HADMÉRNÖK

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Horváth Zoltán
horvath.zoltan@zmne.hu

RECONSTRUCTING OF A GIVEN PIXEL'S THREE- DIMENSIONAL COORDINATES GIVEN BY A PERSPECTIVE DIGITAL AERIAL PHOTOS BY APPLYING DIGITAL TERRAIN MODEL

Absztrakt/Abstract

A katonai döntéshozó számára a hagyományos légi fényképek az egyik legfontosabb információforrásként szolgálnak. A szerző bemutatja, hogy erre a feladatra a pilóta nélküli repülőgépek hogyan alkalmazhatóak.

For the military decision-maker, the traditional aerial photograph is one of the most important information. The author shows how the UAV can use to take this kind of operation.

***Kulcsszavak/Kewywords**: légi fénykép, UAV, felderítés ~ aerial photo, UAV, reconnaissance*

Introduction

The military use of the Unmanned Aerial Vehicle is rapidly growing. Let us overview the main reasons behind: the ground control personnel are not put into danger. While the UAV flies above a dangerous area, the control personnel - staying in a distance, safe area - maneuver it and analyze the collected data. It is difficult to reconnaissance and destroys an UAV, because of its relative small size. The UAV is capable providing reconnaissance data rapidly to the decision makers.

A special characteristic is the installed software and database systems both on board and at the ground control station, which have virtually no mass; however, they create new and complex possibilities.

For the decision-maker, the traditional aerial photograph is one of the most important information. The UAV's basic duty is taking aerial photos and transmitting them digitally to the control unit for further analysis. Due to aerial turbulence and necessary maneuvering it is almost impossible taking ortophotos. Furthermore, that would require heavier instruments on board that the UAV can carry. The analysis of ortophotos is a time consuming task. However, the decision-maker at the control station has to have useful aerial photos as soon as possible. Making optimal decision, there are two critical parameters: the first is time and the other is the quality of analysis of the aerial photos.

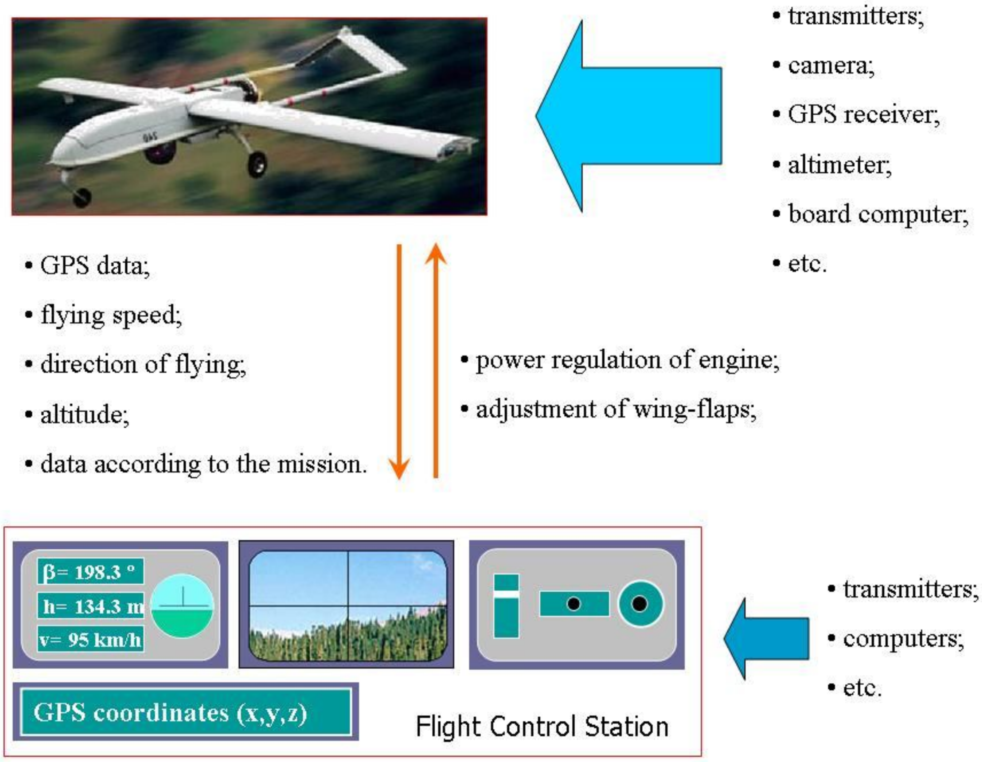


Figure 1. UAV route model

The UAV can carry only a limited weight. That influences the UAV's capability, since it has to carry all equipment, instruments and systems.

The aerial photos taken by the UAV can be easily transmitted to the ground control station by using simple equipment, such as a board computer, a digital camera and a GPS receiver. Now the question is the following: Is it possible to find the appropriate coordinates quickly and easily at the control station? If yes, what equipment, software or calculating method is necessary to get them? Namely, how it is possible finding any coordinates by using the pictures taken with different ankle by the UAV's digital camera and the coordinates provided by the GPS receiver on board.

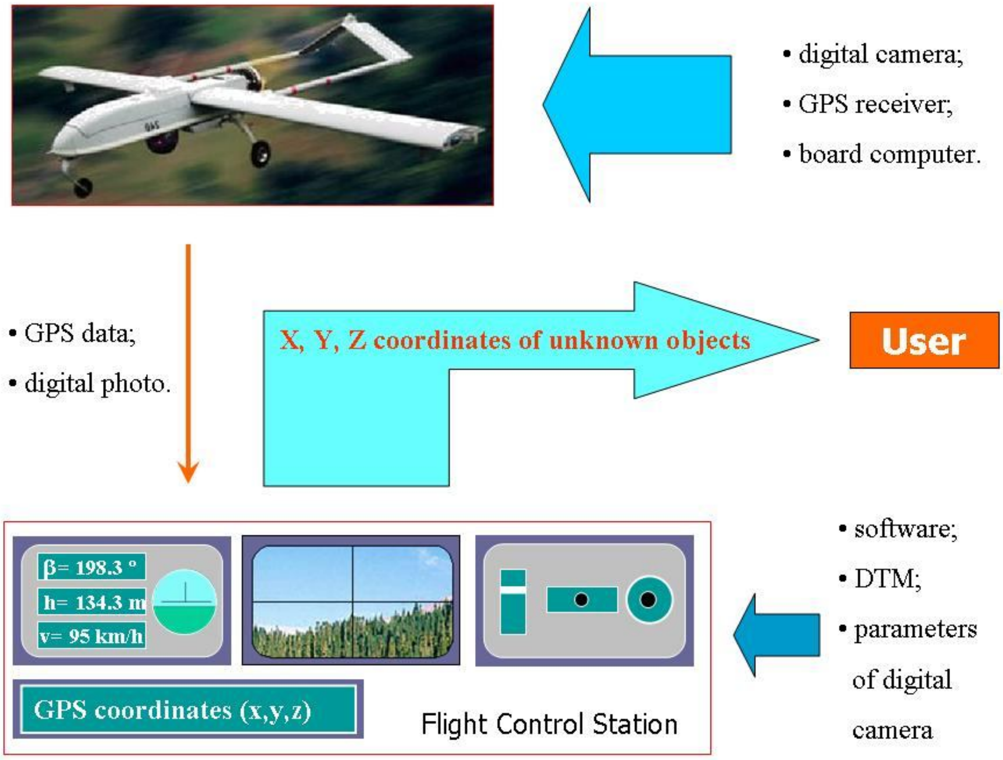


Figure 2. Determination of coordinates of a given point

The digital camera and the digital photo

The digital photo is a two-dimensional copy (plane) of the three-dimensional reality (space). What is the connection between the photo and the three-dimensional world? To be able to answer this question, first we have to understand how the camera works. The camera captures the reality (which is three-dimensional) into a plane (which is two-dimensional) with central projection. It means that the axle of the objective is passing through the center of the photo and this axle is perpendicular to the plane of the photo. The projecting lines passing through the objective make the two-dimensional photo. By definition, an ortophoto is made, when the axle of the objective is perpendicular both to the plane of the photo and to the plane of the target area. In this case the parallel lines on the target area appear parallel on the photo too. Using affin transformation we can easily analyze this photo. Otherwise the photo is considered to be perspective.

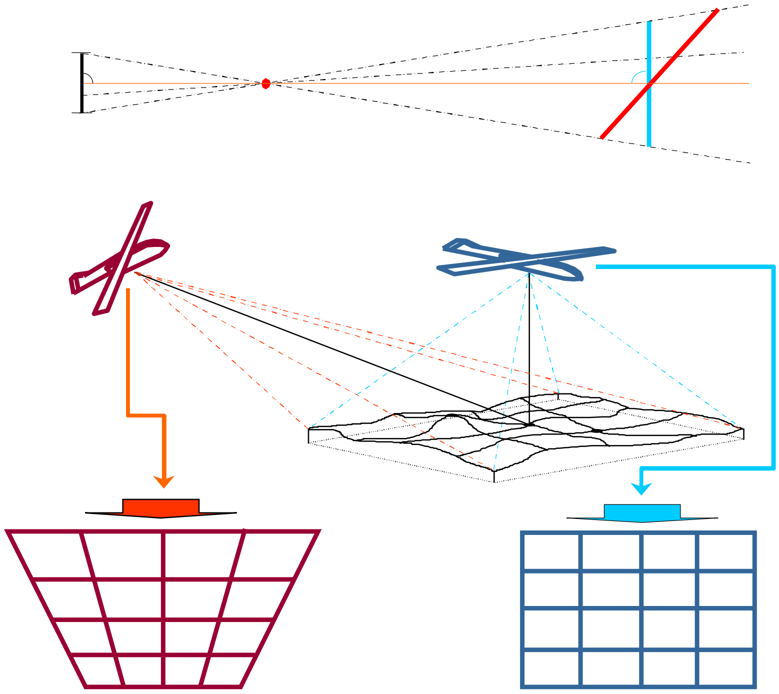
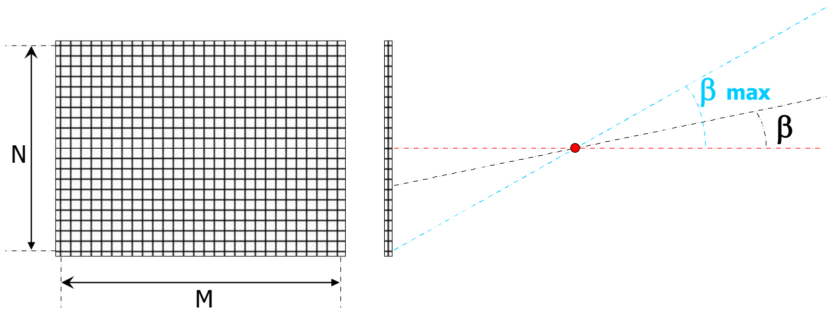


Figure 3. Perspective photo and ortophoto

The digital photo is segmented by columns and rows. Every pixel has got the same size. The objective and the size of the plane of the photo is given. The maximum vertical and horizontal angle of the camera can be measured by an ortophoto. Knowing the maximum horizontal and vertical angle of the camera, it is not difficult to calculate the horizontal and vertical angle of any projecting line that creates the pixel.



$$\beta = f\left(n_{pixel};\beta_{\max}\right);\quad \beta_{\max}\ countable$$
$$\vartheta = f\left(m_{pixel};\vartheta_{\max}\right);\quad \vartheta_{\max}\ countable$$

Figure 4. Connection between the deconvolution and the direction of the projecting line

Reconstructing the three-dimensional space from the two-dimensional picture

We are not able to identify exactly the three-dimensional space based on the direction of any objects on a photo. However, it is not enough to calculate the direction of the projecting lines; the three-dimensional space is determinable only if these three points are not in a line.

Therefore, it is necessary to identify at least three points having known coordinates from the photo. Additionally, the distances between the camera and these points (in pair) have to be known.

The result is a pyramid with the camera on it's peak, the edges of this pyramid correspond to the distances between the camera and these points.

This settlement can be placed in a rectangular coordinate-system. Placing the camera into the center and the axle of the objective is equal with the 'u'-axle, the coordinates of these points can be calculated.

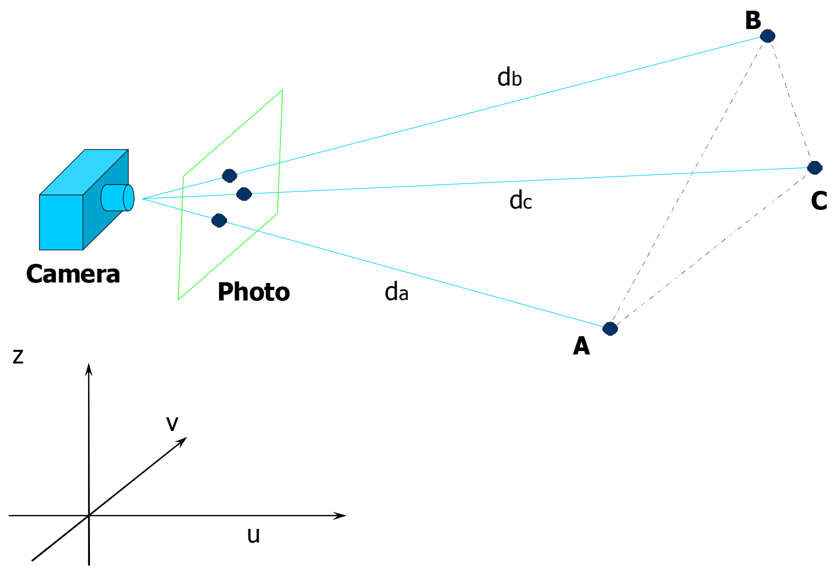


Figure 5. Known base points in the coordinate-system of the camera

Reconstructing the three-dimensional space from three known base points

The location of the camera and the three base points are known.

The GPS on the board of the UAV provides accurate information on the location of the camera in every few seconds. The coordinates of the three base points are known from map or database. There are several coordinate-systems in use locating an object. It is necessary to use a common rectangular coordinate-system, for example EOV or Geocenter coordinate-system. Many GPS receivers are able to transmit coordinates both in EOV or Geocenter coordinate-systems.

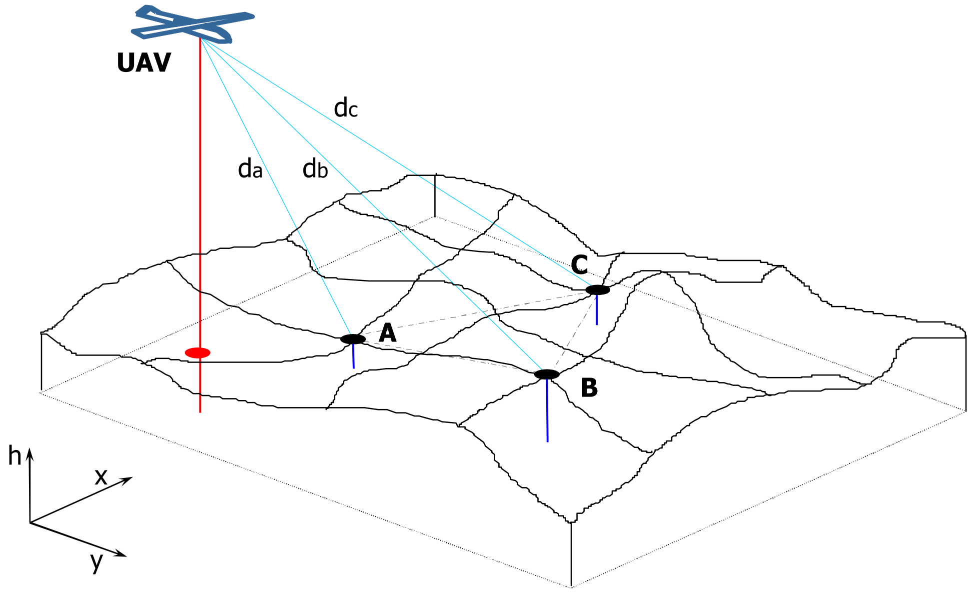
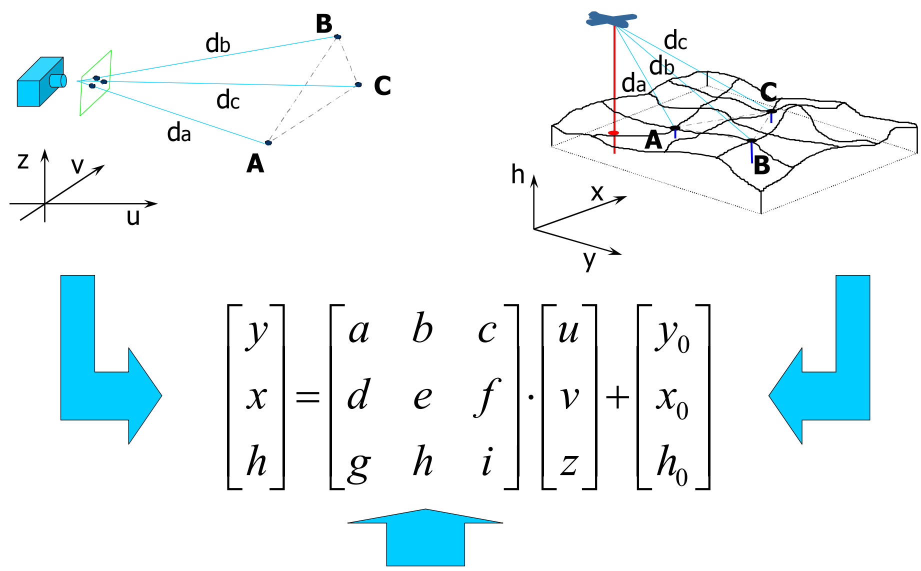


Figure 6. Coordinates of the UAV and the known base points of the terrain

By using the rectangular coordinate-system it is easy to calculate the distance between the camera and an object. This data is an essential. In a special case, where both the coordinate-system of the camera and of the terrain are rectangular, one could be transformed into the other by using affin transformation.



$$\begin{bmatrix} y \\ x \\ h \end{bmatrix} = \begin{bmatrix} a & b & c \\ d & e & f \\ g & h & i \end{bmatrix} \cdot \begin{bmatrix} u \\ v \\ z \end{bmatrix} + \begin{bmatrix} y_0 \\ x_0 \\ h_0 \end{bmatrix}$$

The elements of the affin-transformation matrix are countable

Figure 7. Matrix describing the connection between the two system of coordinates

Identifying the coordinates of a given pixel

Identifying the EOV coordinates of a given point, where the height is unknown is not difficult. In order to solve this issue, the target area's Digital Terrain Model is needed. It is possible to identify the direction of the projecting line that belongs to a certain pixel. This direction can be transformed from the coordinate-system of the camera into the coordinate-system of the terrain by affin transformation, because this is a vector. In this case there is a vector directing from the UAV's camera to the target point. The vector and the location of the UAV together determine a line. The point where this line goes through the fundamental level of the terrain and the coordinates of the UAV creates a section.

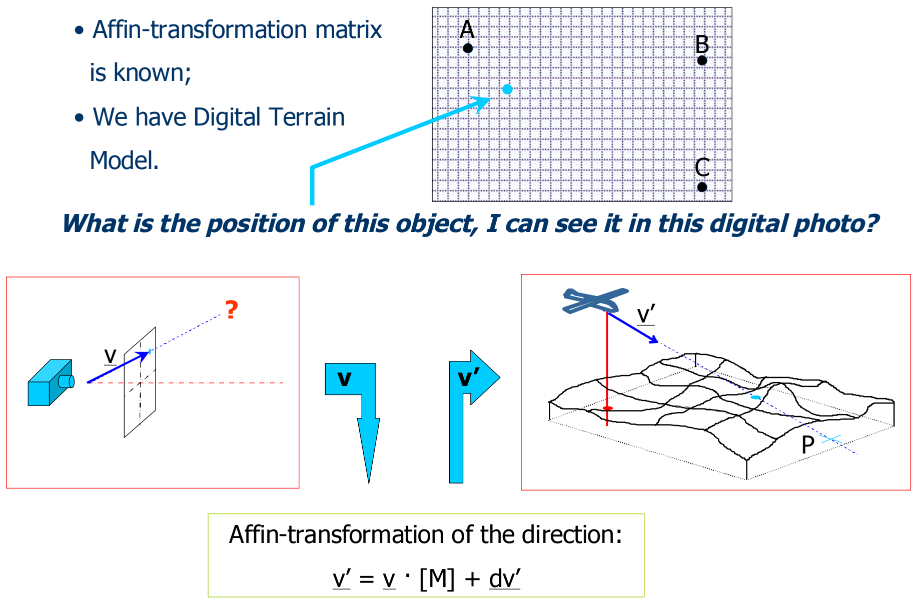


Figure 8. Calculating of the stab point on the fundamental level

Along this section it is possible to make a vertical segment of the terrain, whereas the coordinates of the crossing point of the transformed projecting line and the vertical segment of terrain was the question – the viewer sees this point on the picture.

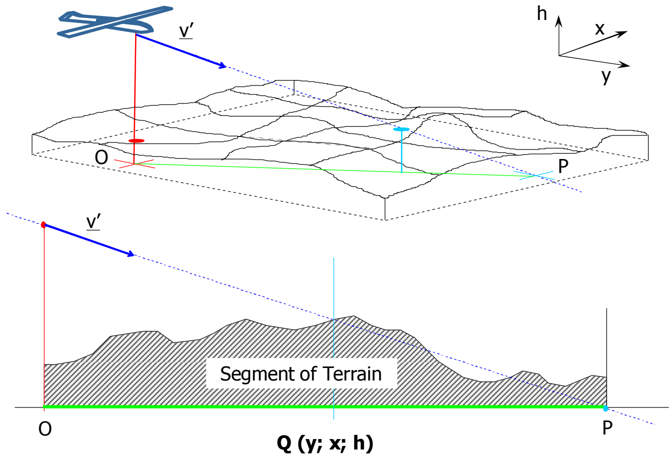


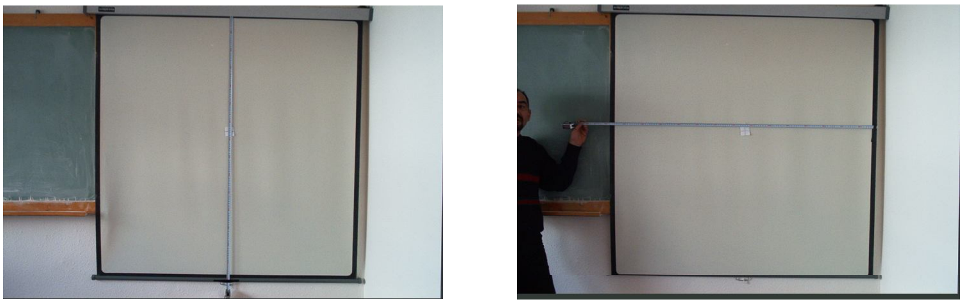
Figure 9.
Determination of the coordinates of a
given point by applying the segment of terrain

Summarizing the theory

According to the theory it is possible to quickly analyze aerial photos made in various ankles. In such a case the location of UAV has to be known. The photo could be taken either by a video camera used to flight-control or by a special rotating digital camera. The necessary equipment to be built to the UAV consist a board-computer, a camera and a GPS receiver. The ground control station have to have the Digital Terrain Model of the area.

Modeling

Since the problem could be solved in theory, we made a laboratory experience. First, we made ortophotos from the distance of 248 cm. The resolution was 1792 pixels vertically and 1200 pixels horizontally. We determined the optic angle with the use of a measuring tape and applying some mathematics.



Verical: 1792 pixels Horizontal: 1200 pixels

Distance: 284 cm

Size of object:150 cm

$$\alpha_{\max} = ArcTg\left(s \cdot \frac{pixel_{\max}}{2 \cdot pixel_s} \div d \right)$$

Figure 10. Determination of the camera’s vertical and horizontal angle

We took some photos from various positions about a prepared 1.5*1.5 square meter area with a digital camera.

Figure 11. Photos of different positions

The distance was less than 4m between the camera and the objects. The objects of this area were signed. This sign is fit to a virtual plain. A Digital Terrain Model have been created by this virtual plain.

A rectangular coordinate-system of the target area was created.

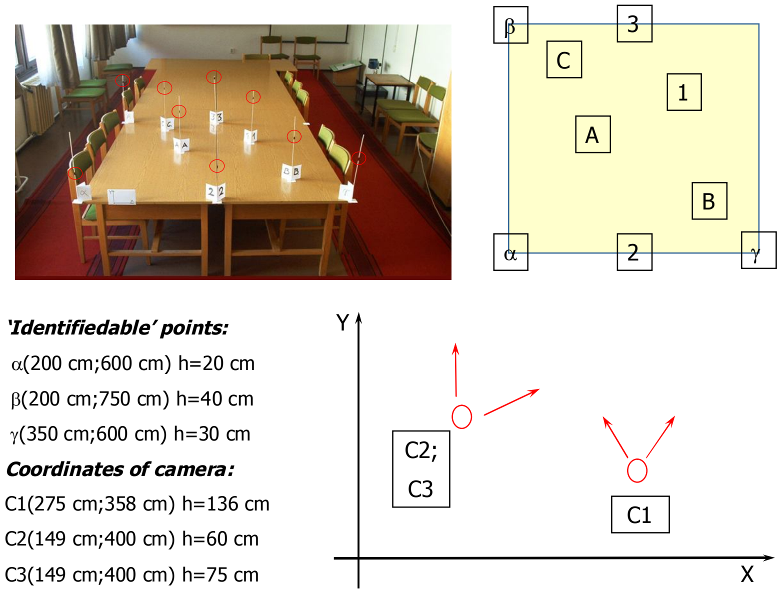


Figure 12. The prepared area with the positions of camera

Within this system, we measured the location of the objects and the digital camera at every photo.

We established the conditions of this experience:

- measured the parameters of the camera;
- made a coordinate-system;
- took photos;
- signed identifiable points.

Then, we wrote a simple software that is able to calculate the coordinates of the signed points on the picture.

After analyzing the coordinates, we were confirmed that the theory works in practice.

Analysis of the modeling

The analyses showed a 1-2mm to 4cm difference between the calculated results and the real position. Applying these data to real-size situation, at 4 km distance this means a 40m error. The distance of the target is greater, the error is bigger. In other words, the error increases if the viewing ankle is decreasing.

In percentage, this error is smaller than 1% of the distance of the object. However, it seems to be big. What can cause this big error?

Since the camera was too close to the target area, it did not behave like a point, rather a “big” construction. Therefore, the size of the camera comparing to the size of the target area could not be neglected in this case. A few millimeter errors in the location of the camera could cause a few centimeter errors after performing affine transformation. To decrease this kind of error the photos have to be made from greater height about a much bigger target area. To get sharp pictures, the camera should be placed further than 10m from the target area – this solves the focusing issue.

Summary

It is possible to make a quick analysis of aerial photographs made by an UAV with simple equipment built on the UAV and with simple software and the Digital Terrain Model of the area at the ground control station. Furthermore, within only a few seconds, this system is capable to provide with the coordinates of rapid changes on the surface, such as impact of a bomb, appearance of an unknown vehicle.