Generation the 3D Model Building by Using the Quadcopter

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Abstract -

Last decade saw a considerable growth in number of methods to create 3D models for buildings. Some companies have developed their own online maps systems. One of the most well-known of them is Google Maps. The maps are infrequently updated because the process is costly and labor-consuming, and, as a rule, the update is not necessary. The process of 3D model creation for a separate building using such equipment as LIDAR and UltraCamD is very expensive; and land-based aerophotogrammetry has its limitations based on the height of the building and its location that should be suitable to place the camera to get an accurate photos.

The article presents results of using 3D reconstruction technique based on 2D pictures of a building taken by a quadcopter . The latter is an unmanned aerial vehicle (UAV) being used to survey buildings of various heights without interfering with public transport. Moreover, the quadcopter can reach any position required to take the necessary angle for a favourable photos.

The building under consideration has been surveyed using Autodesk 123D package to reconstruct 3D geometry of it. The results prove that the quality of regenerated pictures taken by quadcopter is comparable to those received using UltraCamD and Pictometry equipment, façade pictures being even of better quality. The modeling results show good image quality and sufficient area of overlap which makes the model more real.

Keywords -

3D-model; 3D-reconstruction; Building; Aerial photogrammetry; Quadcopter; UAV; Texturing

1 Introduction

Last decade saw a considerable growth in number of surveys concerning methods to create 3D models of buildings on the basis of photographs. Authors in [2], for example, combined aerial photographs and ground mapping pictures to create the 3D model for a building of complex architecture. They used a HexaCopter, an unmanned aerial vehicle (UAV), and special software to create a map based on the photographs. The software program triangulated the pictures and then generated orthophotos to obtain the footprint of the building. After that 3D model and the footprint of the building were combined into one coordinate system. The method described is cost-saving comparing to 3D model plotting, but it is more time consuming as the process takes up several days.

Table 1 Time consumption assessment

Method	Tacheometry method	Manned aircraft	UAV technology
Field-work	Traversing – **1 day** Tacheometry – **2 days**	Traversing, pre-marking and flight planning – **96 hours**	UAV setup – **20 min** Flight – **30 min**
Processing	Generate the topographic plan – **1 day**	Image scanning and processing – **1 month**	Image processing until map production – **4 hours**
Man power	**4 person**	**2 pilots** and **2 person** on the ground	**1 pilot** and **1 person**

Another example of unmanned aerial vehicle application is shown in [3]. Cropcam, a drone with fixed wings, proved its efficiency to create topographic maps as well as showed some advantages such as time consumption, in comparison with other wide-spread methods. The comparison is presented in Table 1. Visual and plotting analysis shows the accuracy of 1 meter for the maps created with the method described.

Highly realistic pictures of facades and roofs are obtained by the authors in [12] using pictometry and photographs taken by UltraCamD camera. Combination of vertical and oblique pictures provides good results to create high-quality 3D models of urban areas. Maximum discrepancy when using UltraCamD reached 0.042 m, maximum discrepancy when using pictometry was no more than 0.396 m. But there are several problems that occur while using the method. The first problem is the difficulty to generate the textures hidden by trees, cars and other objects in front of the façade. You can see the example of a façade blocked by vegetation in Fig. 1.

Figure 1. Façade textures hided by vegetation around the building [8]

3D reconstruction method for facades that uses two parallel 1D high resolution cameras providing stereo-images of textures is presented in [5]. The experiment is carried out by an automobile equipped with cameras moving along the road at the speed of 40 km/h. The authors of the methods are able to overcome the problem of textures blocked by trees and telegraph posts. But the method has its own limitations: the automobile can move only along the roads and cannot overtake some big blocking obstacles in front of a building.

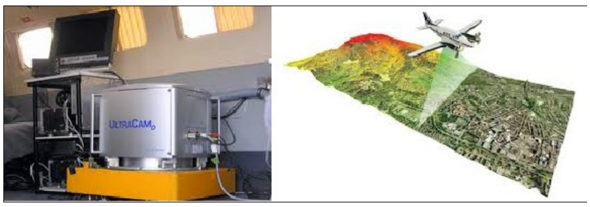

Figure 2. LiDAR-equipped aircraft during the process of 3D landscape survey

The importance of oblique images when texturing the building is described in [1]. They are used to provide better quality of obtained textures.

Considering the abovementioned methods of 3D models creation it is necessary to note that it is unreasonable to use commercial aircraft to generate a model of a single building. The ability of ground photography is also limited. It is worth mentioning that quality increase results in computational expenditure increase, while acceleration of photo-processing speed results in quality decrease, the problem to reduce graphic information processing time is not, though, among the tasks of the presented survey.

2 Aerial Photographs Means

Great majority of all topographic maps and 3D models of buildings are obtained while using commercial aircrafts, as described in [12]. The following equipment, as a rule, is mounted on the aircraft:

- High-resolution camera with IMU sensors to register metrical values, such as Ultracam D with picture accuracy up to 2 mkm [9]. The camera comprises IMUs and a GPS-receiver to register picture location coordinates and to filter noises.

- LiDAR-scanner of high-resolution mode with 18 cm accuracy for vertical pictures and 30 cm accuracy for horizontal pictures [6].

Commercial aircraft application efficiency is proved by high quality of photos taken and by multitude of topographic maps and 3D models created. Fig. 2 shows the cabin of the aircraft equipped with Ultracam D camera. Aerial pictures taken at high altitude from an aircraft are presented in [4], [7] and [8]. The method provides high-resolution pictures and simplifies the process of 3D geometry model creation. But the aircraft application is very expensive especially if a 3D model is needed only for one building.

At present UAV are used for various purposes, both military and civilian ones such as monitoring, payload transportation, medical purposes and others. Their application field is widening daily.

UAVs are robotic transport systems with remote control, sensor sets and sensor control system. They have imbedded function to follow the route of a pre-assigned trajectory. UAVs can be equipped with additional devices. Two types of UAVs are available: with fixed wing and rotor-type ones. The main advantage of the latter is a special flying mode of hovering which is extremely useful for photo data collection. Fig. 4 shows a rotor-type drone to create 3D models of buildings.

3 Methodology

The process of 3D model creation for a building depicted in Fig. 3 begins with working process planning, equipment preparation and its tuning. Quadcopter is a transportation means for GoPro camera which is calibrated in advance to avoid self-calibration.

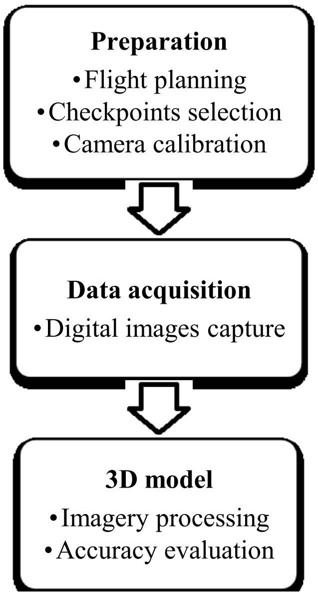

Figure 3. 3D model acquisition process

Then there is the photography stage. The photographs are taken with overlapping to simplify the later search of correspondence points in the pictures, to simplify pictures matching and to increase the quality of model's textures. The working process ends with photographs processing and 3D model creation.

3.1 Equipment

To ensure success of 3D model creation we use four-rotor UAV equipped with high-resolution camera as shown in Fig. 4. UAV simplifies the process of taking pictures because operator can set the trajectory of the vehicle individually. We use 3DR IRIS quadcopter on the basis of Paxhawk autopilot. The vehicle has the embedded function to store the route waypoints to follow them during the flight. To obtain high-resolution photos GoPro Hero 3 camera is used. The camera is of HD resolution with 1920x1080 pixels for HD-video at 60fps and 12MP CMOS-pictures (complementary metal-oxide-semiconductor). Another advantage of the camera is remote control of the shutter as well as preview mode for images. The camera weighs 77 g.

GoPro is a wide-angle camera with high yield of distortion. That is why it is necessary to calibrate it and to take pictures very close to each other with the overlapping as wide as possible. This will diminish the effect of short focus and wide angle of GoPro [10]. The aim of camera coefficients determination when calibrating is to state the exact size of pixel, the optical axel deviation of the lens, the length of focus and lens distortion. The results of calibration process are show in Table 2. But even with all these calibrating efforts the quality is not as high as that of a digital camera. Additional tuning can help reduce errors when radial distortion coefficient is added.

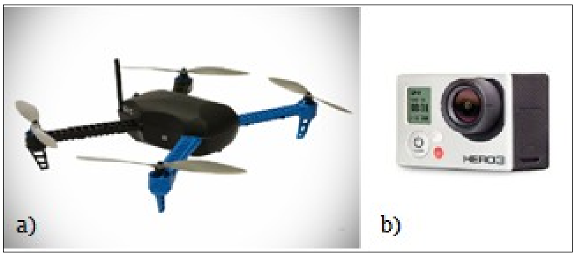

Figure 4. Image acquisition equipment:
a) remote control quadcopter and b) GoPro 3 camera

Table 2 Camera calibration parameters

Changing parameters	Value
Focal LengthX	0.4571
Focal LengthY	0.4571
ImageX Center	0.5023
ImageY Center	0.5178
Radial Distort Param1	-0.2218
Radial Distort Param2	0.399e-1
Tangential Distort Param1	-0.6551e-3
Tangential Distort Param2	-0.71864e-4

3.2 Photo Data Collection Process

Before the flight it is necessary to set the trajectory of the UAV movement. At this stage a set of waypoints, direction and camera resolution is assigned to the UAV by a special software program (Figure 5). When control points are determined and saved in the autopilot system of the UAV, the vehicle takes pictures automatically. During the flight the operator can preview the taken pictures by means of Wi-Fi interface of the GoPro camera and control the shutter.

Majority of UAV flying parameters can be controlled in real time, such as its location, position, distance, altitude, speed, and battery charge level.

3.3 Photo Processing

When pictures have been taken, they are processed in several stages. High-resolution picture processing requires a lot of computation expenditures. Each stage of 3D model creation algorithm includes finding correspondence for pictures, precising them, creating the points cloud for object's surface, defining the surface mesh and then superimposing the textures.

Figure 5. Waypoints assignment with Mission Planner application

1. Preliminary map creation. Initial analysis of the pictures is carries out to identify correlation between pictures. Preliminary map is created either using GPS information or by AtiPE (Automate Tie Points Extraction) [1] procedure for extremely low-resolution pictures.

2. Features Determination. SIFT operator allows deriving features in the pictures. SIFT Algorithm includes four stages: scale-space extreme detection, keypoint localization, orientation assignment, keypoint descriptor creation.

3. Corresponding Features Determination for Pairs of Pictures. Corresponding feature are to be found at comparison of features description acquired at the previous stage. To search for correspondence, kd-tree procedure is used, the latter being based on Approximate Nearest Neighbours (ANN) and Fast Library for Approximate Nearest Neighbours (FLANN) libraries. The method provides a sufficient number of correspondences, though some outliers can be found among the results. To eliminate the outliers the epipolar constraints found in significant E matrix and in fundamental F matrix are used. RANSAC reliable algorithm finds derived E and F values to identify outliers.

4. Integration of Images. When all correspondences between pictures are identified, the method allows integration of all images together. A sequence of images is divided into n-2 groups of three, and correspondences of each three images are determined. Then, image coordinates of the next group is compared with the previous one. The method bears linear computational cost depending on the number of pictures.

5. Image Coordinates refinement. Matched points image coordinates acquired with the help of SIFT descriptor are not accurately oriented. To increase the accuracy of image coordinates least squares matching (LSM) algorithm is used.

6. 3D Model Creation. Image coordinates for all matched points are the result of the method applied. They are later used to orient the image and to create sparse geometry of the object under consideration. Scene reconstruction is then performed using bundle adjustment method in correlation with the scene in the pictures and the object.

The acquired point clouds are converted into a structures network. The object model is then textured using the known camera and pictures parameters.

3.4 Test Site and Data

The new laboratory building of Electromechanical Department of Dortmund Technical University located at the Northern Campus at Dortmund, Germany, is chosen as the surveyed object.

The created 3D model of the building is of a simple form of rectangular parallelepiped as shown in Fig. 6. The building is a good practical example to study as the surface of its walls is flat and the façade is not complicated. The present article does not focus on roof texturing, only on building’s façade texturing.

Figure 6. The building under consideration for 3D reconstruction

Partial model of the building has been acquired by the time the present article is written. The reconstructed 3D model part comprises western and southern parts of the building.

Vertical images overlapping varies from 40% to 50%, horizontal overlapping is from 20% to 30%.

4 Results and Analysis

Pictures, having been taken by the quadcopter, are than processed applying the algorithm of 3D model reconstruction from 2D photographs, Figure 8.

Deviation values are measured by comparison of the known geometrical parameters of the building and the acquired photogrammetry results. Coordinates of 30 points onto an object were used and their 3D coordinates were computed only as intersections of homologous rays, after the bundle adjustment. Check points on the façade were assumed as check points. Their 3D coordinates were derived with a total station.

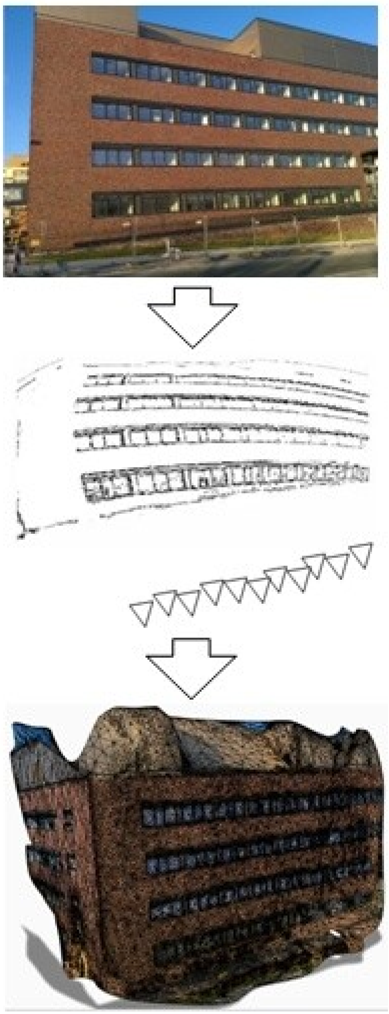

Figure 7. Surface reconstruction for the model

Surface reconstruction for the model takes up one hour; camera position adjustment takes 15 minutes, number of 1920x1080 pictures is 12 (Figure 7).

The results of accuracy calculation are presented in Table 3. Notably, the standard deviation of the model is less than 10 mm, and the depth accuracy deviation is 15 mm. The deviation along the X-axis and the Z-axis lies in the range between 2 mm and 58 mm and between 2 and 45 mm, respectively. The depth accuracy lies in the range up to 115 m.

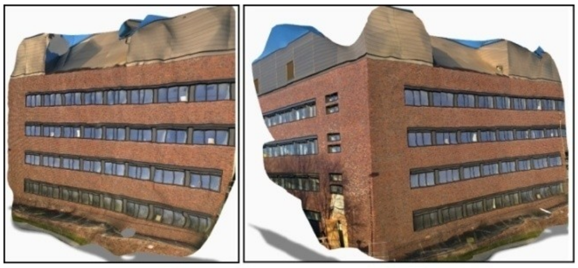

Figure 8. Surface reconstruction for the model

Table 3 Instrumental errors for 30 points of the model

Deviation	X	Depth	Z
Standard deviation, mm	8	15	7
Maximum deviation., mm	58	115	45
Minimum deviation, mm	2	3	2

Table 3 shows the model deviations. Judging by the derived accuracy values for the model it is necessary to note that depth accuracy of some image areas is quite low (up to 1 m.). The problem can be solved by taking more pictures of the required areas from different angles. In general, the model presents a realistic picture of the object's geometric properties and its major parameters with accuracy of up to 8 mm.

5 Conclusion and Future Work

The results of the survey prove that high-resolution aerial pictures can be acquired using quadcopter with a mounted digital camera. The technique simplifies the building facades texturing process. Deviations of the described models are the results of insufficient number of pictures taken. Unmanned aerial vehicle application for photogrammetry is far more cost-effective than usage of commercial aircraft.

Further work will be devoted to creation of full 3D models of buildings with roof texture. Buildings with complicated façade structures are also in the scope of the author's interest.

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