PHOTO-REALISTIC 3D MAPPING FROM AERIAL OBLIQUE IMAGERY

J. Y. Rau [a,*] and C.Y. Chu [b]

Department of Geomatics, National Cheng Kung University, No.1 University Road, Tainan City, Taiwan (R.O.C.)
[a] jyrau@mail.ncku.edu.tw, [b] peter705431@hotmail.com

Commission I, ICWG I/V

KEY WORDS: Oblique Imagery, 3D Mapping, Texture Generation, Occlusion Detection.

ABSTRACT:

The generation of photo-realistic city model is an important task for many geospatial applications, such as 3D GIS, urban planning, virtual city tourism, car navigation, real estate, etc. The purpose of this research is to automatically generate façade texture from aerial oblique imagery. The developed algorithm can be applied to any oblique imagery taken from the air, such as UAV, airplane, or helicopter, as long as they were geo-referenced. Several problems will be encountered based on the use of oblique imagery. The major one is the occlusion comes from the building itself and the other buildings. This is serious especially for a congested urban area or a city with high-rise buildings. The proposed algorithm includes two major steps. The fist step is to generate all façade's texture within one image. However, the façade texture will be generated only when a certain geometric quality has achieved. The imaging geometry was estimated based on the incident angle between the camera-to-facade vector and the façade's normal direction. The second step is to detect and remove the occluded area based on existing 3D building models. Those two steps will be performed for all oblique images. However, in case one façade texture has been generated before and any marked occluded area has found, then a seamless Mosaicking procedure will be applied to achieve a complete texture. Meanwhile, due to errors always exist in exterior/interior orientation parameters and building models, some defect will occur along the boundary of occluded area. Thus, an amendment is necessary to remove this defect. Experimental results demonstrate that the proposed algorithm is effective and useful for automatic façade texture mapping.

1. INTRODUCTION

The usage of a photo-realistic city model is essential for many location-based services (LBS) and geospatial applications, such as real estate, urban planning, virtual city tourism, car navigation, and 3D Web-GIS (Takase *et al*., 2004). A photo-realistic city model contains three major components they are (i) 3D geometry, (ii) appearance texture, and (iii) attributes. For most of the LBS applications in urban area, 3D photo-realistic building models are the most critical one. Since the number of buildings in a medium size of city can be more than 100,000. Thus, a cost-effective way to produce photo-realistic building model has becoming an important research topic in the field of photogrammetry and computer vision.

Many approaches for 3D building model reconstruction can be found in the literatures (Gruen and Wang, 2001; Vosselman & Dijkman, 2001; Rau and Chen, 2003). Meanwhile, many researchers have focused on facade texture generation from terrestrial images. Efficient production and occlusion-free façade texture generation are two major issues to conquer (Varshosaz, 2004; Kada, 2004). The treatment of geometric distortion and occlusion problems are the major bottlenecks for improving the production efficiency.

Brenner & Haala (1998) proposed an interactive scheme with a projective transformation for fast production of building facade texture mapping. Haala (2004) proposed to use a high-resolution panoramic CCD line scanner to improve the efficiency in texture collection. However, this method requires an elevated camera station to minimize occlusions and an expensive rotating CCD scanner.

Varshosaz, (2004) proposed an automatic approach to determine the camera's exterior orientation parameters, which utilized a special designed photo system with a servo-driven theodolite. The system can take images automatically in a step-wise manner at preset locations to cover a complete field of view. The images are indexed by the theodolite angles, thus only one space resection has to be done for each station. The final facade texture is a combination of images with different views. Rau *et al*. (2007) uses close-range photogrammetry with rough GPS location to assist the searching of large quantity of terrestrial images. They also develop a GUI interface to create façade texture semi-automatically through interactive control point marking.

In this paper we propose an algorithm for automatic façade texture generation using aerial oblique imagery. The images can be acquired by airplane, helicopter or Unmanned Aerial Vehicle (UAV) as long as their cameras have been calibrated and the images were geo-referenced. Through the way we acquire the images and some filtering criteria, the most suitable image for façade texture generation can be found effective. Meanwhile, the occlusion introduced by the building itself and the other buildings could be detected and removed. A further compensation of occluded area by means of seamless Mosaicking technique from other images is applied to create an occlusion-free façade texture.

2. METHODOLOGGY

In this section, the proposed scheme for automatic façade texture generation will be presented. Figure 1 illustrates the flowchart of the developed algorithm. In which, several procedures are performed including visibility analysis and imaging geometry analysis for each wall. After completing those two analyses, we know which façades are suitable for texture generation using this image and the texture will be created accordingly. At the next step, we select one façade as a

[*] Corresponding author.

target façade and a vector-based occlusion detection technique is proposed to remove the occluded area. Within the occluded area, we perform occlusion compensation from other images. For better visual effect, we utilize a distance-weighting seamless Mosaicking technique to smooth the gray value within the buffer of the overlapped area. Finally, we get the occlusion-free façade texture.

In this paper, there are two main data sources. One is the oblique images whose exterior and interior (including lens distortion) orientation parameters have been calculated and calibrated by the Photometrix iWitnessPro©. The absolute accuracy of 3D positioning after georeferencing is about 30~50 centimetres, while the spatial resolution within the oblique image is around 20~40 cm. The second data used is 3D polyhedral building models which were generated semi-automatically by the SMS algorithm (Rau and Chen, 2003).

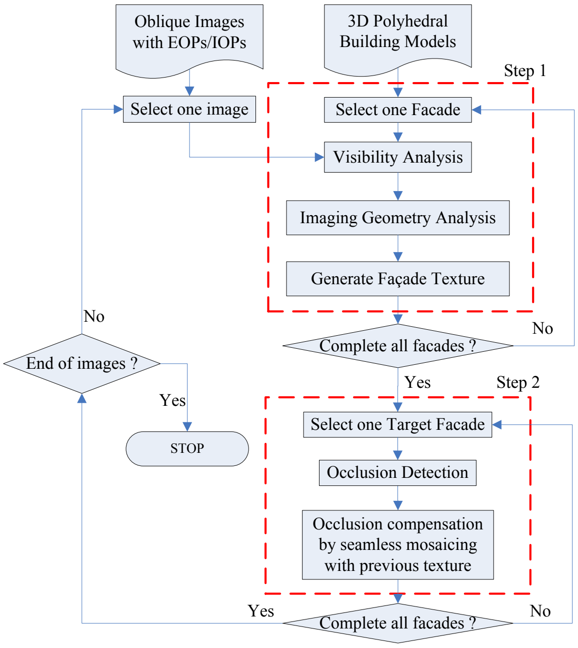


Figure 1. The flowchart of the developed algorithm

2.1 System Introduction

For the purpose of obtaining large quantity of image information and decreasing the occlusion situation, we use a dual-camera oblique imaging system (Rau et al., 2008) to satisfy this demand. The adopted cameras are NIKON© D2X and D2Xs DSLR camera that has a 12 mega pixel image size. In order to capture the image and maintaining the strength of aerial triangulation geometry, those two cameras are fixed by an aluminum frame at the bottom of the helicopter. The cameras are installed with 30˚forward and backward off-nadir looking angle. Figure 2 is one of the images captured, and we can found that the image resolution is good enough to generate façade texture for a photo-realistic city model.

2.2 Visibility Analysis

An image that does not "look at" the façade cannot be used for façade texture generation. Thus, the visibility analysis is necessary to avoid unnecessary computation time. There are two filtering steps within this procedure. The first one is to check if the facade is completely covered within the range of image frame. Equation (1) is the photogrammetric collinearity equation used to back-project the façade's centre coordinates to the image plane. If the corresponding image coordinates were within the range of image frame, we back-project all four vertexes of the facade to check if they were all within the image frame.

In Equation (1), (Δx, Δy) are he lens distortion correction terms and x_p, y_p, c, Xo, Yo, Zo, r_{11}~r_{33} (calculated from ω, φ, κ) are the interior and exterior orientation parameters of the image. For each ground point (X_A, Y_A, Z_A) we can calculate its corresponding image coordinates (x_a, y_a). The lens distortion correction term have to be seriously considered in order to calculate the correct location after back-projection.

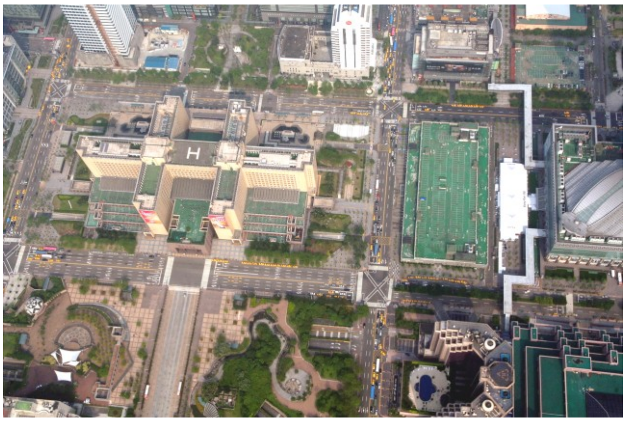


Figure 2. Sample imagery acquired by the proposed system.

The second step is to check if the normal direction of the facade was facing at the camera or not. Figure 3 depicts the idea of this analysis. In which, (N) is the normal vector of the facade calculated from three vertexes of the façade corners and (V) is the viewing direction vector calculated from the perspective centre to the façade's centre. Incident angle (Φ) is calculated from the normal vector (N) of the façade and the viewing direction vector (V). If the incident angle (Φ) was greater than 90˚, it means that the target façade was not "saw" by the image and cannot be used for texture generation.

$$x_a = x_p - c\,\frac{r_{11}(X_A - X_O) + r_{21}(Y_A - Y_O) + r_{31}(Z_A - Z_O)}{r_{13}(X_A - X_O) + r_{23}(Y_A - Y_O) + r_{33}(Z_A - Z_O)} + \Delta x$$

$$y_a = y_p - c\,\frac{r_{12}(X_A - X_O) + r_{22}(Y_A - Y_O) + r_{32}(Z_A - Z_O)}{r_{13}(X_A - X_O) + r_{23}(Y_A - Y_O) + r_{33}(Z_A - Z_O)} + \Delta y \qquad \ldots(1)$$

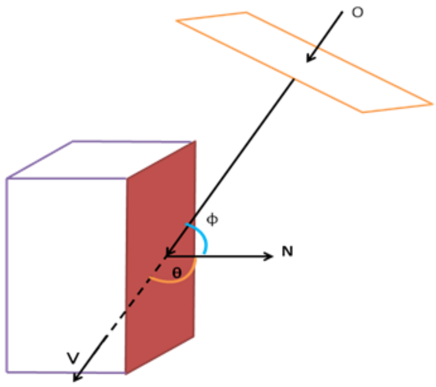


Figure 3. Illustration of visibility analysis.

2.3 Imaging Geometry Analysis

Considering the perspective distortion during the generation of façade texture from aerial oblique imagery, the less of incident angle (Φ) the better image quality can be expected. However, the less of incident angle may introduce higher occlusion effect and less spatial resolution. This is always a problem like "you cannot sell the cow and drink the milk". In this research, we use an angle threshold to filter out those improper images who may introduce large perspective distortion to a certain façade. Due to high density of the urban area, the distance between two buildings could be short thus we set the threshold at 80°. If the image whose incident angle to a certain facade was greater than 80°, we exclude the image for facade texture generation. After finishing the procedure in visibility analysis, we know which polygon (include walls and rooftops) is complete visible and which one is partial visible in the selected image. The complete visible polygon (only walls) will be considered for façade texture generation before imaging geometry analysis. The partial visible polygon (include walls and rooftop) and the complete visible polygon (only rooftop) will be used to detect whether the target façade was occluded by the other polygons or not. After finishing imaging geometry analysis, we realize which target façades can utilize this image for façade texture generation that contain more texture information but less geometric distortion.

2.4 Occlusion Detection

In a congested urban, most occlusion situations happened due to the buildings. Thus, we proposed a vector-based occlusion detection algorithm. Figure 4 shows all possible occlusion situations between two polygons. In order to know whether the target façade is occluded or not, we develop two methods to deal with all occlusion problems mentioned above.

- The first one is the *Point-in-Polygon* verification. Figure 5 illustrates the idea of Point-in-Polygon estimation. In image space, we check if any vertex of the target façade was within the area of a rooftop or the other façade, and vice versa to check if any vertex of a rooftop or the other façade was within the area of the target façade. If the point-in-polygon situation occurred, we consider that the target façade may be occluded and the following range estimation will be performed. Figure 6 illustrates the idea of the range estimation. We calculate the vector (V) in the object space from the camera perspective centre (O) to the vertex (a) in the image plane. Then, we can calculate the coordinates of point (A) by the intersection of vector (V) with the target facade (the yellow polygon) using line-plane intersection algorithm. Finally, we can calculate the distance D and D' from the camera perspective centre (O) to a façade point (A) and the façade corner (A'). If the range distance D was greater than D', we realize that the target façade was occluded by a roof or a wall (the blue polygon).
- The second one is the *Line-Intersection* verification. Figure 7 illustrates this idea. We check if any edge of the target façade intersects with the edge of the rooftop or the other façade in the image plane. If the Line-Intersection situation occurred, we consider that the target façade may be occluded and perform the range verification again. Figure 8 illustrates the idea of range verification again which is similar to the previous one. We calculate the vector (V) from the camera perspective centre (O) to the intersection point (a) in the image plane and obtain the coordinates of point (A) by the intersection of vector (V) and the target facade (the yellow polygon) using line-plane intersection algorithm. The coordinates of point (A') was obtained in the same way. Then, we can calculate the distance of D and D' from the camera perspective centre (O) to the object point A and A'. If the range D was greater than D', we consider that the target façade was occluded by the roof or the other façade (the blue polygon).

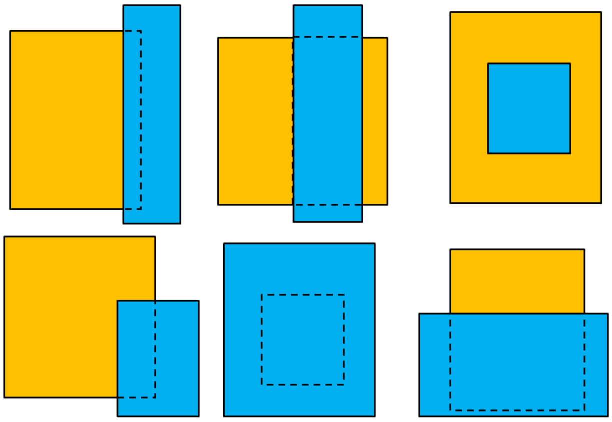


Figure 4. All possible occlusion situations between two polygons (the yellow polygon represents the target façade and the blue polygon represents the other façade or rooftop).

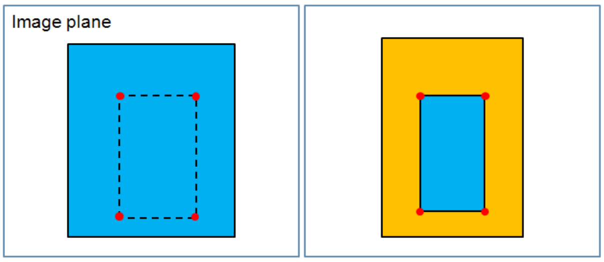


Figure 5. The idea of Point-in-Polygon verification

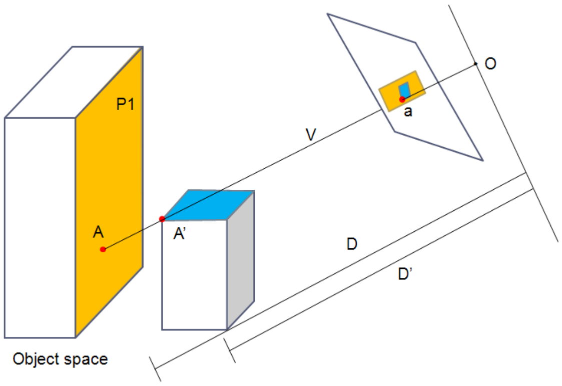


Figure 6. The idea of range verification.

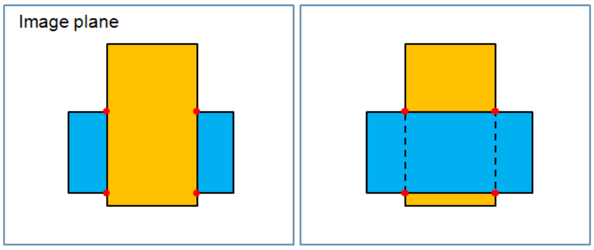


Figure 7. The idea of Line-Intersection verification.

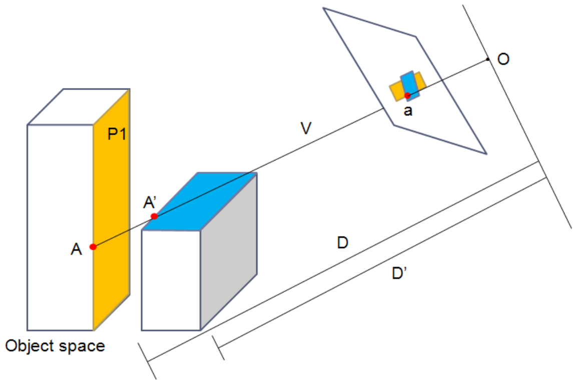


Figure 8. The idea of range verification.

After finish the above two methods of occlusion detection, we know whether the target façade is occluded or not. If the occlusion situation exists, we use point-in-polygon method to remove the occlusion area on the generated texture and mark the area with black. Figure 9 illustrates the concept of occlusion area removal and marking.

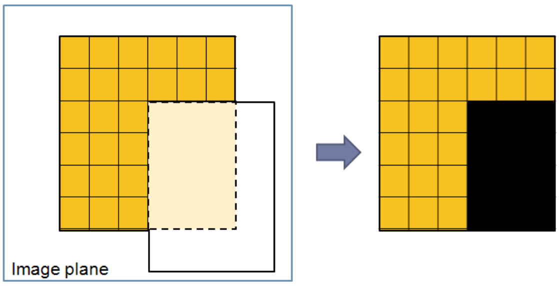


Figure 9. The concept of occlusion area removal and marking.

2.5 Occlusion Compensation

In order to obtain more complete information for the façade texture, we should make the texture more close to the real situation. It is thus important to create an occlusion-free texture. After performing occlusion detection, we extract the texture information for the non-occluded area, but the remaining area (occluded area) was filled with black without any information.

However, due to the errors always exist in the 3D building models and the exterior/interior orientation parameters, sometimes along the border of non-occluded area will be rendered with texture come from the other objects, such as a rooftop and a wall at nearby. Those two sources of texture will introduce high variation of correlation coefficient since they are belonging to different ground objects. Therefore, we adopt the Normalized Cross Correlation (NCC) coefficient to detect these artefacts and remove them like occlusion. Figure 10 illustrates a façade texture with and without improper texturing along the border of occluded area.

Figure 11 illustrates the idea to detect these artefacts with incorrect texturing. In the beginning, we utilize the morphologic erosion filter to search for the edge pixels along the border of the occluded area and index them with a distance number denoting their distance to the occluded area. Then, we compute the correlation coefficient between two neighboured parallel pixels. For example, the coefficient between pixels with index number 1 and 2 was calculated, and then move forward to index number 2 and 3, stop until index number 9 and 10 has reached. Those parallel pixels that do not have stable and high correlation coefficient will be removed and filled with black.

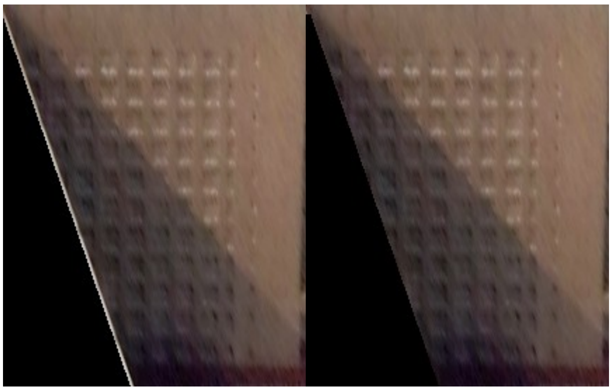


Figure 10. Two sample façade textures with (left) and without (right) improper texturing along the border of occluded area.

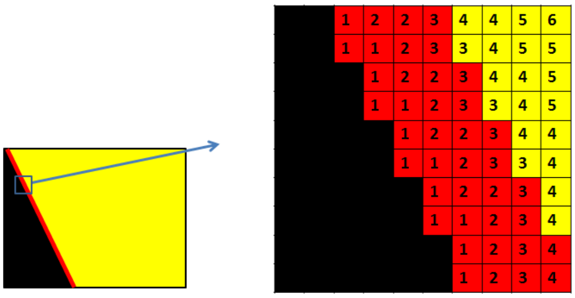


Figure 11. The procedure to detect artefacts by marking edges pixels with distance indices. (The black represents the occluded area, the yellow represent non-occluded areas; the red represents incorrect rendering of texture, and the index number denoting the distance to the occluded area.)

2.6 Seamless Mosaicking

The final step is to perform seamless Mosaicking to avoid gray value discontinuity and to achieve the best quality of façade texture. Two textures of the same façade will be used in this process. Both may contain occluded area at different place but have common overlap. The target façade texture will be treated as the main texture, while the others were treated as the slave one. Figure 12 illustrates the idea about seamless Mosaicking. Figure 12 (A) represents the main texture with black occluded area. Figure 12 (B) represents the façade texture which is generated from the slave image and is used for texture compensation. In which the yellow region is the occluded area in Figure 12 (A) but not occluded in the slave one. Figure 12 (C) shows the buffer zone which was indexed by an erosion filter and denoted as the distance to the occluded area. The gray value within the buffer zone is estimated by the inverse distance weighting average. If any occluded area was existed, we will perform the same procedure of occlusion compensation through all available images. Finally, we can obtain a facade texture as complete as possible.

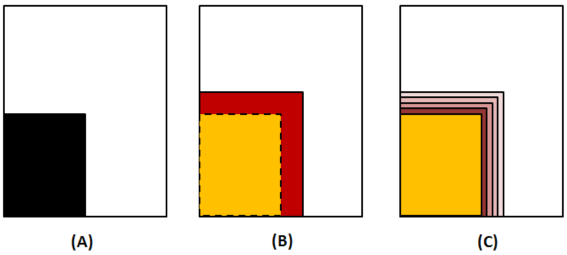
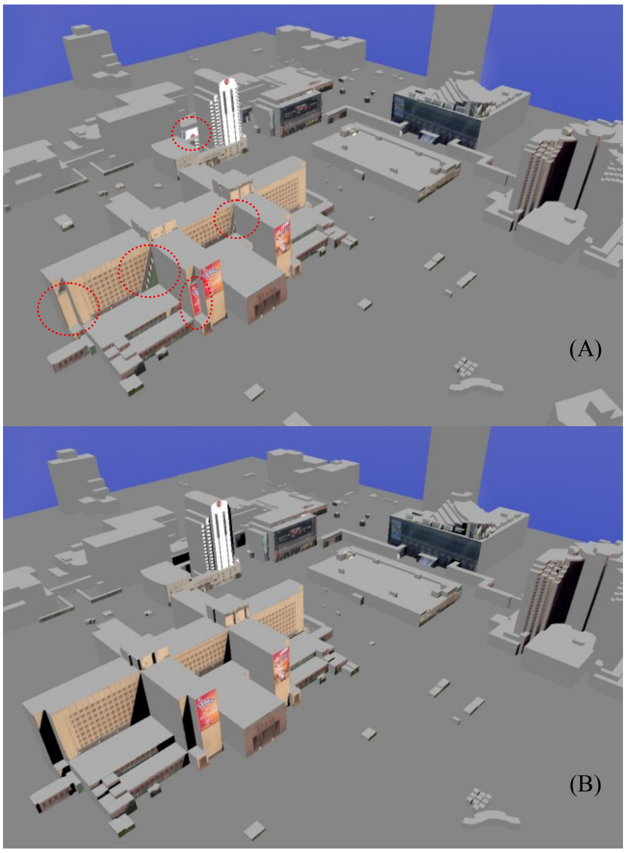


Figure 12. Seamless Mosaicking, (A) is the main façade texture; (B) is the texture used for compensation; (C) is the façade texture after seamless Mosaicking.

3. CASE STUDIES

Figure 13 illustrates the texture generation results that utilize only two images to explain the sequential steps of the proposed algorithm. Figure 13 (A) depicts the first step of texture generation using only one oblique image, same as Figure 2. All façade textures with incident angle small than 80° are generated. One may notice that the textures within the occluded areas were created at the same time, as depicted within the red dashed circles. They may come from the building itself or its neighboured buildings. Those occluded areas are detected and filled with black at Figure 13 (B). Figure 13 (C) shows the occlusion compensation and seamless Mosaicking result using another image.



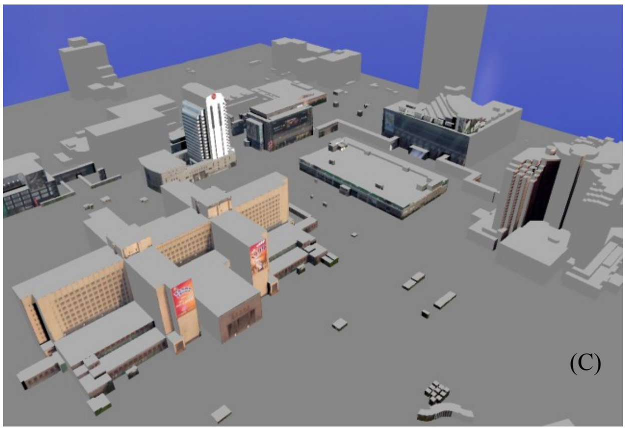


Figure 13. Sequential results of the proposed algorithm.

Figure 14 denotes two detailed description of façade texture generation by means of the proposed algorithm. In Figure 14 (B), we found that the occluded areas are removed by occlusion detection. While in Figure 14 (C) the incorrect texture rendering has removed effectively, especially at the second case. Figure 14 (D) shows the texture generated from a slave image. Direct compensation will introduce serious gray value discontinuity between the main texture and the slave one, as shown in Figure 14 (E). This effect was smoothed out as shown in Figure 14 (F). However, the colour difference still significant among those two textures, since they may be acquired at different sun light conditions. Meanwhile, in Figure 12 (F) some occluded areas still exist, because the façade is very close to another building that causes a complete texture generation not possible.

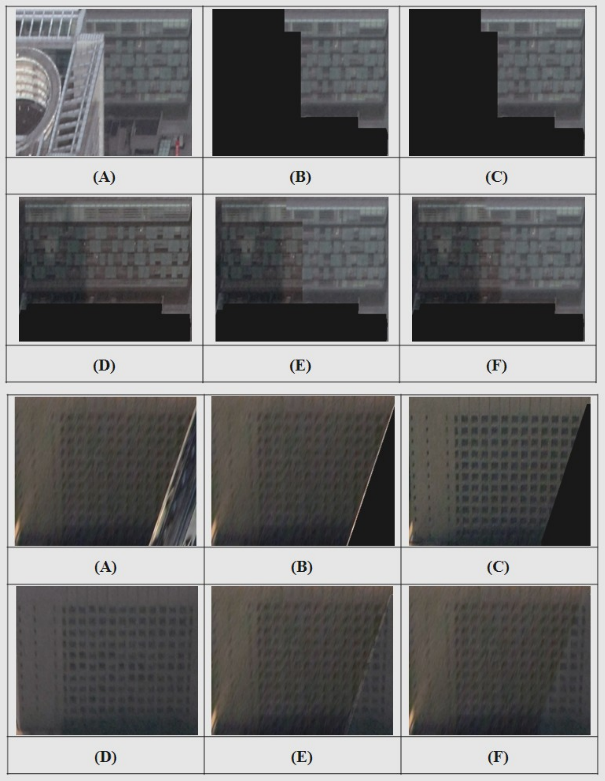


Figure 14. Two examples of the facade texture generation. (A) is the main façade texture; (B) is the texture with black occluded area; (C) is the texture after removing incorrect texturing; (D) is the texture used for compensation; (E) is the compensated texture without seamless Mosaicking; and (F) is the compensated texture with seamless Mosaicking.

Figure 15 demonstrates four groups of buildings after complete façade texture generation using the developed algorithm. The texture quality could be improved by a better oblique imaging system with high-end DSLR camera. The upper-right case shows that the buildings are located at a congested area, but the developed method can work properly. It demonstrates that the proposed method is effective for automatic façade texture mapping.

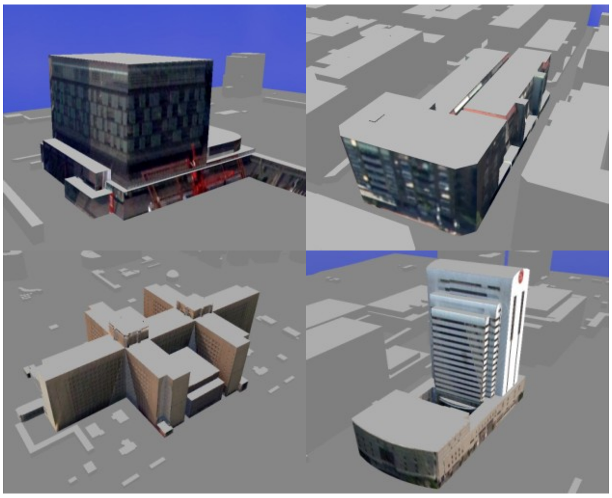


Figure 15. Four group of buildings with complete texture generation.

4. CONCLUSIONS

In conclusion, the experimental results demonstrate that the proposed algorithm can automatically generate façade texture effectively. The occlusion introduced by the building itself or its neighboured buildings can be detected and removed correctly. However, due to inaccuracy of EOPs/IOPS or 3D building models, some incorrect texture may occurred along the border of occluded area. The Normalized Cross Correlation coefficient is useful for detecting this defect, and the inverse distance weighting average method can smooth out the gray value discontinuity problem when occlusion area have to be compensated for from other images. Meanwhile, due to errors always exist in the exterior/interior orientation parameters and the building models, some incorrect texture along the boundary of occluded area are repaired. Experimental results demonstrate that the proposed algorithm is effective and useful for automatic façade texture mapping.

In future research, the colour balancing between the main texture and the slave ones have to be applied. A better image quality is expected in order to improve the visual effect of a photo-realistic city model. In the meantime, the efficiency for the whole procedure needs to be investigated and improved when a large quantity of buildings and oblique images are considered.

5. REFERENCES

Brnner, C., & Haala, N., 1998. Fast Production of Virtual Reality City Models, IAPRS, Vol.32, No.4, pp. 77-84.

Gruen, A. and X. Wang, 2001. News from CyberCity-Modeler, in Automatic Extraction of Man-Made Object from Aerial and Space Images (III), (Eds. Baltsavias, E.P., A. Grüen, and L.Van Gool), Centro Stefano Franscini, Monte Verita, Ascona, 2001, pp.93-102.

Haala, N., 2004. On the Refinement of Urban Models by Terrestrial Data Collection, IAPRS, Vol.35, Part.B3, Istanbul, Turkey, pp.564-569.

Kada, M., 2004. Hardware-based Texture Extraction for Building Facades, IAPRS, Vol.35, Part.B4, Istanbul, Turkey, pp. 420-425.

Rau, J. Y., and Chen, L. C., 2003, “Robust Reconstruction of Building Models from Three-Dimensional Line Segments”, Photogrammetric Engineering and Remote Sensing, Vol. 69.No.2, pp. 181-188.

Rau, J.Y., Chen, L.C., Wen, J.Y., Huang, D.M., Chen, C.T. and Hsu, H.C., 2008, “Direct Georeferencing of Airborne Oblique Imagery from Multiple DSLR Cameras”, Proceedings of Asian Conference on Remote Sensing, Nov. 10-14, Colombo, Sri Lanka, CD-ROM.

Rau, J.Y., Chen, L.C., Teo, T.A., Tseng, Y.H., Chen, C.T., and Chen, S.J., 2007. Adopting 2D Maps and Aerial Imagery for Semi-automatic 3D Building Modeling, Proceedings of The 8th Conference on Optical 3D Measurement Techniques. 278-285.

Takase, Y., Sone, A., Hatanaka, T. and Shiroki, M., 2004. A Development of 3D Urban Information System on Web, Proc. of Processing and Visualization Using High-Resolution Images, Pitsanulok, 18-20 November. (on CDROM)

Varshosaz, M., 2003. True realistic 3D model of buildings in urban areas, Int. Archives of the Photogrammetry, Remotes Sensing and Spatial Information Sciences, Vol.XXXIV-5/W1.

Vosselman, G. & Dijkman, S., 2001. 3D building model reconstruction from point clouds and ground plans. In ISPRS Workshop Land Surface Mapping and Characterization Using Laser Altimetry; International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences: Annapolis, MD, USA, Vol. 34, pp. 37-43.

Wang, S., Tseng, Y. H. and Fu, P. K., 2008. Automated Texture Mapping on 3D Building Model Using Photogrammetric Images, Journal of Photogrammetry and Remote Sensing, Vol. 13, No.2, pp. 75-84.

6. ACKNOWLEDGEMENTS

This paper was partial supported by the Department of Land Administration, MOI and the National Science Council (NSC-96-2628-E-006-257-MY3 and NSC 98-2622-E-006-033-CC1), Taiwan. The authors are grateful for their financial support. In the meantime, the authors also like to thank Prof. L.C. Chen of CSRSR, NCU, for providing the 3D building models and helicopter oblique imagery.