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HARDWARE AND SOFTWARE COMPLEX OF INTELLECTUALIZED ORNITHOPTER-TYPE UAV FOR MILITARY APPLICATIONS

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The problem of the development of miniature, cost-effective, unmanned aerial-terrestrial ornithopter for military applications is considered. Solutions from leading foreign and domestic companies and research laboratories on the design and testing of aircraft systems are analyzed. The hardware complex was built up as a small-sized ornithopter using state-of-the-art electronic components such as Ardupilot Mega 2.6 chip and a GSM module to provide autonomy and orientation in space capability. By increasing the load capacity of the device, it is possible to install additional modules, in particular, a photo or video camera and an OSD module that will allow to overlay the telemetry settings on the image transmitted from the camera. Controlled stable hovering will minimize the negative impact of vibrations that arise during the model's wings movement and save battery life. The principal fly modes of the ornithopter have been worked out in the Mission Planner environment: manual mode, stabilization mode, return to the launch point and the flight through predefined points. There is also ability to modify and optimize autonomous flight modes, improve handling and increase the functionality of the ornithopter.

Key words: unmanned aerial vehicle, design, hardware and software complex, microcontroller, ornithopter.

Introduction. In an unstable and security-oriented environment, developers are increasingly focusing on the use of defense-oriented technologies based on small, remotely-managed mobile platforms or can be programmed for autonomous use without the immediate presence of a person within a range of combat activities or on the territory, which should be monitored.

In the field of defense, real-time observation from a close distance has long become an important necessity, which contributes to the study of various methods of "live" communication on the battlefield to provide the necessary support for the troops. For this purpose, unmanned aerial vehicles (UAVs) are often used - miniature devices that "imitate" the flight of birds.

These aircraft are ideal platforms for a variety of tasks, including monitoring and control systems, where the tidal fleet "flock" will be invisible and thus will have better chances to access secure places than, for example, large aircraft. These systems are widely used in the field of defense for intelligence gathering and surveillance of enemy territory without the detection of the device and without causing suspicion.

Usually real UAV developments include a microcontroller, a set of sensors for determining the required parameters and a surveillance camera for transmitting video information to the receiver in real time. Important attention is paid to optimization of load-carrying capacity, stability during an accident and the ability to repair in field conditions. Due to miniaturization of electronics and the emergence of new composite materials, commercial companies, military units and research laboratories are working on the development of numerous unmanned machines and entire platforms for their research and implementation.

Among the most widely used are propeller vehicles and fixed wing vehicles. However, these devices have a number of disadvantages and are expensive. Therefore, other types of devices with non-standard approaches to the construction and working principles are often considered as an alternative. Such devices are UAVs like ornithopters, which use wing swings to create lift and traction forces. Small ornithopters using wing swings to create aerodynamic forces have a number of advantages as compared to fixed and propeller wings. They are safe to operate because they do not have rotary parts and fuel tanks. It is assumed that by simulating the agility of living flying creatures, ornithopters can be made multi-purpose UAVs.

Analysis of developments and publications. Despite the widespread use of UAV in various fields such as meteorological observations [1], prevention of unauthorized deforestation, emergency forecasting, border patrols (RQ-9 Reaper, USA) [2], etc., the main designation of the UAV is a military branch. Therefore, most of the developments are aimed at defense issues.

With respect to ornithopter-type UAV, the main efforts of the world's developers and researchers are aimed at designing the devices themselves, as well as creating test platforms for the development of autonomous and remote control. One of the known complexes is the prototype of the "Odyssey" ornithopter proposed by laboratory of the University of Merilyn [3,4], whose task is to study the swing of the wings. The data collection is carried out with the using of a specialized chip - an aviation electronics system that contains gyroscopes, accelerometers, magnetometers and other sensors that allow measurements during test flights. Engineers from the same university built a small aircraft with an ornithopter pattern, in which half the area of the surface of the wings is covered with flexible solar panels, which allows to increase the battery life [5,6]. This idea can form the basis of the creation of completely independent miniature drone.

Festo has developed a number of radio-controlled bird-robots of various sizes [7,8], and Clear Flight Solutions - an ornithoplant-type UAV for scavenging birds in selected areas [9]. A research team from Delft University of Technology (The Netherlands) designed a miniature, autonomous, DelFly Explorer micro air vehicle, which holds in the air due to the movement of the wings [10,11]. The device is capable of navigating independently in the air, avoiding collisions with obstacles, and the stock of its battery is enough for 9 minutes of movement. The device has a wingspan 28 cm, and the total weight of the design is 20 grams.

The works of the domestic scientific schools are oriented mainly on the research and development of quadcopter machines, the development of remote control systems [12], methods of vertical takeoff and landing [13], simulation of takeoff and landing control processes [14], software development [15] etc. However, the design of ornithopters is not attracting enough attention.

The aim of this work is to develop own model of hardware and software complex of intellectualized ornithopter-type UAV using the Ardupilot Mega module and GPS to provide autonomy and orientation in space, as well as the development of flight modes of the ornithopter software.

Design of hardware and software complex. In the designed UAV, all elements of the system are connected to the Ardupilot Mega 2.6 chip. The selected platform is positioned as a flight controller, which includes both a regular microcontroller and a fully-fledged autopilot.

Ardupilot is based on ARM 2.x (DIY Drones) and the project contains open source code. The control board combines not only the computing power to deal with the controllers of engines or servo drives, but also a set of sensors (accelerometer, gyroscope, barometer), based on readings of which flight algorithm can be adjusted. The advantage of the board is the availability of autopilot function, which allows the machine to move independently on the given trajectories without external intervention. Various configurations can be used to connect an APM autopilot. In this paper, an airplane type connection is used, which allocates channels for controlling the power plant (Turnigy 2615 EDF Outrunner) and servo drives (Hitec HS-65MG) that are responsible for the control surfaces. Used configurations exploit model of elevator, ailerons and stub (Fig. 1, a) and elevators only (Fig. 1, b).

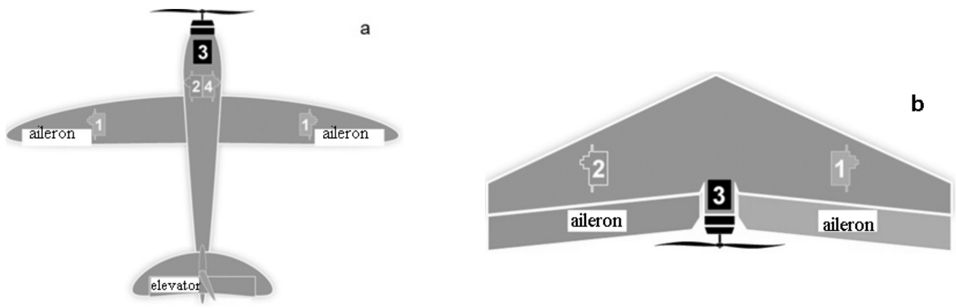

Fig. 1. Ardupilot autopilot configuration using elevator model, aileron and stubble (a) and elevators (b).

In the designed ornithopter model, the main control surface is the tail, which can control pitch movement up and down and provide mixed control - a combination of tail movements from side to side, along the axis of the roll, and up and down for seek mode (the hybrid elevon is realized).

Two models of servomotors are used to control the direction of the model, one of which will bend along with the tail while moving up and down (for controlling the elevon). The servo drive on the pitch is fixed on the fuselage, and for the board on the roll - fixed on a frame that comes back along with the tail. On the lever of this servo, the tail is fixed with two screws. In addition, in this model we implemented the principle of a flexible wing. The fuselage has a fixed movement mechanism (engine, gearbox and two cranks), from which traction with ball pointers goes to the front edges of the wings. Also, the mechanism of the wings flapping provides the possibility of securing a certain position to ensure the planar flight of the ornithopter is maintained as in [16]. View of the designed ornithopter is shown in Fig. 2.

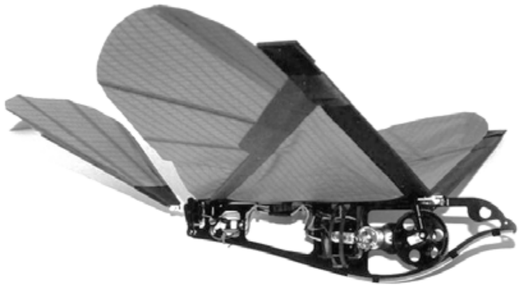

Fig. 2. View of the designed ornithopter.

The electric motor through the two-stage gear reduces the movement of the wings. The configuration connection is organized in such a way that the inputs of the autopilot boards are connected to the four ports of the radio signal receiver. One of them is used to control the engine's turns, the second one - to choose the flight mode and two more - to control the servo drives. Structural and functional diagrams are shown in Fig. 3 and Fig. 4, respectively.

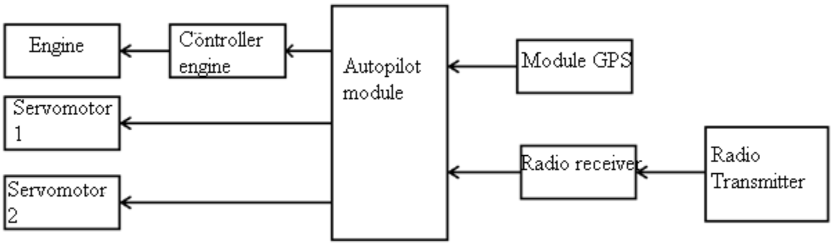

Fig. 3. The block diagram of the connection of the main elements of the designed ornithopter-type UAV.

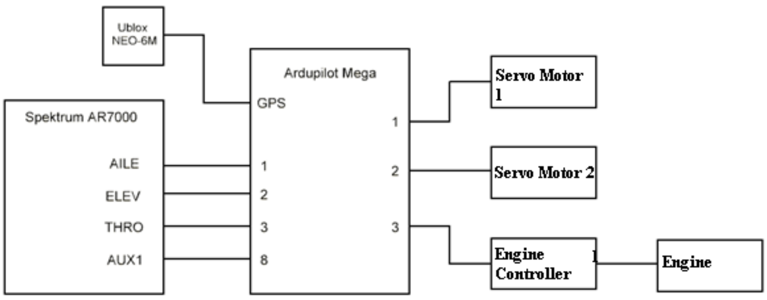

Fig. 4. Functional scheme of the connection of the main elements of the designed ornithopter-type UAV.

Described working algorithm of the system is shown in Fig. 5.

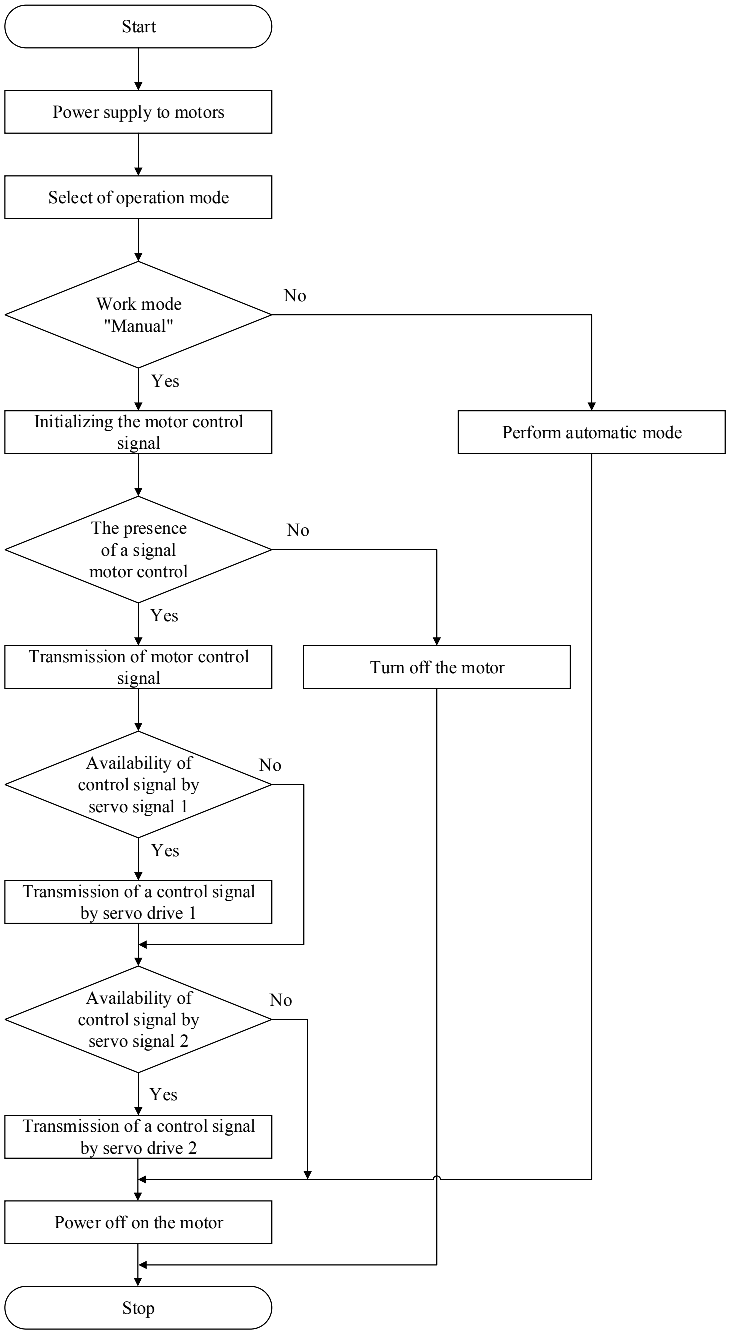

Fig. 5. Algorithm of the functioning of the ornithopter-type UAV system.

Autopilot outputs are connected to the servo drives and to the motor (via the ESC circuit - the speed controller). The GPS module is connected to the corresponding port. The module of autopilot itself is mounted on the fuselage. To recognize the directions of motion and correct positioning, it is mounted on a special stand to reduce the negative impact of vibrations on gyroscopes and accelerometers.

With this configuration, one of the levers of the control panel will be responsible for controlling the speed of the engine and, accordingly, the speed of the model, and the second - for managing the servo, that is, the direction of movement of the device. One of the available switches will be responsible for changing the flight modes.

The designed ornithopter can operate in on of 12 available modes using developed software, those including manual and autonomous control of the device. In this work, attention is focused on the adjustment of several regimes: manual, Stabilize, RTL (return to start location), and AUTO flyover by points (Fig. 6).

The configuration and programming of the board is implemented with the use of the Mission Planner [17,18], which additionally allows you to change the sensor display, build a flight plan, simulate flight for manual control skills, view the so-called “logs” (a separate memory chip in the board for “logging” of flight data, so-called “black box”) etc.

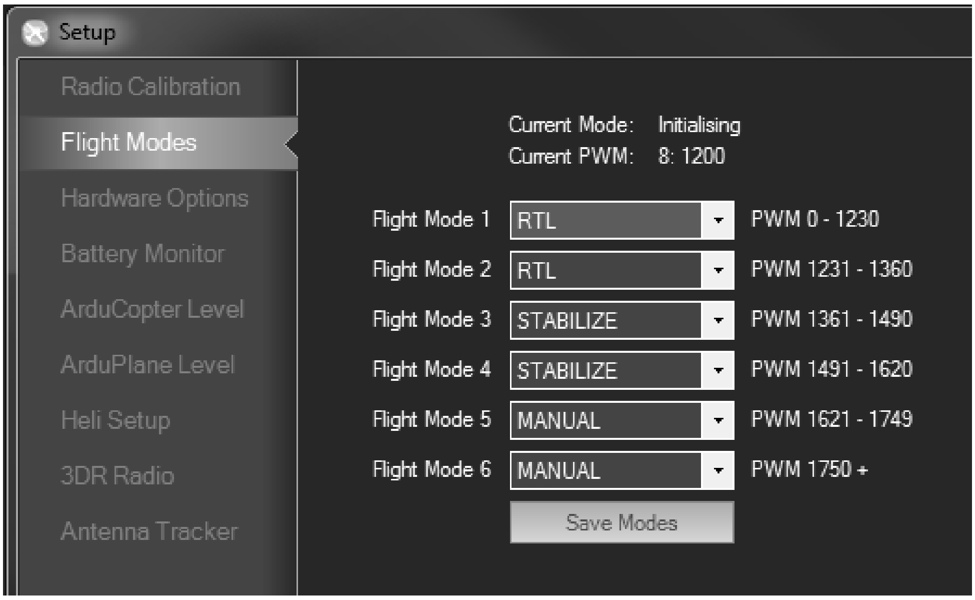

Fig. 6. Configuration of the flight modes of the ornithopter.

Change of regimes was implemented with the switches on the remote control (transmitters) [19,20]. A certain position of the switch corresponds to a certain mode. It is also possible to switch modes through a ground control station, which usually is a computer. For this purpose it is mandatory to install a radio modem module, the availability of which will allow not only to switch modes, but also to obtain telemetry data (Fig. 7).

Fig. 7. Receiving telemetric data with Mission Planner.

In this case, the Mission Planner displays the elevation, speed, conditional horizon, flight mode, the number of the next point and the distance to it. In the absence of such a module, telemetry data can be stored on a memory chip and analyzed later.

Conclusions. Summarizing, the hardware and software complex in the form of a small-sized ornithopter-type UAV can be used to monitor the territory of both military operations and areas of civilian significance. To increase the capacity of the device, additional modules, such as a photo or video camera and an OSD module, which will allow to apply telemetry parameters to the image transmitted from the camera can be installed. Controlled stable hovering will minimize the negative impact of vibrations that arise during the model's wings flapping and save battery life. Changing and optimizing autonomous flight modes can improve handling and enhance the functionality of the ornithopter.

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АПАРАТНО-ПРОГРАМНИЙ КОМПЛЕКС ІНТЕЛЕКТУАЛІЗОВАНОГО БПЛА ДЛЯ ВІЙСЬКОВИХ ЗАСТОСУВАНЬ

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Розглянуто проблему розроблення мініатюрних економних безпілотних літальних апаратів типу орнітоптер для військових застосувань. Проаналізовані основні розробки провідних закордонних та вітчизняних компаній та дослідних лабораторій щодо розроблення та тестування літальних систем. Спроектовано апаратний комплекс у вигляді малогабаритного орнітоптера з використанням сучасної елементної бази на основі мікросхеми Ardupilot Mega 2.6 та модуля GSM для забезпечення автономності та орієнтування у просторі. Вісімнадцять сервоприводів забезпечують рух робота. Конструкцію складових частин робота-гексапода було розроблено у програмному комплексі Solid Works. Відлагодження програми для правильного функціонування проводилася у середовищі Arduino IDE. Також описано налаштування Android додатку Arduino Bluetooth controller, що забезпечує надсилання команд управління з планшетного комп'ютера до робота-гексапода через Bluetooth канал.

Відпрацьовано основні режими керування орнітоптером у середовищі програми Mission Planner: ручний режим, режим стабілізації, режим повернення у точку запуску та облітання за точками. Розглянуто основні класичні алгоритми руху робота, зокрема, рух «вперед», «назад» (полягає у пересуванні трьох кінцівок по черзі, а три інші утримують основу робота), рух «вправо», «вліво» (полягаю у віддаленні кінцівок з однієї сторони та притягувані з іншої), повертання «навколо своєї осі» (полягає у почерговому підтягуванні кінцівок вперед та назад з однієї та іншої сторони), рух «вгору вниз» та «збоку у бік».

Розроблено власні алгоритми руху робота-гексапода, проведено їх дослідження та порівняльний аналіз з класичними алгоритмами. Показано, що запропоновані алгоритми

виконуються за меншої кількості етапів пересування кінцівок, їм властива невелика затримка між пересуваннями сусідніх кінцівок. Розроблені алгоритми забезпечують високу стійкість конструкції до вібрацій під час руху, високу швидкість пересування, стійкість роботи робота до моменту відновлення роботи кінцівок у випадку виходу з ладу однієї з них.

На основі проведених досліджень здійснено вибір найоптимальнішого алгоритму руху робота-гексапода між класичними та розробленими алгоритмами з програмної та технічної точки зору. Також проведено дослідження складності створення алгоритмів руху крокуючих механізмів.

Ключові слова: безпілотний літальний апарат, проектування, апаратно-програмний комплекс, мікроконтролер, орнітоптер, інтелектуалізація.

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