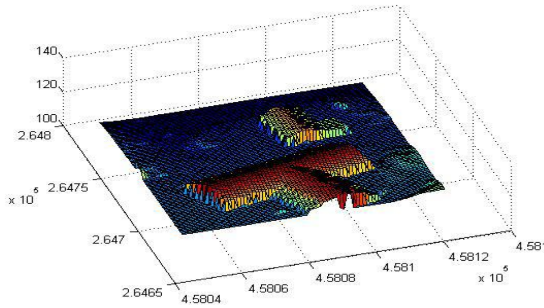

Figure3. The generated 3D building model in Matlab.

[The results show a mismatch between the digital map and 2D building model, due to the unavailability of the updated Lidar data of the same region. The new building (shown as white region in the digital map) was not present during the collection Lidar data. The Lidar data for the other two buildings were only recorded at that time.]

The figure 3 shows the 3d building model generated in Matlab. This visualization gives idea about the height or elevation of the building in a faster and more accurate manner than the traditional techniques in [2], [3]. Another advantage of this technique is that same software is used for the 2D building generation as well as 3D building model reconstruction which was not possible in the previous methods. Also, Lidar data has high point density since it collects thousands of points from a small area. This gives better results for certain applications like floodplain delineation. In dense forests, Lidar collects elevation data where photogrammetric fails to obtain the accurate terrain surface due to dense canopy cover. Also, when compared to traditional photogrammetric techniques, Lidar data can be collected day or night since it uses active illumination sensor.

4. CONCLUSIONS

From the Lidar data, the 3D building model is generated efficiently and automatically. Without using any other data source, building points are identified easily by the generation of Digital Surface Model. For that, the 3D data is converted into 2D array for simplicity. After the DSM generation, building points are identified and 2D building model is generated. Finally, this 2D model is converted into 3D model for better visualization. In this paper, for the generation of building models only Lidar data is used and no other data is needed. Also 3D conversion is done using same software which was not done in previous method. Previously, the Lidar data based analysis was carried out in integration with the digital map generated by aerial imagery or by satellite imaging. But the lack of updated digital maps creates problem in building model generation. So the proposed method of building model construction is advantageous since it doesn't require the aid of digital map for building model generation.

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BIOGRAPHIES

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