Outdoor Illegal Construction Identification Algorithm Based on 3D Point Cloud Segmentation

To cite this article: Lu An and Baolong Guo 2018 IOP Conf. Ser.: Mater. Sci. Eng. 322 052013

View the article online for updates and enhancements.

You may also like

- State revenue of the fishery sector after the prohibition policy on illegal unreported and unregulated fishing
  Muhamad Azhar, Budi Ispriyarso, Nabitaus Sa’adah et al.

- The implementation of vessel-sinking policy as an effort to protect Indonesian fishery resources and territorial waters
  Nurdin, Ikaningtyas and Rika Kurniaty

- Environmental law enforcement in forestry crime: A disjunction between ideality and reality
  S Muchtar and A Yunus
Outdoor Illegal Construction Identification Algorithm Based on 3D Point Cloud Segmentation

Lu An¹ and Baolong Guo²,*

¹,² Institute of Intelligent Control and Image Engineering, Xidian University, Xi’an, China

*Corresponding author e-mail: blguo@xidian.edu.cn

Abstract. Recently, various illegal constructions occur significantly in our surroundings, which seriously restrict the orderly development of urban modernization. The 3D point cloud data technology is used to identify the illegal buildings, which could address the problem above effectively. This paper proposes an outdoor illegal construction identification algorithm based on 3D point cloud segmentation. Initially, in order to save memory space and reduce processing time, a lossless point cloud compression method based on minimum spanning tree is proposed. Then, a ground point removing method based on the multi-scale filtering is introduced to increase accuracy. Finally, building clusters on the ground can be obtained using a region growing method, as a result, the illegal construction can be marked. The effectiveness of the proposed algorithm is verified using a publicly data set collected from the International Society for Photogrammetry and Remote Sensing (ISPRS).

1. Introduction
With the development of social economy, various illegal construction often occurs, which seriously restricts the orderly development of urban modernization. Therefore, it is of great significance to discover illegal buildings and to monitor their removal. The existing methods of identifying illegal constructions can be divided into two categories. In the first category, by using the Digital Terrain Model and the Digital Surface Model, the illegal constructions are compared to the supplemental data in the same region after being extracted by using 2D image. To compare the digital surface models with extracted buildings, Charalabos Ioannidis et al. [1] proposed an identifying method based on high resolution 2D images and an automatic change detection technique. The second category is to analyze the priori gray scale value, spectral information, and morphological information of the remote sensing image, then detecting the changes of the 2D image. In other words, processing multi temporal remote sensing images followed by the change detection of buildings in 2D images, where remote sensing images with different time phases are handled. Tan Qulin [2] detected buildings using spectral, spatial, textural and contextual parameters. However, the information devoted to detect object-covered buildings is not enough. In addition, these kinds of methods lack altitude data which is useful for identifying buildings, and the objects may be obscured by other natural targets such as trees. the gray value of the building shadow is similar to that of the building itself, which maybe causes the recognition accuracy inaccurate compared with former. Both these two kinds of methods detect targets by dealing with 2D images along with auxiliary data.

The appearance of the illegal buildings is similar to the legal ones. In addition, some special methods are adopted during the construction of illegal buildings, such as covered camouflage cloth
and plants. Therefore, the aerial view of illegal buildings may be very similar to the surrounding environment, which increases the difficulty of recognizing and monitoring by the aerial 2D image. The development of 3D point cloud technology provides a new opportunity to solve this problem. The accuracy of recognizing 3D illegal constructions can be improved by exploiting aerial 3D point cloud images, especially for the buildings which is similar to their surroundings. Distribution and intensities are used in the 2D image processing, while spatial information is used for identification in 3D LiDAR (Radio Detection and Ranging) techniques.

This paper presents a new method for identifying illegal constructions based on 3D LiDAR. The algorithm focuses on the 3D point cloud processing for outdoor environments. The identification algorithm proposed in this paper has three main steps. Firstly, a lossless point cloud compression method based on minimum spanning tree is proposed. Secondly, a ground point removing method based on the multi-scale filtering is proposed. Finally, building clusters on the ground are obtained by a region growing method, and the illegal construction is marked.

The remainder of this paper is organized as follows. Section 2 describes the details of the proposed outdoor illegal constructions identification algorithm based on 3D point cloud segmentation. Experiments are carried out and analyzed in Section 3. Section 4 discuss and conclude the paper.

2. Proposed Algorithm

Figure 1 shows the flowchart of the proposed algorithm, which is composed of the following three steps: point cloud data compressing, ground point removing, non-plane segmentation with region growing algorithm and selected field display.

![Flowchart](image)

**Figure 1.** The flowchart of identifying an illegal construction through the High-altitude 3D cloud image

2.1. Point Cloud Data Compressing

With the great improvements in the speed and accuracy of 3D scanning system, the point cloud data grows up, the burden of the computer such as storage, computing and sharing increases. Hence, the compression of point cloud data is the key point to avoid the problems such as insufficient storage space and long processing time, which could reduce the high-volume data to a small data sets while keeping the accuracy of geometric shape at the same level. Therefore, the speed of the subsequent treatment and the accuracy of result is improved effectively.

A lossless point cloud compression method based on minimum spanning tree is a non-destructive and rapid analysis method [3]. First, the whole model is divided into small model elements by using Octree method (the size of the cloud data compression time and rate was determined by the size of the cloud model segmentation). Then through the combination of real and linear predictions, the weight of the entire spanning tree is reduced, which is beneficial to the prediction compression of the floating
point in the subsequent process. Meanwhile, the calculation unit structure is established, which is helpful to find nearest query, reduce query time and improve the time efficiency (e.g., Figure 2).

Figure 2. The flowchart of the lossless point cloud compression method based on minimum spanning tree.

In order to facilitate the subsequent processing, point cloud model need to be cut. In other words, point cloud number within the unit is controlled within a range. it is used to balance the compression rate and compression speed.

In order to further improve the compression speed, the cloud data for each cell is segment by an octree of depth n, which makes the whole model into $8^n$ cube grids. The adjacent cube can be quickly found by cube center point, meanwhile, the center index for each cube grid is set up. Assign each point cloud to a small cube, and find adjacent non-empty cube with each cube as the center, then combined them into a computing unit. The weight between the cloud is calculated only once, and the calculation result is retained. Update the corresponding cube grid based on the forecast value. Combine the spanning tree according to the entire point cloud lookup method to form a complete minimum spanning tree.

The segmentation method may cause the point cloud nearest the point not in the cell. The Manhattan distances were used in the minimum spanning tree weights, and the Manhattan equidistant distance from a point cloud is shown in Figure 3. It can be seen from the figure that points outside the computing unit may be smaller than weights in the calculation unit. The minimum spanning tree used in this paper is an approximate minimum spanning tree. The weights of the method are basically the same as those of the completely minimal spanning tree, which has little effect on the subsequent floating point compression.

The point cloud model used for testing is based on the Stanford University standard point cloud model, bunny, dragon and armadillo. The compression rate of the method is 48.87, 36.23 and 33.54 respectively. And the rate using the traditional 7zip algorithm is 69.46, 45.74 and 52.46, respectively. The units of the compression time and rate is second and Bpp, respectively. As in results, it is indicated that the compression speed and rate of the method are improved obviously. Then compressing the point cloud data in minimum spanning tree, the processing time decreases from 19.469s to 6.878s with the compression, and the processing speed increases more than 60%.

Figure 3. The Manhattan equidistant distance from a point cloud
2.2. Ground Point Removing

Ground point removing is to identify and deal with the discrete points scattered on the ground and object by the mobile measurement system. In other words, separating the ground-point (e.g., land and road) and non-ground points (buildings, trees and vegetation etc.). This method helps to reduce the amount of computation and complexity of threshold set, meanwhile, the speed and accuracy can increase [4].

The normal mathematical morphology theory often used in this method. But the disadvantage is that the process of LiDAR point cloud data filtering is susceptible to filter window size. This reflected in the following aspects:

(a) If the window size is too small, some large bump points (such as buildings) will be ignored.
(b) If the window size is too large, the larger object can be identified while the undulated point can be neglected, this result in excessive filtering of terrain details. However, due to the complexity of the actual terrain, it is difficult to find a mathematical structure not only protect ground objects but also can filter out terrain details.

This paper introduced a multi-scale filtering method that the filter window size is gradually increased [5]. In other words, in the wave filtering process, with the change of windows size, the threshold of opening operation changed as well. The height threshold is calculated as:

\[
\begin{cases}
    d h_k, \omega_k \leq 3 \\
    d h_k = s \times (\omega_k - \omega_{k-1}) + d h_0, \omega_k > 3 \\
    d h_{max}, d h_k > d h_{max}
\end{cases}
\]  

Where \( \omega_k \) indicates the kth filtered window size, the growth mode are linear growth \( \omega_k = 2kb + 1 \) and index increase \( \omega_k = 2b^k + 1 \), \( b \) is initial window side length. \( s \) is the grid spacing of digital surface model. \( d h_0 \) is the minimum elevation threshold, \( d h_{max} \) is the maximum elevation threshold, \( s \) is the slope parameter of the terrain.

As the window size increase, the elevation difference threshold \( d h_k \) increase, the increment is determined by the terrain slope \( s \). After the open operation, when the height difference of a grid in the model is less than the corresponding elevation difference threshold, the point is determined the ground point. On the other hand, when the height difference of a grid in the model is larger than the corresponding elevation difference threshold. It is considered non-ground point.

2.3. Non-plane Segmentation with Region Growing Method

The roof surface of most buildings can be approximated regard as regular geometries, such as rectangles and triangles. On the contrary, the vegetation group has a very irregular structure and shape. Therefore, points on the same building surface have the same characteristic attributes (slope, normal vector, distance etc.). After removed ground points below the building, points suspend in the 3D space is acquired. Then the same point cluster can be acquired after using segmentation method [6].

Segmentation methods can be classified as model fitting-based method, region growing-based method and clustering feature based method. The common method for model fitting-based method are Hough Transform and Random sample consensus method. It has the advantage of being less susceptible to noise and abnormal data. But the segmentation is affected by the characteristics and it is not suitable for large point data segmentation. Region growing-based method is convenient, but the calculation time need to be reduced. Clustering feature based method are suitable for calculating the larger data set, but it cannot detect the continuous boundary point.

The purpose of the method is to merge the short distance points according to the smooth constraint. The output of the method is a cluster, and each cluster is considered as a set of points having the same smooth surface. The process of segment point clouds uses smoothness constraints, and the work of the methods based on the comparison of the angles between the points normal [7].
2.4. Selected Field Display
After non-plane segmentation, building clusters with different colors can be obtained. The ground points marked with white color, while other colors represent for the different building clusters. Then place each identified building cluster with a rectangular box. By comparing the priori database, it is easy to get changes of structures and occupied area at different times.

3. Experiments validation
In order to appraise the quality of recognizing target, region growing method is used to segment original point cloud and non-ground point cloud. To demonstrate the method, segment non-ground points using European clustering method is compared.

Applying region growing method, the result (Figure 4 (b)) based on original point cloud (Figure 4 (a)) is shown. Region growing methods based on normal vector and seeded. It is observed from the result that the output is not ideal, there is no distinction between ground and woods. It became apparent that the segmentation accuracy is improved after ground point filtering (Figure 5 (a)).

![Original point cloud](image1)

![The result of applying region growing method for original point cloud](image2)

**Figure 4.**

Using region growing method to non-ground point clouds, the KDTree data structure is to achieve access to neighbours and Euclidean distance is used as the clustering function for determine segment boundaries. Segmentation quality largely depends on clustering search radius value. For instance, object can be over segmented due to small search radius. Therefore, the suitable parameter need to be selected in advance. It can be seen from the result that the segmentation method using region growing methods is not suitable for the division of anomalous architecture (Figure 5 (b)).
Terrain features are similar in the small region. Therefore, for segmentation, it is necessary to set the normal angle and curvature threshold according to the terrain feature, then it can be applied to region growing method. Figure 6 (a) shows the result of applying region growing method, with setting normal deviation 5.15625 and curvature threshold 5.

After segmenting non-ground points (skip the low-impact points such as single plant), ground points are added with white color. Then identify the structures with rectangle and compared it with database. Thus warning or not can be determined (Figure 6 (b)).

4. Discussion and Conclusion
This paper proposes an identification algorithm based on 3D point cloud segmentation for the purpose of identifying outdoor illegal construction. Illegal construction identification algorithm was completed by processing outdoor 3D point cloud data. Since the Point cloud data compression is the pretreatment, the efficient of calculation increased significantly. Based on above, segmentation and
Identification method can be used. Segmentation has been used in many fields such as autonomous navigation, reverse engineering, games and entertainments. It combined with two segmentation method. The first is to distinguish non-ground points from original point cloud by setting the window size value of the filter and using elevation difference thresholds. The second is using region growing method based on the comparison of the angles between the normal of the points. The effectiveness of the proposed algorithm is verified by real 3D point cloud dataset collected from The International Society for Photogrammetry and Remote Sensing (ISPRS).

However, it should be noted that the current focus is on off-line point cloud data, and the threshold is determined by experience. Therefore, how to adjust the angle threshold between the normals and improve the adaptive ability and speed of the algorithm is a problem to be solved in the further study.

Acknowledgments
This work was financially supported by National Natural Science Foundation of China under Grants No. 61571346.

References
[1] Charalabos Ioannidis. Towards a strategy for control of suburban informal buildings through automatic change detection. Computers, Environment and Urban Systems, 33:64-74, 2009.
[2] TAN QuLin. Urban Building Extraction from VHR Multi-spectral Images Using Object-based Classification. Acta Geodaetica Et Cartographica Sircica, 39(6):618-623, 2010.
[3] Shuai Lv. Research on 3D Point Cloud Data Compression Algorithm Based on Minimum Spanning Tree. Master's thesis, Southeast University, 2016.
[4] Yan Liu, Lichun Sui, Yibin Zhang. Filtering of airborne lidar point cloud data based on the adaptive mathematical morphology. Acta Geodaetica et Cartographica Sircica, 39(4):390-396, 2010.
[5] Keqi Zhang. A Progressive Morphological Filter for Removing Nonground Measurements from Airborne LIDAR Data. IEEE Transactions On Geoscience and Remote Sensing, 41(4):872-882, 2003.
[6] Wuling Lang. Improved Morphometrics Filtering and Region Grow Method Based Buildings's LiDAR Cloud Points Exploration. Master's thesis, Southwest Jiaotong University, 2012.
[7] Information on http://pointclouds.org/documentation/tutorials/region_growing_segmentation.php#region-growing-segmentation, 2005.