BUILDING FACADE RECONSTRUCTION USING CITYGML LOD2 BUILDING MODEL AND CLOSE RANGE IMAGES

Tee-Ann Teo

Assistant Professor, Department of Civil Engineering, National Chiao Tung University,
1001 University Road, Hsinchu 30010, Taiwan; Tel: + 886-3-5712121#54929;
E-mail: tateo@mail.nctu.edu.tw

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Abstract: Three-dimensional building model is an important digital content for Cyber City and Location-based Service. This research is to establish an OGC-LOD3 building model from OGC-LOD2 building models and close range images. The major works of this research are space registration, façade detection, façade grammar and façade reconstruction. In space registration, the Speeded Up Robust Features (SURF) is applied to extract tie points automatically. Then, tie points and control points from OGC-LOD2 building models are combined for block adjustment. The façade detection is used to classify the wall the window objects. Then, a hierarchical façade grammar includes the location and façade type is applied to describe the façade. In order to refine the consistency between façade objects, geometric regularization is preformed to adjust the size and location of façade objects. Finally, a model-driven reconstruction is applied to select the appropriate 3-D primitives manually. The experimental results indicate that the proposed method is suitable for symmetrical façade reconstruction.

1. INTRODUCTION

The geometry of a 3D building model contains roof top and façade. The roof top of buildings is usually reconstructed by airborne sensor while the façade of a building is usually built up by ground-based close range data. The façade information is the essential element to build up an Open Geospatial Consortium (OGC) CityGML LOD3 building model (OGC, 2009).

In the automation of façade reconstruction, the façade reconstruction can be divided into automatic and semi-automatic procedures. The automatic process is unable to handle complex buildings. Moreover, the problem of insufficient information such as hidden area and shadow also leads to unreliable results. Hence, the semi-automatic process is more suitable in building reconstruction. In semi-automatic building reconstruction, the high level interpretation such as object recognition is done by human while the low level computation such as edge extraction is done by computers. The role of the operator is to guide the procedures and avoid the unnecessary results.

The data set for façade reconstruction include images, 3D lidar points and architectural graphic. In image-based façade reconstruction, image matching and space intersection are the major works to extract the 3D linear information. Then, the 3D linear information is further produced to a façade model by geometric inference engine (Laycock and Day, 2006; Wang et al., 2002; Xiao et al., 2008). In lidar-based façade reconstruction, the 3D information is obtained by laser directly. These 3D points are used to fit the façade model. Moreover, the images and lidar points can be integrated to obtain linear and planar features (Becker and Haala, 2007; Stamos, et. al., 2008; Pu and Vosselman, 2009). If the architectural graphic is available, one of the possibilities is to reorganize the 2D plans into façade models (Lu et al., 2005). As the image acquisition is more cost effective, this study uses multiple close range images in facade reconstruction.

The strategy of façade reconstruction include data-driven (Ripperda and Brenner, 2009) and model-driven (Tseng and Wang, 2003). Data-driven is a bottom-up process. This method extracts the feature entities at the beginning; then, these extracted entities are combined to generate a 3D façade model. On the contrary, model-driven is a top-down process. This method selects a 3D primitive from the database; then, the parameters of this primitive are determined by model fitting. The data-driven and model driven can be integrated and named as hybrid method. Hybrid method integrates the advantages of both methods in façade reconstruction (Teo, 2008).

The objective of this research is to generate a façade model by close range images and LOD2 building models. The major works of this research are space registration, façade detection, façade grammar and façade reconstruction. In space registration, the Speeded Up Robust Features (SURF) (Bay et al., 2006) is applied to extract tie points automatically. Then, tie points and control points from OGC-LOD2 building models are combined for block adjustment. The façade detection is used to classify the wall and window objects. Then, a hierarchical façade grammar includes the location and façade type is applied to describe the façade. In order to refine the consistency between façade objects, geometric regularization is preformed to adjust the size and the location of the façade objects. Finally, a model-driven reconstruction is applied to select the appropriate 3-D primitives manually.

2. METHODOLOGIES

The proposed method includes four major parts: (1) space registration of multiple images and LOD2 building models, (2) detection of different façade objects, (3) façade grammar for façade model, and (4) model-based façade reconstruction. The explanations of each step are stated below.

2.1 Space Registration

The aim of space registration is to build up the relationship between 3D LOD2 building models and 2D images. The 3D LOD2 building models provide object coordinates to rectify the 2D images. Assuming that the interior orientation parameters are available, space registration establishes the relationship between multiple close-range images using tie points and control points. Speeded Up Robust Features (SURF) (Bay et al., 2006) is applied in automatic tie point extraction as it can overcome the scale and rotation effects between close-range images. Then, a large number of automatic-extracted tie points and sparse of manual-measured control points are integrated in bundle block adjustment. As the mismatching is unavoidable in tie point matching, the tie points with large positioning error are removed iteratively in bundle block adjustment. Once the accurate 3D to 2D transformation parameters are obtained, the tilt displacement can be corrected by re-projecting the image into the plane of a building wall.

2.2 Façade Detection

The façade elements are windows and doors. The characteristics of a façade are symmetric and repetitive. This means, most of the façade elements are repeated on a wall. In façade detection, we use supervised image classification to separate the wall and the non-wall areas. The non-wall areas indicate the location of the façade elements. However, the misclassification may generate incorrect façade elements. In order to improve the results of façade detection, we also analyze the edge of images to remove the incorrect façade elements. We assume that the boundaries of the façade elements are regular. This study uses canny edge detection (Canny, 1986) and line tracing to determine the lines in a façade image. Then, we apply line regression to obtain the straight lines. Finally, the connected straight lines are linked together to define the region of the façade elements.

2.3 Façade Grammar

Façade grammar (Becker and Haala, 2009) is a tree structure to describe a façade. As the façade elements are repetitive, a complex façade can be decomposed into many simple façade elements. Figure 1 is an example of façade grammar. In Figure 1, the root of the tree is a façade. A façade can be divided into different floors. Then, a floor can be divided into different elements. At the end of this tree, the attribute of elements include the actual location, size and type. This façade grammar is useful to describe a symmetrical façade. Moreover, all the elements can be aligned using this grammar. For example, all the elements at the same floor have the same height and size. This research uses this structure to describe a façade model. The parameters of façade grammar include number of floors, and number of façade elements on a floor. These parameters are provided by an operator. The parameters of elements such as location, size and type are determined by image-to-model matching.

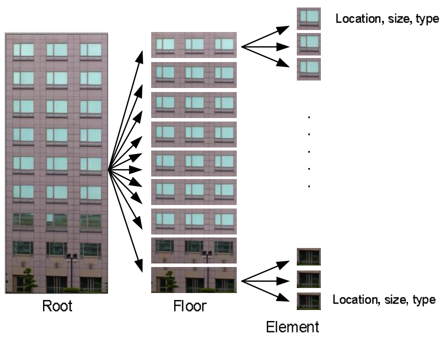


Figure 1: An example of façade grammar

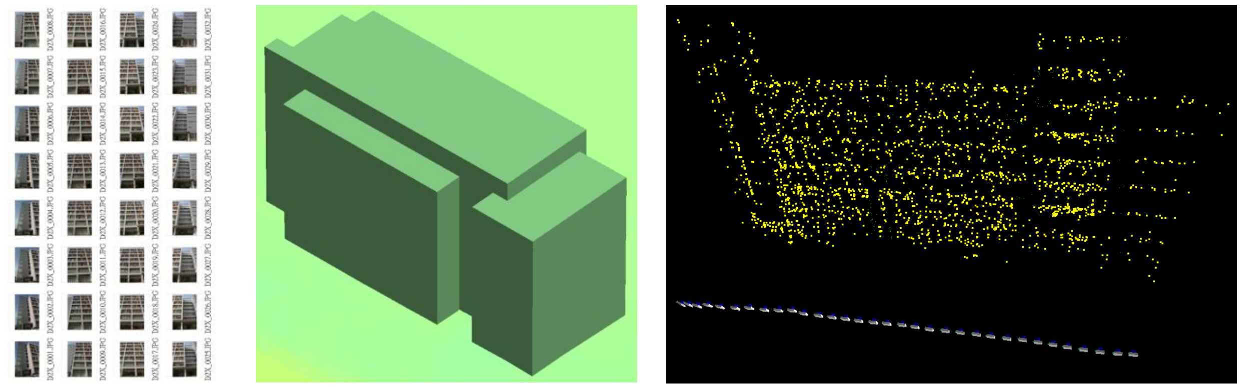
2.4 Façade Reconstruction

A model-based façade reconstruction is utilized in this step. We manually build up limited 3D windows and door models in a model database. These manual generated models are called primitives. The actual location, size and type of each primitive can be determined by model-to-image fitting. This study compares the primitive and extracted façade elements by similarity analysis. The similarity index is the summation of edge-to-primitive difference. If the boundaries of façade elements are similar to the boundaries of primitive, then, the 3D primitive is attached at the location of façade elements.

3. EXPERIMENTAL RESULTS

The test data are multiple close-range images taken by a Nikon D2X camera. The target is a façade of a building. The average image scale is about 1/3000. The base-to-depth ratio between the two camera stations is about 1/10. The LOD 2 building model is generated from 1/5000 aerial images. The estimated accuracy of the building model is about 30cm. Figures 2(a) and 2(b) shows the test images and LOD 2 building model.

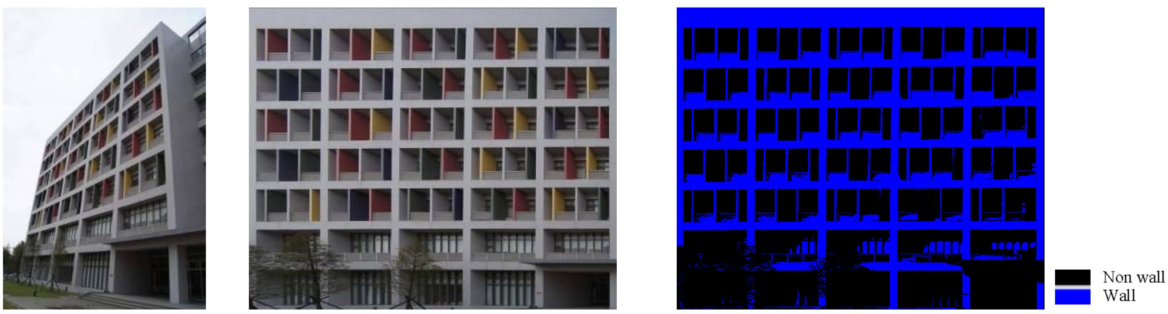
In space registration, the automatic image matching has generated 2515 tie points. Among these tie points, 2166 points are the intersection of two rays, while the remaining points are the intersection of three or more rays. The control and check points are collected by a total station. The number of control and check points are 4 and 26 points, respectively. The RMSE of check points in three directions are 4.1, 4.5 and 1.8 cm, respectively. As the Y direction is the look direction of the camera, the error in Y direction is larger than the other directions. Figure 2(c) shows the distribution of 33 camera stations.



(a) Multiple images (b) LOD2 building model (c) perspective view of camera station and matched 3D points

Figure 2: Test data and result of space registration.

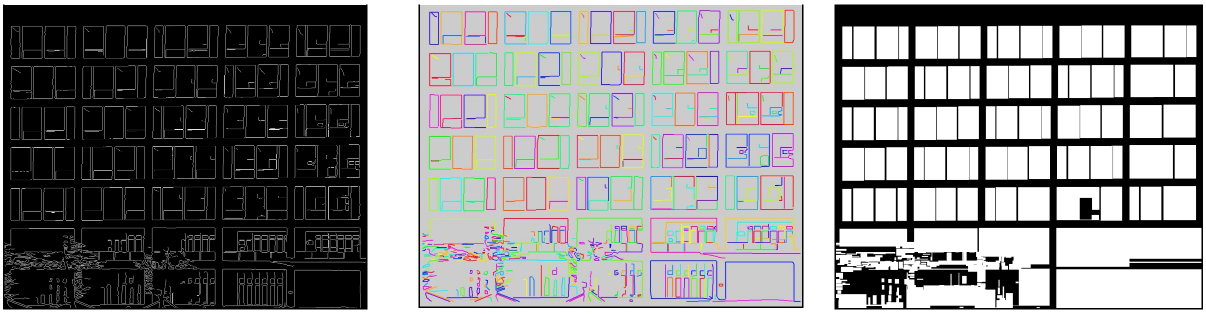
After bundle adjustment, we have the orientation parameters of the images. It is used to transform an object point to image space. This study re-projects an image onto the wall of a LOD 2 building. The tilt displacement can be corrected and the boundaries of façade elements may parallel to horizontal and vertical lines. Figure 3(a) is an original image which is taken from a large tile angle. After image rectification, the displacement of the window can be corrected, as shown as Figure 3(b). The façade elements are extracted from the rectified image.



(a) raw image (b) rectified image (c) classified image

Figure 3: Rectification and classification

In façade detection, this study uses supervised classification to detect the non-wall areas. The result is shown as Figure 3(c). The higher region is more reliable than the lower region because the lower region is easily affected by trees.. The edges of the rectified image are also obtained by edge detector (Figure 4(a)). Line tracking technique is used to remove the short and nonlinear edges (Figure 4(b)). All the connected lines are linked together and the region of façade objects is defined. (Figure 4(c)).



(a) extracted edges (b) extracted line segments (c) extracted façade elements

Figure 4: Façade detection

The structure of façade grammar is set up for façade reconstruction. The test façade has 7 floors and each floor has 5 façade elements. These parameters are predefined by human interpretation. Four type of façade primitives are generated in the model database (Figure 5(a). The comparison of façade primitives and façade elements is used to define the location, size and type parameters in façade grammar. Notice that, this study employed semi-automatic strategy, an operator is guiding the matching process especially the lower region of façade. Finally, the reconstructed façade model is shown as Figure 5(b).

(a) façade primitives (b) 3D façade models

Figure 5: 3D primitives and reconstruct models

4. CONCLUSIONS AND FUTURE WORKS

In this research, we have proposed a scheme to reconstruct a façade model from multiple images and a LOD2 building model. A coarse LOD2 building model is employed to correct the tilt displacement of the façade structure. It is beneficial to extract the symmetrical façade elements. Façade grammar and model-based method are integrated in façade reconstruction. Façade grammar is used to describe the structure of a façade while the model-based method is used to provide the geometric attribute of primitives. This experiment indicates that the proposed method is able to reconstruct a symmetrical façade. This method can be used to generate LOD3 building models. The future work will focus on the processing of non-symmetrical façade, as well as the removal of hidden objects like trees as they may affect the experiment results..

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