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Segmentation and determination of grid points of curve points in terrestrial laser scanning data for regular curve surfaces via C-means integrated fuzzy logic approach

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ABSTRACT

Terrestrial Laser Scanners (TLS) are used frequently in three dimensional documentation studies and present an alternative method for three dimensional modeling without any deformation of scale. In this study, point cloud data segmentation is used for photogrammetrical image data production from laser scanner data. The segmentation studies suggest several methods for automation of curve surface determination for digital terrain modeling.

In this study, fuzzy logic approach has been used for the automatic segmentation of the regular curve surfaces which differ in their depths to the instrument. This type of shapes has been usually observed in the dome surfaces for close range architectural documentation. The model of C-means integrated fuzzy logic approach has been developed with MatLAB 7.0 software. Gauss2mf membership functions algorithm has been tested with original data set. These results were used in photogrammetric 3D modeling process.

As the result of the study, testing the results of point cloud data set has been discussed and interpreted with all of its advantages and disadvantages in Section 5.

1. Introduction

Today, terrestrial laser scanning and modeling technology are densely used in architectural documentation and cultural heritage studies besides the technique of close range photogrammetry. In the perception of engineering perspective, these two methods are independent of each other. However, these two methods can be combined with each other as being the essential parts of architectural documentation and cultural heritage studies [1].

A terrestrial laser scanner could be simply explained as a complete motorized station [2]. It benefits from the three dimensional surface data which is the three dimensional coordinate point cloud from the scanned object. The scanning process can be done automatically in a second within x, y, z coordinates with more than a thousand points. Moreover, if the scanner has a camera, each point acquires a color data [3]. This type of terrestrial laser scanners are generally used in the cultural heritage documentation and deformation measurement studies in three dimensions [4,5].

In the literature, many mathematical models have been used on the curve surfaces for automatic data segmentation and have determined the digital terrain model.

The development of a surface segmentation method has been explained as such: “point cloud into smooth surfaces is the first important step of the developed filtering”. If there is a smooth path of adjacent points, four points are considered to be part of the same surface. This definition allows for discontinuities in a surface as long as there is a path around a discontinuity that connects points on both sides. According to this definition, although they also contain points with significant height differences to nearby bare Earth points, ramps, bridges, and flyovers are considered as a part of the bare Earth [6]. Some of the new approaches to segmenting air borne laser scanner data have been presented in the literature. Instead of a point-wise classification based on the distribution of the points, a local area classification has been performed on segments of the original point cloud [6]. In another suggested method, surfaces are considered as a graph of intersecting planar curves as opposed to surface patches. In this graph structure, the curves intersect at common points and terminate at surface discontinuities. This characteristic of the curves makes it possible to determine point segments with connected components [7]. A method for the detection of curves in the profiles has been presented. These are called “surface based segmentation

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techniques". They typically begin by triangulating the point cloud. Then, seed triangles are randomly chosen. Triangles in the neighborhood of these seed triangles are tested. Triangles that meet the given similarity criteria are aggregated with the seed triangles. This aggregation forms the initial segment. The process of testing neighbor triangles is repeated with the previously identified triangles being used as seed points [7]. Surface based segmentation algorithms describe surfaces using explicit surface functions (cylinders, planes, surface patches). This operation complicates the segmentation of implicit surfaces, since these algorithms are designed for specific scenes [8], e.g. for industrial installations [7]. This segmentation method has two steps, normal estimation and region growing [8]. Normal estimation uses the K nearest neighbors (KNN) mathematical model. In this model, we select the k points from the point cloud having the minimum distance. Alternatively, it uses the Fixed Distance Neighbors (FDN) mathematical model in which the search of the number of points changes according to the density of the point cloud. As the number of points is directly proportional to the density of the points in the neighborhood, this method does not have the adaptive behavior of KNN. The next step in the segmentation process is region development. This stage uses the point normals and their residuals, in accordance with user specified parameters to group points belonging to the smooth surfaces [8]. The segmentation algorithm treats surfaces as a series of interconnected curves which end at discontinuities or surface boundaries. The algorithm identifies connected points on continuous curves in profiles using proximities and changes in curvature [7]. In another work for human body scanning which deals with the irregular curve surfaces, [9] one of the earliest significant works on fitting analytic entities to digitalized data has been presented. In this study, fitting of conic sections to the scattered data has been examined. Subsequent works resulted in the development of a number of algorithms for conic fitting. These are best summarized in the referred study [10]. [11] as well as [12] go further by fitting hyperquadric closed surfaces using an energy minimizing within this approach. [13] present a method of deriving surface patches from range descriptions, although the approach is limited to human-made CAD objects with a restricted range of types of patches [14]. The idea behind the proposed algorithm is quite simple. By assessing curvature at each point in the given point cloud, the surface is locally approximated by an analytic representation ("surface patch"). The differential properties of the patch at the point of interest are then calculated analytically and assigned back to the point. The process is repeated for each point in the point cloud. The analytic representation of the choice is an implicit surface of the form: $F(x,y,z)=0$ [14]. [15] also presents the basic planar surface determination with this mathematical function. Additionally, a new filtering function has been given for point by point filtering in surface determination [15]. This is an advantage that representations of the form $z=f(x,y)$ do not have, since they cannot represent surfaces where a line of the form $(x=x_c, y=y_c)$ intersects the surface at more than one point (e.g. spheres, ellipsoids, and most other conic sections) [14].

These suggested algorithms of segmentation are defined in two groups: area based and object based. In this study, the suggested algorithm includes the object based segmentation algorithm for regular curve surface detection. The curve surfaces focus on point cloud data for the photogrammetric rectification and its benefits. Curve surfaces are used usually inside and outside of the historical buildings. Therefore, in this type of structures, automatic point detection is made more precisely. The rectification processes of curve surfaces and planar surfaces are almost the same in close range photogrammetry [15]. Fuzzy segmentation has also been used in literature previously and planar surfaces have been separated robustly. With reference to a similar study in literature, segmentation is understood as the process of splitting data into separable regions that maintain both unique and homogeneous features from their surroundings. Therefore, segmentation can be considered as a labeling process to classify data according to the region it belongs to. Segmentation based on fuzzy clustering is able to detect not only surfaces that are clearly separated, but also surfaces that can not be discriminated by the human eye. Therefore, it can be used for a variety of applications from large structures such as building constructions and 3-D modeling to performance evaluation of terrestrial laser scanners and control of micrometric deformations for industrial analysis [16].

However, the number of points and point coordinates of the curve surfaces are more than the planar rectification. Determining digital terrain model has become more important in the fundamental process of the curve rectification because of the small areas in the construction facades of historical buildings. Determining the borders of the planar surfaces and curve surfaces is preferred especially in the engraving parts of the monuments. In this study, a new automatic segmentation method investigates the point clouds of regular curve test areas in order to determine the best fitting rectification points from the point cloud on the test field. Then, photogrammetric rectification results are compared with the same curve surfaces. Photogrammetric measurements of three dimensional coordinate data were necessary for the conventional mathematical algorithms. Afterwards, the triangulation methods such as nearest neighbor interpolation have been used for gridding and determining digital terrain model. This kind of process is an operator based process. It spends too much time for the photogrammetric rectification. The artificial fuzzy approach automatically generates the rectification points from the general shape of the point cloud.

This paper is organized as follows: After the introduction, Section 2 gives a description of the algorithm. Section 3 presents the acquisition of laser scanner data in the study site and application of algorithm which has been developed for the curve surfaces. Section 4 points out the results of the study and presents a discussion of these results. Finally, Section 5 summarizes the main achievements that have been attained by this study.

2. Algorithm

In laser scanning data, the segmentation methods could be summarized in three different categories [17].

First one is the edge-based methods which attempt to detect the discontinuities in the surface that form close boundaries of different segments. Typical examples on the edge based methods are three typical methods for edge detection proposed in [18]. [19] implemented the boundary detection, using surface curvature. A scan line grouping technique has been presented in [20] for fast segmentation of range images [21] for extracting close contours from a binary edge map. A drawback of these methods is that they are sensitive to noisy points [17].

The second one is composed of region-based approaches. They can be classified in two categories: bottom-up and top-down. Top-down method begins with assigning all the points into one group and then, they are fixed to a surface. As long as a chosen figure of merit for fitting is higher than a threshold, subdivision region continues [22]. For bottom-up approaches, at first, a number of seed regions or a seed point are chosen, and neighbor points based on some compatibility thresholds are added. Some of the representative works are reported in [23–26]. However, choosing seed regions as well as controlling the growing process would be difficult and time consuming, and the segmental results could be sensitive to the chosen compatibility thresholds [17].