SEGMENTATION OF LIDAR DATA FOR EXTRACTING BUILDING'S ROOF SHAPES, USING FUZZY LOGIC CONCEPTS

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Abstract

Building extraction becomes one of important fields of research in photogrammetry and machine vision. Involving airborne laser scanner (LiDAR) in geomatics, as an active sensor of 3D data acquisition, great evolution happened in data preparing to 3D outdoor object modeling. In consequence a great trend in developers and geomatics science researcher's communities leaded them to develop techniques in extraction of interesting objects from point cloud such as buildings. The LiDAR data don't explicitly contain any geometric information and feature of objects. The feature such as planes, lines and corners can be only indirectly extracted by segmentation algorithms.

In this research, a method for segmentation of LiDAR data for extracting buildings is proposed. In the proposed method, input data is an irregular LiDAR data and an adaptive clustering method for roof plane extraction from LiDAR data is implemented. So, to extract the roof structure, an assumption of planarity has been made. It is assumed that the roof can be modeled by a set of planar segments. In the proposed method the clustering is done without having any prior information about the number of the clusters. The clustering is done using FCM algorithm with considering maximum cluster number and then the extracted cluster will be modified using an iteratively split and merge technique. This approach was evaluated using some buildings of used data set and the results prove high efficiency and reliability of this method for extraction of buildings.

Keywords: Clustering, Segmentation, LiDAR data, Building extraction, Fuzzy Logic.

1. INTRODUTION

Airborne laser scanning is an established technology for highly automated acquisition of digital surface models. Furthermore, in recent years LIDAR data has become as a highly acknowledged data source for interactive mapping of 3D man-made and natural objects from the physical earth's surface. The dense and accurate recording of surface points have encouraged research in processing and analysing the data to develop automated processes for feature extraction, object recognition and object reconstruction [1]. Also, the need of achieving 3D model of buildings with acceptable precision, become important information in several fields in engineering. For example monitoring of changes in urban area or in the case of managing crisis, need the accurate 3D model of cities. But achieving a reliable automatic method needs so much tries. Still a challenge of surface extraction from laser scanning is the high amount of data to process. Strategies for efficient data processing such as segmentation are needed to extract features from high resolution LIDAR data. LIDAR data is dense, with high accuracy, but one still needs to extract higher level features from it [2]. Building representations are needed in cartographic analysis, urban planning, and visualization. We propose "Split and Merge" method for clustering to find building segments using fuzzy reasoning strategy [3].

The paper is structured as follows. Section 2 obtains the proposed method for clustering and segmentation. The test site and the used data sets and achieved results are discussed in Section 3 followed by a conclusion (Sec. 4).

2. PROPOSED METHOD

The simple way for extraction of building information from LiDAR data is partial and local analysis. This means that a part of point cloud should be analysed which is related to a building in object space [4]. So, it is possible to use a 2D map of area for selecting coincident points between a building and point cloud. In the other hand it is known that building roofs have clearly different height comparing with surrounding objects. This knowledge will be helpful for segmentation of buildings from ground points. So, after extracting clusters from probable building points, an efficient segmentation method is needed to generate parts of buildings from extracted clusters. So, after clustering step, a novel method will be implemented for segmentation of extracted clusters.

2.1. CLUSTERING TECHNIQUE

Clustering is a process of assigning pixels to categories or clusters based on some logic which acts on similarity of the pixels feature vectors. Three clustering techniques are popular to use in photogrammetry are K-means (or hard C-means) clustering, fuzzy C-means clustering and competitive learning networks. K-means is a representative for a classical and well explored unsupervised classification algorithm [5]. Its counterpart in the fuzzy techniques is the fuzzy C-means algorithm which considers each cluster as a fuzzy set, while a membership function measures the possibility that each feature vector belongs to a cluster. With respect to the advantage of fuzzy concept, FCM algorithm will be used in the experiments [6,7].

2.1.1. FUZZY C-MEANS CLUSTERING ALGORITHM:

Fuzzy C-means clustering (FCM), also known as fuzzy ISODATA, is a data clustering algorithm in which each data point belongs to a cluster to a degree specified by its membership grade. Bezdek proposed this algorithm as an alternative to earlier (hard) K-means clustering [6]. FCM partitions a collection of n vector x_i , $i = 1, \dots, n$ into c fuzzy groups, and finds a cluster centre in each group such that an objective function of a dissimilarity measure is minimized. The major difference between FCM and K-means is that FCM employs fuzzy partitioning such that a given data point can belong to several groups with the degree of belongingness specified by membership grades between 0 and 1[8]. In FCM, the membership matrix U is allowed to have not only 0 and 1 but also the elements with any values between 0 and 1 [9].

$$\sum_{i=1}^{c} U_{ij} = 1, \forall j = 1,\dots,n \quad (1)$$

The objective function for FCM is then a generalization of K-Means Equation as following:

$$J(U, c_1, \dots, c_c) = \sum_{i=1}^{c} J_i = \sum_{i=1}^{c} \sum_{j=1}^{n} u_{ij}^{m} \left\| x_j - c_i \right\|^2 \quad (2)$$

Where u_{ij} is between 0 and 1; c_i is the cluster centre of fuzzy group i. Fuzzy partitioning is carried out through an iterative optimization of the objective function shown above, with the update of membership u_{ij} and the cluster centres c_i by:

$$c_i = \frac{\sum_{j=1}^{n} u_{ij}^{m} x_j}{\sum_{j=1}^{n} u_{ij}^{m}}, \quad (3)$$

$$u_{ij} = \frac{1}{\sum_{k=1}^{c} \left(\frac{\left\| x_j - c_i \right\|}{\left\| x_j - c_k \right\|} \right)^{2/(m-1)}} \quad (4)$$

The FCM clustering algorithm is composed of the following steps:

Step 1: Initialized the membership matrix U with random values between 0 and 1 such that the constraints in Equation (1) are satisfied.

Step 2: Calculate c fuzzy cluster centres c_i , i= 1, ... , c. using Equation (3).

Step 3: Compute the cost function (objective function) according to Equation (2). Stop if either it is below a certain tolerance value or its improvement over previous iteration is below a certain threshold.

Step 4: Compute a new U using Equation (4). Go to step 2.

The cluster centres also can be initialized firstly and then iterative process carried out [10, 11, 12].

2.2. SEGMENTATION WITH SPLIT AND MERGE TECHNIQUE

It is obtainable that LIDAR data from a roof plane must lie in a same group after transferring to object space. Normal segmentation algorithms for LIDAR data such as region growing satisfy this condition. But, in this research another condition will be used that called "split & merge". In case of splitting, for each point group of extracted cluster, a plane will be fitted using least square method. So, the angle between two planes will be calculated using normal vector of generated plane as shown in equation (5). If the value of the angle was smaller than threshold (ε), two planes will be merged and a new plane will be generated.

$$arc\ \cos(nv_i.nv_j) < \varepsilon \quad \textbf{(5)}$$

After merging planes with discussed property, many of extracted classes will merge together and then the number of new class members will increase. so, the new normal vector will slightly change. This process will continue until satisfy tree main conditions:

- None of the contiguous planes should not have angle smaller than ten degrees.
- Distance between points and new plane should be smaller than a threshold.
- Population of a group member must be larger than a threshold.

The last condition, set for avoiding from generating unnecessary planes. It is desirable that the segments achieved from this method will be pure and homogenous. Flowchart of this method for development is shown in figure (1).

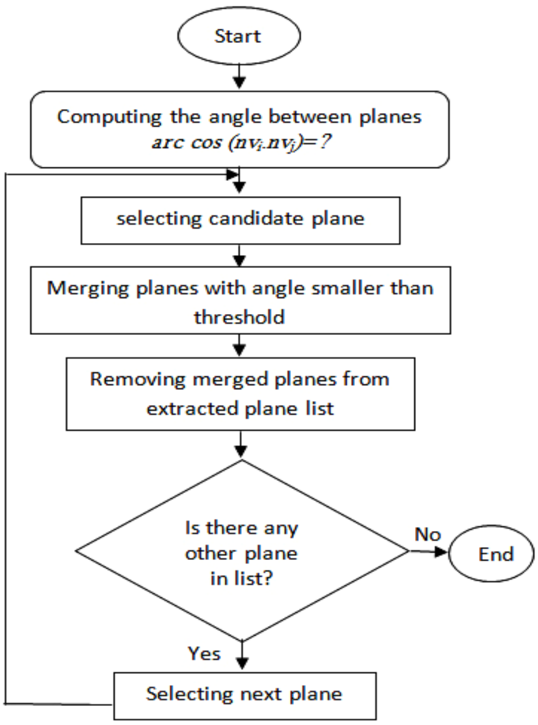


Fig. 1. Flowchart of merging technique.

2.3. USING 2D MAP AS ADDITIONAL DATA

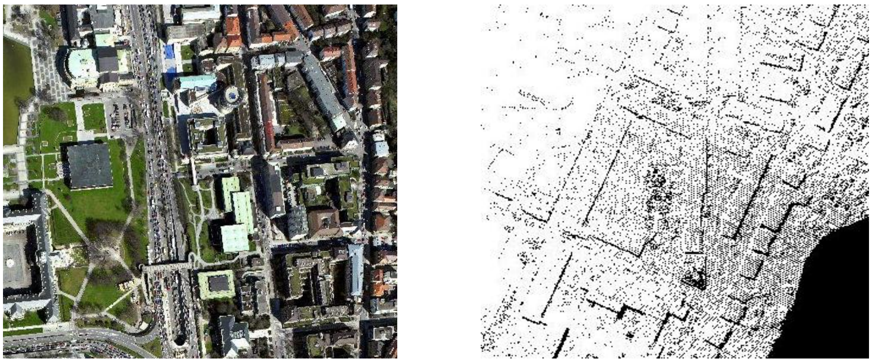
Two dimensional map of the related area is an important data source for validating clustering process with providing reliable point candidates for buildings. This additional data helps the algorithm for finding probable building position in shorter time interval and with high level of reliability. Therefore just probable areas positions from object space will be candidate for finding buildings. So, relation between object space and image space will be defined by Direct Linear Transformation (DLT) as shown in equation (6).

$$x = \frac{L_1 X + L_2 Y + L_3 Z + L_4}{L_9 X + L_{10} Y + L_{11} Z + 1}$$
$$y = \frac{L_5 X + L_6 Y + L_7 Z + L_8}{L_9 X + L_{10} Y + L_{11} Z + 1} \quad (\mathbf{6})$$

Where, $L_1, ..., L_{11}$ are the coefficients between map space (x, y) and object space (X,Y,Z).

3. EXPERIMENTAL INVESTIGATIONS

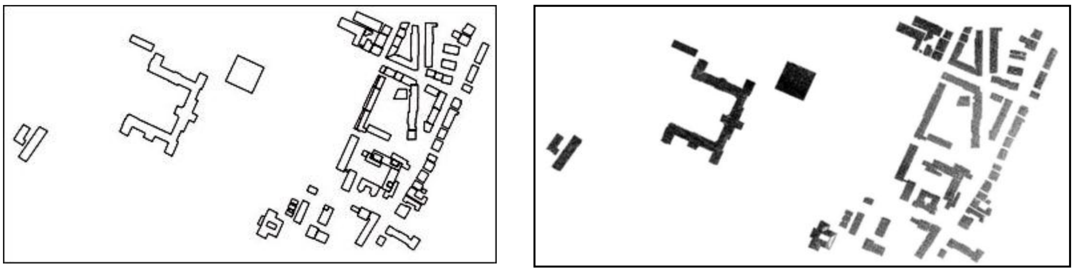
The airborne LIDAR data used in the experimental investigations have been recorded with TopScan's Airborne Laser Terrain Mapper system ALTM 1225 (TopScan, 2004). The pixel size of the range images is one meter per pixel. This reflects the average density of the irregularly recorded 3D points which is fairly close to one per m^2. Figure (2) shows the point cloud and image of test area [4].



(a) (b)

Fig. 2. Test area, aerial image (a), point cloud (b)

For evaluating the proposed methods in this research, a guide user interface (GUI) developed in MATLAB programming software. In the first step the point cloud related to buildings truncated from data source using 2D map of the area using DLT equation. Figure (3) shows, 2D map of the selected area and correspondence point cloud from source data set that selected with above approach.

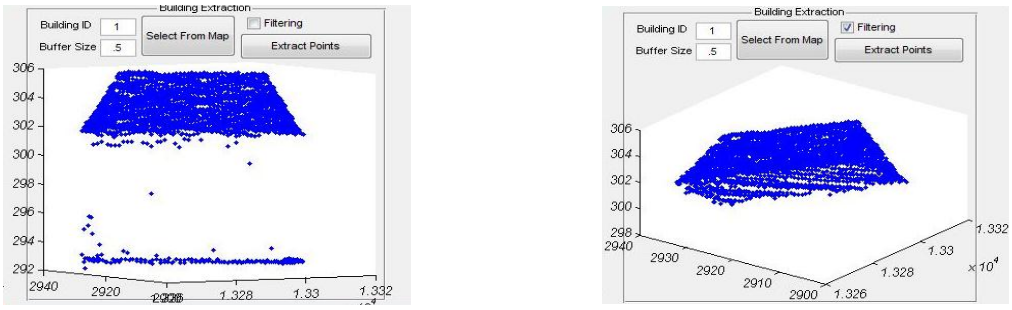


(a) (b)

Fig. 3. 2D map (a), and selected point clouds (b)

In the second step, pre-process stage for preparing data, selection of points from buildings polygons have been done by filtering non-roof points from data source as shown in figure (4). Also, selecting candidate points for probable buildings have been done by using an extra buffer area for being points involving roof and ground data. This technique will help the algorithm for separating roof points with the knowledge that roof points have more height in comparison with ground points. So, roof points will be separated from non-roof points.

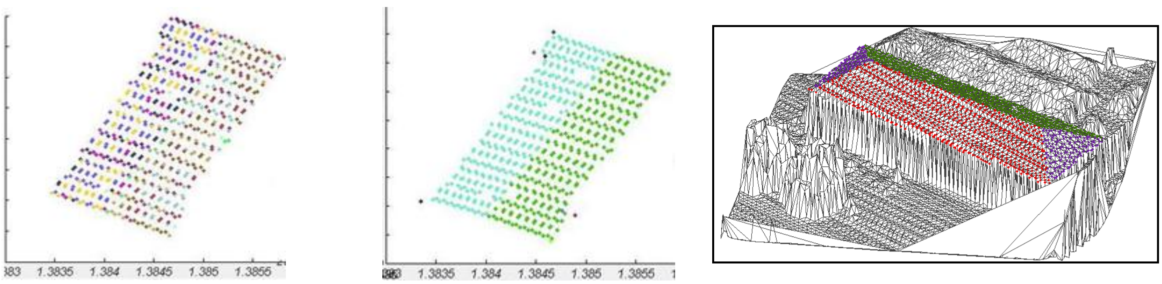
As discussed above, the link between image space and object space is obtained by DLT transformation. By comparing the elevation of roof and ground points with a logical buffer area, filtering is performed as shown in figure (4).



(a) (b)

Fig. 4. Pre-process of data, selecting points with 0.5 meter buffer (a), filtering of non-roof points (b)

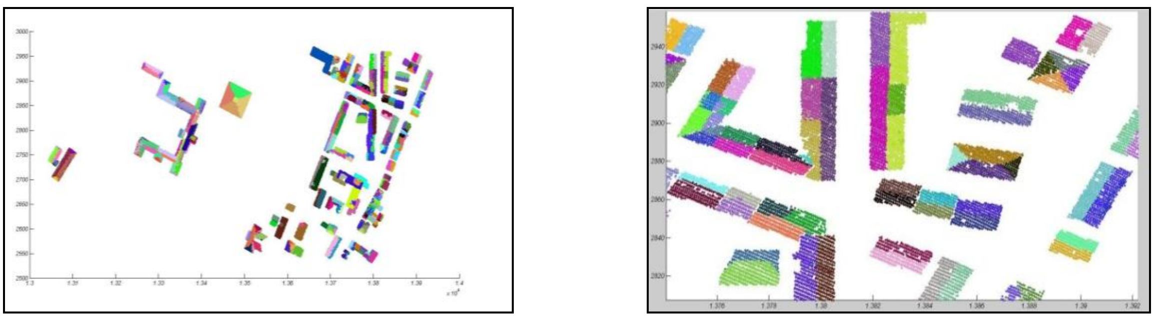
FMC method is used for clustering as mentioned. For automating this method, the maximum class number for clustering algorithm is set to fifteen classes desiring that the numbers of classes are so smaller than fifteen. So, it is claimable that this algorithm is independent from number of initial class number. After extracting features, the proposed method called "Split & merge" is implemented segmentation of roof data as shown in figure (5).



(a) (b) (c)

Fig. 5. Feature extraction result (a), segmentation with “split and merge” method (b), overlay with TIN (c)

Final result of segmentation in selected area is shown in figure (6). With respect to the density of point cloud in this research, extractions of the small parts of the roofs such as chimneys and dormers are neglected.



(a) (b)

Fig. 6. Result of segmentation on selected area (a), and in closer view (b).

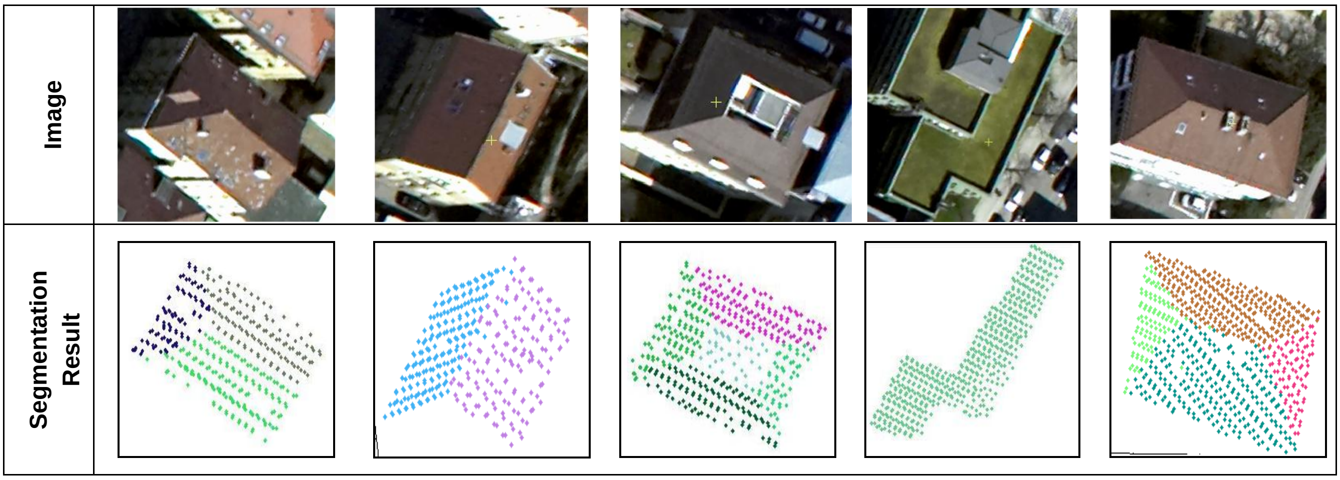
Accuracy of segmentation is computed by using three criterions for each building individually and final accuracy computed from getting mean value of these three values [12]. Criterions which used are Purity, F-measure and NMI, that for computing them, it is necessary to have the reference data [13]. Reference data is provided with visual extracting method for each roof plane. Numerical and graphical assessments of accuracy for each type of roofs are presented in table (1) and figure (7).

Table 1. Accuracy assessment of segmentation considering roof types

Roof type	Purity	NMI	F-measure	MEAN VALUE
Flat	0.834	0.812	0.612	**0.752**
Gable	0.956	0.839	0.681	**0.825**
Hipped	0.829	0.787	0.583	**0.733**
Complex	0.667	0.423	0.482	**0.524**

Proposed method is tested in several roof types that are in test area and the result of segmentation is shown for each image (Table. 2. After generating valid segments of roof's structure, it is possible to fit a proper plane for each segment) [14, 15, 16]. So, reconstructed shape of the building will be the topic of future researches [16].

Table 2. Segmentation result with several types of roofs.



4. CONCLUSION

This paper presented and tested a new segmentation method based on the iterative "split & merge" method in extracting buildings and roof shapes form LiDAR data based on fuzzy C-means method. One of the advantages of this method is that it doesn't need the initial number of classes while it is possible to set this value to maximum number of desirable classes. The other advantage is the efficiency of segmentation technique that proposed in this research. Numerical and visual results, demonstrate high capability of segmentation process that specially achieved in gable type roofs because of distinguished slopes in these kinds of roofs. But, in the other hand because of the repeated filtering on clusters, small side effects such as noise, chimneys and dormers will have not a significant effect on final outcome.

But, in some cases non-homogeneous points also have been seen in some segments. As is shown in figure (8), despite the successive filtering and applied "split & merge" method, three points are located within the heterogeneous class. It should be noted that the number of these points doesn't make a large negative effect on the final results but removing these wrong points will make the proposed method more reliable. Furthermore, if it is necessary to extract dormers or chimneys from roofs, obtained methods may change in setting of thresholds. In such case, the resolution of the LiDAR data source is significant parameter for extracting accurate shape of roof details.

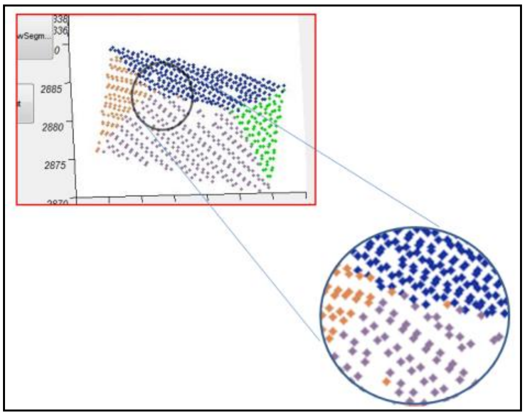


Fig. 8. There are three points in the heterogeneous classes

5. ACKNOWLEDGMENT

The authors would like to thank the Islamic Azad University's (South Tehran Branch) research deputy Office for supporting this work. We also would like to thank Dr. Michael Hahn from Stuttgart University of Applied Sciences for providing the data set used in the paper.

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