

AUTOMATIZATION THE 3D RECONSTRUCTION OF THE BUILDING MODEL USING 2D IMAGES

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ABSTRACT

This paper studies photogrammetric procedure performed by miniature unmanned rotorcraft, a quadrocopter. As a solution to build up 3D model for buildings facades, UAV can be a real asset as it can reach difficult corners of the building and take repeated captures. The high maneuverability of the quadrocopter permits us to take diagonal pictures containing information about the depth of the building, which is very critical factor while generating the 3D model. The aim of the paper is to have the best quality of 2D captured pictures in order to superpose them to generate 3D model of the building. Therefore, an essential part of the paper concentrates on the capturing angles techniques. The generated trajectory takes into consideration the deviation factor of the ultrasonic altitude sensor and GPS module. Tracking the desired coordinates allows us to automate the photogrammetric procedure and wisely use manpower to generate the 3D model.

Index Terms - Quadrocopter, modal control, photogrammetry.

1. INTRODUCTION

3D model is a tool used to simulate an object and to get more understanding about its nature. It also gives us better understanding in terms of visualization and perception. Nowadays this technology is used in different fields such as medical, civil and marketing with noticeable success.

In terms of civil application, 3D models can be used to train fire fighters, rescuers and SWAT teams in case needed. In a related matter the 3D application can be used to examine building facades and assists in providing periodic maintenance.

3D models are generated by superposing multiple 2D images. The quality of the 3D model directly depends on the captured images. Superposing techniques are several with different level of success. The other important factor is time. 3D models require lots of resources including manpower, repeated captures of the facade from the same angle to assure the best quality.

Terrestrial capturing has two major limitations: the operating ground condition and the limited working radius. The productivity of the operators is directly related to climatic condition, mobility and condition of the working area. The reach of the terrestrial capturing is a huge limitation, thus it cannot capture roofs and high-rise structures. Therefore, most of the companies producing 3D maps use aerial capturing as well.

It exists two categories of aerial scanning: manned and unmanned. Manned aerial missions

are more expensive due to fuel consumption and the type of airplane used to perform the tasks. Dimension wise these airplanes are big and are not optimized to capture the difficult corners of the buildings. Therefore, we suggest in this paper to use unmanned aerial vehicle to perform 2D image capturing, hereafter used to generate 3D models.

2. AUTOMATING PHOTOGRAMMETRY PROCESS

Automating image acquisition process is one of the most important improvement in photogrammetry; this can keep the operators more focused to process the images rather than taking them. Image capturing can be done using miniature and small sized unmanned aerial vehicles such as quadrotors. These aerial robots can reach difficult corners and can be equipped with several high definition cameras.

The operators will be involved only in assigning waypoints representing the capturing areas before the flight. This can be done using global path planning methods or with GPS assistance as shown in figure 1.



Figure 1. Assigning waypoints

In this paper, we suggest to use GPS generated trajectories using UBLOX-6H module. It has a general deviation from the real position within the meter. In terms of photogrammetry, this deviation does not have critical influence on the capturing process because all the pictures are taken with an overlap of at least 20%.

During the assigned trajectory, the autopilot is responsible for maintaining the stability of the quadcopter over the desired trajectory, leading the it as per the assigned waypoints and capturing images as per operator inputs.

2.1. Quadcopter position control

The quadcopter motion is described mathematically using 6 differential equations which allow this aerial robot to acquire 6 degrees of freedom. Physically, the quadrotor can only perform 4 flight regimes: roll, yaw, pitch and hover. The first three regimes are rotational movement. They permit the quadcopter to tilt three-dimensionally. The rotational acceleration is given using the following equation

$$J\dot{\omega} = -\omega \times J\omega + G \quad (1)$$

Where J - inertia matrix (3x3), ω - angular velocity, $G = (\tau_x, \tau_y, \tau_z)$ T is the rotating torque applied to the frame quadcopter (roll, pitch and yaw).

The quadcopter is nonlinear object where the position loops are interconnected to achieve linear movement. The forces and moments produced by the 4 rotors are illustrated in figure 2.

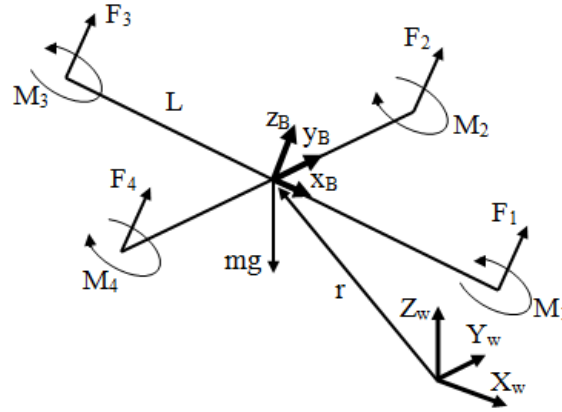


Figure 2. Quadcopter forces and moments

Linear motion of the quadcopter is described using the following equation

$$m\ddot{r} = \begin{bmatrix} 0 \\ 0 \\ -mg \end{bmatrix} + R \begin{bmatrix} 0 \\ 0 \\ \sum F_i \end{bmatrix}, \quad (2)$$

Where m is the mass of the quadcopter, \ddot{r} - acceleration of the quadcopter, R - transformation matrix transformation between fixed and body axis and F_i - force generated by each rotor ($i = 1 \dots 4$).

Three-dimensional trajectory of the quadcopter P is defined by a set (N) of desired waypoints (x_i^*) and desired (v_i^*) along the path segment between points i and $i+1$, as shown in figure 3.

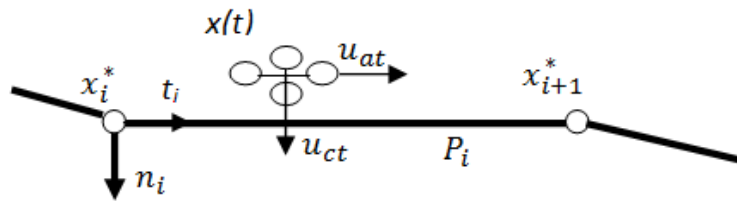


Figure 3. Quadrotor path planning

Assuming that t_i is a tangent vector along the trajectory between the two points (x_i^*) and (x_{i+1}^*) and n_i is a perpendicular vector to the movement of the quadcopter, the transverse error e_{ct} and its variation overtime \dot{e}_{ct} as well as the positioning error \dot{e}_{at} can be found using the following equations

$$e_{ct} = (x_i^* - x(t)) \cdot n_i \quad (3)$$

$$\dot{e}_{ct} = -v(t) \cdot n_i \quad (4)$$

$$\dot{e}_{at} = v_i^* - v(t) \cdot t_i \quad (5)$$

The aforementioned equations show that the rate of change of the error along the trajectory depends on the speed of the UAV. Therefore, it is required to control the velocity of the quadcopter to avoid positioning error.

2.2. Modular Controller design

Static stabilization system involves calculation of static coefficients k_p and k , connection of the negative feedback, as well as adding ideal integrator (block W) in the straight loop as shown in figure 4.

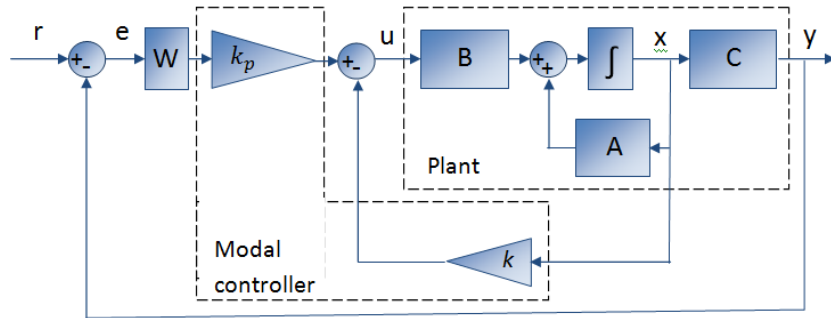


Figure 4. Structure of the modular controller

Using state space presentation, extended quadcopter dynamics can be described as follows

$$\begin{bmatrix} \dot{x}(t) \\ \dot{x}_I(t) \end{bmatrix} = \begin{bmatrix} A & 0 \\ -C & 0 \end{bmatrix} \begin{bmatrix} x(t) \\ x_I(t) \end{bmatrix} + \begin{bmatrix} B \\ 0 \end{bmatrix} u(t) + \begin{bmatrix} 0 \\ I \end{bmatrix} r(t), \quad (6)$$

Where $x(t)$ - vector function of the state of the control object, $x_I(t)$ - error stabilization vector, A, B, C - numeric matrices of the quadcopter model, $u(t)$ and $r(t)$ – control and reference respectively.

With new position requirement $\bar{x}(t) = [x(t) \quad x_I(t)]^T$ the quadratic position optimization can be described using the following equation

$$J = \int_0^{\infty} [\bar{x}^T(t) R_{zz} \bar{x}(t) + u^T(t) R_{uu} u(t)] dt \quad (7)$$

where R_{zz}, R_{uu} are strictly positive limitation functions.

The optimal control signal is calculated from the following equation

$$u(t) = -[K \quad K_I] \begin{bmatrix} x(t) \\ x_I(t) \end{bmatrix} = -\bar{K} \bar{x}(t), \quad (8)$$

The next step is to find the state space matrices A, B and C and modal controller coefficients k and k_p and substitute the values into the model. The results of rotational stabilization for roll (30 degrees), pitch (10 degrees) and yaw (5 degrees) angles is shown in figure 5.

The simulation results the control results, with process time equals to 1.5 seconds. This is achieved using an integrator in the straight control loop, which helps by improving the static state and minimize the error value in the steady state.

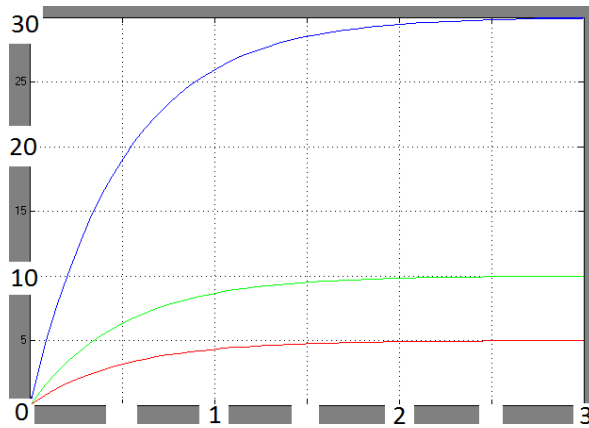


Figure 5. Angles stabilization over time.

2.3. Assigning numbers of captures

To obtain high-quality 3D model of a building, we must consider the following factors: when capturing facades pictures are taken in vertical projection, and for details of the facade oblique images are required as shown in figure 6.

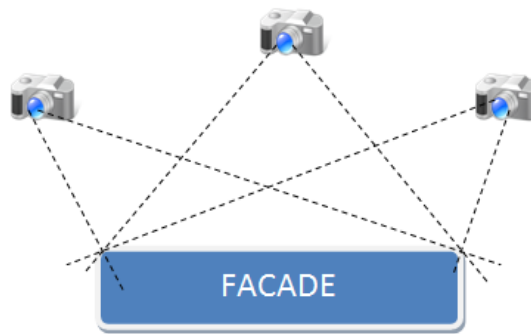


Figure 6. Capturing angles required in Photogrammetry

Example of inclined and vertical captures is shown in Fig. 7. With vertical acquisition not all the details of the facade are viewed (red dots in the figure), and many remain hidden. Vertical pictures will not allow the operator to extract the "depth" parameter, which can be done using oblique images (green dots in the figure).

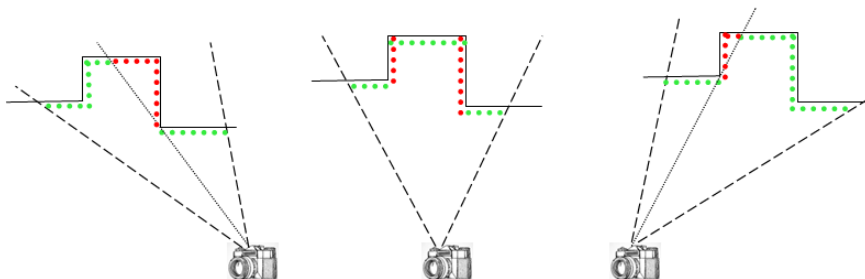


Figure 7. Limitation of vertical image acquisition

To automate the capturing process, the autopilot has automatically to lead the quadcopter to the desired coordinates the coordinates, which depend on the geometry of the building and the area of the captured plan. In addition to that, when capturing the lower floors, the autopilot is

responsible to avoid collisions.

Determination of the capturing area can be described using the following system of equations

$$\begin{aligned} f &= v \cdot \frac{S}{V} \\ f &= h \cdot \frac{S}{H} \end{aligned} \quad (9)$$

where f - is the focal length, v - vertical size of the matrix, S - the distance to the object, V is the vertical size of the object, h - horizontal size of the matrix, H - horizontal size of the object. With the equations (9) it is possible to determine the width and height of the captured object.

In addition to the area calculation, one of the main problems to be solved, is positioning the quadcopter in front of the building so that the optical axis is orthogonal to the plane of the facade. The difficulty occurs because the walls of the building may not necessarily be perfectly vertical and continuous to the earth as shown in figure 8.

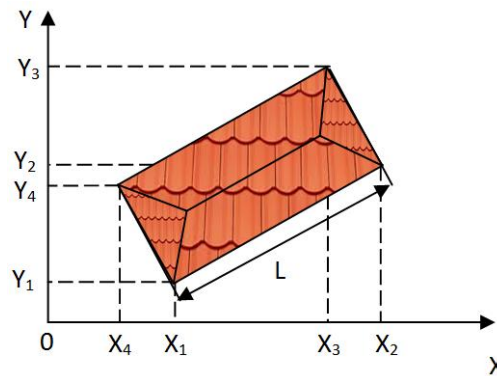


Figure 8. Top view of the building

In this situation it is necessary to make adjustments to the angle of yaw (rotation around body-axis Z in Fig. 3) hence to get the value of the angle between the segment λ (X_1Y_1, X_2Y_2) and its projection on OX - (X_1, X_2). The distance L is defined by the following equation:

$$L = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2} \quad (10)$$

Hereafter, the angle λ can be found easily using the following equation

$$\lambda = \frac{X_1 X_2}{L} \quad (11)$$

2.4. Automatic pictures

Capturing the facade should include longitudinal and transversal overlaps. We assume that the coordinates of building are $X_1, X_2, Z_{min}, Z_{lim}, Z_{max}$. Knowing the camera parameters $f, h,$ and v , we can determine the width and height of the goal object. Thus, it is possible to know what area is covered by a single shot depending on the distance between the camera and the wall as shown in figure 9.

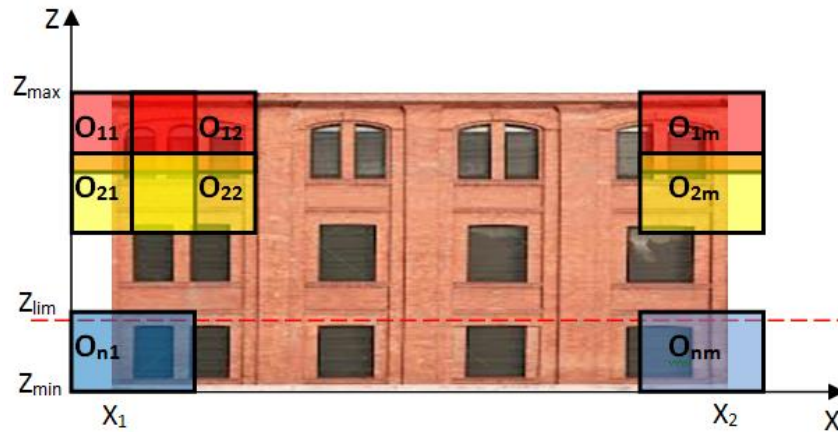


Figure 9. Capturing coordinates

Now we need to get the coordinates of waypoints, which should be maintained by the quadcopter while capturing. Taking into consideration the inaccuracy of the GPS U_{GPS} and the ultrasonic altitude sensor U_{bar} , pictures are taken at the points with coordinates (X, Y, Z) , where:

$$\begin{aligned} X &= X_1 + \cos\lambda \cdot (0,5 \cdot m \cdot H - U_{GPS}) \\ Y &= Y_1 + \sin\lambda \cdot (0,5 \cdot m \cdot H - U_{GPS}) \\ Z &= Z_{max} - (0,5 \cdot n \cdot V + U_{bar}) \end{aligned} \quad (12)$$

Horizontal captures are taken with respect to a cycle from 1 to M , with $M = \text{ceil}[(X_2 - X_1 + 2U_{GPS})/H]$ and the vertical captures from 1 to N , where $N = \text{ceil}[(Z_{max} - Z_{min} + U_{bar})/V]$. Ceil is rounding operator to the nearest whole number in ascending order.

At each waypoint, facade is captured vertically and tilted at an angle of -30° counterclockwise and 45° clockwise from the body axis Z . To determine the required step of motion along the axis OZ need at each cycle from 1 to N the value of Z should be checked. If $Z_V < Z_{lim}$, then the quadcopter is not allow not move down the altitude axis.

As result, we obtain a roadmap for automating the photogrammetry process. The algorithm consists of the following steps:

1. Obtain the coordinates of the building.
2. Calculate the number of images N and M , which must be done. Calculate the initial coordinates of the UAV, the values of S and λ .
3. Calculating new position coordinates of the quadcopter.
4. Acquiring vertical picture and two pictures with oblique angles -30° and 45° .
5. Upon reaching the end position, the quadcopter rotates -45° toward the corner and making a snapshot of a vertical and two oblique angles of -10° and 20° .
6. When crossing trajectories along the walls i and $i+1$, the quadcopter rotates by -45° and moves along the wall $i+1$.
7. Landing phase.

3. CONCLUSION

This paper presents a solution to create 3D building model using quadcopter. Major problems, faced in automating the process of creating 3D models were reviewed. The risk

analysis showed that improvements can be made in terms of quadcopter stability and processing algorithm.

The quadcopter was lead to waypoints representing the desired capturing angles using modular controller optimized using quadratic optimization criteria. The controller was robust and allowed to perform different tilting position along roll, yaw and pitch axes. This granted us the opportunity to automate the capturing algorithm by reaching difficult angles and acquire diagonal pictures. This is extremely importance when generating the 3D model as the diagonal pictures contains the depth coordinates of the façade.

The automation cycle consists of several overlapping algorithms [1] that are discussed in details in the paper.

REFERENCES

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