Construction of digital terrain models for testing active-pulse television measuring systems

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Abstract. The paper considers algorithm for creating a dense cloud of points and an orthomosaic plan of the terrain based on images obtained from a television camera of an unmanned aircraft. Geographic referencing of models is carried out using control points, the exact coordinates of which are determined by the instrumental method in the required coordinate system. The analysis of the number of identification marks involved influence in photogrammetric processing on the final model accuracy is carried out. The possibility of using the obtained models for testing active-pulse television measuring systems is considered.

1. Introduction
Currently, georeferenced digital models and orthophotomaps of the terrain built from aerial photographs from unmanned aerial vehicles (UAVs) have high spatial resolution, as well as high accuracy of geospatial data [1]. These data are used in many areas of human activity: construction, monitoring, agriculture, design, land management, cadastral work, etc. This has become possible due to the rapid development of ultralight UAVs and the devices that are used on them as payloads. Depending on the tasks, various types of UAVs are used: aircraft or helicopter types. To create a georeferenced orthophotomap of the area, a television camera is used as a payload installed on the UAV. GPS receivers or geodetic single/dual-frequency GNSS modules are used as a navigation system [2].

Geodetic GNSS receivers on board UAVs have a number of advantages over traditional GPS receivers. They make it possible to obtain the exact coordinates of the photographing centers in the post-processing of satellite measurements [3].

Thus, the geographic referencing of the terrain orthomosaic can be carried out without the use of identification marks. This algorithm saves a significant amount of time during field and office work.

The disadvantage of this algorithm is that it requires a stable signal from the constellation of satellites. Otherwise, if the phase of the carrier signal from the satellites is lost, it will become impossible to post-process the results of satellite observations. The accuracy of the photography centers will be about 5 m, which casts doubt on the possibility of using such photographic materials in practice. In this case, in order to build an orthomosaic of the terrain with the required accuracy, it will be necessary to re-conduct aerial work in the places where the failure occurred. This leads to a lot of waste of time and money. Usually, this happens on a terrain where there is a source of strong electromagnetic interference and the UAV is flying at an altitude of up to 150 m.
2. An algorithm is used in this work
As a UAV, the DJI Phantom 4 Pro quadrocopter with a standard GPS receiver on board is used. This receiver provides low accuracy of coordinates measuring of photographing centers. In this regard, the work uses an algorithm by which the geographical mapping of models is carried out by identification marks on the ground. Figure 1 below shows a diagram of obtaining the initial data of aerial photography.

![Diagram of obtaining initial data of aerial photography](image)

Figure 1. The diagram for obtaining the initial data

Aerial work was carried out over The Radio Engineering Building territory of The Tomsk State University of Control Systems and Radio Electronics. Geographical coordinates: 56°27′07″ N, 84°57′40″ E. The total area of the territory was 9 hectares. Several markings were laid on the ground, the coordinates of which were accurately determined by the Trimble R8 GNSS geodetic receiver in RTK mode. The average distance between the identification marks was 50 m [4]. The total number of identification marks is 13 pcs (Figure 2).
To perform aerial work, a flight task with a total length of 3.8 km was formed (Figure 3).

The main flight parameters are shown in Table 1.

| Parameter                      | Value          |
|--------------------------------|----------------|
| Camera orientation            | perpendicular |
| UAV flight altitude           | 60 m           |
| Longitudinal image overlap    | 80 %           |
| Cross image overlap           | 60 %           |
| Flight speed                  | 6 m/s          |

In the process of performing flight missions, a video sequence of 184 aerial photographs was generated.
Further image processing was carried out in the program for photogrammetric image processing Agisoft Metashape. The main stages of image processing are shown in Figure 4.

![Figure 4. The main stages of photogrammetric processing](image)

The GPS equipment of the UAV records the coordinates of the image centers in the WGS 84 system, and the coordinates of the identification marks were obtained in the local coordinate system MSK70 zone 4. Therefore, first of all, after the video sequence was imported into the software, the coordinates of the image centers were also transferred to the MSK70 system (zone 4).

The next step was to align the photos. The software determines the position of the cameras and builds a thin "point cloud" (Figure 5).

![Figure 5. Thin cloud of points](image)

Next, the markers are placed on the identification marks on each image. This operation is carried out for accurate georeferencing of the future model. After that, the images are georeferenced using these markers. In the work, some of the identification marks were used as reference ones, which were directly involved in the binding of the model, the other part served to check the accuracy of geospatial data. Table 2 shows the data that reflect the dependence of the standard deviation (SD) of distance measurements at control points on the number of used identification marks as reference points during photogrammetric processing.

| Quantity of control points | SD on control points, X (cm) | SD on control points, Y (cm) | SD on control points, Z (cm) |
|----------------------------|-------------------------------|-------------------------------|-------------------------------|
| 11                         | 1.27                          | 0.71                          | 4.8                           |
| 9                          | 1.05                          | 0.61                          | 4.1                           |
| 7                          | 1.02                          | 0.9                           | 4.3                           |
| 5                          | 1.92                          | 1.4                           | 7.1                           |
Table 2 shows that for territories with a small area, it is sufficient to use 3 identification marks as reference. Their more frequent use does not significantly improve the accuracy of geospatial data. On the contrary, having reduced the number of control points to two or less, the measurement result sharply deteriorates, which casts doubt on the application of such models in practice. Further photogrammetric processing was carried out using three identification marks as reference.

The next step is a dense point cloud. Dense point cloud represents points with known coordinates \( X, Y, Z \) in the object coordinate system and brightness taken from the original image.

A fragment of the modelled dense point cloud is shown in Figure 6.

![Figure 6. Dense cloud of points](image)

Based on the data of the dense point cloud, the spatial coordinates of various objects \( X, Y, Z \) are determined in the object's coordinate system. Also, a dense point cloud is similar to a 3D terrain model.

The high accuracy of the geospatial data of the resulting model makes it possible to measure the distances between objects on the ground. This fact presupposes the use of the obtained model as a digital twin of the "testing ground" for testing active-pulse television measuring systems (AP TMS) [5-6]. At the same time, it is possible to select the location of the system both on the earth's surface and on a hill, for example, on the roof of the building or in the room window. This increases the variability of the conditions for conducting the experiment and comparing it with the digital model.

Figure 7 shows an example of the location of the AP TMS on the roof of the educational building and the proposed options for measuring distances to objects. The device is installed at a known point, the coordinates of which are determined by a digital terrain model. Distances are measured to geostationary objects (container corner, soccer goal, building corners). The same distances are determined from the digital terrain model, as shown in Figure 7. The results are then compared.
Figure 7. An example of the AP TMS location with options for measuring distances to objects

The final result of photogrammetric processing of aerial photographs is an orthomosaic of the area, which is built on the basis of the initial images, which allows creating the resulting high-resolution images (Figure 8).

Figure 8. Orthophotomap of the terrain ("polygon")

3. Conclusion
The use of a helicopter-type UAV DJI PHANTOM 4 PRO with a television camera allows you to build digital models and orthophotomaps of the terrain. The standard deviation of measuring distances using control points does not exceed 10 cm, when using three identification marks as reference marks. This fact indicates the high accuracy of the built model and makes it possible to test active-pulse television measuring systems in order to determine the accuracy of their operation.
The aerial photography results are applicable to the construction of plane objects topographic plans for various practical applications. The proposed algorithm is applicable for large areas. The disadvantage is that more complex terrain (mountains) will increase the error in elevations of the digital terrain model. The algorithm is applicable for planning and conducting research on the accuracy of measuring distances to objects using AP TMS. The paper indicates a possible example of AP TMS location for its testing.

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