Photogrammetry and 3D city modeling

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Abstract

3D city modeling and urban visualization using the technology of photogrammetry is one of the most growing research topics in digital architecture. There are many different methods of 3D city modeling and many different applications of 3D city models. This paper introduces a modeling method of creating 3D city model from aerial images using commercial off-the-shelf photogrammetry tool and discusses the efficiency and effectiveness in terms of time, labor, and reusability. The 3D city model is created not only for scientific visualization but also for architectural design evaluations. In this project, a 3D city model of downtown Phoenix, USA, is demonstrated.

Keywords: Photogrammetry, city modelling, computer graphics, GIS,

1 Introduction

Recently 3D city models are utilized in various fields such as scientific visualization, 3D maps, car-navigation systems, 3D-GIS, and 3D games. In this paper, *3D city model* is defined as a digitalized three-dimensional computer model of an existing city rather than a virtual city model. There are many different methods for creating 3D city models, and researchers are trying to develop more efficient and effective methods. These modeling methods are mainly categorized into three approaches; automatic, semi-automatic, and manual. The automatic approach is to extract 3D objects such as buildings, streets, and trees from aerial or satellite images by using the technologies of image process and pattern recognition in artificial intelligence [1, 2]. The Semi-automatic approach is to create 3D objects one by one with the support of technologies like photogrammetry and 3D vision [3]. The manual approach is to create all geometries of an object one by one in CAD and CG software packages that are commercially available such as 3D Studio Max and Maya. Spine3D [4] is one of the well-known CG design companies that develop 3D city models manually.

The methods of 3D city modeling also vary from available resource. LiDAR (Light detection and ranging) and Photogrammetry are the technologies commonly used in extracting 3D geometries. The LiDAR instrument transmits light to a target and measures it by using the reflected signals. There are two approaches in using LiDAR. One is to acquire the LiDAR data from an airplane. This is commonly used in remote sensing for creating digital surface model (DSM) and digital terrain model (DTM). Another approach is to get the LiDAR data from the ground and extract the complicated geometries like architectural components and civil structure [5]. A set of points extracted from LiDAR is converted into polygons. This makes it possible to obtain very details, but it requires researchers to fly or walk over to get the necessary data.

Photogrammetry is the other solution. Like LiDAR, it can be used for both aerial and ground images. Aerial images are used to extract abstract forms of buildings, and the ground images are used to extract their details. Nverse Photo [6] and Shape Capture [7] are the example commercial software packages for 3D modeling that use photogrammetry.

2 Classification of 3D city models

Choosing the most suitable method for creating 3D city models depends on given resources and objectives of using them. The given resources are based on time and labor, and the objectives are on quality and scale. 3D city models are categorized into 9 classes based on quality and scale in Table 1.

Table 1: 9 classes of city models

	Low Quality (Online Quality)	Middle Quality (PC Quality)	High Quality (Movie Quality)
Street Level	SL	SM	SH
Block Level	BL	BM	BH
City Level	CL	CM	CH

There are three scale categories; *Street Level, Block Level, and City Level.* The *Street Level* model is used to visualize a street with buildings and landmarks, such as trees, traffic lights, signs, and bus stops, from human’s views. The *Block Level* model is to visualize street blocks in a city including buildings and landmarks form bird’s eye views. The *City Level* model is to visualize a whole city from airplane’s views.

In addition to the classification based on scale, the 3D city models are classified into 3 quality classes; low, middle, and high. The low quality model is designed to render interactively in real time on Internet browsers, the middle quality model is to render in real time on PCs, and the high quality model is not for interactive rendering but for static rendering. .

1) The Street level &low quality model (SL) is the model with buildings and landmark components without any textures or materials. The model is usually used for evaluating the height and volume of buildings from views of human. Usually it is seen at the beginning phase of design in architectural design studios. The model is created with commercial 3D computer graphics software packages such as FormZ [8] and SketchUp [9].
2) The Street Level & middle quality model (SM) has more details and textures than SL. Many of 3D game models such as DOOM3 [10] is classified into this model. In order to visualize the model interactively in real time, the details are created with minimum polygons. With the improvement on graphics cards, very realistic images can be rendered with high-resolution textures even without details.
3) The Street Level & high quality model (SH) is the highest quality model and seen in architectural presentations and Hollywood movies. Since it is necessary to create 3D objects one by one using CG packages, it takes a lot of time and labors. The images are very realistic and beautiful, but it cannot be rendered in real time.
4) The Block Level & low quality model (BL) is used for visualize street blocks in a city. Since a model usually have hundreds of buildings, each building should be represented as a simple volume without any textures in order to render them in real time. Google earth is one example that shows this model in 3D views [11]. 3D-GIS model with digital terrain model (DTM) and 3D buildings, which are created by extruding 2D polygons with building height values, is classified into this class as well.
5) The Block Level & middle quality model (BM) is an upgraded model of BL with textures for buildings and ground. The ground object has textures based on the ortho-images. Many automatic approaches have been researched and developed for creating models in this class using the photogrammetry and image processing technologies [12].
6) The Block Level & high quality model (BH) is based on BM, and a little more details are added to each building. The model is usually used for static rendering because it is too heavy to render the model interactively in real time. A model of 1930's New York city used in the Hollywood movie "King Kong" [13] is the typical example of this class.
7) The City Level & low quality model (CL) shows only DTM mapped with ortho-image without buildings, street, or landmarks.
8) The City Level & middle quality model (CM) has DTM and buildings without textures. Each building is represented as a box.
9) The City Level & high quality model (CH) has DTM and buildings with textures.

3 3D city models using photogrammetry

Photogrammetry is one of the technologies most commonly used in 3D city modeling. By using it, the attributes of object are extracted automatically from multiple images. There are two approaches for photogrammetry. One is to use photos taken from the ground. An advantage of this approach is that taking photos does not cost much. On the other hand, there are some disadvantages. 1) It is difficult to take photos of building from backsides because of security and privacy issues. 2) Since it needs to take several photos to cover all elevations for each building, it is necessary to manage a number of image files. 3) It is difficult to match the two images with different white balances on the same building. In short, the approach using ground photos is useful for extracting building geometries when the more details are required such as for SH and CH models, but it needs more time to manage and fix the textures.

Another approach is to use aerial or satellite images. It is advantageous because it needs only a few images. Since the textures of buildings are extracted from the same image, the color balances of image are not required to fix. One disadvantage is that it costs more to take aerial photos than ground photos.

4 Problem statements

There are many different methods of 3D city modeling, and there are many different applications using 3D city models. Therefore, it is important to choose the most suitable method for a specific application. In this paper, the most efficient and effective modeling method is defined as the one in which the reusable model in the most various applications is created in minimum time and with minimum labor. In other words, it is more effective and efficient if a model can be reusable among the classes in Table 1, and it is better if a model is created with less time and cost.

5 Methodology

The method of creating 3D city models from aerial photos using photogrammetry is used in this project. The reasons why this approach is chosen is that it seems to be able to create a model that can be used in 8 classes (SL, SM, BL, BM, BH, CL, CM, and CH). Another reason is that it seems possible to finish modelling in a few days after taking aerial photos.

The processes of taking aerial photos, scanning images, extracting buildings from the images, and editing 3D objects are explained as follows.

5.1 Aerial photo and scanning

The most important point in creating 3D city models from aerial photos is to acquire high quality aerial photos, because they affect textures of buildings.

In this project, several different kinds of aerial photo were investigated to find the best aerial photo. Two different cameras were tested. One was Canon Eos-1Ds Mark-II [15] that could take the highest resolution image among the digital cameras commercially available. The images were shot from 6000ft altitude by airplane and from 2000ft altitude by helicopter. In the flight, an aerial photographer held the camera and took images manually.

In addition to Canon Eos-1Ds Mark-II, a regular aerial photo camera for 9”x9” negative films was used to take the photos from 6000ft altitude and from 10,000ft altitude. The camera was fixed on the airplane, and a pilot released the shutter.

As explained in Table2 below, the image taken from 6000ft altitude using the regular aerial photo camera was the best for this project. The other images were not good enough because the side images of buildings were not clear enough to use for the building textures.

In order to take clearer images of textures for the side of building, it is necessary to take several oblique shots in addition to the vertical shots. The flight path for taking regular stereo-pair aerial photos is usually straight as shown in the left image of Figure 1. However, in order to take several oblique shots of the same target, the airplane needs to fly over the same position repeatedly as shown in the right image of Figure 1. In addition, the pilot needs to release the shutter for each shot looking at the screen monitor in order to check the position of target in the image, and the photos are taken during a circulate flight. The pilot needs to be skilled in order to get the proper oblique aerial photos. Three flights were made for this project since the first two were failed because of an inexperienced pilot.

Each aerial photo is scanned with 2000dpi, and saved as TIF formatted image without any compression. Each scanned image has about 18,000 x 18,000 pixels as shown in Figure 2.

Table 2: Aerial Photo

	6000ft Film	10000ft Film	6000ft Digital	2000ft Digital (Helicopter)
Pros	Best quality	Cover 3x 3 miles	Easy shot	Easy shot
Cons	Need an expert pilot	Low quality	Blur images	Blur images Many images

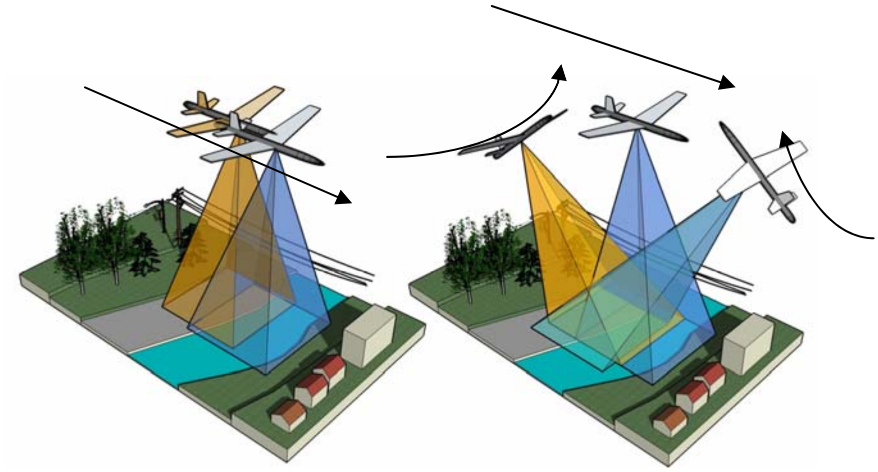

Figure 1. Flight path for stereo shots

Figure 2. Aerial images scanned with 2000dpi

5.2 Modelling process

Nverse-Photo 2.7 [6], one of the commercial off-the-shelf photogrammetry tools, is used to extract 3D buildings and the ground from aerial images. First of all, the following camera parameters are defined for stereo matching. (1) Calibration Focal Length = 152.884mm. (2)Lens Distortion is input as,

$$K_0 = -0.2877 \text{ x } 10^{-6}, K_1 = 0.8168 \text{ x } 10^{-8}, K_2 = -0.4265 \text{ x } 10^{-22} \quad K_3, K_4 = 0.0000$$

(3) The scanning resolution is 2000 dpi. (4) X and Y offsets are defined using fiducial marks.

Once the camera registration is completed for all aerial images, the stereo matching process is done. After the matching process, each building is created by drawing polygons on all images. For example, a polygon is created in the first image, and it is sent to the second image. The user needs to edit the polygon in the second image corresponding to the building. This process defines the height and form of the building. By repeating this process, the geometries of building are defined, and the textures of building are automatically assigned from some parts of aerial images. The ground is defined by inputting the ground truth points with the information of latitude and longitude instead of polygons. The texture for ground is also generated automatically.

The model is saved as a 3DS formatted file, which is one of the most common 3D formats. In order to visualize the model at 3D stereo theater, the model is converted from 3DS format to OSG [16] format. Figure 3 shows the workflow of this project.

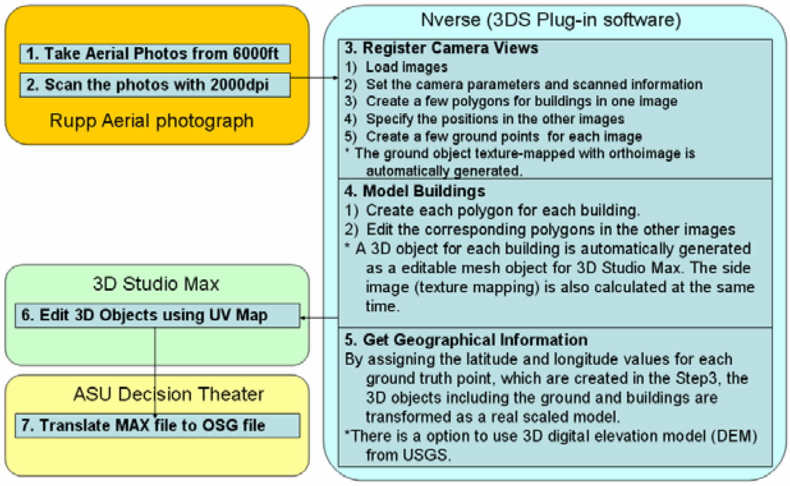

Figure 3. Modelling Process

5.3 Editing 3D model

Autodesk 3D Studio Max [17] is a professional 3D computer graphics modeling and rendering package. The package is used for editing the buildings when they have some problems on their textures. If some parts of building are not visible in some images, the texture are distorted or not generated. In the case, the images taken from the ground can be used to fix the problems. UV-mapping, which is one of the most advanced techniques commonly used in developing 3D games, is applied to edit the side images of buildings as shown in Figure 4. It is not recommended to use heavily because it takes a few hours to fix the problems on each building.

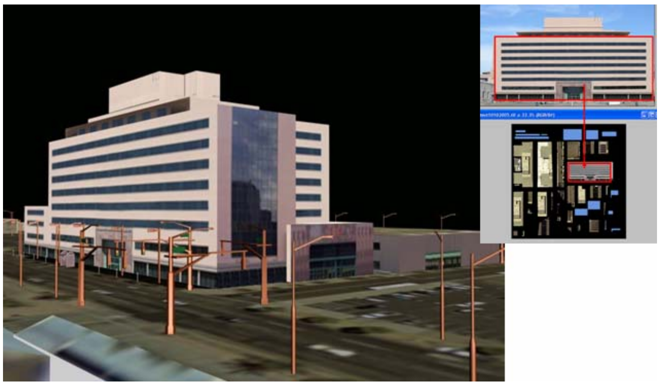

Figure 4. Editing buildings

6 Results and application

6.1 3D city model of downtown Phoenix, AZ

Figure 5 shows the model created in this project. The model covers about one square mile (1.6 km x 1.6 km) area in the center of downtown Phoenix with more than 700 buildings. The model was created within 16 hours by one person.

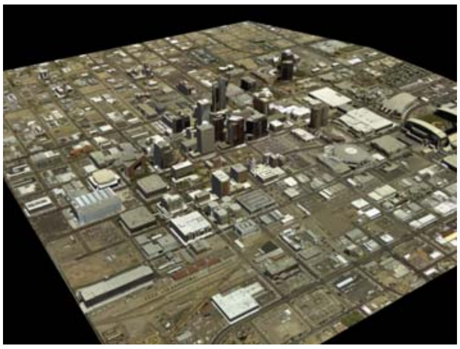

Figure 5. 3D city model of Downtown Phoenix, Arizona in US.

6.2 Application of 3D city model

Four applications that used the 3D city model of downtown Phoenix was created and demonstrated in Figure 6. (1) The left top image in Figure 6 shows the online web-3D application using the model (www.ruthron.com/purl). The user can change the views and get the information of buildings on Internet browsers. (2) The left bottom image demonstrates the application of 3D printing. By using the device [18] to get the XYZ position on the physical model, the building information is displayed. (3) The right top image is the conceptual image to integrate the application 1) and 2) with a big 1/32" physical model. (4) The right bottom image shows the scene of visualizing the 3D city model in a VR environment.

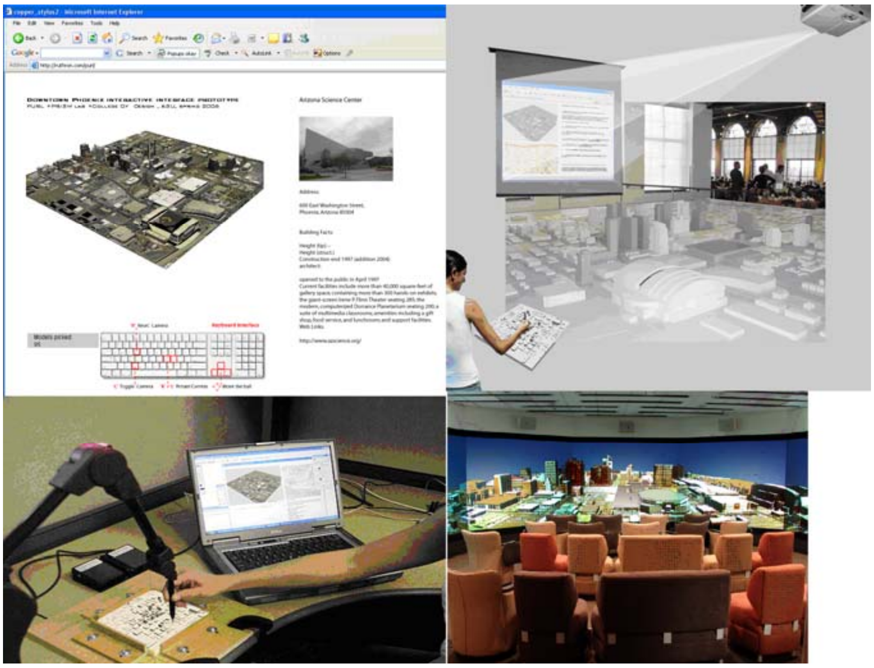

Figure 6. Application of 3D city model
(1: left top) Online application
(2: left bottom) Tangible interface
(3: right top) Physical model
(4: right bottom) VR model

7 Conclusion & future work

The followings are demonstrated in this paper.

- 3D city models were categorized into 9 classes based on the scale and quality.
- Several different aerial photos were examined for creating 3D city models with photogrammetry, and the regular 9" x 9" film scanned with 2000 dpi got the best result.
- The modeling process of 3D city model using the technology of photogrammetry was explained step by step.

- 3D city model of downtown Phoenix covering about one mile square with more than 700 buildings was created within 2 days after taking aerial photos.
- Four applications that used the 3D city model of downtown Phoenix were introduced.
- The future work is to implement a computer-based tool for generating more details with the support of photogrammetry in order to make use of the model for SH (Street level & high quality) class.

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[18] Microscribe http://www.immersion.com/digitizer/