EXPERIMENTAL REALIZATION OF
URBAN LARGE-SCALE TRUE ORTHOIMAGE GENERATION

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ABSTRACT:

When using the traditional orthorectification methods to generate urban large-scale orthophoto, there exist many problems, for example, the spatial objects of orthoimage in urban areas are distorted from their true positions. This distortion shows that buildings lean over a street. Recent years, some researcher addressed the concept of true orthophoto. This paper mainly discusses the problem of shadow and occlusion, and presents a method of DBM-based true orthophoto generation. An experimental field located in downtown of Denver, Colorado has been used to test our methods. The experimental results demonstrated that the proposed method in this paper can effectively solve the problem mentioned above.

1. INTRODUCTION

The National Digital Orthophoto Program was first proposed in 1990. The mainly purpose of this program is to ensure the public domain availability of digital orthophoto quadrangle (DOQ) data for the U.S. Nation. The DOQ will be updated on a cycle of 5 or 10 years in area where land use change is more rapid.

However, this 1990's program and the Standard for Digital Orthophoto has not considered the requirements of large-scale urban orthophoto generation. These early procedures and algorithms for digital orthophoto generation were based on earlier USGS mapping operations, such as field control, aerotriangulation, and 2.5D digital elevation models. The procedures used in the 1990's are not appropriate for large-scale urban orthorectification. The algorithms and procedures in traditional digital orthoimage generation did not consider the spatial objects, such as buildings, thus the spatial objects of orthoimage in urban areas are distorted from their true positions. This distortion shows that buildings lean over a street, thereby, occlude the street and other artificial buildings.

The impacts of the above problems have significantly influenced the usefulness of the digital orthophoto in city planning because the error of these incompletely rectified large-scale urban orthoimage maps no longer can be tolerated when applied to updating and planning urban tasks. Thus, a study on true orthophoto generation, including algorithms and data processing procedures, for the future national large-scale city orthophoto generation deployment is highly desirable.

2. DBM-BASED TRUE ORTHOIMAGE GENERATION

True orthoimage generation has been investigated in recent years. Many significant efforts have been made such as Amhar (1998), Rau and Chen (2002), Nielsen (2004), Biason (2004), Zhou et al. (2005), and Zhou and Xie (2006). The true orthoimage generation is composed of DTM-based orthoimage generation, DBM-based orthoimage generation, and their merging as well as the occlusion detection and refilling, shadow

detection and compensation (Zhou et al., 2005). This paper proposed some novel methods about true orthoimage generation.

Parameterized CSG building model

For true orthoimage, in order to orthorectify a building to its correct, upright position, the building must be represented as part of the surface to be rectified. Therefore, an exact digital building model, which describes the building structure, three-dimensional coordinates, topologic relationship, etc., is required. This paper presents the parametrerized CSG building model for exactly describing urban 3D buildings for large-scale urban true orthoimage generation. According to this type of building model, this paper designs the technique of three-level data structure. The first level is 2D basic graphs with parameters, such as rectangle, circle, triangle, polygon etc. Each graph has respectively parameters of its own. The second level is 3D primitive. 2D basic graph with height parameter becomes 3D graph. The third level is building model. The combination of 3D primitives can generate the CSG building model. In this process, topological relationship should be considered for the convenience of data retrieve (See Fig.1).

The process of extracting building knowledge is a bottom-up procedure from low-level data to high-level information. First, the vector edge data of buildings can be obtained from aerial images or LIDAR data by using a series of image processing such as edge detecting, tracking and segmenting etc. after feature grouping, the upper-level building outline is generated. As we know, most of architectures are with regular shapes, where the lines and planes on them have the properties of parallel, vertical, orthogonality etc. With these geometric constraints these outlines can be matched with corresponding CSG primitives in the database of primitives. These CSG primitives are parameterized from digital surface model. For the complex buildings, they are decomposed into several parts. We can combine a complete building model via Boolean set operations, which include union ($\cup$), intersection ($\cap$), difference ($-$), etc. Boolean operations make the CSG model more flexible. For example, the redundancy in space may be occurred for complex building where some parts cover the

others in the ground map. In this case, the Boolean difference operated can reduce the data redundancy. With the connection of Boolean operations, the whole composition process of a

complex building model likes a CSG tree. The leaf nodes are those CSG primitives; the middle node links two branches of combined parts and the root is the complete building model.
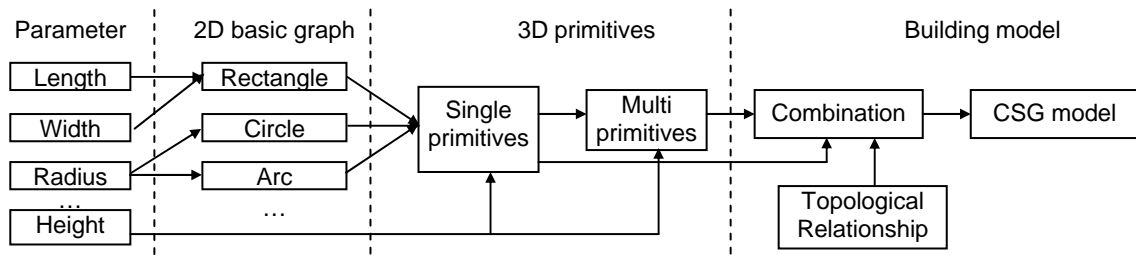

Figure 1. Three-level data structure

Occlusion detection

Detecting occlusion is a challenging task for the fields of computer vision and photogrammetry. There have been some efforts to detect occlusion regions. The most purposes of detecting occlusion in computer vision are to try to find the structure of 3D objects and track or predict their movements by using serial stereo images. However, in the field of photogrammetry, the 3D model of object is as prior information. A commonly used method for occlusion detection is the so-called Z-buffer algorithm where an image matrix is used to store for each pixel the distances (Z) between the projection centre and the object surface (Rau and Chen, 2002).

Usually occlusion detection is time-consuming processes. In Z-buffer algorithm, each element of matrixes in ground surface plane will be calculated. In urban area with large scale, artificial buildings mainly occlude the occlusion areas. Aiming at the urban area, this paper presents the method of DBM-based occlusion detection. This method originally deprived from Z-buffer algorithm. Z-buffer method consists of two fictitious matrixes. One in the image plane stores the distance from the projection center to the surface point, which is calculated with orientation parameters using the collinearity equation. The other one in the ground surface plane is used as a binary index map with the same resolution, dimension and projection properties as the digital terrain model. Occlusion means that several surface points corresponds the same coordinate in the image plane. This method needs searching the whole ground surface plane area, it result in the lower efficiency of algorithm.

In the method of DBM-based occlusion detection, there is one more matrix in the ground surface plane with the same resolution, dimension and projection properties as the digital terrain model, which stores the building model index at the possible occlusion areas. In this paper, the building model is based on CSG structure, each complex building consists of many simple 3D CSG primitives with variable parameters, such as box, cylinder etc,. According to the known orientation parameters and collinearity equation, the corner features of the CSG primitives can be projected into ground surface plane. All of the corner projection belonging to one building will form a minimum bounding rectangle (MBR) of this building on the ground plane. The area located into the MBR is viewed as candidate area of occlusion and marked with corresponding building model index and the sub-index of its CSG primitive. The sub-index is used for the detection of self-occlusion.

Shadow detection and removal

Shadows of buildings are another important concern in urban areas. Because the traditional orthorectification model cannot remove a building shadow, the shadow of a tall building can hide features within it. Building shadows thus affect the appearance and usefulness of orthoimages. In order to produce high-quality orthoimages, an operation for automatic detection and radiometric balance for shadowed areas must be carried out.

Some methods are to detect and segment shadows only using image analysis. The results are correct in most cases. However, because of the complicity of the urban circumstance, there may be some factors effecting the detection of the shadow. For example, the high reflectivity ground, the glass wall of the building, make shadow somewhere bright, and cause their intensities close to the non-shadow area. These shadows may not be detected by image analysis technology. Besides, the threshold of the segmentation is difficult to decide. Thus, the segmentation of the shadow is not reliable.

Most of shadows are resulted from sun. The altitudes of the sun can be represented by the zenith angle and the altitude angle. The two angles are independent obviously. The proposed method is supposed to be based on the following principles:

1) The length of shadow depends on both building height and the zenith of the sun; the direction of shadow depends on the position of the sun relative to buildings.

2) The zenith and the position of the sun relative to buildings at the time of imaging remain a constant. This means that the direction of the shadow for all buildings within an aerial image is the same, and the length of shadow of each building can be measured using building model if the zenith of sun is known.

This paper presents an innovative method, which makes full use of digital building model data for building shadow detection.The whole process of shadow detection is illustrated as following Figure 2.

This shadow detection don't concern self-shadow because the walls of buildings will be invisible in true orthoimage. If the zenith and altitude angle are known, a ray can be traced from the sun to the ground point. Each point corresponds to each ray. If the ray is occluded by building model, this point belongs to

shadow area. Search each point on the ground in constant ground sampling distance, and then shadow area can be detected and labeled. According to the known orientation parameters, the corner points of the building model can be projected into ground surface plane. All of the corner projection belonging to one building will form a minimum bounding rectangle of this building on the ground plane. The area located into the MBR is viewed as candidate area of shadow and marked with corresponding building model index. The one out of MBR must be non-shadow area.
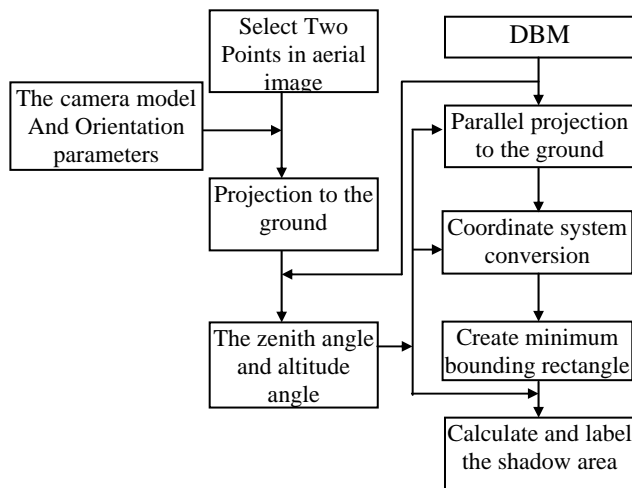

Figure 2. Flow chart of the shadow detection process

Regarding to shadow removal, digital image processing techniques are used in our system to resolve this question. The intensities of the shadow pixels can be restored by mapping them to the bright pixels refer to the same objects, which is called companion area intensity mapping. So the shadow removal module contains two stages. The first stage is deciding the companion area to the shadow area. The second stage is computing the statistics of the two regions and mapping shadow intensities to their companion intensities.

3. ACCURATE IMPROVEMENT OF URBAN TRUE ORTHOIMAGE

Theoretically, the orthorectified buildings in true orthoimage should be in their correct, upright positions. However, when generating the true orthoimage for urban high building area, Some of high buildings cannot be completely orthorectified into their upright and correct position; Small buildings on the top of the main body of building have not been completely orthorectified.

The proposed improvement method in this paper takes advantage of geometric characteristics of the building edges, such as perpendicularity, parallel, etc. as relative control information. The relative control information is merged into the traditional orthorectification model to increase the accuracy of orthoimage generation.

In building models, there exists plenty of geometric information in the façade of building, such as perpendicularity, parallelism among straight lines and planes. All of these relationships can

be regarded as the constraint conditions of unknown parameters (i.e. relative control conditions).

According to the collinear equation of photogrammetry, the general matrix form of its error equations is
V=AT+BX-L

where, T is the matrix of orientation parameters; X is the matrix of the coordinates of object points.

$$T = \left(\Delta f \ \Delta x_0 \ \Delta y_0 \ \Delta \varphi \ \Delta \omega \ \Delta \kappa \right)^T$$

$$X = \left(\Delta X_1 \ \Delta Y_1 \ \Delta Z_1 \cdots \Delta X_i \ \Delta Y_i \ \Delta Z_i \cdots \right)^T$$

The geometric constraints can be found in the information of building model:

$$C\hat{X} + W_x = 0$$

Combining two formulas, the adjustment model is:

$$\begin{cases} V = AT + BX - L \\ C\hat{X} + W_x = 0 \end{cases}$$

In this paper, perpendicular and collinear constraint controls are applied to the adjustment model.

4. EXPERIMENTS AND ANALYSES

The experimental field is located in downtown Denver, Colorado. The six original aerial images from two flight strips were acquired using an RC30 aerial. Two of the six aerial images (dv1119 and dv1120) covered the downtown area with approximately 65% endlap and 30% sidelap. The parts of two scanned aerial images are shown as Fig. 3. Fig. 4 is the 2D representation of the digital surface model of the same area.

(a) dv1119   (b)dv1120

Figure 3. Part of original aerial images

Figure 4. Digital surface model in downtown Denver used for the experiment.

4.1 Extraction of Building Model

From the digital surface model, we first can extract edge objects including point, line and arc objects. After feature grouping, the building parts are used for 2D GIS vector map where every object has the property of height. According to 2D geometric information and 3D height information, all the GIS vector objects can be matched with parameterized CSG primitives. In this experiment, by combining CSG primitives, 106 buildings are finally extracted. Fig. 5 shows the partial extracting result compared with corresponding aerial image.
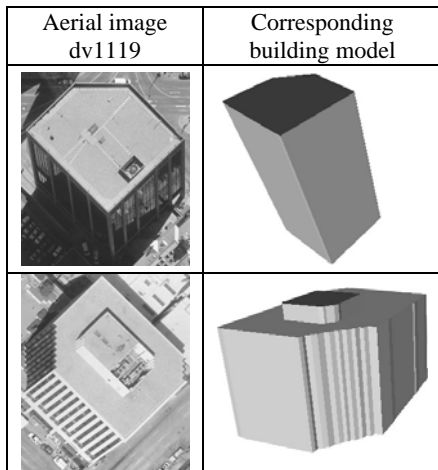
Aerial image dv1119	Corresponding building model

Figure 5. The extracting result compared with corresponding aerial image

4.2 True Orthoimage Generation

In traditional large-scale urban orthorectification, there exist lots of shadow and occlusion areas, especially for high building in downtown area. Fig. 6 Shows the shadow and occlusion areas. There are two roof images shown for one building in orthoimage, which is also called "ghost image".
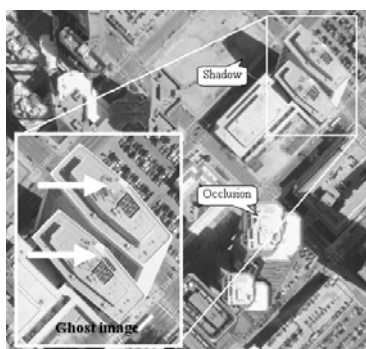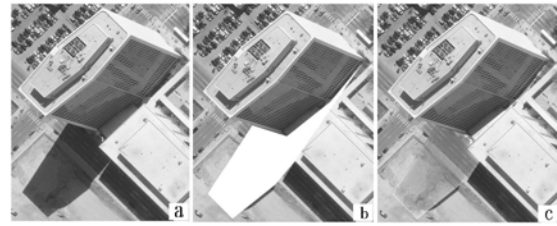

Figure 6. The occlusion and shadow area existing in orthophoto

Fig. 7 takes one building for example to show the process and the result of shadow removal. The white area is the automatically detected shadow area using the method of this paper.

(a) Original aerial image   (b) detected shadow area
(c) shadow removal

Figure 7. Shadow removal example for one building

Fig.8 is the partial experimental result of shadow detection based on DBM on Denver downtown area. The detected shadow area is expressed as white color.

Figure 8. The result of shadow detection based on DBM

Fig. 9 shows the occlusion detection occurred from dv1119 and dv1120. Fig. 9(a) is the orthophoto deprived from dv1119 and fig. 9(b) is deprived from dv1120. The region enclosed with white edge is the detected occlusion area.

Combining two orthophotos, the occlusion refilling can be executed. Fig. 9(c) shows the process of refilling. However, from this figure, one can see the occlusion refilling is not complete, because there still are common occluded areas in orthophoto from dv1119 and dv1120, which is marked as white lines. Generally speaking, more occlusion areas can be eliminated with more neighbor aerial images.
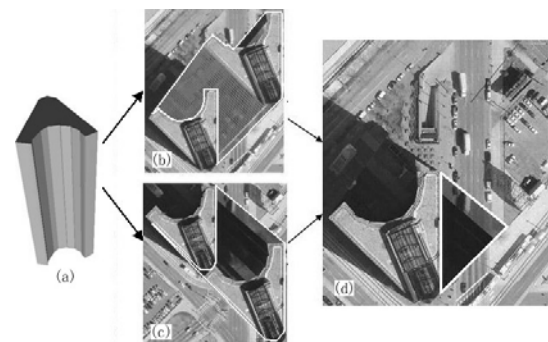

Figure 9. Occlusion refilling of one building in orthoimage

In this experiment, the occlusion of the whole area can be detected automatically using the method of this paper. The occlusion areas in 1119 cover 1,337,599 square feet. These occlusion areas in 1120 cover 1,489,735 square feet. Combing these two orthophotos with different occlusion areas, one can generate an orthophoto without occlusion. Here "without occlusion" means "less occlusion". The common occlusion areas in the orthophotos from 1119 and 1120 only cover 316,948 square feet. From the results, nearly 80% occlusion areas have been eliminated.

After shadow removal and occlusion refilling, true orthoimage can be generated. Fig. 10 is shown as a part of true orthoimage.

Figure 10. True orthophoto after occlusion refilling and shadow removal

5. CONCLUSIONS

In this paper several methods and solutions on generating large-scale urban true orthoimage are addressed, including 3D urban building model representation, shadow detection and removal, occlusion detection and refilling, accurate improvement of orthorectification, etc. These methods successfully applied to the true orthoimage generation project of Denver.

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