QEM-BASED SIMPLIFICATION OF BUILDING FOOTPRINTS FROM AIRBORNE LIDAR DATA

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1. INTRODUCTION

This paper presents a QEM-based simplification approach for extracting and delineating building footprints from Airborne LiDAR data. Our approach consists of three steps: first of all, Digital Surface Model (DSM) is generated from the raw point cloud by using the interpolation method. Secondly, the potential points on building outlines have to be aggregated to form connected building blobs. Those blobs that exceed a certain size and have certain characteristics (e.g. consisting of planes) are supposed to be building candidates. In a third step these outlines are simplified to building footprints. The focus lies on taking the characteristics of buildings into account to produce a meaningful 2D building shape and simplifying different possibilities to generalize the building footprints.

2. EXTRACTION OF BUILDING CANDIDATES

First of all, as shown in Figure 1(a), the processing step generates a DSM of high quality based on the raw LiDAR point clouds. During the generation, a 2D-interpolation method is applied, which is a common procedure to approximate a real surface that is irregularly sampled by points. Secondly, the points on the building boundary have to be detected to form connected building candidates.

In order to achieve this goal, an edge detection will be implemented. The Canny edge detector [1] is widely used in computer vision to locate sharp intensity changes and find object boundaries in an image. However, Canny edge detector using inappropriate fixed upper threshold τ_u and low threshold τ_l may miss some obvious edges or involve weak edges (as shown in Figure 1(b)). In this paper, an adaptive algorithm [2], which is capable of performing hysteresis threshold adaptively based on finding edge region and background region in the gradient magnitude histogram plot, is employed for extracting building outlines from DSM.

We define N is the number of the pixels in DSM and H_i is the gradient magnitude of the pixels which amount is i ($0 < i < N$). It is known that only a few pixels are edges in an image. So the peak in the gradient magnitude histogram represents the aggregate of the pixels which locate in background region, not in edge region. We define $H_{\max}$ as the gradient magnitude which the most pixels have. We define $\sigma_{\max}$ as the measure of the dispersion of a frequency distribution using equation 1.

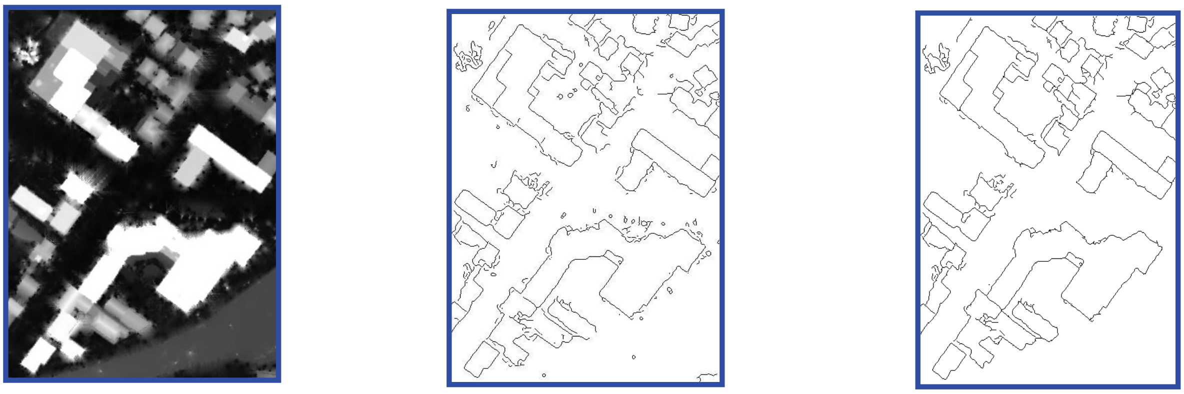
$$\sigma_{\max} = \sqrt{\sum_{i=0}^{N} (H_i - H_{\max})^2 / N} \qquad (1)$$

The variable $\sigma_{\max}$ shows the deviation of the other class members in gradient magnitude histogram from the $H_{\max}$. We can sure that τ_u is determined out of the background region and the results should not involve fake edges by using equation 2.

$$\tau_u = H_{\max} + \sigma_{\max} \qquad (2)$$

After we determined τ_u, taking no account of the pixels which gradient magnitude is larger than τ_u, we can compute $\sigma'_{\max}$ and τ_1 in same strategy by using underlying equation:

$$\sigma'_{\max} = \sqrt{\sum_{i=0}^{N} (H_i - H_{\max})^2 / N} \qquad \tau_1 = H_{\max} + \sigma'_{\max} \qquad (3)$$



(a) original DSM. (b) building candidates from Canny. (c) building candidates from adaptive Canny.

. Figure 1. Extraction of building candidates from original DSM.

Tests are carried out on real DSM data using original Canny method and adaptive Canny method. Figure 1(b)-(c) shows how our method revises the Canny edge detector and improve detection results. It demonstrates that the adaptive Canny algorithm is capable of performing hysteresis threshold adaptively to get better results.

3. QEM-BASED SIMPLIFICATION OF BUILDING FOOTPRINTS

In the third step, the outline is simplified by using a QEM-based simplification [3-4] which is capable of rapidly generating high-quality approximations. This greedy edge contraction algorithm requires O(n)

iterations to simplify a model with n lines to a fixed level with a plane-based error metric which called quadric error metric, or QEM for short. Given a plane which is the set of all points $n \cdot v + d = 0$ with a unit normal $n = [a\ b\ c]^T$ (i.e., $a^2 + b^2 + c^2 = 1$) and a scalar constant d, the squared distance of a vertex $v = [x\ y\ z]^T$ from this plane is given by the equation

$$D^2(v) = (n^T v + d)^2 = \left(v^T (nn^T)v + 2(dn)^T v + d^2\right) \tag{4}$$

Then, a quadric Q is defined as a triple $Q = (A, b, c) = (nn^T, dn, d^2)$, where A is a 3×3 outer product matrix, $A = nn^T$, b is a 3-vector, $b = dn$ and c is a scalar. The squared distance $Q_{(v)}$ of point v to the plane can be calculated using the second order equation

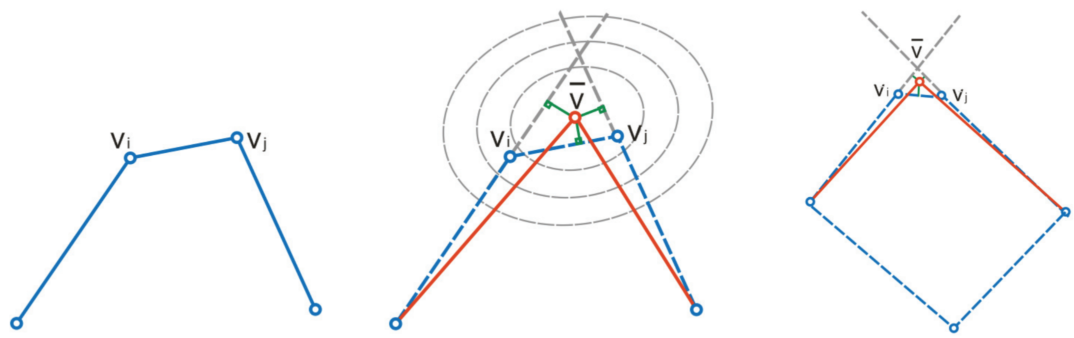
$$Q_{(v)} = v^T A v + 2b^T v + c \tag{5}$$

Therefore, given a set of fundamental quadrics Q_i determined by a set of planes and weighted by areas of triangles adjacent to v, $Q_{(v)} = \sum_i^n area(f_i) Q_v$, the quadric error $E_{Q(v)}$ is computed by the sum of the quadrics:

$$E_{Q(v)} = \sum_i Q_i(v) = (\sum_i Q_i)(v) \tag{6}$$

In other words, to compute the sum of squared distances to a set of planes, we only need one quadric which is the sum of the quadrics defined by each of the individual planes in the set. When contracting the edge $(v_i, v_j) \rightarrow \bar{v}$, the resulting quadric is merely $Q_{\bar{v}} = Q_i + Q_j$. After initialization, for each edge collapse $(v_i, v_j) \rightarrow \bar{v}$, the optimal position is $\bar{v} = -A^{-1}b$ and the cost is $Q_{(\bar{v})} = b^T \bar{v} + c = -b^T A^{-1} b + c$

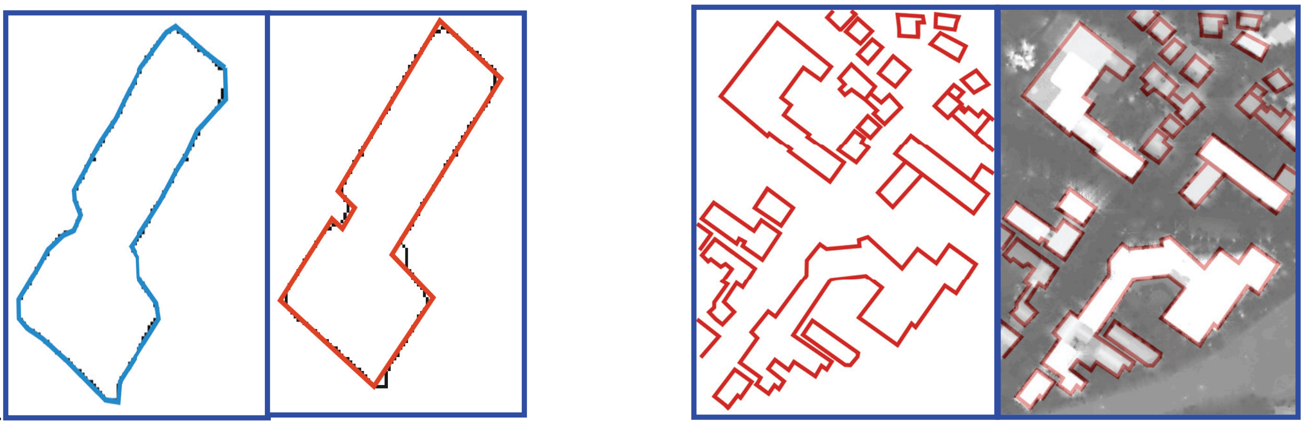
Once this edge is collapsed (as shown in Figure 2), the new vertex $\bar{v}$ accumulates the planes associated with the edge by $Q_{\bar{v}} = Q_i + Q_j$. Figure 3 shows the result when processing a larger area with proposed method.



(a) building outlines. (b) Edge collapse transformation. (c) QEM-based simplification of outlines.

. Figure 2. QEM-based simplification.

As shown in Figure 2, the result of the QEM-based simplification method achieves good results. Our method has solved the problem of all the point-reduction approaches which is that the final ground plan can only consist of a subset of the original points [5], i.e. as show in Figure 2 if a building corner is not given, it still can appear in the final shape of our method.



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(a) building outline after straight lines adjust. (b) building outline after the application of QEM-based simplification (c) final result of building footprints. (d) for comparison the DSM cadastral information is overlaid.

. Figure 3. QEM-based simplification of building footprints.

4. CONCLUSION AND OUTLOOK

In this paper we presented our research on the simplification of building footprints from laser scanning data. As shown in the examples, the approach is able to find an optimal shape given the original data points in terms of the outline generated by the laser data and additional constraints which characterize a building. In the future, we plan to integrate the Douglas-Peucker-like approximation method with the Least Squares approach in order to reduce the randomness from the whole process.

5. REFERENCES

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