Determining Building Footprints
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A new approach for determining building boundaries through automatic processing of light detection and ranging (LIDAR) data is presented. In general, LIDAR data is processed and interpolated into grayscale images with pixel values corresponding to height measurements. In a recent work, a progressive morphologic filter was used to separate ground from non-ground measurements. Further separation of non-ground measurements into building and non-building measurements was performed by growing regions with similar characteristics. The initially identified building outlines were then refined using a polygonal fitting algorithm to obtain ground plan building representations known as building footprints. In this paper, the building outline refinement process is improved through a clean-up and sorting procedure, in order to provide more accurate building footprints.

INTRODUCTION

LIDAR data processing plays a significant role in a wide range of applications, including seismology, flood control, traffic control analysis, adaptive cruise control systems in cars, height measuring applications in the forestry industry, and mapping. Mapping often requires identification of forested areas and detection of roads and buildings. Specifically, representations of refined building outlines are known as building footprints [3]. LIDAR data consist of elevation measurements along with associated GPS coordinates. These measurements collected by LIDAR sensors together with advanced signal and image processing filtering algorithms have been found to be suitable for generating ground terrain profiles, as well as for identifying non-ground objects emerging above the ground terrain level. Such objects may include vegetation and buildings. The identification of building footprints has been shown to be important in various real-life applications, including the study of urban population, the development of ground plans, and the development of three-dimensional building models.

In previous work, building footprints were identified using filtering, region growing, and dominant direction estimation [1]. However, the use of dominant direction estimation as a means of cleaning building footprints assumes a particular relationship between near-perpendicular or near-parallel building edges and oblique building edges.

In this work, the proposed method for refining building footprints does not make any prior assumptions regarding building shapes or edge relationships. The outline refinement of a particular building is achieved by a specific sorting of pixels located on the outline, followed by a polygonal fitting algorithm. This paper is organized as follows. Section 2 reviews some background regarding LIDAR processing and footprint identification. Section 3 presents the proposed technique, and section 4 presents some experimental results. Finally, section 4 closes with some concluding remarks.

BACKGROUND

LIDAR data acquisition systems collect data as point clouds. In order to be suitable for processing, LIDAR data are commonly represented as images (grids) by mapping GPS coordinates to pixel coordinates, and height measurements to pixel intensities. In general, it is possible that multiple points are mapped to the same pixel. In this case, the point with the minimum elevation is usually assigned to that pixel, since higher elevations may correspond to non-ground returns. Interpolation is used to assign values to pixels that are not directly assigned a height measurement value, but are located in the neighborhood of pixels with assigned values.

An example of an image obtained from LIDAR data is shown in Figure 1. This image represents a subset of Lenoir County, North Carolina. Lower intensities represent low-lying areas relative to the rest of the coverage area, while higher intensities indicate higher elevation corresponding to buildings or vegetation. It should be mentioned that image pixels that are not assigned a height measurement are shown as white pixels. This pre-processed image represents the starting point for all further analysis. Next, the basic steps for building footprint identification are presented:

GROUND/NON-GROUND SEPARATION

In order to detect building locations, non-ground and ground pixels must be separated. Many methods have been employed in the literature in order to accomplish this task. Zhang [2] proposed a progressive morphological filter approach to remove non-ground points from a LIDAR grayscale image such as the one shown in Figure 1. A morphological filter is a filter that
utilizes a combination of dilations and erosions in order to dilate and/or erode features in an image. In the case of grayscale images, dilations and erosions correspond to maximum and minimum filters, respectively.

The progressive morphological filter is based on a series of opening operations applied on the image of interest. An opening operation is defined as minimum filtering followed by maximum filtering. The minimum filter effectively removes any non-ground objects smaller than the filter’s window size, while the maximum filter repairs any damage done to non-ground objects of size larger than the window size. The progressive morphological filter starts using a small window size. Once the initial opening operation is performed, the difference between the original image and the filtered image is obtained. Since ground pixels correspond to low pixel intensity values in the difference image, a threshold may be used to identify ground pixels. Ground pixels are left untouched in the original image, while non-ground pixels are substituted by the pixels resulted from the opening operation. A small filter window may not be sufficient for removing large non-ground objects. Therefore, the opening operation is repeated by progressively increasing the filter window sizes, and by reducing the threshold used on the difference image. The progressive morphological filter result using the image of Figure 1 is given in Figure 2.

![Figure 1: Pre-processed LIDAR image after interpolation](image1)

![Figure 2: Grayscale image after morphological processing](image2)

**THE REGION GROWING ALGORITHM**

Once non-ground pixels are separated from ground pixels, building areas should be identified. This can be achieved by applying region growing on the image obtained as the difference between the original image and the morphologically processed image.

Zhang [2] referred to two different types of non-ground pixels, namely inside points and boundary points. An inside point is a non-ground pixel whose all eight neighbors are also non-ground pixels. A boundary point is defined as a non-ground pixel with at least one of its eight neighbors being a ground pixel.
The process starts from a non-ground pixel with intensity above a certain threshold. If the intensities of all eight pixel neighbors are also above the threshold, the pixel effectively becomes the first pixel of the region. Then, the eight neighbors of the pixel are examined, and if a pixel and all its eight neighbors have intensity above the threshold, it is also considered as part of the region. The process continues until no new pixels are added to the region. Once all regions consisting of inside pixels are identified, the image is scanned once more in order to detect the boundary points. Figure 3 shows the detected inside points and Figure 4 shows the detected boundary points. The boundary points are the initial building footprints. In [3], a technique to develop a cleaner building footprint followed is based on the Douglas-Peucker algorithm [7]. The Douglas-Peucker algorithm allows for a simplification of any polyline by a recursive threshold technique. In addition, building footprints are further refined assuming certain conditions regarding building shapes and edge relationships.

**PROPOSED MODIFICATIONS**

In [3], boundary points were initially identified as non-ground pixels with at least one neighboring ground pixel. In this paper, the definition of what constitutes a boundary point was made more strict, requiring three conditions:

(i) the intensity of the difference image should be greater than a given height threshold,
(ii) at least one neighboring pixel should be identified as a ground pixel, and
(iii) at least one neighboring pixel should be identified as an inside point.

The third condition results in fewer and less noisy boundaries as illustrated in Figure 5.

Moreover, investigation of the Douglas-Peucker algorithm revealed that the algorithm is extremely sensitive to the order with which the boundary points are presented to the algorithm. Specifically, the Douglas-Peucker algorithm approximates the obtained polyline by connecting boundary points in the order that they are presented to the algorithm. For instance, if the
boundary points of a rectangular building are presented in a random order, the algorithm will attempt to approximate a polyline that is not a rectangle. As indicated in [3], the Douglas-Peucker algorithm is not always successful in retaining the corners of building footprints. In order to improve the performance of the Douglas-Peucker algorithm, boundary points were initially sorted following a clock-wise ordering scheme. As expected, experimental results illustrated that the proposed scheme is more appropriate for refining building footprints, by providing a more summarized and accurate building footprint representation.

Figure 5: Boundary point region identification – New definition

RESULTS

A side-by-side comparison illustrates the improved building footprint results obtained by the proposed modifications of the algorithm presented in [3]. Figure 6 shows a zoomed-in section of the Lenoir County study area, comparing the old boundary point definition to the new boundary point definition.

This building footprint comparison clearly shows that redefining what a boundary point really is results in a less noisy and simplified footprint that more accurately represents the actual building boundaries. The extreme jagged nature of the footprint on the left is replaced by a fairly smooth representation on the right, considering that LIDAR data is irregularly spaced and therefore noisy to begin with.

Figure 6: Boundary point identification comparison – Top: Original, Bottom: Proposed
Figure 7 shows a comparison between the original Douglas-Peucker algorithm and the proposed algorithm where order boundary points are used.

The image on the top is unsuccessful in identifying building boundaries for most cases. However, this is corrected fairly well in the image on the bottom with all corners being identified owing to the improved boundary point sorting.

Figure 8 shows another example where the proposed technique is applied. The building boundaries are again correctly identified. Moreover, connecting the boundary points together results in the final footprint representation. It should be mentioned at this point that, owing to the successful identification of the building corners, the proposed technique does not require any additional refinement or assumptions regarding building shapes or edge relationships such as the ones made in [3].
CONCLUSIONS

A modified algorithm was presented in order to extract building footprints from LIDAR data. It was shown that redefining what constitutes a building boundary as well as appropriate sorting of the boundary points prior to applying the Douglas-Peucker polyline fitting algorithm helped to improve identification of building corners. Future work includes verification of the proposed algorithmic performance on LIDAR data where ground truth is available.

REFERENCES


