An Application of Triangle Mesh Models in Detecting Patterns of Vegetation

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ABSTRACT

This contribution presents the results of a work in progress, attempting to use discrete curvature for triangle meshes in order to automatically identify specific structures in remote sensing data. Specifically, the focus was on determining isolated trees, on the basis of data acquired through airborne laser scanning. Five methods for discrete curvatures were tested and compared for a triangle mesh derived from a high density point cloud. The best performance was obtained for the mean curvature computed by using the shape operator.

Keywords

discrete curvatures; shape detection; LiDAR point cloud; Hough transform

1 INTRODUCTION

One of the applications of pattern recognition techniques is detecting specific vegetation structures or measuring its characteristics. The development of novel remote sensing technologies triggered the appearance of various approaches attempting to automatically extract information related to vegetation features, such as estimating tree height or crown diameter, determining the location of isolated trees, etc. The techniques used cover a wide range of mathematical tools, such as detection of local maxima [PWN03], second-order image derivatives [BWLM03] or multi-resolution techniques [FSH*06]. A comprehensive overview of recent developments and several alternative methods can be found in [KHY*12]. Generally, the techniques are based on the use of the so-called canopy height model in the form of a regular grid.

Since the canopy grids are derived from point clouds through interpolation techniques, some information might get lost during the averaging process. In particular, fine structures might remain undetected. An alternative to the regular grids could be the use of triangle meshes, which can be derived directly from the point cloud by using appropriate triangulation techniques. The presence of vegetation structures can be related to the lack of flatness of the canopy model, which is quantified, in turn, by discrete curvatures computed for the triangle mesh.

The aim of the study was to examine to which extent discrete curvatures for triangle meshes indeed capture remote sensing data information related to presence of isolated trees. This was achieved by performing numerical experiments and by considering several state of the art methods for computing Gaussian and mean curvatures.

2 APPROACH DESCRIPTION

We used a high density LiDAR point cloud ($\sim$20 points/m^2) acquired through customized airborne laser scanning in a mountain region characterized both by variable topography and presence of various vegetation structures. The high quality of the laser scanning together with a pre-processing step mitigated the noise influence in the remote sensing data. The point cloud contained approximately 400K points and covered a surface of 20480m^2. Then, in the next step, a 2.5 Delaunay triangulation was generated by using a standard approach: the points were projected on the horizontal plane, a Delaunay triangulation was generated and then the topology was lifted to the original set of points. The (x,y) duplicates (occurring due to the multiple returns in regions with vegetation) were removed. For the triangle mesh created in this way, we computed the values of discrete curvatures as provided by five methods widely used and which rely on various geometric elements of the triangle mesh (Figure 1). Specifically, we considered a method based on Euler's theorem (ET), see [WB01]; two methods based on the Gauss-Bonnet scheme (GB1, GB2), see [DHKL01, MDSB03]; a method relying on the shape operator (SO), see [HP04] and the tensor approach (TA), see [Tau95]. A list of the methods as well as the geometric elements required by each method for defining the Gaussian and the mean curvature can be found in Table 1.

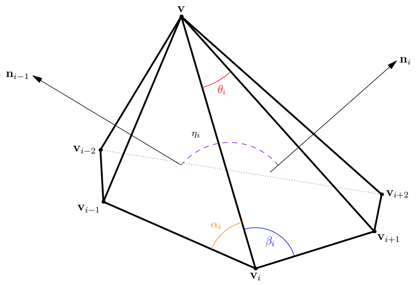


Figure 1: Geometric quantities and the one-ring neighbourhood $\mathcal{N}_\mathbf{v}$ of a vertex $\mathbf{v}$. One denotes by θ_i the angle between the adjacent edges $\vec{\mathbf{e}}_i=\overrightarrow{\mathbf{v}\mathbf{v}_i}$ and $\vec{\mathbf{e}}_{i+1}=\overrightarrow{\mathbf{v}\mathbf{v}_{i+1}}$. The angle between the vectors $\vec{\mathbf{n}}_{i-1}$ and $\vec{\mathbf{n}}_i$, normal to the adjacent faces $\Delta\mathbf{v}\mathbf{v}_{i-1}\mathbf{v}_i$ and $\Delta\mathbf{v}\mathbf{v}_i\mathbf{v}_{i+1}$, is denoted by η_i. The angles $\widehat{\mathbf{v}\mathbf{v}_i\mathbf{v}_{i-1}}$ and $\widehat{\mathbf{v}\mathbf{v}_i\mathbf{v}_{i+1}}$ are denoted by α_i and β_i, respectively.

Subsequently, we constructed a regular grid having cell size 1m; such that each vertex belonged to a unique cell. In this way, for each discrete curvature one got a 'grid' of averaged curvatures, having cell size 1m, obtained as follows. For each cell one firstly considered the vertices lying in that cell and then one computed the average value of the curvatures corresponding to these vertices. Finally, we used the Hough transform (e.g. [IK88]) for detecting circles. The main reason for proceeding in this way was that horizontal projections of tree crowns usually yield circular shapes. This step was achieved by using an appropriate function of the Matlab software. The sensitivity factor was set to be equal to 0.85, which is the default value.

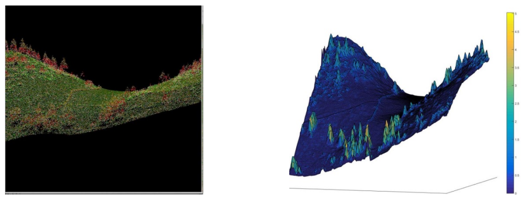
3 RESULTS

The points of the point cloud were classified in a preprocessing step. Due to the high point density, vegetation structures are already visible in the cloud (Figure 2a and Figure 3a), facilitating an empirical comparison. The regular grids derived from discrete curvatures capture for certain methods the occurrence of isolated trees (Figure 2b). While for the Gaussian curvature none of the methods does provide consistent and conclusive results, the situation changes for the mean curvature. The

Method	*Gaussian curvature*	*Mean curvature*
ET	Weighted normals Edges Edge angles θ	Weighted normals Edges Edge angles θ
GB1	Edge angles θ Face areas	Face / normal angles η Edge lengths Face areas
GB2	Edge angles θ Mixed areas	Cotangent of angles α, β Edges Mixed areas
SO	Normals Edges Face / normal angles η	Normals Edges Face / normal angles η
TA	Weighted normals Edges Face areas	Weighted normals Edges Face areas

Table 1: Methods for computing discrete curvatures considered in the study. The geometric elements are denoted as in Figure 1.

structures that can be visually detected in the LiDAR point cloud are recovered very good when one uses the shape operator method SO (Figure 3e). Other methods (such as the Gauss-Bonnet schemes GB1, GB2) detect false positives (Figure 3c,d), while the method ET based on Euler's theorem and the tensor approach TA detect fewer trees (Figure 3b,f). It is worth to notice that by using the shape operator one can detect not only circular structures such as trees, but also linear structures such as fences (Figure 3e). Moreover, the variation of the shape operator reflects the terrain variability (almost null in flat regions), higher values were recorded exactly where some variability occurs.



a. **b.**

Figure 2: **a.** The LiDAR point cloud. **b.** 3D Representation of the grid (the height of each cell is the average of the height of the vertices lying in the cell; the colour is the averaged mean curvature, computed by using the shape operator).

It is a natural question for which reasons the methods provide different outcomes. A first hypothesis could be that the methods providing the best results are those that explicitly use the lengths of the edges of the triangle mesh. This could provide a certain 'scale' sensitivity of these methods, enabling the detection of fine scale structures. Another hypothesis refers to the existence of a local autocorrelation for the methods providing better results. This makes it possible the detection of spatial structures and decreases the noise effects.

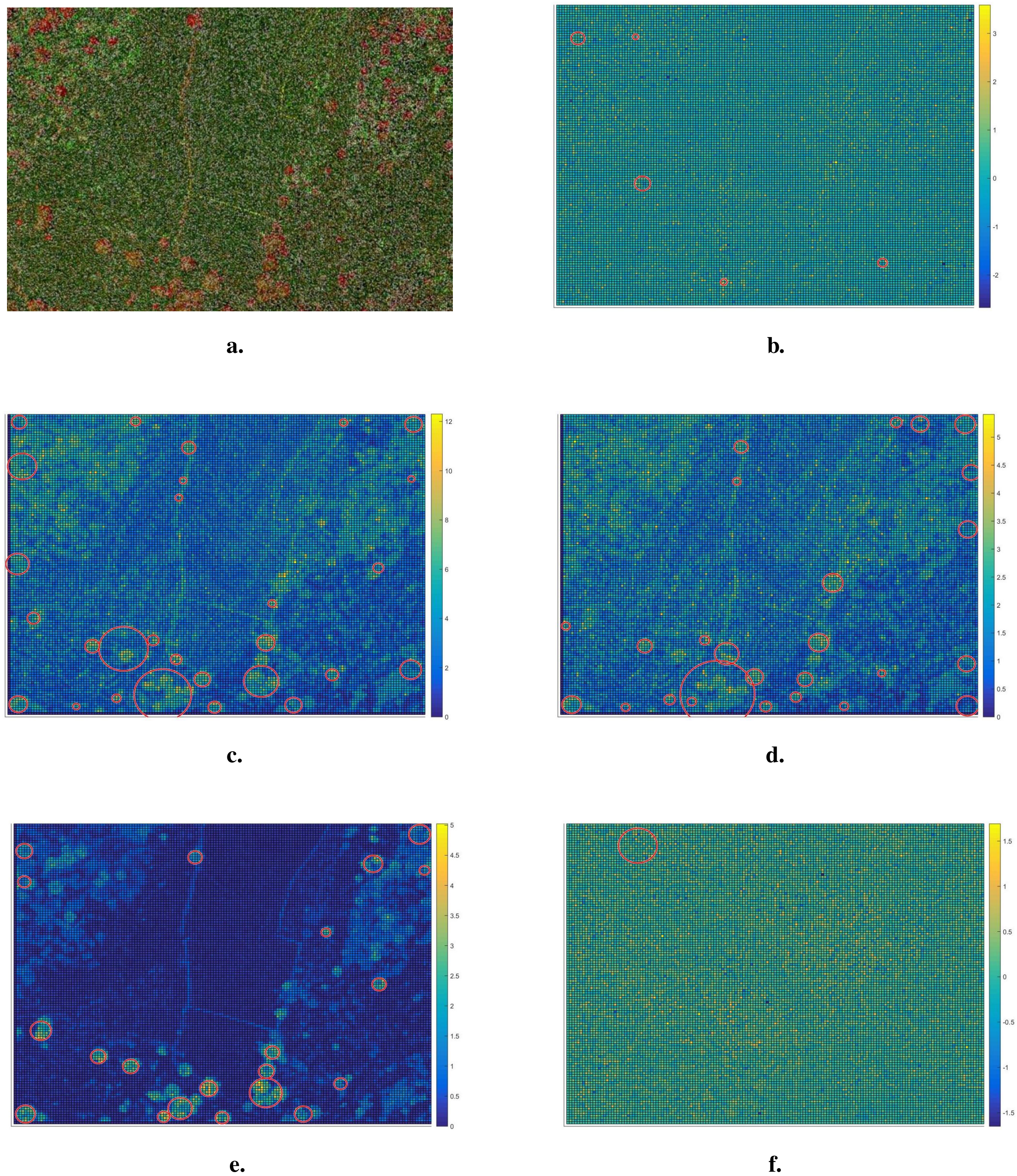


Figure 3: **a.** 2D view of the LiDAR point cloud. Data was pre-processed and colours represent height above ground. Trees are coloured in red. **b.**−**f.** Grids of averaged mean curvature: method based on Euler's theorem ET (**b**); methods based on the Gauss-Bonnet scheme GB1, GB2 (**c, d**) shape operator SO (**e**), tensor approach TA (**f**). The colours are determined by the values of the averaged mean curvature: for each cell one considered the vertices lying in that cell and computed the arithmetic mean of the curvatures corresponding to these vertices. The circular shapes were detected by using the Hough transform, as implemented in the Matlab software.

4 DISCUSSION

The method discussed in the paper has some strengths compared to other methods. For instance, standard state of the art techniques, such as the one based on local maxima in [PWN03] require a preliminary field survey, enabling an appropriate calibration and developing suitable regression models, while the method presented in the paper is completely independent on any *a priori* knowledge. Another advantage is the independence on tree species, while other approaches are species sensitive. For instance, the method in [FSH*06] is based on the Mexican Hat wavelet and is appropriate for coniferous trees. Finally, since one estimates the lack of flatness at local level, the method can be applied both to the canopy height model and to the digital surface model: the former includes only vegetation information and assumes the terrain to be flat while the latter includes both the vegetation and terrain variability.

There are still some shortcomings that can be mitigated and some issues that need to be further investigated. A major assumption of the method is that the trees to be detected are perfectly circular, which is not always the case, and that they are completely isolated. In particular, a major challenge is to detect groups of trees or to identify single trees in a forest. Both the lack of roundness and the neighborhood influence could be addressed by adapting the shape detection algorithm. The method works well for very high resolution data and it is a natural question to what extent it could be useful for less accurate input. The time complexity is a weakness of the method, since generating a triangulation for a high resolution point cloud requires a higher computational effort. However, efficient algorithms, combined with the increase of the computational power of modern hardware could decrease the running time even for larger data sets.

5 FUTURE WORK

Instead of conclusion, we briefly discuss some tracks that can be further investigated. From a rather theoretical perspective, it is a need to understand the hypotheses related to the role played by the formal definitions and whether a certain autocorrelation exists for some methods. Another important issue, regarding both the theoretical and practical perspective, is to understand how the outcomes change when the sensitivity parameter is changed in the circle detection step. Thus, 'fine tuning' could be crucial in improving the performances of the method. Last but not least, comparative analyses with other methods relying on different techniques, combined with a field survey and a cross-check of the results would be desirable. One could understand whether the method presented in this study could be used as a stand-alone technique or could be useful in hybrid approaches, by bringing added-value to other well-established methods.

6 ACKNOWLEDGMENTS

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