RECONSTRUCTION OF BUILDINGS FROM A SINGLE UAV IMAGE

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ABSTRACT:

Today we are up against the puzzle that how to acquire the 3D information of city efficiently and quickly. Many researchers distributed all over the world put forward different methods towards their own applications, but there is still lack of a approach which can meet most demands from various users. In this paper, we design and implement a 3D reconstruction method of city buildings from single UAV(Unmanned Aerial Vehicle) image. As a new platform of Remote Sensing, UAV has many good characteristics such as low cost, simple manipulation, high resolution, flexibility and etc, so we choose it as the tool for city image acquisition. We can extract both geometry and texture information from UAV images. In a single UAV image, at first we get the inner elements (x_0, y_0) and f by checking up the camera, secondly we divide the parallel lines in buildings into three groups which parallel X, Y and Z coordinate axis respectively and compute the three joint points based on related photogrammetry theory, thirdly calculate the three angle elements $A,\alpha$and$\kappa$to implement the image relative orientation, fourthly compute the scale between reality and image using the real coordinate information drawn from 2D GIS databases, then on the basis of all the above parameters we can measure the real height of buildings and reconstruct their 3D models. In the paper, we have also build some accurate models to test the feasibility and practicability of this method.

1. INTRODUCTION

Digital Earth and Digital City have become the research focuses in geographic information field. High-resolution remote sensing images are the most important sources for the city 3D information acquisition, and there are increasing demands. The general remote sensing techniques by satellite and aircraft can get the geographic information of large area, but there are some limitations in detail information acquisition of city. The satellite is restricted by the running cycle, height, cloud and some other factors. And the aircraft is also affected by many things such as airspace limit and weather. So theses techniques can't completely meet the require of subtle 3D information acquisition in city. Unmanned Air Vehicle, and the acronym is UAV, is a new platform of Remote Sensing. There is no man in UAV, and it is navigated by the telecontrol device. UAV has many good characteristics such as low cost, simple manipulation, high resolution, flexibility and etc. UAV can implement many tasks that traditional aircraft can't finish. Lots of practices prove that UAV is a ideal tool for high-resolution photos collection of city.

The city is the main inhabitation of people, which is mostly composed of buildings. And how to factually describe the building is the core task of Digital City. Researchers distributed all over the world put forward various means to reconstruct buildings as the following.

a. Using the design drawing of building and the city map together. This means is only fit for few buildings reconstruction, because it needs drawing recognition and lots of data input work. And the building drawing is always very complex, it needs professional knowledge to understand.

b. Extracting the layer information form the city map, and using assumed layer height and virtual texture to reconstruct buildings. The method is easy and needs no additional information. The main shortcoming is too artificial and lack of facticity.

c. Overlapping the digital orthoimage on the digital elevation model can easily found the three-dimensional scene of large area city. But this scene is superficial ,the user can do scanning and analyzing on a single object.

d. Digital photogrammetry. From the aerial remote sensing image, we can derive plenty of geometric, texture and topologic information by the means of digital photogrammetry, and it is one of the most important method to reconstruct the 3D models of buildings.

e. Integration of multiple means.

In the paper, we put forward a building reconstruction method from a single UAV image. We use the UAVRS-II to get the high resolution image of city, then analyze every image and derive the height and texture of buildings with the aid of digital map in existence, at last reconstruct the corresponding 3D models.

2. IMAGE ACQUISITION USING UAVRS-II

The UAVRS-II remote sensing system is developed by the Chinese Academy of Surveying and Mapping which has integrated the RS and UAV technology. The system comprises of RS device, RS platform and tele-controlling system. RS device is used to acquire the photo, such as the CCD camera which we used in the paper experiments. The platform is the carrier of RS device which is made mainly of glass fibre reinforced plastic, and it has a lighter weight but a higher intension. The tele-controlling system is used to control the flying state and all devices working normally. Fig.1 shows the outline of UAVRS-II.

Fig.1 UAVRS-II RS System

In traditional aerial photograph, because the photo is taken nearly vertically to the earth surface, we can only get the height and top texture information of the main part of building, and lose plenty side face information. That can’t meet the demand of acquiring subtle city information. Unlike the traditional aerial photograph, we should photograph the object building obliquely (Fig.2) when we want to get the information as much as possible. From the oblique photo, we can derive various types of information including the height of every main part and small part, the top texture and the side texture.

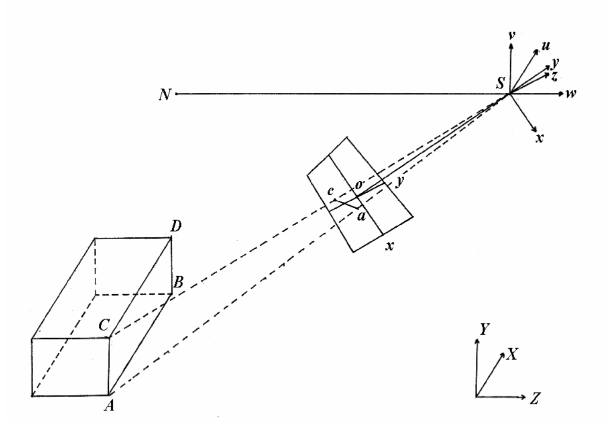

Fig.2 Oblique Photograph

UAVRS-II can do remote sensing in the height range from 50 to 4,000 meters. Although we can acquire the high resolution image with the vehicle flying in a low height, there may be a danger of bumping tall buildings and the photo could only cover a small region. And if the vehicle is flying very high, the resolution of photo will be low grade. From lots of tests, we get the UAV images on various shooting conditions, and at last we draw the conclusion that 45° and 300 meters are the ideal shooting angle and height (Fig.3).

Although UAVRS-II has many good characteristics such as low cost, high resolution, flexibility and etc, it also has some disadvantages. Because it has a very light weight, UAVRS-II is much more influenced by outside environment such as the wind and it is difficult to control the vehicle photographing on a same pose. Therefore we have relatively much trouble in putting the images together. In the paper, we put forward a new method to do surveying on a single image, so we successfully avoid the limitation of UAVRS-II.

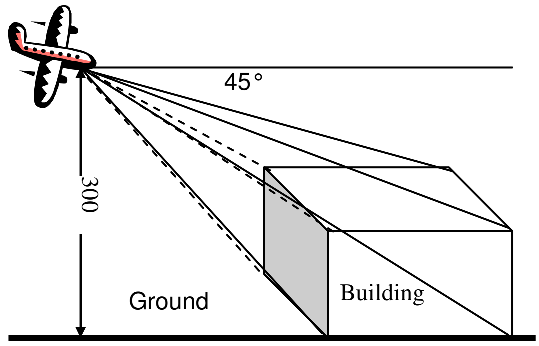

Fig.3 The Ideal Photographing Pose

3. SURVEYING ON A SINGLE IMAGE

In traditional photogrammetry, we usually use an image pair to reconstruct the 3D model of spatial object. But to some objects which have regular shapes such as building, because there are certain geometric relations among the out lines, for example as showed in Fig.4, Top line is parallel to Ground line and vertical to Side line, we can reconstruct the 3D model of building using these geometric attributes. Many scholars distributed all over the world have done researches on such subject (T.E. Chen, Chen Zen, Frank A.van den Heuvel, Zuxun Zhang, et al).

In the paper, we design and implement an single image surveying method, by which we can get both the height and texture of buildings. The whole process could be divided into four steps. In a single UAV image, at first we get the inner elements (x_0, y_0) and f by checking up the camera, secondly we divide the parallel lines in buildings into three groups which parallel X, Y and Z coordinate axis respectively and compute the three joint points, thirdly calculate the three angle elements A, α and κ to implement the image relative orientation, fourthly compute the scale between reality and image using the real coordinate information abstracted from 2D GIS databases, then on the basis of all the above parameters we can get the real height and the ortho-texture of buildings.

a. Checking the camera

The purpose of camera checking is to get the inner elements including (x_0, y_0) and f and the lens aberration parameter K_1. In the tests we used Nikon D100 digital camera, and the checking results is showed in the following formula.

$$\begin{aligned} x_0 &= 5.69 \\ y_0 &= 12.09 \\ f &= 2612.83 \\ K_1 &= -1.29e-008 \end{aligned} \qquad (1)$$

The result unit is pixel, and by multiplying 7.8μm which is the width of a pixel we can transform it to millimeter.

The following is the model to rectify lens aberration.

$$x = (x_1 - x_0) + K_1(x_1 - x_0) * r^2$$
$$y = (y_1 - y_0) + K_1(y_1 - y_0) * r^2 \quad (2)$$
$$r^2 = (x_1 - x_0)^2 + (y_1 - y_0)^2$$

b. Computing the joint points

Fig.5 shows the projection of a building in a photo. In principle, all the lines that respectively parallel *X*, *Y* and *Z* coordinate axis should join in three points *I, J* and *K*. If we pick some points along *13* and get the coordinate sets $\{(x_1,y_1),(x_2,y_2),\ldots\ \ldots,(x_m,y_n)\}$, then we can get the line $Ax + By = 1$ using the formula below.

$$A = \frac{\sum x * \sum y^2 - \sum y * \sum xy}{\sum x^2 * \sum y^2 - \sum xy * \sum xy}$$
$$B = \frac{\sum y * \sum x^2 - \sum x * \sum xy}{\sum x^2 * \sum y^2 - \sum xy * \sum xy} \quad (3)$$

And by the same means, we can get the description of line *24*, then compute the coordinate of point *I* using the following formula.

$$x_I = \frac{\sum A * \sum B^2 - \sum B * \sum AB}{\sum A^2 * \sum B^2 - \sum AB * \sum AB}$$
$$y_I = \frac{\sum B * \sum A^2 - \sum A * \sum AB}{\sum A^2 * \sum B^2 - \sum AB * \sum AB} \quad (4)$$

And the coordinates of point *I* and *K* can be computed using the formula 3and 4. To ensure the precision of results, in practice, we usually take redundant points and compute the average.

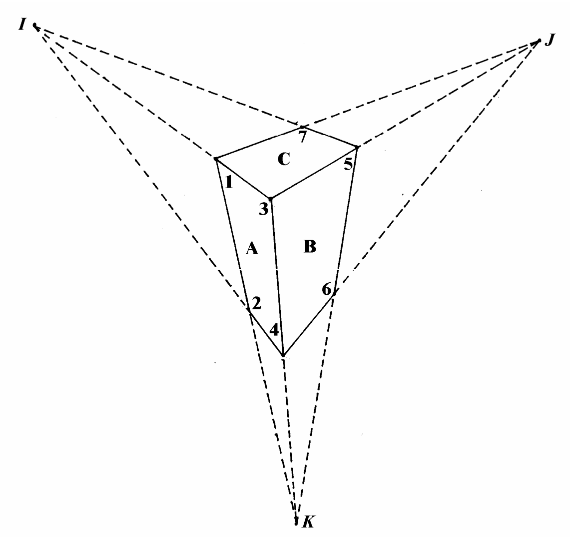

Fig.5 The Joint Points in A Image

c. Computing the angle elements

After the determination of the three joint points, next we will compute the three exterior angle elements *A*,αandκ. Taking one side face *A* of the building showed in Fig.5 as an example, we calculate the three elements. Fig.6 shows the detail. The angle α is photo obliquity, and the range is from 0°to 90°. *A* is attitude angle, and it also ranges from 0°to 90°. And κ is the angle from *x* coordinate axis counter-clockwise to the u coordinate axis with the range from 0°to 360°.

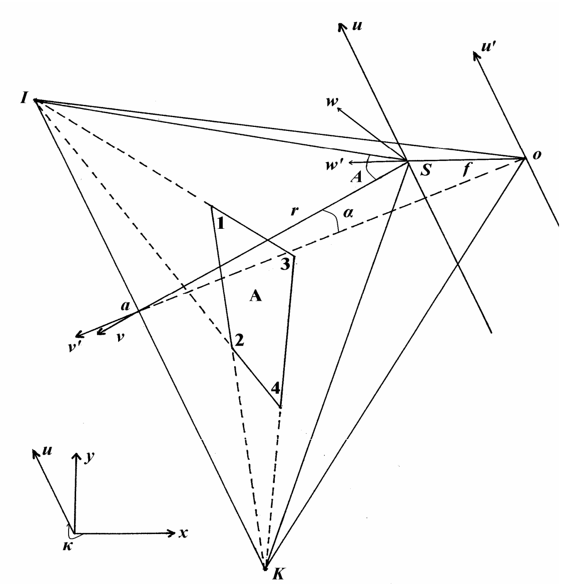

Fig.6 The Angle Elements in A Image

From the geometric relation of special *Points*, *Lines* and *Faces* in photogrammetry, obviously $So \perp oIK$ and $ov \perp IK$, so we can draw the conclusion that $\triangle oaS$, $\triangle Isa$, $\triangle SaK$, $\triangle Ioa$ and $\triangle Koa$ are all right-angled triangles. Based on relations of the right-angle and the coordinate axis, we can deduce the following formula.

$$A = \angle ISa$$
$$\alpha = \angle Sao \quad (5)$$
$$\kappa = \angle xu = \angle xu' = \angle xoI + \angle Iou' = \angle xoI + \angle oIa$$

And the angle$\kappa$is determined by the quadrant of the point *a* which is the cross of *IK* and *Sv*. Using coordinates of the points *I, J, K, o* and *f*, we can compute the length of *oa*, *Sa*, *Io* and *SI*, then we can calculate the three exterior angle elements *A*,αandκ by the formula 6.

$$A = \arcsin(\frac{Sa}{SI})$$
$$\alpha = \arcsin(\frac{f}{Sa}) \quad (6)$$
$$\kappa = arctg(\frac{y_I - y_0}{x_I - x_0}) + \arcsin(\frac{oa}{Io})$$

d. Computing the scale

Based on the above parameters x_0, y_0, *f*, *A*,α and κ,we can found the model of building in object space. But without any coordinate and length information of reality, we can't determinate the size of the model. There are a few kinds of means could be used to get the scale between the model and reality. For that we have already possessed plenty of digital map, we can draw the length information we need, and then compute the scale.

Following the above computing process, we have get all the necessary parameters and built the formula transforming the image length to real length.

4. 3D MODELING OF BUILDINGS

On the image which is acquired by UAVRS-II on the 300 meters height, as showed in Fig.7, we derived the height and texture information with the aid of 2D GIS database, and reconstructed the 3D models of buildings. Fig.8 shows detail of the models.

Fig.7 The Image of UAVRS-□

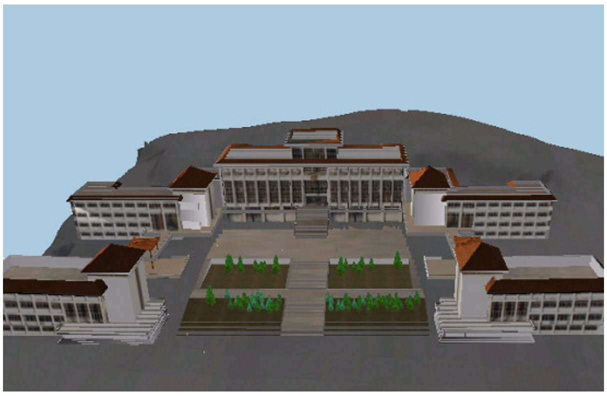

Fig.8 Reconstructed 3D Models

5. CONCLUSIONS

Today with the development of Digital Earth, Digital City and other digital projects, we have to be up against the puzzle that how to acquire the 3D information of city efficiently and quickly. In this paper, we have design a 3D reconstruction method of city buildings from single UAV image, and have also built some accurate models to test the feasibility and practicability of this method. The practice proved that it is an effectual means to solve the bottle-neck problem of 3D city modeling.

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