PICTOMETRY'S PROPRIETARY AIRBORNE DIGITAL IMAGING SYSTEM AND ITS APPLICATION IN 3D CITY MODELLING

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ABSTRACT:

One of the most significant achievements in digital photogrammetry in the last decade is the development of large format digital mapping cameras. In addition to large format digital mapping cameras, a number of medium format digital mapping cameras systems have also been developed. At Pictometry, a medium format digital imaging system has been developed and been widely used for acquisition of both vertical and oblique images around the world. Since oblique images exhibits rich 3D like information of objects on ground, they are widely used in not only 3D measurement and visualization, but also creation of 3D city models. In this paper, Pictometry's proprietary medium format digital imaging system will be briefly introduced. Some issues in generation of 3D city models using Pictometry digital oblique images will also be discussed.

1. INTRODUCTION

With the rapid development of CCD and computer technology, a number of large and medium format digital mapping cameras have been developed in photogrammetric field (Sandau et al, 2000, Hinz et al, 2001; Leberl et al, 2003; DIMAC 2008; Mostafa, 2003). In contrast to analog mapping cameras, digital mapping cameras exhibit a number of advantages. One of the most important features of digital mapping cameras is that they produce digital images directly without need of photographic processing and scanning of negatives and diapositives, and thus photogrammetric production cycle can be reduced. At the same time, image quality is improved since digital images are free from dust marks, spots and scratches. Most digital mapping cameras produce 12-bit digital images which have much larger dynamic range compared to images produced by films. Thus, high accuracy of point measurement can be achieved with digital images, especially in difficult situations such as in shadow areas. At Pictometry, a medium format digital imaging system was developed for acquiring both vertical and oblique digital images. Up to now, more than 50 Pictometry imaging systems have been deployed in the USA and tens of systems are being used around the world.

3D city modeling has been an active research area in digital photogrammetry for a decade and a number of methods and systems have been developed for creating 3D city models from digital images and other auxiliary data automatically or semi-automatically. Two major steps involved in generating 3D city models are creation of building models and adding textures to the building models. Various methods have been developed for creating building models from digital images automatically or semi-automatically (Haala and Hahn, 1995; Gülch, 1997; Henricsson, 1996; Vosselman, 1999), or from LiDAR data (Haala and Brenner, 1997; Rotternsteiner and Briese, 2003; Schwalbe et al, 2005). Since both digital aerial images and LiDAR data supplement to each other, accurate and reliable building extraction can be achieved by fusing digital images and LiDAR data (Rotternsteiner and Jansa, 2002; Vosselman, 2002; Hu et al, 2006). Adding texture to the created building models is important since it makes 3D models more realistic. Different approaches for creating building textures have been developed to create building textures automatically from aerial vertical and oblique images (Brenner et al, 2001; Frueh et al, 2004; Zhang et al, 2004). In this paper, Pictometry digital imaging system will be briefly introduced. Some issues in creation of 3D city models using Pictometry digital oblique images will also be discussed.

2. PICTOMETRY DIGITAL IMAGING SYSTEM

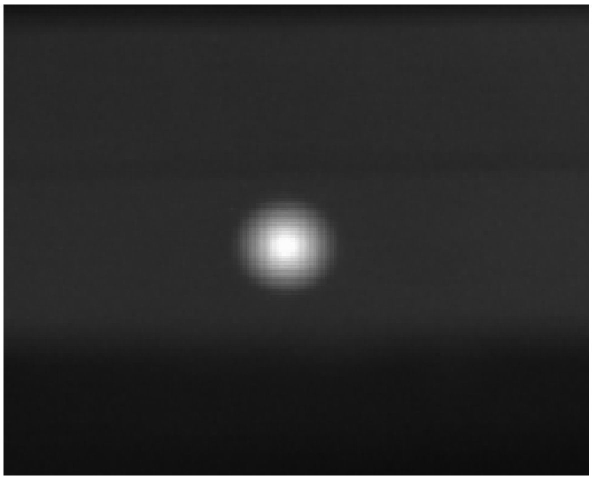
2.1. Components of Pictometry Digital Imaging System

Pictometry digital imaging system has some unique features, compared with other digital mapping cameras/systems. The imaging system consists of five digital cameras, an integrated Global Positioning System (GPS) and Inertial Measurement Unit (IMU) and a flight management system. Each camera has an array of CCD with about 4.9k x 3.2k pixels. The five digital cameras are arranged in such a way that four of them look forward, backward, left and right directions at a certain view angle respectively and one looks straight down. The camera in the vertical direction captures high-resolution vertical images and the other four acquire oblique images at different view directions at the same time. The onboard GPS and IMU provide an accurate position and attitude of each sensor at exposure time, thus the images produced by Pictometry imaging system are directly geo-referenced images. Like traditional aerial images, vertical images provide a vertical view of the terrain surface, while oblique images show the side looking of objects on the ground such as buildings. Vertical images can be used for creation of accurate large scale orthophotos (Wang et al, 2008) and oblique images can be utilized for visualization, measurement and 3D modeling. Pictometry oblique images have been widely used in various applications such as public safety, tax assessment, urban planning, 3D city modeling, etc. The flight management system is flight planning software which determines flight lines, control image overlaps, etc. before and during the flight for both vertical and oblique images. In order to better use and visualize both oblique and ortho images, Electronic Field Study (EFS) has been developed at Pictometry. Both vertical and oblique images can be easily viewed in EFS, and spatial measurement such as distance and height of objects on the ground can be easily performed on both oblique and vertical images. The results can be exported into ArcGIS directly to update the existing geo-spatial information in the database.

2.2. Camera Calibration

Camera calibration is an important process in photogrammetric mapping to ensure extraction of accurate and reliable 3D information from imagery. In camera calibration, the principal length of the camera, the coordinates of the principal point in image coordinate system and the coefficients of lens distortion including radial distortion, tangential distortion and affinity and shearing are computed. Various calibration methods have been developed for calibration of digital mapping cameras and the performance of some medium format digital cameras can be found in Cramer (2004). At Pictometry, a calibration system has been developed for calibration of its digital cameras and the system was provided to EROS center of USGS at Sioux Falls for establishing a calibration system for calibration of various digital mapping cameras in mapping community (Pictometry, 2002). Basically, the Pictometry's calibration system includes an indoor calibration cage with evenly distributed targets as shown in Figure 1 and software Australis which is the well-known calibration software (Fraser and Edmundson, 2000).

(a) Calibration cage



(b) Calibration target

Figure 1. Camera calibration cage and target

In calibration, the camera to be calibrated captures a number of images against the calibration cage from different locations to form a network, and Australis is then used to measure the targets in the images automatically and accurately and to perform a free network bundle adjustment to compute the interior orientation parameters and distortion coefficients of the camera. Figure 2 shows the calibration result of Pictometry digital camera. It can be seen that the radial lens distortion of the camera is very small in most area of the image and high accuracy of point measurement can be achieved after correction of lens distortion.

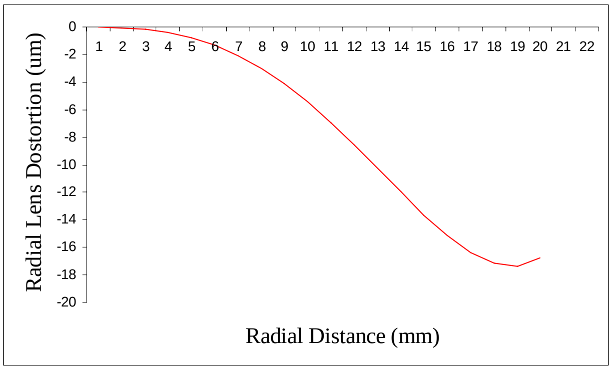


Figure 2. Radial lens distortion

The advantage of Pictometry's calibration system lies on its efficiency and reliability. It is very easy to run calibration of digital cameras with Pictometry's calibration system and very economic, compared with other approaches such as *in-situ* calibration method. Figure 3 shows the radial lens distortion of a Pictometry digital camera obtained at calibrations repeated in a short time period. It can be seen that the results are consistent and the difference between two calibrations is very small. It is very important that each digital mapping camera is calibrated regularly so that the changes of camera's interior orientation parameters and lens distortion parameters between two consecutive calibrations are within the defined tolerance and do not affect the mapping accuracy.

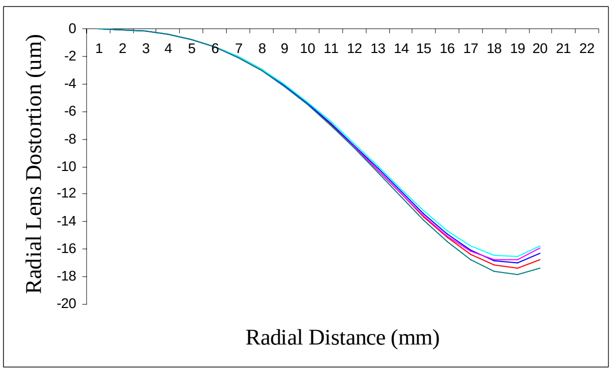


Figure 3. Radial lens distortion at repeated calibrations

3. 3D CITY MODELLING WITH PICTOMETRY DIGITAL IMAGERY

Oblique images have advantage against vertical images in creating building textures since they provide better side view of building facades. Pictometry imaging system captures oblique images from different directions which are ideal for generating building textures. The vertical images taken in the same area can be used to generate 3D building models or to refine 3D building models created from other data source such as LiDAR data. In this section, some issues in generating 3D city models using Pictometry digital images will be addressed.

3.1. Refining 3D Building Models

3D building models can be extracted from both aerial images and LiDAR data. In automatic building extraction from aerial images, image matching technique is usually used to extract 3D information of buildings. One major problem with automatic approaches is that the extraction may fail when occlusions and shadows occur in the images. Modern LiDAR systems are capable of receiving multiple returns with some penetrating vegetation, and thus, the effect of occlusions can be reduced by combining the information from different returns, e.g. first and last returns and buildings can be extracted reliably. Figure 4 shows an example of building footprints extracted from LiDAR data in downtown area of Buffalo, New York. However, the problem with extraction of building models from LiDAR data is that the extracted models may not be very accurate because of point spacing, scanning angle, the performance of line extraction algorithm, etc. Therefore, building models derived from LiDAR data need to be refined, in order to create accurate 3D city models. To correct building models, they are projected back on the vertical image triangulated with accurate ground control points. The difference between a projected roof edge and its corresponding edge extracted from the image is usually just a few pixels, as shown in Figure 5. Therefore, an affine transformation can be used to correct the building models and the transformation parameters can be estimated by using the distance between the projected roof edges and the extracted edges from the image.

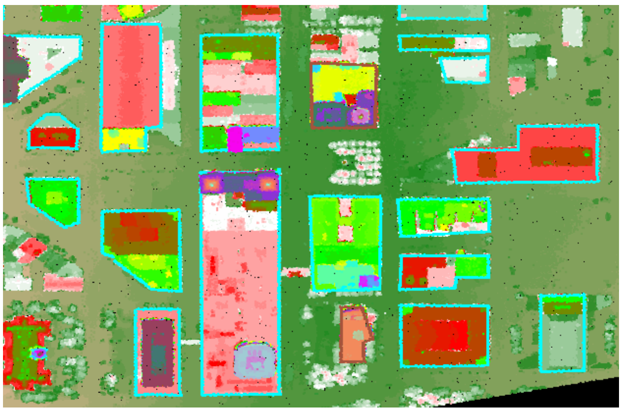


Figure 4. Building footprints extracted from LiDAR data

3.2. Selection of Oblique Image

Due to the image overlap, each building is imaged on several oblique images. It is very important to choose one from them to give the best texture of the building. In Zebedin et al (2006), a score is assigned to all oblique images based on the angle between the normal vector of the facade to be textured and the vector from the center of the façade to the camera center of an oblique image and the one with highest score is chosen. Since Pictometry oblique images are captured at a certain angle, a reference vector with a certain angle to the building facade within the vertical plane passing through the normal vector instead of a normal vector is chosen as shown in Figure 6 and a

Figure 5. Projected building footprint on aerial image

score is given to an oblique image based on the angle between the reference vector and the vector from the center of the façade to the camera center of the oblique image. At the same time, a visibility analysis is performed to make sure that the façade is not blocked by other buildings.

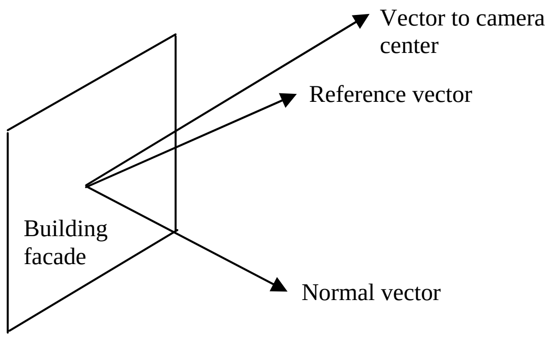


Figure 6. Selection of oblique image

3.3. Texturing with Oblique Image

Once a right oblique image is chosen, the next step is to pick up the right image portion and add it to the building façade. To make sure the right image portion is selected, it is necessary to check whether the building façade projected onto the oblique image matches the building edges on the image. The projected boundaries of the façade should match the corresponding building edges in the image when the oblique image has accurate exterior orientation (EO) parameters. However, they may not exactly coincide with the actual edges of the building as shown in Figure 7, when image's EO parameters from GPS/IMU are used directly. To create accurate 3D city models, accurate EO parameters of images must be used. The usual way to obtain accurate EO parameters of images is by automatic triangulation (AT). However, most commercial AT software cannot handle oblique images because of the nature of oblique images. A least squares method is proposed in this paper. In the proposed method, the differences between edges of the building façade extracted from the oblique image and the corresponding

Figure 7. Projected building boundary on oblique image

projected boundaries are used to estimate the corrections of EO parameters. The differences of x and y coordinates of end points of edges are used as observations given in formula (1) and the corrections of EO parameters are treated as unknowns.

$$\begin{aligned} \Delta x_i &= x_i - x_i^{'} \\ \Delta y_i &= y_i - y_i^{'} \end{aligned} \tag{1}$$

where: x_i, y_i = coordinates of i^{th} end point on oblique image
$x_i^{'}$, $y_i^{'}$ = coordinates of corresponding projected end point.

The EO parameters from GPS/IMU are used as approximate values and their corrections are computed by the least squares adjustment. Once the accurate EO parameters of the image are computed, the right image portion can be determined by projecting the building façade onto the oblique image with the corrected EO parameters and added to the 3D building model.

4. SUMMERY

In this paper, Pictometry's proprietary digital imaging system is introduced briefly and some issues in 3D city modeling using Pictometry's digital images are discussed. The unique feature of Pictometry's digital imaging system is that it produces both direct geo-referencing digital vertical and oblique images at one time. The vertical images can be used for photogrammetric mapping such as generation of accurate large scale digital orthophotos while oblique images can be utilized for other applications such as public safety, 3D city modeling, etc. In 3D city modeling, vertical images can be used to create building models or refine building models generated from LiDAR data and building textures can be created from oblique images.

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