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Analysis mobile fly area scanning systems

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Abstract. The rapid development of intelligent microprocessor technology, the availability of global navigation systems (GPS) and inertial imaging units (IMU) with the progress of the creation of a new generation of mobile autonomous systems from a distance This is the concept of autonomous robots and unmanned aerial vehicles. Recently, actively using unmanned aerial vehicles (UAVs) and mobile robots, they are solving the tasks of photogrammetric and laser scanning of the terrain quite quickly. High spatial resolution data collected from available platforms such as satellites and manned aircraft are typically in the range of 20–50 cm/pixel, while UAVs are capable of flying at much lower altitudes and can therefore collect images with a much higher resolution of the image.

Mobile robots and UAVs in combination with modern technologies of digital video and photo processing, as well as programs for intelligent image recognition, have gained actual use, both for military tasks and in the civil sphere as a tool for remote sensing of territories and infrastructure high-resolution objects. On the basis of scanned UAV images, 3D models of the terrain can be reproduced.

This article deals with the analysis of technical means of mobile scanning of territories and some well-known algorithms for controlling the scanning system.

Keywords: drone, quadcopter, unmanned aerial vehicle.

INTRODUCTION

One of the actively developing directions in construction is aerial photography for monitoring open areas and 3D scanning of objects, which can be carried out using unmanned aerial vehicles (UAVs) and mobile scanners [1, 2]. Aerial photography and monitoring of quarries is currently a perfect and accurate method of geodetic scanning of the terrain. This approach is economical, fast and, in comparison with manual laser scanning, has the least distortion of information, which affects the quality of work [3, 4].

With the help of geoscanning technologies, perfect point clouds of a digital terrain model are obtained, which are further processed in special engineering programs. This approach excludes the influence of the human factor during field work, and therefore increases the accuracy of scanning large areas and productivity. For example, it takes about six hours to scan an area of 5 square kilometers and process the received materials using an unmanned aerial vehicle, which is much faster than doing it by traditional manual methods [5 - 8].

In the construction industry, remote sensing using UAVs and mobile robots is relevant in such areas as assessment and monitoring of the environment, atmosphere [9, 10], assessment of the consequences of destruction of civil infrastructure facilities for its restoration [11, 12], 3D scanning of buildings and mapping of the landscape [13, 14], mapping of places and buildings of archaeological and cultural heritage [15 - 17].

PURPOSE OF THE WORK

Analyze the technologies, technical means, and door control algorithms used for mobile scanning of territories.

STATEMENT OF THE PROBLEM AND RESEARCH RESULTS

Quadrocopters or drones have become an integral part of modern geodetic and cartographic studies. Due to their maneuverability, small size and the ability to fly at different heights, quadcopters provide new opportunities in geoscanning and geodetic data collection, in particular, with the help of quadcopters, you can:

- high-precision mapping made possible by built-in GPS receivers and advanced positioning systems, quadcopters can collect geodetic data with high precision (see Fig. 1). This systems can fly at a given altitude and collect a large number of photos or videos, which are then processed to create accurate maps and terrain models [9];
- monitoring and assessment of the state of various types of infrastructure, such as roads, bridges, buildings, etc. (see Fig. 2). With the help of high-resolution cameras and thermal imaging cameras, quadcopters can detect defects, damage or problems that occur on infrastructure objects. This allows you to quickly identify problem areas and carry out necessary repairs [18];
- detailed mapping of different types of terrain, including mountainous areas, forests, fields, etc. Using photogrammetry and point cloud mapping, quadcopters can create three-dimensional terrain models with high detail (see Fig. 3). It provides valuable data on terrain, elevation, land cover, and other geographic features that can be used in various fields, including geology, agriculture, and ecology [19];
- research in places that are inaccessible or dangerous for humans. They can be used to explore volcanoes, glaciers, danger zones or hard-to-reach areas. Quadcopters provide the ability to collect data and visualize these locations with high precision.

Fig. 1. Example of programing geodetic mapping of territory by drone into PX4 autopilot

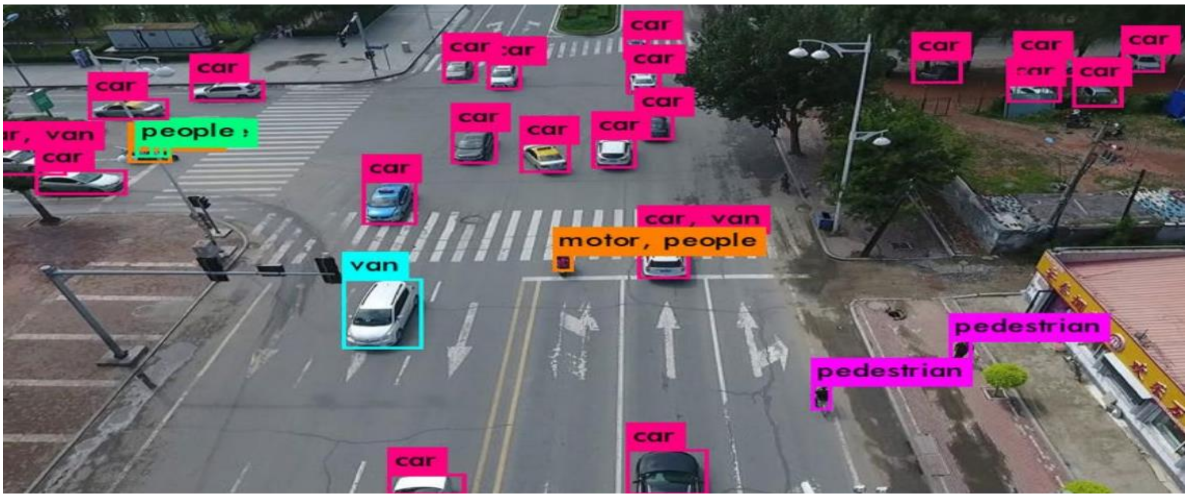
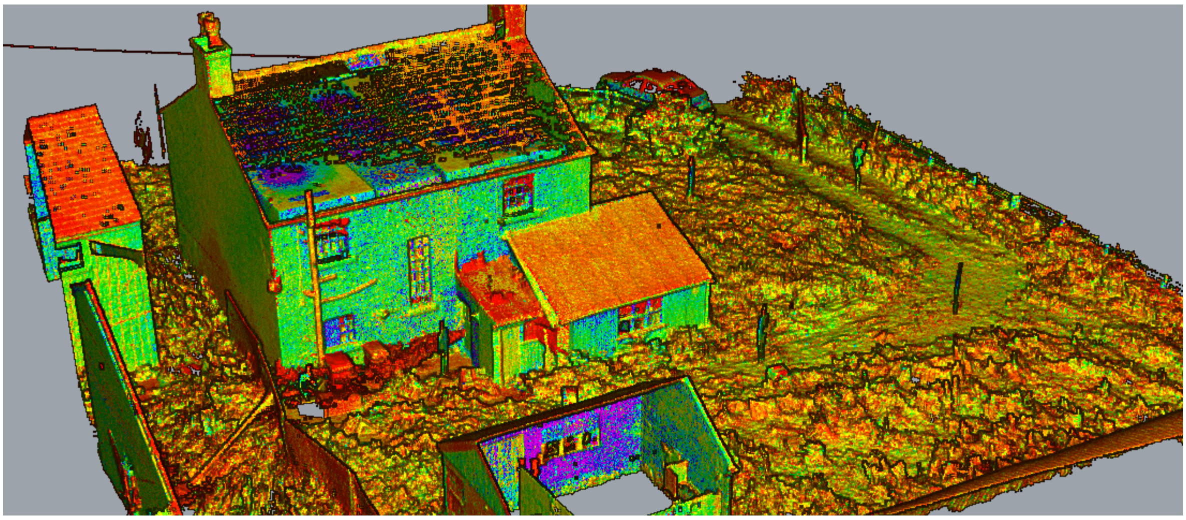
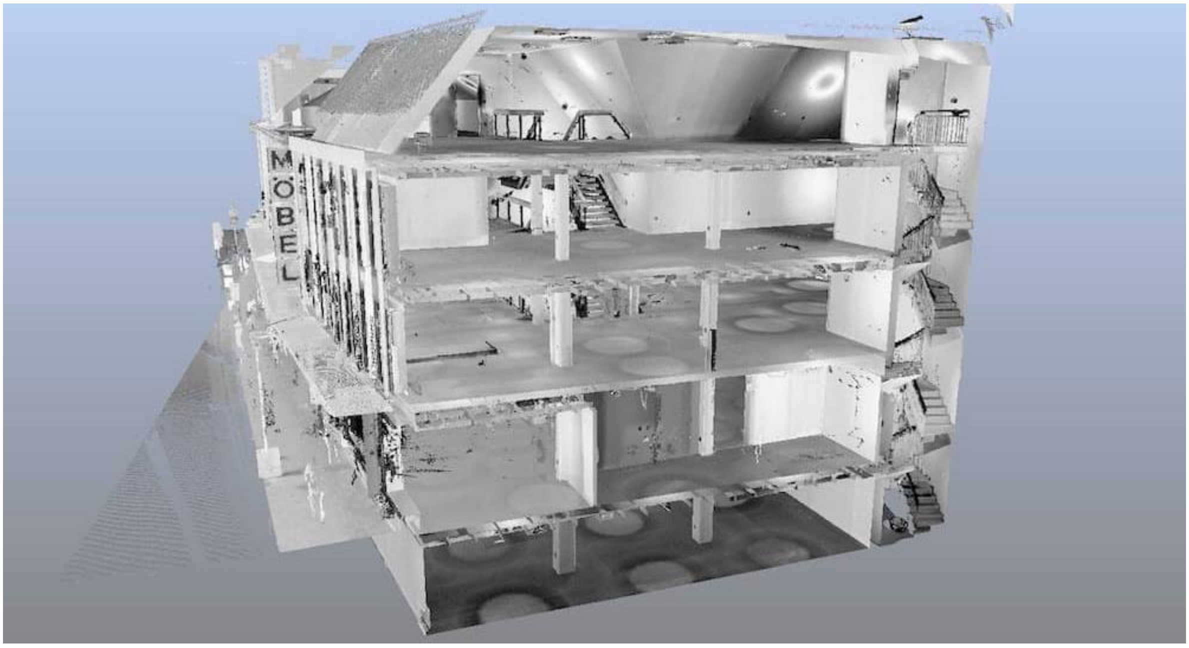


Fig. 2. Vision Meets Drones



a



b

Fig. 3. Laser (*a*) and photo (*b*) scanning for drones

FPV quadcopters are one of the most popular types of drones for photographing engineering objects and small areas. The basis of the design of such a drone includes a frame, usually made of carbon, brushless valve electric motors (BLDC), an engine control controller (ESC), a flight controller (Flight Controller), a video transmitter, an FPV camera and a transmitter (see Fig. 4.). In vertical take-off drones that have more than 4 engines, for example, in octocopters, instead of one central controller, an individual controller is installed for each engine (Fig. 5).

ESC is an electric motor speed controller that can switch two-phase or three-phase current with a high switching frequency, which can be changed depending on the frequency of the control signal.

Flight controllers are created on the basis of microcontrollers or microcomputers capable of generating PWM pulses (PWM) for ESC, depending on the received command or program. For example, in order to give a command to the speed controller to turn on the maximum speed of the engine, the controller forms pulses of 2 ms duration with a delay of 10-20 ms. In standard civilian ESCs, the pulse duration of 1 ms corresponds to the engine stop mode, 1,1 ms to 10% of the maximum speed, 1,2 ms to 20%.

In this work, the technical characteristics of a number of quadcopter models were analyzed and their efficiency of application was evaluated.

DJI Phantom 3 Professional 4k is the most advanced Phantom model of the third series, which is equipped with a 12-megapixel camera and a suspension (see Fig. 6). The DJI Phantom 3 platform implements a live video broadcast through the DJI App program to a smartphone or tablet, which is connected as a screen to the control system of this drone [21].

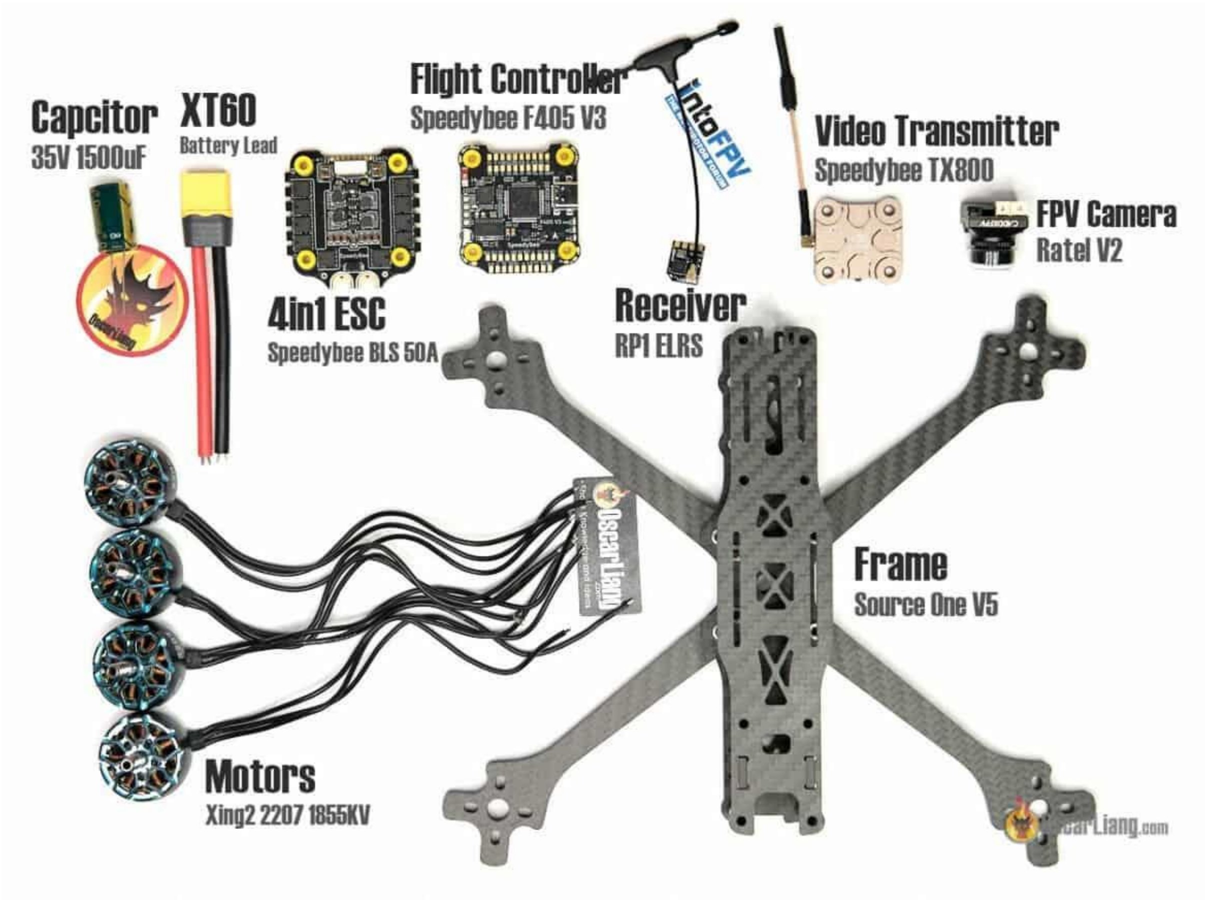


Fig. 4. The general structure of the FPV quadcopter [20]

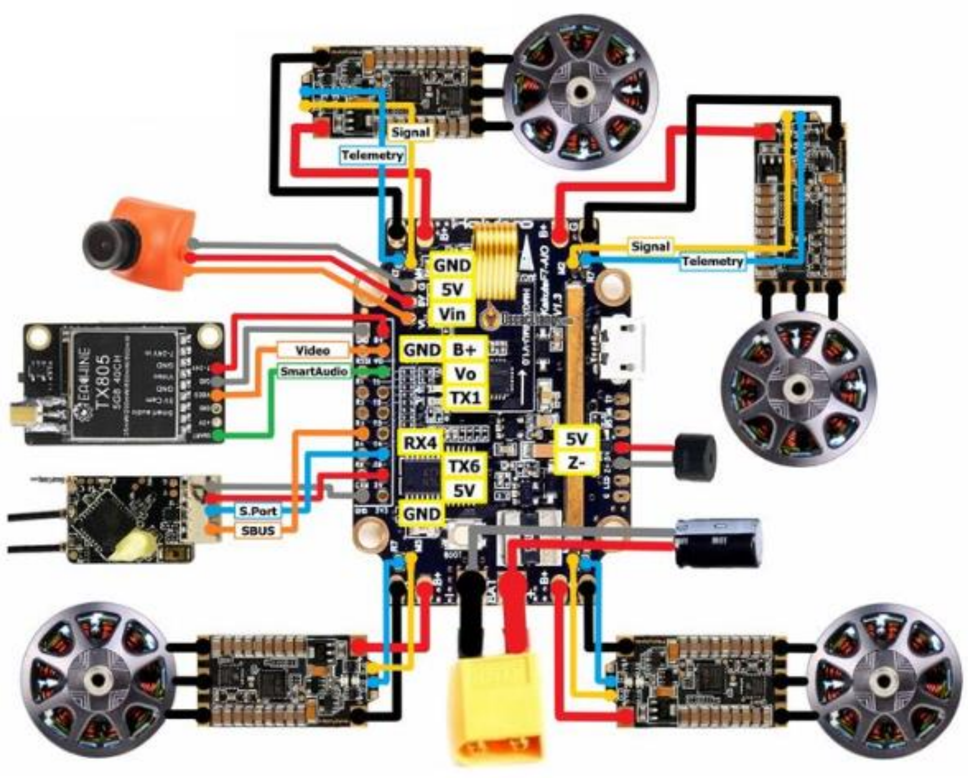


Fig. 5. Scheme of the octocopter

Fig. 6. DJI Phantom 3(4) Pro drone

Fig. 7. DJI Mavic 3 drone

The DJI Mavic 3 quadcopter (Fig. 7) can record video in the air with a high resolution and a frame rate of up to 1 billion colors with a 10-bit D-Log color profile, which provides a natural gradation of colors while preserving more number of details for high flexibility in image processing [22].

The DJI Inspire 2 quadcopter (Fig. 8) uses advanced machine vision technology to detect obstacles.

The DJI Inspire 2 drone contains two sensors and a camera located below, an additional two sensors are located in front, and an additional two cameras are located on top, which allows you to launch the drone indoors even with low ceilings. The range of reaction to an obstacle in front reaches 30 m, from below – 10 m, and the upper camera has sensitivity at a distance of 5 meters [23].

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Fig. 8. Inspire-2 T650A drone

Fig. 9. EVO II Refurbished drone

Autel EVO II 640 T (Fig. 9) is a quadcopter that contains a video camera with a resolution of 8K and an infrared matrix. The resolution of the thermal camera of the drone is up to 640x512, which allows you to shoot objects with a large number of details at a distance of up to 146 meters. The frame refresh rate is only 9 Hz and allows you to record video in 720p mode at a speed of 30 frames per second [24].

Table shows the technical characteristics of the considered quadcopters.

For a qualitative assessment of the parameters, consider those quadcopters in Fig. 10 shows the graphs of the criterion characteristics of the technical parameters of the considered quadcopters from Table 1.

The energy efficiency evaluation criterion was evaluated based on the ratio of the weight of the drone to the capacity of the power battery:

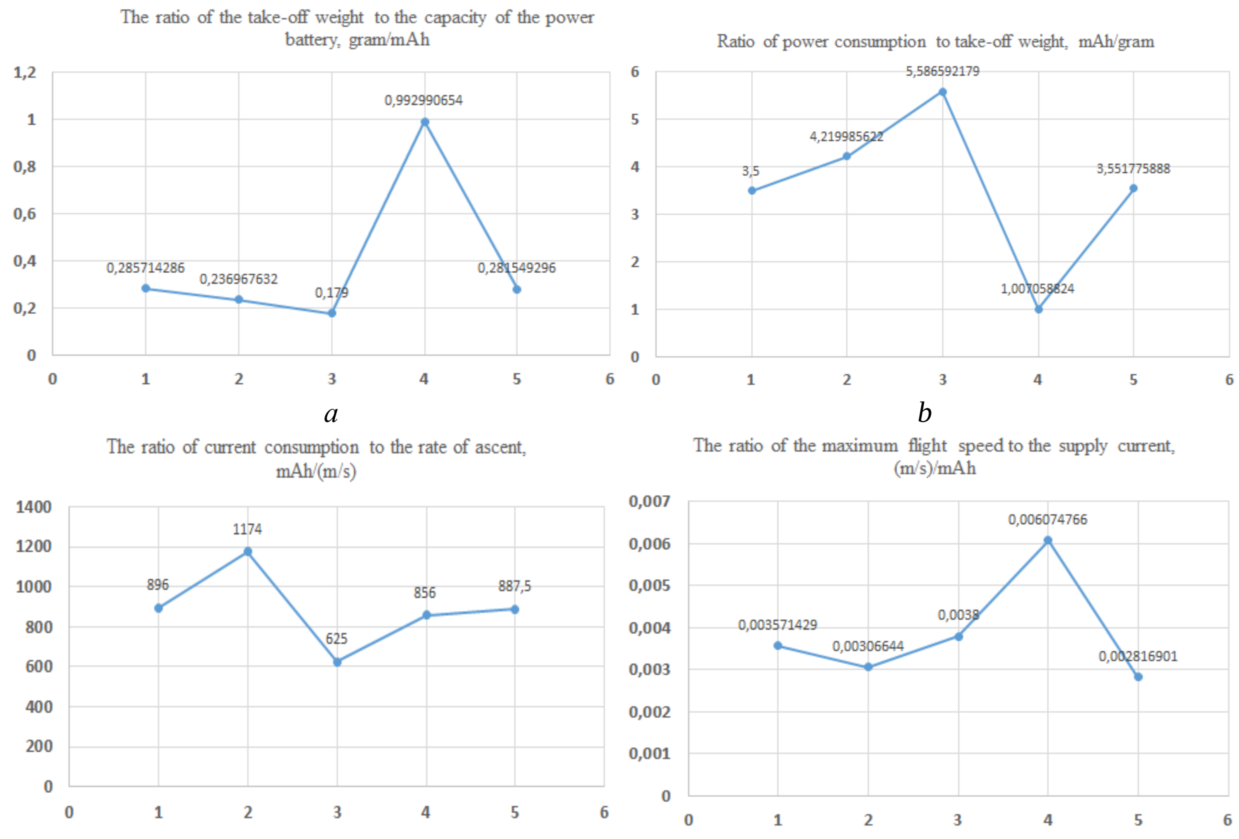

Fig. 10. Graphs of comparative evaluations of technical parameters of quadcopters:
1 – Phantom 3 Pro; *2* – Phantom 4 Pro V2.0; *3* – DJI Mavic 3; *4* – Inspire-2 T650A; *5* – EVO II Refurbished

Table. Technical parameters of quadcopters

Nr.	Parameters	Phantom 3 Pro	Phantom 4 Pro V2.0	DJI Mavic 3	Inspire-2 T650A	EVO II Re-furbished
1	Maximum take-off weight, gr	1280	1391	895	4250	1999
2	Diagonal size (except propellers), mm	350	350	380,1	605	397
3	Maximum speed of ascent, m/s	5	5	8	5	8
4	Maximum speed of descent, m/s	3	3	6	4	4
5	Maximum speed, m/s	16	18	19	26	20
6	The maximum angle of inclination	35°	35°	35°	40°	40°
7	Maximum angular speed, °/s	150	150	150	150	150
8	The maximum service height above sea level, m	6000	6000	6000	2500	7000
9	Maximum flight time, min	23	30	40	23	40
10	Image size, px	4000×3000	4096×2160	5280×3956	-	7680×4320
11	Maximum video bi-trate, Mbit/s	60	100	200	-	120
12	Photo shooting modes	Burst shooting: 3/5/7 frames	Serial shoot-ing of single frames: 3/5/7/10/14 frames	Continuous shooting: 3/5 frames	-	Continuous shooting: 3/5 frames
13	Video Lens	FOV 94° 20mm (35mm format equivalent) f/2.8 focus	FOV 84° 8.8mm/24mm (35mm format equivalent) f/2.8-f/11 autofocus at 1m	FOV: 84° Format equivalent: 24 mm Aperture: f/2.8 to f/11 Focus: 1 m	FOV 60°	FOV 79°
14	Battery voltage, V	15,2 (4480 mAh)	15,2 (5870 hAh)	15,4 (5000 mAh)	22,8 (4280 mAh)	11,5 (7100 mAh)

$$K1 = \frac{m}{VA}, \quad (1)$$

where m - mass, kg; VA - capacity of the power battery, mAh.

The efficiency of energy consumption is suggested to be evaluated by the ratio of ener-gy consumption in milliampere hours to the drone's flight speed:

$$K2 = \frac{VA}{\upsilon}, \quad (2)$$

where υ - is the flight speed, m/s.

The inverse ratios of these indicators make it possible to assess the technical perfection of the drone drive system.

From the graphs in Fig. 10 shows that the Inspire-2 T650A quadcopter has better per-formance in the ratio of the efficiency of moving a unit of cargo mass to the energy consumption for its movement. At the same time, the energy consumption at the maximum speed of movement in such a quadcopter will be the largest among the ones under consideration. According to the technical data, DJI Mavic 3 and EVO II Refurbished are the best in terms of flight duration, but DJI Mavic 3 consumes 29,5% less energy when taking off at maximum speed compared to EVO II. Inspire-2 T650A in comparison with other quadcopters from the table. 1 contains power cells with a higher supply voltage, namely 22,8 volts.

An alternative to quadcopter-type vertical flight drones are drones with a rigid wing (Fig. 11). Such systems usually have one drive motor, which gives an advantage in a significant flight duration compared to multi-motor drones.

For example, the considered Boeing ScanEagle UAV with a rigid wing (see Fig. 11) has a stabilized electro-optical and/or infrared camera on a light inertial stabilized turret system and an integrated communication system with a range of more than 100 km. The ScanEagle has a flight duration of more than 20 hours, a wingspan of 3,1 m, a length of 1,4 m and a mass of 20 kg, and can reach speeds of up to 150 km/h, an average cruising speed of 89 km/h [14].

Planning the drone's flight path is an important part of the task. Global and local algorithms for trajectory planning are used when planning flight trajectories.

The global trajectory planning algorithm belongs to the static programming algorithm, which performs trajectory planning on the basis of available map information and searches for the optimal trajectory from the initial point to the target point. Global algorithms can be traditional, usually based on examples of living nature, and intelligent, which are formed by machine learning and heuristics, due to the imitation of human or animal.

The local trajectory planning algorithm belongs to dynamic trajectory planning algorithms. This means that the pilot collects current information about the location and local obstacles in real time using the sensors of the drone or group of drones, and then forms the optimal flight path between the starting and ending.

Among the existing traditional algorithms for controlling quadcopter-type drones, we note the algorithms of Dijkstra, Dabbins, Floyd, the method of the Voronoi count, probabilistic road maps (PRM) and rapid random tree research (RRT).

Intelligent algorithms are based on the principles of bionics, which simulate the processes of group biological behavior for the joint search for an optimal solution and are

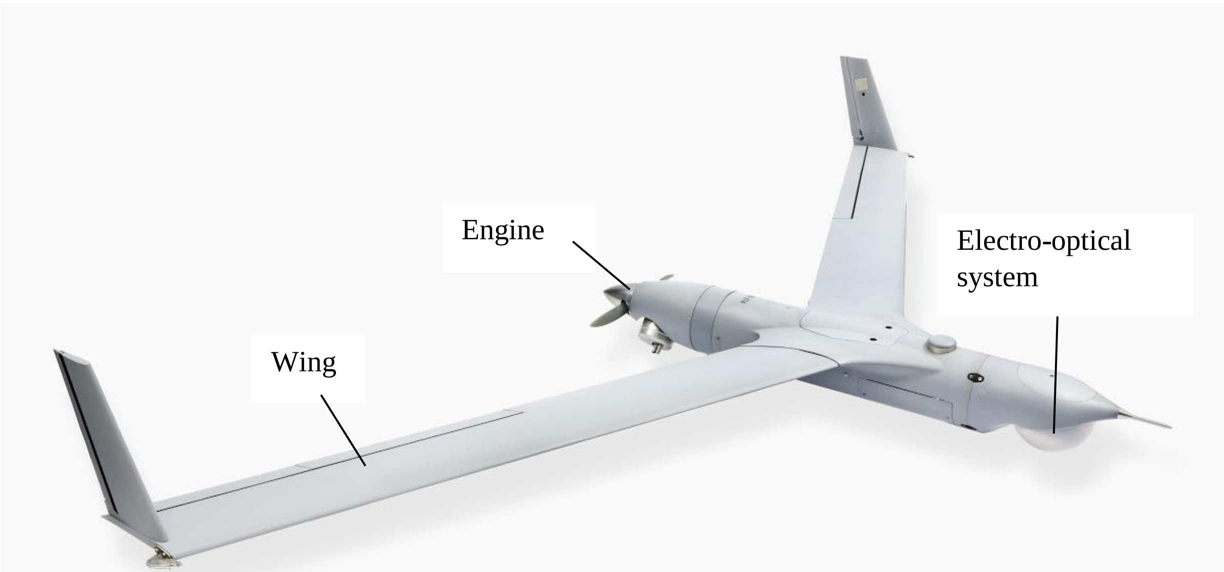

Fig. 11. Boeing insitu ScaneAgle

divided into two types: heuristic and machine learning algorithms.

Heuristic algorithms are used to plan the flight trajectories of quadcopters and include the simulation annealing algorithm (SA), the A-star algorithm, the evolutionary algorithm (EA), the particle swarm optimization algorithm (PSO), the pigeon-motive optimization algorithm (PIO). , Fruit Fly Algorithm (FOA), Artificial Bee Colony Algorithm (ABC), Salp Swarm Algorithm (SSA), Ant Colony Optimization Algorithm (ACO), Gray Wolf Optimization Algorithm (GWO), Harmony Search Algorithm (HS), etc.

A machine learning algorithm basically imitates or implements human learning behavior, transforms the drone flight path planning problem into a decision-making problem, and formulates optimal or near-optimal search strategies through constant learning and interaction in complex environments. Machine learning algorithms currently used for drone flight path planning include neural network (NN), reinforcement learning (RL), and deep reinforcement learning (DRL).

Algorithms for local planning of the drone's trajectory include the Artificial Potential Field (APF), Dynamic Window Approach (DWA), Mathematical Optimization Algorithm (MOA), and Model Predictive Control (MPC).

Dijkstra's algorithm is a classical algorithm for finding all the shortest paths from one predetermined vertex of a graph to all its other vertices. In the graph, the vertex represents the points of the trajectory, and the edges represent possible flight trajectories. The line between nodes is called an edge, and each edge has a corresponding weight that estimates distance or cost.

In [25], the authors used Dijkstra's algorithm to determine the minimum flight trajectory of a drone, while complying with the requirement of fast calculation of the time of movement along the trajectory, which was generated in the shortest time, and therefore the trajectory will be optimal.

The Dubins curve is the shortest geometric curve that connects two two-dimensional Euclidean planes, subject to restrictions on the curvature of the path and given initial and final tangents to the path. The authors of the work [26] modeled the behavior of a group of drones flying along a trajectory of a given shape with existing obstacles, and the determination of the trajectory of the movement is performed using the Dubins algorithm, which is based on reduced visibility graphics. By connecting selected nodes with arcs and segments and adding Rendez-Vous waypoints (RVW) thereby minimizing the length of each path.

Floyd's algorithm is used to determine the smallest path between the vertices of a given weighted graph. This is a dynamic programming algorithm in which the connection weight between nodes of a path graph can be either positive or negative, similar to Dijkstra's algorithm, but differs from it in that it is used to find the smallest distance between any pairs of vertices of a graph with with negative weights, while Dijkstra's algorithm is used to find the shortest path from one to all other vertices of the graph, and schemes with negative weights cannot be calculated. In work [27], to determine the flight path of groups of drones, the Floyd algorithm is used, which generates the initial route, and the optimal solution of the problem is obtained due to the Push Forward Insertion heuristic algorithm.

The Dirichlet algorithm (also known as the Voronov method) is a space segmentation algorithm. According to this algorithm, the space is divided into many regions through a series of initial nodes. The distance between all points in each region and the starting points at the current node is taken to be less than the distance to all other starting points. According to the distribution of obstacles, the Dirichlet algorithm squares the free space between the edges of the obstacles and at the same time draws a vertical line of adjacent obstacles to form a polygon around the obstacles so that each side is the same distance from the obstacle. Then, the start and end nodes can be connected into a graph by constructing trajectories from the nodes to the edges closest to each node.

Probabilistic road map (PRM) algorithm – this method is based on the creation of graphs by transforming continuous space into discrete. RRT grows a tree rooted in the initial configuration using random samples from the

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search space. As each sample is mapped, an attempt is made to establish a relationship between it and the nearest state in the tree. If the connection is possible (passes completely through the free space and obeys any restrictions), this leads to the addition of a new state to the tree.

Rapid Random Tree Search (RRT) is a one-query, sample-based random search algorithm. Its basic idea is to randomly sample in the state space, use a graph structure or extend a tree structure to construct a possible set of trajectories, and then search for a complete possible trajectory from the set of trajectories.

The simulated annealing algorithm (Simulated Annealing, SA) is an optimization algorithm based on the physics of the metal annealing process. The main idea of the SA algorithm is to find the global minimum (or maximum) of a function that can have many local minimums (or maxima). The algorithm first takes an initial decision and gradually changes it in the course of iterations. The objective function of an optimization problem is equivalent to energy, and the optimal solution is equivalent to the lowest energy state. The main idea of the algorithm is to first allow the solution to move in space quickly and gradually reduce this speed over time to increase the probability of finding a global minimum.

The most common evolutionary algorithm is the genetic algorithm (GA). The main idea of such an algorithm is to first rasterize the flight space, find the obstacle area, and then randomly generate the initial points on the map. In order to ensure a collision-free trajectory to the destination point, in the trajectory planning process, each collision-free trajectory from the starting point to the destination point is represented as an individual, and each individual has a chromosome, so each collision-free trajectory can also become a chromosome. Each segment of the trajectory is represented as a gene. The set of all individuals, that is, all generated trajectories without collisions from the starting point to the target point is called the population. The goal of the optimization problem of the genetic algorithm is to select the right individuals from the population. Individuals with high physical fitness are elite individuals; due to the cross-mutation operation between the elite individuals, the best elite individuals are continuously checked until the termination conditions are met, and finally what remains is the necessary path to avoid obstacles.

Particle Swarm Optimization initializes the trajectory planning problem with a group of random particles and then iterates to find the optimal solution. In each iteration, the particles update their position and velocity by tracking individual and global extreme values, and then use the search space to complete optimal trajectory planning.

Pigeon-Inspired Optimization algorithm (PIO) is a swarm intelligent optimization algorithm designed to imitate the behavior of pigeons, which is based on the mechanism of cooperation and competition.

Ant Colony Optimization (ACO) is a heuristic global optimization algorithm obtained on the basis of the trajectory of ants' behavior in the process of searching for food. The ant colony algorithm uses the trajectories of ants to represent a possible solution to the problem to be optimized. All trajectories of the entire ant colony make up the solution space of the problem to be optimized, and ants with shorter trajectories emit more pheromones.

Commercial applications of drones require autonomous flight, which is due to the fact that flights often need to be carried out regularly in the same place, following a typical flight path that can be programmed.

For autonomous control of the drone, it is necessary to set the coordinates of its movement in space. In open space, you can use GPS, the error of which reaches several meters. An additional ground station and GPS RTK technology (real-time kinematic positioning) allow you to increase the positioning accuracy to several centimeters. The drone can also determine its coordinates on board, processing the video stream from on-board cameras - stereo cameras or depth cameras. Such an algorithm is called SLAM (Simultaneous Localization and Mapping).

Let's consider several standard quadcopter flight algorithms on the example of the Tello DJI training drone with a description of the flight algorithms of such a UAV in the Python programming language of the flight controller.

Flight #1. Take-off, forward movement and landing according to the diagram in Fig. 12.

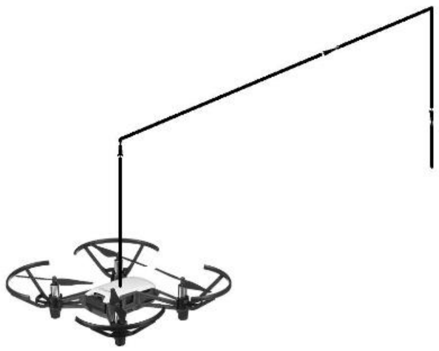

Fig. 12. Scheme of algorithm "take off, move, land"

Algorithm of the function "take off, move, land" is next:

```
def moveTo (distance, t):
    from time import sleep
   import tello
   tello.takeoff()
   tello.move_forward(distance)
   sleep(t)
   tello.land()
```

Flight #2. Shuttle movement forward horizontally with a turning angle to the right by 90 degrees (Fig. 13).

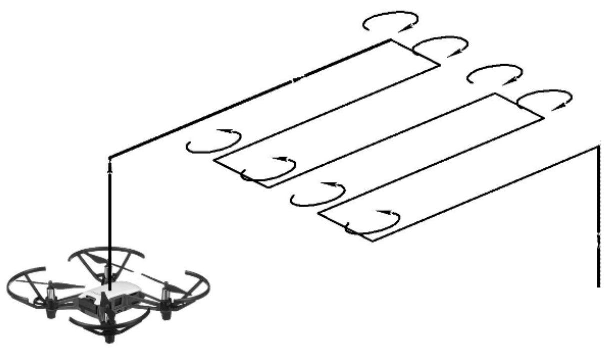

Fig. 13. Scheme of algorithm of horizontal shuttle movement

Algorithm of the horizontal shuttle motion function is next:

```
def moveToHorizonlArea (distance, angle, overlap, count, t):
    from time import sleep
    import tello
    tello.takeoff()
     for i in range(count):
        tello.move_forward(distance)
        sleep(t)
        tello.rotate_counter_clockwise(angle)
        sleep(t)
        tello.move_forward(overlap)
       sleep(t)
    tello.land()
```

Flight #3. Take-off, moving forward for a given distance, barrage to the right and landing according to Fig. 14.

Algorithm of the "takeoff, move, barrage to the right, landing" function is next:

```
def moveToVertacalArea (distance, overlap, height, count, t):
     from time import sleep
     import tello
     tello.takeoff()
     tello.move_forward(distance)
 for i in range(count):
     tello.move_down(height)
     sleep(t)
     tello.move_right(overlap)
     sleep(t)
     tello.move_up(height)
     sleep(t)
 tello.land()
```

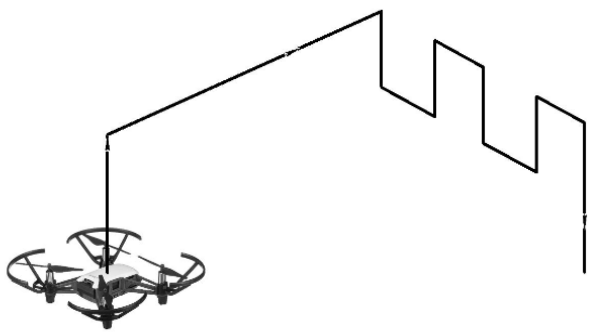

Fig. 14. Algorithm "takeoff, approach, barrage to the right, landing"

Flight #4. Take-off, movement along a radius with a turn to a given angle and landing according to Fig. 15.

Algorithm of the function of the algorithm "takeoff, barrage to the left along a certain constant radius at a given angle, landing”:

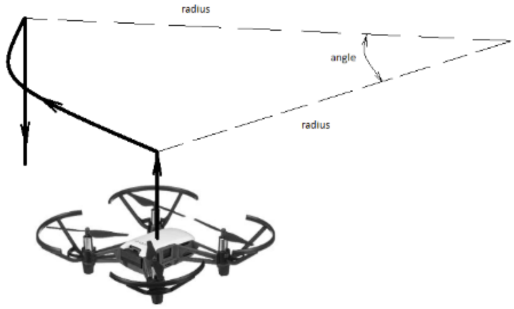

Fig. 15. Algorithm "takeoff, movement along the radius, landing"

```
def moveLeftToRadiusArea (radius, angle, t):
    from time import sleep
    from math import cos
    tello.takeoff()
    for i in range(angle):
        tello.move_forward(radius * (1-cos(i))
        tello.move_left(radius * sin(i))
        sleep(t)
    tello.move_down(height)
    tello.land()
```

On Fig. 16 shows an example of the practical application of the composition of the considered algorithms in the task of scanning the building facade in the Facade Scan UgCS program.

CONCLUSIONS

Autonomous unmanned terrain scanning systems that are built on the basis of aerial systems must use route planning algorithms to determine the optimal flight path that takes into account movement restrictions, obstacles and targets to ensure flight safety and efficiency. Algorithms A* (A-star), RRT (Rapidly-exploring Random Tree) and MPC (Model Predictive Control) are often used for UAV route planning.

Global navigation is usually based on the use of GPS to determine the position and plot the route. Local navigation uses internal sensors (such as IMUs) and external sensors (such as laser rangefinders or cameras) to measure distance and orientation. Algorithms such as SLAM (Simultaneous Localization and Mapping) allow you to create a map of the sur-

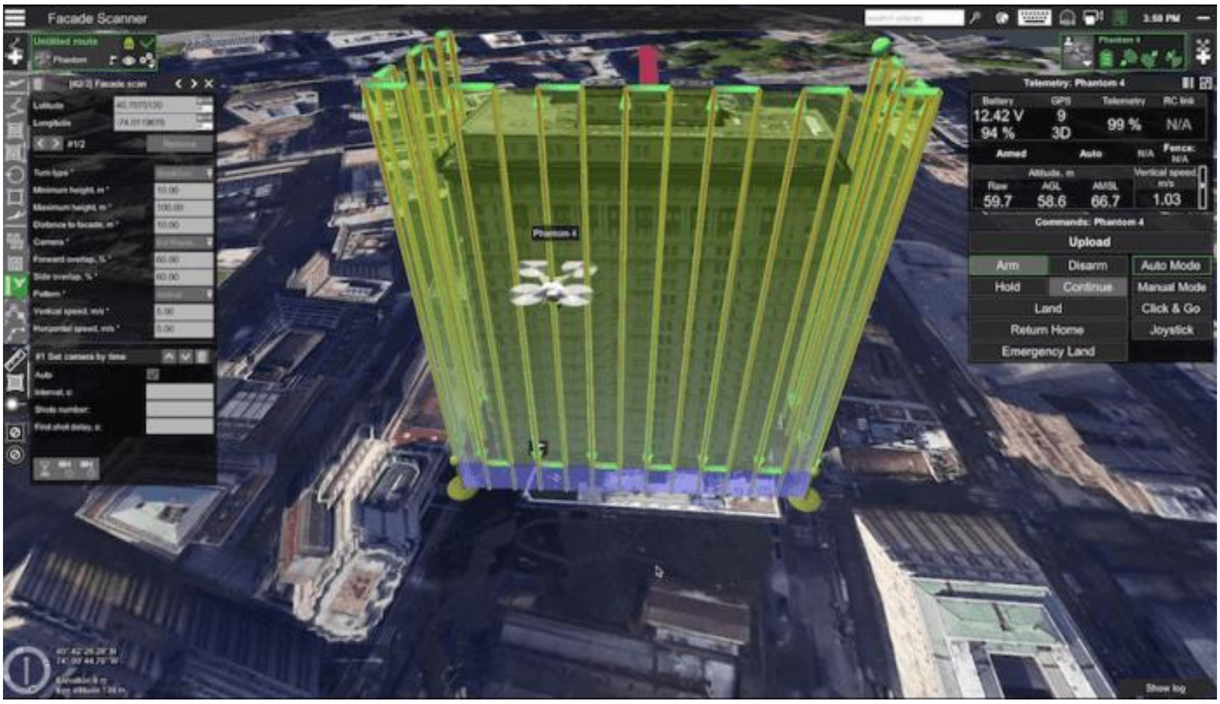

Fig. 16. Automatic vertical scanning for drones in SPH Engineering's

rounding environment and determine your location in real time.

Algorithms for controlling unmanned aerial systems cover stabilization and flight control, navigation, location and route planning. These algorithms make it possible to achieve stable and accurate control, and also provide the possibility of performing complex maneuvers and autonomous flight. With the development of artificial intelligence and machine learning technologies, new approaches to management also appear, which expand the capabilities of mobile geoscanning systems of territories in various areas.

REFERENCES

1. **Brennan M**. (2017). UAV/Drone Survey with Agisoft Photoscan (Part 1). Sketchfab blog, e-source (url: https://sketchfab.com/blogs/community/uavdrone-survey-with-agisoft-photoscan-part-1).
2. **Brennan M**. (2017). UAV/Drone Survey with Agisoft Photoscan (Part 2). Sketchfab blog, e-source (url: https://sketchfab.com/blogs/community/uavdrone-survey-agisoft-photoscan-part-2/).
3. **Palestini C., Basso A.** (2019). 3D detection and reconstruction experiments in river basins. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLII-2/W9, 2019 8th Intl. Workshop 3D-ARCH "3D Virtual Reconstruction and Visualization of Complex Architectures", 6–8 February 2019, Bergamo, Italy, 543-550. https://isprsarchives.copernicus.org/arti-cles/XLII-2-W9/543/2019/
4. **Magallanes Guijón, G., Hruby, F., Ressl, R., Aguilar Sierra, V., De la Borbolla del Valle, G. and Rodríguez Paz, O.** (2018). Modelling of collective movement in immersive environments. In: International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-4, 397-402.
5. **Barrilel V., Gelsominol B., Bilotta G.** (2017). UAV and Computer Vision in 3D Modeling of Cultural Heritage in Southern Italy. IOP Conference Series: Materials Science and Engineering. 225 012196. https://doi.org/10.1088/1757899X/225/1/012196.
6. **Khaloo, A., and Lattanzi, D.** (2016). Hierarchical dense structure-from-motion reconstructions for infrastructure condition assessment. J. Comput. Civil Eng, 31, 04016047. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000616.
7. **Khaloo A, Lattanzi D, Jachimowicz A and Devaney C**. (2018) Utilizing UAV and 3D Computer Vision for Visual Inspection of a Large Gravity Dam. Front. Built Environ. 4:31. https://doi.org/10.3389/fbuil. 2018.00031.
8. **Tong X., Liu X., Chen P., Liu S., Luan K., Li L., Liu S., Liu X., Xie H., Jin Y., et al.** (2015). Integration of UAV-Based Photogrammetry and Terrestrial Laser Scanning for the Three-Dimensional Mapping and Monitoring of Open-Pit Mine Areas. *Remote Sensing*. 7(6), 6635-6662. https:// doi.org/10.3390/rs70606635.
9. **Zhou G. Q.** (2010). Geo-referencing of video flow from small low-cost civilian UAV. IEEE Trans. Autom. Sci. Eng., 7, 156–166 https://dx.doi.org/10.1109/TASE.2008.2010948
10. **Turner D., Lucieer A., Watson C.** (2012). An automated technique for generating georectified mosaics from ultra-high resolution unmanned aerial vehicle (UAV) imagery, based on Structure from Motion (SfM) point clouds. Remote Sens., 4, 1392–1410. https://dx.doi.org/10.3390/rs4051392
11. **Nebiker, S., Annena A., Scherrerb M., Oeschc, D.** (2008). A light-weight multispectral sensor for micro UAV—Opportunities for very high resolution airborne remote sensing. Int. Arch. Photogramm. Remote Sens. Spatial Inform. Sci, 37, Part 1, 1193–1198.
12. **Scaioni M., Barazzetti, L., Brumana R., Cuca B., Fassi F., Prandi F.** (2009). Rc-Heli and Structure & Motion Techniques for the 3-D Reconstruction of a Milan Dome Spire. Proceedings of the 3rd ISPRS International Workshop 3D-ARCH 2009: "3D Virtual Reconstruction and Visualization of Complex Architectures", Trento, Italy, 25–28, February, 8.
13. **Tong, Xiaohua, Xiangfeng Liu, Peng Chen, Shijie Liu, Kuifeng Luan, Lingyun Li, Shuang Liu, Xianglei Liu, Huan Xie, Yanmin Jin, and Zhonghua Hong**. (2015). Integration of UAV-Based Photogrammetry and Terrestrial Laser Scanning for the Three-Dimensional Mapping and Monitoring of Open-Pit Mine Areas. Remote Sensing 7, No.6, 6635-6662. https://doi.org/10.3390/rs70606635.
14. **Nagai M., Chen T., Shibasaki R., Kumugai H., Ahmed A.** (2009). UAV-borne 3-D mapping system by multisensory integration. IEEE Trans. Geosci. Remote Sens., 47, 701–708. https://dx.doi.org/10.1109/TGRS.2008.2010314
15. **Bolognesi M, Furini A, Russo V, Pellegrinelli A, Russo P.** (2014). Accuracy of cultural herit-

age 3D models by RPAS and terrestrial photogrammetry. Int Arch Photogramm Remote Sens Spatial Inf Sci., XL-5:113–119. https://doi.org/10.5194/isprsarchives-XL-5-113-2014.

16. **Buffi G, Grassi S, Manciola P, Niemeier W.** (2016). Comparison of 3D model derived from UAV and TLS. The experience at Ridracoli Dam, Italy. Terrestrisches Laserscanning (TLS). Proceedings of Terrestrisches Laserscanning, Nov 28–29, Fulda.
17. **Giulia Buffi, Piergiorgio Manciola, Silvia Grassi, Marco Barberini & Andrea Gambi** (2017) Survey of the Ridracoli Dam: UAV–based photogrammetry and traditional topographic techniques in the inspection of vertical structures, Geomatics, Natural Hazards and Risk, 8(2), 1562-1579, https://doi.org/10.1080/19475705.2017.1362039.
18. **Eugster, H., & Nebiker, S.** (2008). UAV-based Augmented Monitoring – Real-time Georeferencing and Integration of Video Imagery with Virtual Globes. XXIst ISPRS Congress, Beijing.
19. **Tong X, Liu X, Chen P, Liu S, Luan K, Li L, Liu S, Liu X, Xie H, Jin Y, Hong Z**. (2015). Integration of UAV-Based Photogrammetry and Terrestrial Laser Scanning for the Three-Dimensional Mapping and Monitoring of Open-Pit Mine Areas. Remote Sensing, 7(6), 6635-6662. https://doi.org/10.3390/rs70606635.
20. **Oscar Liang**. (2023). How to Build an FPV Drone Tutorial (DJI & Analog). E-source (url: https://oscarliang.com/how-to-build-fpv-drone).
21. **Official** DJI Phantom 3 e-source (url: https://www.dji.com/global/phantom-3-pro).
22. **Official** DJI Mavic 3 e-source (url: https://www.dji.com/global/mavic-3).
23. **Official** DJI Inspire-2 T650A e-source (url: https://www.dji.com/global/inspire-2/info).
24. **Official** EVO II Refurbished e-source (url: https://www.autelrobotics.com).
25. **Ueno S., Kwon S. J.** (2007). Optimal reconfiguration of UAVs in formation flight. In Proceedings of the SICE Annual Conference 2007, Takamatsu, Japan, 17–20 September, 2611–2614.
26. **D'Amato E., Mattei M., Notaro I.** (2019). Bi-level flight path planning of UAV formations with collision avoidance. J. Intell. Robot. Syst., 93, 193–211.
27. **Yang J., Xi J., Wang C., Xie X**. (2018). Multi-base multi-UAV cooperative patrol route planning novel method. In Proceedings of the 2018 33rd Youth Academic Annual Conference of Chinese Association of Automation (YAC), Nanjing, China, 18–20 May, 688–693.

Аналіз літаючих систем мобільного сканування території

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Анотація. Стрімкий процес розвитку якісної мікропроцесорної техніки, доступність глобальних навігаційних систем (GPS) та інерційних вимірювальних блоків (IMU) сприяв прогресу створення нового покоління мобільних автономних систем з дистанційним керування, зокрема автономних роботів та безпілотних літальних засобів. Активно застосовуючи безпілотні літальні апарати (БПЛА) та мобільні роботи останнім часом досить швидко вирішують задачі фотограмметричного і лазерного сканування місцевості. Дані з високими просторовими розширеннями, зібрані з таких доступних платформ, як супутники та пілотовані літальні апарати, зазвичай знаходяться в діапазоні 20–50 см/піксель, а БПЛА здатні літати на набагато нижчих висотах і, відповідно, можуть збирати зображення з набагато більшою роздільною якістю зображення.

Мобільні роботи та БПЛА в поєднанні із сучасними технологіями цифрової обробки відео та фото, а також програмами інтелектуального розпізнання зображень набули актуального використання, як для військових задач так і в цивільній сфері в якості інструменту дистанційного зондування територій та інфраструктурних об'єктів з високою роздільною здатністю. На основі сканованих БПЛА зображень можна відтворювати 3D моделі місцевості.

В даній статті розглянуто аналіз технічних засобів мобільного сканування територій та деяких відомих алгоритмів управління систем для сканування.

Ключові слова: дрон, квадрокоптер, безпілотник.