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Application of Unmanned Aerial Vehicles in Construction Industry

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Abstract

Technological advances in the field of electronics, such as miniature electromechanical devices and small powerful electric motors, have made it possible to develop small and light devices, such as unmanned aerial vehicles (UAVs). Recently, civilian UAVs are rapidly gaining popularity. Undoubtedly, UAVs will be used for many services in the future. There is already a growing demand for such fields of application of unmanned aerial vehicles as agriculture, emergency services, energy, fuel, mining, construction, geodesy (cartography), transportation, etc. Thanks to modern technologies it possible to produce light and low-power but accurate sensors that can be used by controllers with high computing power and low energy consumption. This makes it possible to develop complex control systems for UAVs that can be implemented on board. Today's quadcopters are used for design, surveillance, search, construction inspections, and a variety of other applications.

Keywords: UAV; standardization; information technologies; control methods; reliability analysis.

1. Introduction

Day by day drones are making their fast way into various areas of economy and are becoming an integral part of routine workflows, according to Teal Group reports [1]. Now they are used not only for military reconnaissance, but also in construction industry, production, agriculture, security or services [2]–[6]. Hundreds of development companies are implementing drone technologies at all stages of construction cycle from design and construction to operation and demolition [7]–[9]. Industry 4.0 in construction engages and combines such digital technologies as BIM, GIS, IoT and UAV [10],[11]. According to last year reports, the construction industry is top of the list sector where UAVs (unmanned aerial vehicles) data is used. Using UAVs data enables photo and video reports on the progress of construction works on a daily, weekly or monthly basis. The images obtained are applicable for monitoring the changes, they help promptly detect problems (for instance a wrong order of operations, which entails delays in works) and properly plan the construction process. Therefore, use of drones in the construction industry makes it possible to obtain detailed information on every construction element and see the general picture of planning and progress of works [14],[15].

One of the decisive advantages of using unmanned aerial vehicles is that they meet the criterion of cost-effectiveness and do not pose a risk to the lives of pilots. UAV-based complexes have low operating costs as compared to manned aeronautical equipment [7], due to the lack of costs for flight crew training [8]. Unmanned aerial complexes are used when manned aviation cannot be applied, for instance in case of lack of infrastructure, threat of chemical, bacteriological and radioactive contamination. Unmanned aerial vehicles, including unmanned aerial, offshore and submarine stations, have great prospects for creating a smart city or a country network.

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The issue of UAV navigation is an important task for unmanned aviation. Effective geolocation systems can simplify this task, but cannot solve it. The task of controlling a set of devices needs to be solved, because the system "one device – one pilot" has long been obsolete. There is a need to develop machine-to-machine (m2m) communication interfaces, methods of forming sets of devices according to such criteria as the type of devices, common tasks, and general aviation safety. The method of collecting data on the environment and the decision-making algorithm have not been defined either [23].

Development of UAV production technologies requires not only operational, legal and commercial solutions, but also standardization of control methods for both ground-based systems aircrafts and platforms. Internet giants such as Google and Facebook continue to support the development of drone start-ups for various fields of use, from the delivery of goods, to the creation of flying platforms to provide the Internet in regions where it is impossible to locate ground or surface stations. Increasing the number of aircrafts requires searching for autonomous navigation methods and methods of group formation. Therefore, the issue of introducing new control methods is very important. Worldwide, robots are being built to create unmanned aerial systems as backbone elements of UAVs. The priority is given to the information systems, the task of which is to monitor the surrounding space, the cost of which is much lower in comparison with piloted equipment. UAVs are designed for accomplishment of monitoring tasks, and this feature should be provided while developing unmanned aerial systems. As a consequence, it is necessary to use specialized techniques for their creation and application for each UAV type. In order to implement the tasks set, it is necessary to develop the theoretical basis for the creation and use of unmanned aerial systems. The development of such a theory is dictated by fact that modern unmanned aerial systems were allocated into a separate type of unmanned aerial vehicles. The main tasks of the UAVs include monitoring of surface, atmosphere and infrastructure objects, retransmission of radio signals.

The goal of this work is to analyze UAV control methods and their metrological base. Additionally, the research aims at studying the specific features of implementing UAVs in the construction industry and substantiating the methods of their applications in engineering and geodetic works and urban infrastructure design.

2. Application of UAVs for obtaining accurate geospatial data

When designing construction works and laying new linear structures, it is necessary to take into account the geographical characteristics of the selected area. Basically, to solve such a task, the services of surveyors are resorted to, who study the place, draw up a plan of the area with all the details, and then transfer all the information gathered to construction specialists. After that, construction works begin.

The main problems arising in the process of monitoring and construction of objects are poor accessibility of the object (features of the terrain, water and mountain obstacles); long-term preparation of geodetic data of the research object; difficulties in monitoring construction works on high-rise buildings [22]. Aerial photography, which is carried out using UAV, allows overcoming these difficulties. Unmanned monitoring speeds up and reduces the cost of works manifold compared to conventional methods. The tasks being solved with the help of UAVs for construction and road design include aerial photography of the area for the preparation of the construction project; assessment of the object's degree of completion; aerial photography of finished objects and control of their condition, analysis of damage, accidents; planning of repair works; forecast and modeling of environmental impacts [16],[17],[19].

3. Technical application

The advent of unmanned aerial vehicles has significantly simplified the procedure for obtaining accurate geospatial data for designing objects. Now there is no need to wait a long time for the completion of the time-consuming instrumental geodetic surveying. Instead, one can use a UAV to obtain instant, precisely geo-positioned images of the terrain with the smallest elements, and in a short period of time collect the necessary information for designing construction works [18],[21],[25]

Flying over the object, the drone receives high-resolution images and video data, which allows determining the features of the relief of the area on which construction works will be carried out. All data is recorded in the built-in on-board storage unit. At the same time, the UAV transmits a video sequence in real time to the ground control station [24].

After the flight, the cartographers process the received data in a specialized software environment, and the decipherers select the necessary semantic information to create topographic maps, which cannot be determined in the images. Created orthophotomaps with a scale of 1:500 and smaller, 3D terrain models and digital topographic maps allow designers to solve many tasks that arise when designing objects, and builders to correctly select the necessary equipment and plan the performance of certain types of linear works, taking into account the effective use and protection of the environment [26]–[28].

In the event of emergencies at construction sites or on a long roadway, the UAV technologies make it possible to quickly detect the location of the failure or accident on the road and, taking into account the scope of damage, to assess the duration and cost of repairs [35].

Based on the customer's needs, the UAV can be equipped with a high-resolution photo and video camera with the option of multiple magnifications and a camera with a thermal imager allowing data reception at night [36]. The duration of the flight of unmanned aircrafts reaches over 4.5 hours, and the flight range is over 1500 km. This enables monitoring and obtaining accurate data for terrain mapping even for large-area objects. For a more detailed inspection of a separate construction object or part of the roadway, the use of unmanned multicopters that have a mode of hovering over the object is an efficient option [29],[30],[48].

Prompt pre-flight preparation of the UAV (10–15 minutes), ease of operation, option of parachute landing in automatic or semi-automatic mode make it possible to use unmanned aerial vehicles in design, construction, engineering and geodetic research and road industry even in remote areas and without a special landing pad. Technically, aerial photography using UAVs consists of three stages. These are preparation, aerial photography and processing of the obtained data.

3.1. Preparation stage

This stage includes such activities as the study of available data, formulation or collection of requirements to the data to be obtained as a result (the type and scale of the map, the boundaries of the survey object), bringing them in compliance with the technical requirements to the images (resolution, coordinates of the contour of the photography area, overlap of images, accuracy of determining the coordinates of the centres of photographing, requirements to the ground reference network (in case of combined shooting, for example, when the photo plan is tied to the points of the ground reference network, requirements to the accuracy of the coordinates determination are not laid down at all). [32],[33]. The flight-planning software (Fig.1), which is part of the complex, performs formation of the UAV flight task. The operator selects the UAV complex used (if the software allows working with several configurations of UAVs and camera equipment), puts the contour of the shooting area and the position of the launch pad on the map and sets the required resolution and overlap. After that, the software computes the flight plan and checks its feasibility [34].

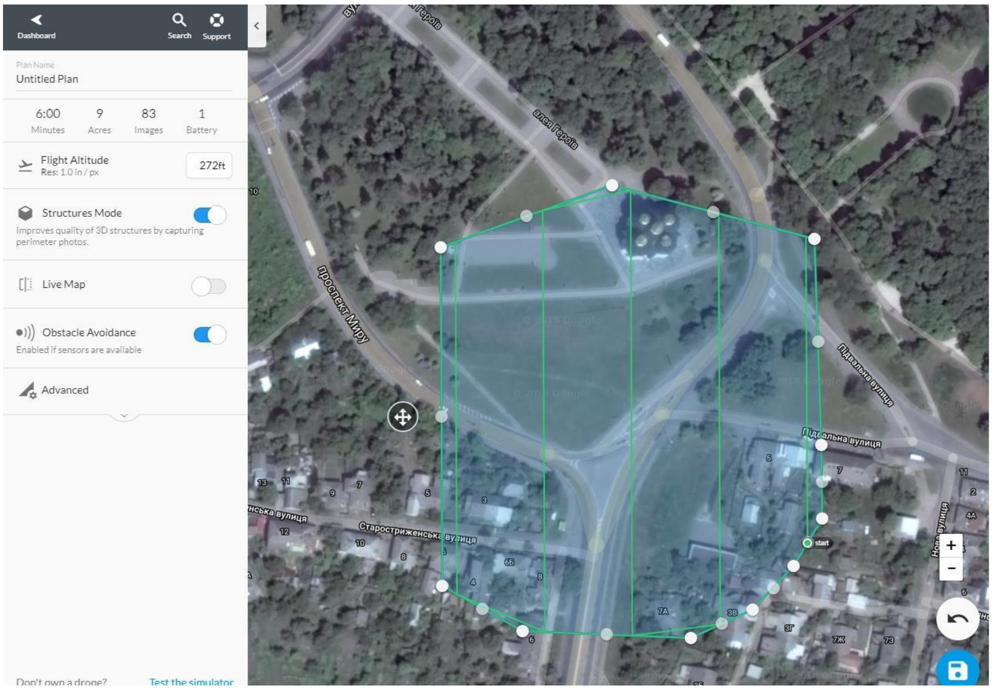

Fig.1. Formation of the flight task for unmanned aerial vehicle using DroneDeploy.

At the preparation stage, points 1,2,3,4 are photographed using GPS-receiver and marked on the terrain so that they can be further recognized in the aerial photographs. As the result, the coordinates of the points were obtained in the WGS 84 coordinate system:

1) N = 51° 24' 47.56", E = 53° 35' 32.68", H = 115.10 m;

2) N = 51° 24' 47.58", E = 53° 35' 32.26", H = 115.20 m;

3) N = 51° 24' 49.81", E = 53° 35' 32.82", H = 116.74 m;

4) N = 51° 24' 49.97", E = 53° 35' 33.03", H = 116.93 m.

The number of points depends on the surface area of the plot to be photographed. To increase the accuracy of the orthophotoplan, the anchor points must be selected along the entire perimeter of the exposed plot. Prior to aerial photography, the flight task is formed using DroneDeploy software. This is a cloud service and application for high-resolution 2D mapping and 3D terrain modeling [33],[39]. The compatible drones are DJI Mavic Pro, Phantom 3/3 Adv/3 Pro, Phantom 4/4 Pro, Inspire 1/1 Pro, Matrice 100/600. The application for iOS and Android can be used instead of the standard application DJI Go 4 for drones' control. In the mobile application, one can plan the route and launch the drone along the calculated route. It will automatically capture images in the required points and under a certain angle. After the flight, the captured images need to be downloaded from the SD Memory Card to the DroneDeploy sever for processing. After the processing, the photoplans and 3D models can be viewed both in the mobile application and via the browser and also emailed with an option of viewing in the browser without special software [31],[37]. The mobile application can operate offline with the pre-saved route and Google Maps. The application enables resuming the flight from the spot in which the flight was interrupted.

The resolution is set at 12 megapixels (3000x4000 pixels), the flight height is 83 meters, the speed of the quadcopter is 5 m/s, the longitudinal overlap is 80% and the transverse is 60%, and the position of the launch pad is refined. After the preparatory stage operations, one can proceed to the aerial photography stage.

3.2. Performance of aerial photography

Upon arrival at the launch pad, the following measures are taken to refine the position of the launch pad: determining the return point and entering data on the wind speed and direction at the working height, if available; automatic clarification of the flight plan and rechecking it for the aerial photography viability; launch of the UAV from the launcher; capturing images in the automatic mode; landing.

When using the combined method, the coordinates of the selected anchor points are determined. Data processing consists in transferring data (images and a flight log) from on-board data storage media, visually evaluating the quality of images and removing so-called technical images, if such have been recorded (technical images are those taken outside the area of photography - when approaching the area, on turning arcs, and other images of poor quality), generation of a reference file of centres of photographing [38]. During the flight, the control equipment records various parameters, including the coordinates, speed and orientation parameters of the drone. After the photographing is finished, the coordinates corresponding to the moments of capturing must be selected from the flight log file and identified according to the images. Such processing, as a rule, is performed in the same environment - the flight task planner. Pinning of the necessary accuracy is achieved by measuring the coordinates of the photographing centers using high-precision GNSS receivers within the reference network or by involving the ground reference network, the points of which are anchored with an error of no more than 30 cm [40].

3.3. Processing of captured data

Data processing consists in transference of data (images and flight log) from on-board data storage media, visual assessment of images quality, and deleting of low-quality images and images taken outside the area of photography. The images are manually anchored to the points with known coordinates, using the software. In the DroneDeploy environment, a complete orthophotoplan is generated from 85 separate images and a 3D model of the area [41],[42].

The output is an orthophotoplan (Fig. 2), a WGS 84 coordinate system, with the resolution of 9842x10005 pixels, accuracy of 3.45 cm per pixel and 3D models of the area (Fig. 3).

In the course of the design work, the road traffic scheme is put on the orthophotoplan.

Fig.2. Orthophotoplan of the area.

Fig.3. Working project of major repair of the road section.

4. Results and their discussion

The range of services provided by drone operators in the construction industry includes such areas as looking for sites for construction, studying the area, analysing the infrastructure and pre-design work, monitoring the progress of construction works, inspecting unfinished buildings, monitoring the compliance with the regulations during dangerous works, inspecting tower cranes, inspection of buildings and high-rise objects, protection of objects and assets, photo and video recording of the construction process, real estate advertising using 3D tours [43],[44].

Object images, schematic maps, thermal maps, interactive 3D models, fast and accurate measurements are easily integrated into routine tools that enhance the efficiency of engineering and construction operations. Considering the issue in the speed-cost-result context, undoubtedly, drones are indispensable, as they combine the options of planning, monitoring, inspection of construction objects and sites with minimal expenditure of time and resources [45],[46],[49].

Using UAVs results in a reduction in the cost of inspection and topographic works, due to reducing the amount of equipment required for typical construction surveys (geodetic surveys, inspection surveys) and the number of workers involved in these works. Depending on the volume and scale, conventionally, it is from two to six people, while with UAV it is just one person, regardless of the volume and scale of work. The duration of works is 1–2 days using conventional methods, and the use of UAV reduces it to 1–3 hours. Using conventional methods, the map is developed manually by entering data followed by drawing a topographic plan. With UAV, data is transmitted in real time and the result is calculated automatically after the work is completed. The cost is several times lower, as it requires less time, personnel and equipment.

UAVs created new opportunities for technologies that otherwise would be extremely expensive and labour-intensive, helping business of any scale reduce costs and offering completely new and efficient ways of working with projects [47],[50].

5. Conclusion

UAVs in the construction industry results in timesaving and cost-reducing effects compared to conventional ground or aerial equipment. Drones provide accurate data collection, photo and video capturing. The research shows that with UAVs, works that would be characterized as high-volume using traditional methods (construction surveys), become more cost-effective.

Due to their small size and simple control, drones can approach hard-to-reach places of engineering structures and buildings. As a result, aerial photographs of construction projects are now becoming available. It is enough for the developer's representative to purchase a drone, spend several days training 1–2 people who are already working on the construction of the object, and then start fully operating the device to obtain the necessary information.

Compared to conventional ground photography, drones offer the information obtained with greater detail. Panoramic images made by a drone not only provide information about construction objects, structural elements or individual plots, but also allow seeing the general picture, in particular the adjacent territories and roads, which is important for implementing large-scale construction projects. Another advantage of drones is the ability to fly over the same route an unlimited number of times. This makes it possible to monitor the work progress at various stages, control the completion of tasks by the builders, and make prompt decisions during the work.

With the help of common access maps, communication between project managers, engineers, supervisors and builders is simplified. The works are becoming more efficient and safer. There are also advantages for investors or potential tenants. Aerial photos allow getting information about the progress of work without visiting the construction site itself.

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Застосування безпілотних літальних апаратів у будівельній сфері

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Анотація

Технологічні досягнення у сфері електроніки, такі як мініатюрні електромеханічні прилади і невеликі потужні електродвигуни, дозволили розробити невеликі і легкі пристрої – безпілотні літальні апарати. Останнім часом цивільні безпілотні літальні апарати починають стрімко набирати популярність. Безсумнівно, у майбутньому використання БПЛА буде використовуватися для багатьох служб. Вже зараз зростає попит на такі сфери застосування безпілотних літальних апаратів, як сільське господарство, екстрені служби, енергетика, паливо, видобуток корисних копалин, будівництво, геодезія (картографія), транспортування тощо. Завдяки сучасним технологіям стало можливим випускати легкі й малопотужні, але точні сенсори, які можуть використовуватися контролерами з високою обчислювальною потужністю і низьким споживанням енергії. Це дає можливість розробити складні системи управління, що можуть бути реалізовані на борту даного апарата. Сучасні квадрокоптери використовуються для проектування, спостереження, пошуку, будівельних перевірок і низки інших завдань.

Ключові слова: БПЛА; стандартизація; інформаційні технології; методи керування; аналіз надійності.