Geometric Object Based Building Reconstruction from Satellite Imagery Derived Point Clouds

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ABSTRACT:
3D building models are digital models of urban areas that represent buildings, which have important role in urban planning and smart city . Their components are described and represented by corresponding 2D and 3D spatial data and geo-referenced data. Those models can be generated from stereo aerial images, satellite images or LiDAR point cloud. In this paper, we propose a geometric object based building reconstruction method. The paper is structured as three parts: the first part introduces our motivation and related work, the second part introduces the methodology and processes we used and the third part is about the test result. Results from the point clouds generated from WorldView high resolution satellite images are used to demonstrate the performance of our approach.

1. INTRODUCTION

3D building model reconstruction has been investigated for decades. The library-based or model-based method, which fits building with predefined primitives (GEON, Geometric Icon), estimates parameters and integrates them as an object, is a powerful way to reconstruct complete and realistic building models. Point clouds, either from images or laser scanning are the main datasets for 3D building reconstruction. However, points cloud from satellite images often has high noise and irregular boundary. Incomplete buildings often exist in reconstructed models. To solve this issue, we propose a polygon decomposition method for primitives fitting to get more complete building models. Polygon decomposition or partition is to generate a set of primitive units from input polygon, which do not overlap and whose union equals the input polygon. Compared with primitive estimation with minimum bounding box or other predefined primitives, decomposing a polygon into units and estimating its parts will achieve higher quality and less over-estimation. This paper proposes the following solution. Firstly, we generate building boundary directly from point cloud using alpha-shape. Secondly, irregular building boundary is regularized with rectilinear boundary for decomposition. Finally, a novel shortest-edge-based rectilinear polygon decomposition approach is proposed to get GEONs part by part. For each decomposed building part, a simple, predefined GEON will be estimated to achieve a best it. After decomposition and estimation, a set of GEON parameters representing a building model are generated. Point clouds generated from WorldView satellite images over complex urban areas are used for our study. The approach achieves satisfactory and superior results.

2. METHODOLOGY

This section will describe the workflow and methodology for fitting an irregular roof surface segmented from the input point clouds. We will discuss segmented roof surface firstly, then develop a methodology to fit the primitives in three steps. Firstly, from the input irregular polygon we calculate a rectilinear polygon. Then, we decompose it recursively based on shortest edge until the remaining polygon is a rectangle. Finally, we use specific GEON to fit each decomposed rectangle and get GEON parameters.

2.1 Roof surface segmentation

Extraction of building roof surfaces is necessary for reconstruction. In this process, we use standard Random Sample Consensus (RANSAC), to derive the input surfaces from the point cloud generated through satellite images. Those surfaces provide initial information of the shape of the building and become entrance to estimate the GEON parameters [1,8]. However, because of shadow and occlusion, the point cloud from satellite images is not as satisfactory as LiDAR point cloud. For example, void areas in point cloud will make holes on the segmented surfaces. Limited resolution causes irregular building edges which makes regularization necessary.

2.2 Regularization

Once segmented points for each roof surface are found, there will exist a crucial step to determine the boundary of the roof surface. We use the alpha-shape algorithm for this purpose [2]. However, boundary extracted from alpha shape is not sufficient for GEON fitting because the initial boundary is irregular and has redundant vertices. Further refinement must be carried out before decomposition and fitting.

In general case, most traditional building edges are perpendicular to each other, which provides an input to boundary regularization. The first step for regularization is to find the dominant direction of the building boundary and rotate the coordinates to make those points perpendicular to coordinate system x or y axis. To achieve this goal, we propose a projection density-based algorithm for estimating the dominant direction.

Then given by a simplified building boundary after rotation with dominant direction θ_{domain} , we propose a regularization method to generate a rectilinear boundary. The criterion is to include all initial vertices in the smallest rectilinear polygon. For each oblique segmented line, we consider inserting vertex to generate perpendicular line pair outside the input polygon.

2.3 Decomposition

A partition of a polygon is a set of primitive units, which do not overlap and whose union equals the input polygon. Polygon decomposition is a problem of finding a partition which minimal in some objective functions, for example a partition with a smallest number of units [4,9,10,11] or with units of smallest total side-length [5].

Through all decomposition methods, rectilinear decomposition is the best way to restore the shape of an input building boundary since most buildings have a rectilinear boundary. Building boundary should be represented with several sub primitives and the main primitives (or called main subjects) should be kept. Based on this criterion, we propose a shortest-edge-based algorithm to decompose a

Boundary simplification is used to remove redundant vertices on the boundary. One most popular method to do so is the Douglas-Peucker algorithm [3]. This algorithm will repeat itself with the first point and the farthest point and then with the farthest point and the last point. Through this process, a simplified curve or polygon boundary is generated with less vertices.

rectilinear polygon into main parts and sub-parts. Firstly, we distinguish concave vertex and convex vertex on the rectilinear polygon [7]. Then, for shortest edge in the rectilinear polygon with one or more convex vertices, we assign a rectangle using the shortest edge and its neighbour edge. Then, we put the rectangle into the decomposed part set and cut it from initial polygon. Finally, we go back to second stage and recursively process the shortest edge until the remaining part is a rectangle.

2.4 GEON Fitting

Given a set of decomposed part, we use cube and trapezoid to estimate the parameters. Common parameters including centroid, affine transformation and coordinate system parameters. Parameters for cube GEON include length, width and height. For trapezoid, we add top surface normal as additional parameters. Those parameters are stored in JSON format. Given those GEON parameters, different building models can be reconstructed.

3. EXPERIMENTS

We use point cloud over UCSD (University of California at San Diego) generated from stereo satellite images to create both initial input building model and GEON-based model. See Figure 1 below for a few sample results from a complex building. Figure 1a shows satellite image, Figure 1b shows the corresponding point cloud derived from stereo satellite images, Figure 1c shows segmented surfaces, and Figure 1d shows the reconstructed GEON models. We can see after using perpendicular feature of building boundary, some missing parts are fixed through our process.

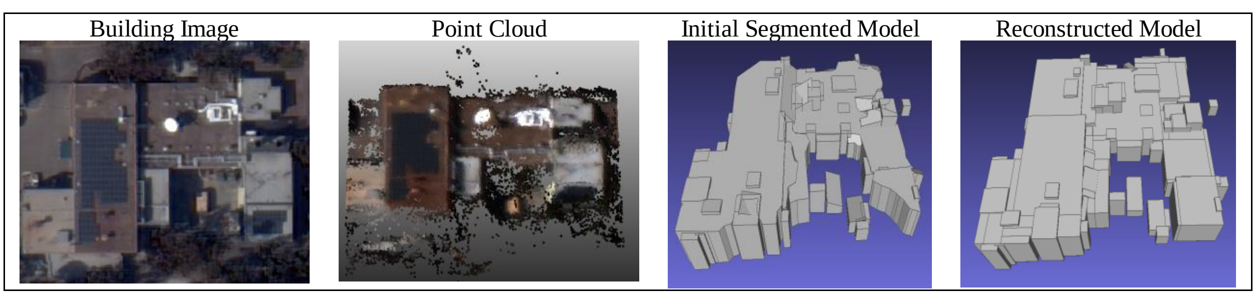

Fig 1. Sample building models on UCSD

4. CONCLUSION

Primitive-based building model reconstruction from satellite image-derived point cloud is solved in a three-step process: segmentation, regularization (including boundary tracking and simplification) and decomposition. Segmentation gives initial input polygon and is the most important part through all processes. Using building feature, perpendicular edges exist in most building, our algorithm can fix missing part caused by shadow or occlusion in the point cloud. By decomposing segments polygon, the algorithm gives a best estimation result to fit the initial polygon. The decomposed parts are useful for generating building models with multiple levels of details. By reconstructing building model with decomposition and primitives, more realistic and complete models can be generated. Future work will concentrate on import more types of primitives (including sphere, cylinder, shed roof, gable, etc) and non-rectilinear decomposition.

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