Application of unmanned aerial vehicles for solving engineering tasks

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Abstract. The article discusses the use of unmanned aerial vehicles in solving engineering tasks. Information about the current state of the market of unmanned aerial vehicles and services with their use is provided. The most frequently used unmanned aerial vehicles and their characteristics are considered. Modern methods of obtaining and principles of processing images obtained from unmanned aerial vehicles and trends towards further development of the aerial photography process are described. The results are presented: modeling the influence of angular elements of external orientation on the accuracy of the obtained spatial coordinates of terrain points; studies of determining the volume of soil and creating a three-dimensional model of an engineering object (building) based on aerial photography obtained from an unmanned aerial vehicle multicopter. The accuracy of determining the volume of soil was controlled using a digital terrain model obtained using a total station. Control of the accuracy of building a three-dimensional model of an engineering object was performed by comparing the distances between the points of the object obtained from the three-dimensional model and the total station measurements. As follows from the results of the article, an unmanned aerial vehicle can be an effective tool for solving some engineering problems. The results obtained are comparable to the accuracy of classical methods, provided that the correct choice of the type of unmanned aerial vehicle and the correct approach to processing obtained images.

Key words: 3D-model, external orientation elements, inertial measurement unit, internal orientation elements, unmanned aerial vehicle.

1 Introduction

Research by Skylogic Research, LLC (USA) has established that almost 68% of UAVs – small drones – are purchased for professional purposes. At the same time, the share of UAVs used for monitoring and mapping (including GIS) is 5%; for architecture, construction and design – 6%, for real estate (cadastre) – 5% [1]. Consulting firm ABI Research (USA) notes that the annual growth in revenue from the sale of UAVs is 31%. Revenue growth is projected to reach 74% in 2027. At the same time, UAV platforms form only a part of the profits in the industry (UAVs). Most of the revenue is generated by application services, such as analytics and data processing [2].

Spatial coordinates are the basis for the production of various products: topographic maps and plans, digital terrain models (DTM), digital elevation models (DEM), 3D-models of objects, and so on with the required, guaranteed accuracy.

The use of UAVs to obtain spatial information about the surrounding area, objects and phenomena from the processing of digital images obtained from UAVs is an intensively developing technology that competes with ground and air scanning technologies (Lidar), geodesic technologies based on the
use of equipment that has become classic – electronic total stations, GNSS. Some of the possible applications of UAVs are given in articles [3-9].

The effectiveness of using UAVs for mapping is well considered in [10]. Practical experience in the use and research of UAVs for obtaining spatial data shows that the effectiveness of UAV use and obtaining the final material that meets the specified requirements will be determined by the type of problem to be solved, the size of the object under study and the type of UAV chosen to solve the problem, while meeting the basic requirements for aerial photography [11-13]. Data on the achieved accuracy of spatial data obtained from aerial photography from UAVs are considered in [14-16]. To control the accuracy of obtaining spatial coordinates, various methods are used, described in [17-19]. Many publications confirm the need for calibration of cameras, the results of which can significantly improve the accuracy of determining coordinates [20-22]. Recommendations for choosing the optimal camera parameters for aerial photography are given in article [23]. Modern software for processing aerial photography data is considered in [24].

For unmanned aerial vehicles of helicopter type design multicopter (UAV-multicopter) has its own range of tasks. The characteristics of the most commonly used types of UAV-multicopter are shown in table 1. In addition to mapping the UAV-multicopter allows solving engineering tasks effectively. The question of achieving possible accuracy when using UAVs to solve practical problems and the conditions that should accompany them is the main goal of research.

### Table 1. The most commonly used UAV-multicopter.

| UAV          | Action radius | Flight time | Max. flight height | Camera (focal length f, number of pixels of the matrix) | Navigation system |
|--------------|---------------|-------------|--------------------|-------------------------------------------------------|------------------|
| Geoscan 401  | up to 15 km   | 60 min      | 500 m              | Sony A5000 (f=20 mm, 24 Mpix)                          | GPS L1           |
| Trimble ZX5  | up to 2 km    | 20 min      | 3000 m             | Olympus (f=14 mm, 16 Mpix)                            | GPS L1+IMU       |
| DJI Phantom 4 Pro | up to 7 km | 30 min      | 6000 m             | DJI (f=24 mm, 20 Mpix)                                | GPS L1, L2       |
| ZALA 421-22 | up to 5 km    | 35 min      | 1000 m             | Sony A5000 (f=20 mm, 24 Mpix)                          | GPS L1           |

2 Materials and methods

2.1 Ensuring accuracy of processing results of aerial photography from unmanned aerial vehicles

For each image it is required: external orientation elements, that characterize the position of the UAV at the time of shooting – three coordinates and three angles; internal orientation elements – the parameters of the shooting camera (three elements). Internal orientation elements are determined by performing camera calibration either on a special stand, or by reference points, for example, when constructing and equalizing a phototriangulation.

Determining the elements of external orientation is performed using the following technological processes:

In the first case, elements of external orientation are determined by the UAV's onboard navigation system using the global satellite navigation system (GNSS), inertial navigation equipment (IMU), or GNSS+IMU, including differential GNSS +IMU (DG-technology) [25]. This technology has a drawback:

- determining the spatial coordinates of object points with high accuracy (millimeter and centimeter) in post-processing mode, and even more so in real time, is not possible due to the lack of accuracy of the standard on-board navigation systems of the UAV.
DG-technology allows in post-processing mode, under certain conditions, obtaining coordinates of points of objects with an accuracy of no more than 5 cm. Installing more accurate navigation systems will increase the cost of the UAV and possibly reduce the weight of the payload.

In the second case, reference points are fixed on the object, the coordinates of which are determined by geodetic measurements before or after aerial photography (AT – aerial triangulation). This technology has the following disadvantages:

- it is not possible to determine the spatial coordinates of multiple points of an object from real-time image processing;
- achieving high (millimeter and even centimeter) accuracy in post-processing mode requires significant time (from several hours to several days) and material costs.

In [25], it is noted that effective mapping from UAVs cannot be based on classical phototriangulation using ground reference (control) points.

The market trend is developing in the direction of reducing the time to get the final product (topographic plans, 3D models), increasing accuracy without performing additional work on the site. Manufacturers of UAVs for advertising purposes indicate the high performance achieved with the help of their solutions, both in the case of using only GNSS+IMU, and in the case of using reference points. For example, Trimble Navigation, Ltd. (USA) notes that the achieved positioning accuracy in postprocessing mode using the Trimble X100 (UAVS) is: in terms of up to 0.05 m, height 0.10 m, from a height of shooting of 150 m. The authors of research results presented in [25] lead to the fact that accuracy is achieved by using the UAV md4-1000 (only GNSS+IMU): in the 0.12 m and 0.39 m in height, at an altitude of 80 metres. These results are also obtained in post-processing mode.

Obviously, the main task is to get the spatial coordinates of points from their images from the UAV in real time or in close to real time (for example, at a time interval of no more than 30 minutes). One of the problems that must be solved along this way is the determination of external orientation elements: millimeter accuracy of the UAV position, accuracy of the angular position of 0.05°-0.1° and better, in real time or in close to real time (for example, in a time interval of 2-5 seconds).

The accuracy with which spatial coordinates of points of an object will be obtained based on a photogrammetric intersection is determined by a number of errors, and in particular by the accuracy with which angular elements of exterior orientations are known. Table 2 shows errors modeled on a single stereo pair.

| The accuracy of the angles, the second (degrees) | Spatial intersection error, mm |
|-----------------------------------------------|-------------------------------|
| roll/pitch 20” (0.006”)                       | 2                             |
|       40” (0.011”)                            | 4                             |
|       60” (0.017”)                            | 6                             |
|       96” (0.027”)                            | 10                            |
| yaw 27” (0.008”)                             | 20                            |
|       52” (0.014”)                            | 39                            |
|       80” (0.022”)                            | 61                            |
|       125” (0.035”)                           | 96                            |

Note: the tilt angles of images do not exceed 5°; errors of linear elements of external orientation, errors of image measurement, and errors of elements of internal orientation are assumed to be zero.

It should be noted that there are OEM solutions (GNSS+IMU) for UAVs, for example, APX-15 UAV and APX-20 UAV (weight 60 and 330 grams respectively), which allow determining the orientation angles in real time with accuracy: roll/pitch 0.03, yaw 0.18 [26]. However, under certain conditions, these characteristics may not be sufficient.
2.2. Determination of soil volumes based on images obtained from unmanned aerial vehicles. Creating topographic plans based on the results of aerial photography from UAVs

A fairly common engineering task based on the results of aerial photography from UAVs is to determine the volume of soil. Studies of the possibility of using UAVs to solve this problem were performed using a control area (polygon), for which a digital terrain model (DEM) was built – a control DEM. The control DEM was built based on the materials of total station survey – the basic method for performing such works (Trimble M3 DR 5” equipment). The coordinates of reference points for aerial photography processing were determined using GNSS in Stop and Go mode (Trimble R8 equipment). The discrepancy between the volume of aerial photography from the UAV and the volume obtained from the control DEM was 9.5%. It should be noted that these results were achieved with a significant number of reference points, the coordinates of which were determined with high accuracy: 0.02 m in plan and 0.03 m in height.

Another, even more common task is to create orthophotoplanes for building topographic plans of scale M 1:2000 and larger. This task is easy enough to solve, however, to achieve the required quality and quality control, it is necessary to have reference and control points, the coordinates of which must be known with an accuracy that exceeds the graphic accuracy of the created topographic materials. The use of a UAV-multicopter allows achieving accuracy in post-processing mode no worse than 0.08 m in plan and 0.13 mm in height, at a flight height of 150 m. (UAV Geoscan-401, Sony A5000, f=25 mm.) At the same time, the accuracy of the coordinates of the reference points should not be less than 0.03 m in plan and height. By comparison: UAV md4-1000, f=50 mm (only GNSS+IMU) accuracy in terms of 0.12 m, 0.39 m in height, at a flight altitude of 80 meters [25].

2.3. Application of unmanned aerial vehicles for shooting engineering structures and building 3D models of objects

The object of research for building a 3D model was a cultural heritage site – "Shamovskaya hospital", located in the city of Kazan, Republic of Tatarstan.

To create a 3D-model, a DJI Spreading Wings S1000 multicopter with a Zenmuse Z15-5D III gimbal was used, which allows setting the vertical position of the optical axis of the shooting camera. The camera used was a Canon EOS 5D Mark III (matrix size 24mm x 36mm, focal length 25 mm). Overlap was selected about 70-80%.

One of the characteristic photographs of the object is shown in (figure 1).

Figure 1. Shamovskaya hospital – "Characteristic photo of the object".
Processing overlapping images allowed you to build a point cloud for building facades (figure 2).

![Shamovskaya hospital – a cloud of points on the right (Eastern) facade.](image)

The accuracy of point cloud construction is estimated by comparing distances obtained from measurements made by the total station and measurements of the same distances on the point cloud (Pix4D). When analyzing the accuracy of the results, two statistical procedures were applied: the classical least squares method and the method of least modules. The results of the analysis made it possible to reliably determine the average square error – 2.6 mm.

3 Discussion
The results obtained in the course of research and practical work, allow us to draw conclusions about the possibility of using UAVs to solve problems of topography and some problems of applied geodesy. At the same time, the use of UAVs requires a careful approach and compliance with the basic rules and requirements laid down at the stage of analog photogrammetry. In fact, the UAV becomes a tool, a means of measurement similar to a total station, a laser scanner. The use of UAV technologies allows you to quickly obtain high-quality, objective materials and achieve positive results in difficult economic conditions.

It can be noted that the accuracy of building measurements using UAVs is comparable to the RMS error of a laser scanner, in particular, the FARO Focus 3D X 130 scanner. At the same time, it should be noted that the cost of the UAV complex is almost more than two times cheaper than a laser scanner.

4 Conclusions
The use of UAVs, including multicopter UAVs, for solving topographic and some engineering tasks requires a professional approach. Effective mapping and solution of applied (engineering) problems using UAVs cannot be based on classical phototriangulation using ground reference (control) points. To use UAVs effectively for engineering purposes, new solutions are required to determine the exact spatial and angular position of the UAV in real time.

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