

**MINISTRY OF EDUCATION AND SCIENCE OF THE REPUBLIC OF
KAZAKHSTAN**

**Non-profit joint - stock corporation
ALMATY UNIVERSITY OF POWER ENGINEERING AND
TELECOMMUNICATION named after G. Daukeev
Department of Electronics and robotics**

«Allowed to defence»

The head of department of «Electronics and robotics»

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(Full name, academic degree, rank)

_____ « _____ » _____ 2020 year
(sign)

DEGREE PROJECT

On the topic: Design of an autonomous UAV for special purposes

Done by: _____ Suleimenov A.B. _____ PSa-16-3
(Surname and initials of a student) (group)

Specialty _____ 5B071600 Instrumentation Engineering

Research supervisor _____ Balbayev G.K. PhD , docent
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_____ « _____ » _____ 2020 year
(sign)

Consultants

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_____ « _____ » _____ 2020 year
(sign)

Almaty, 2020

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Institute of _____ space engineering and telecommunications
Department of _____ Electronics and robotics
Specialty _____ 5B071600 Instrumentation Engineering

ASSIGNMENT
for execution of degree project

Student _____ Suleimenov Alibek Batyruly

(Full name)

Topic of the work _____ Design of an autonomous UAV for special purposes

Approved by the order of the rector № 155 from « 23 » october 2020 y.

Deadline of the finished work « 8 » june 2020 y.

Initial data required parameters of the results and initial data:

1. Omnibus F4V3 flight controller
2. GPS Ublox Neo – 7M
3. Lenovo laptop

List of issues to be developed in a degree project or a summary:

1. analyze the world experience in using an automated system in UAVs
2. choose a flight controller that provides the most acceptable flight conditions
3. chart the flight management process
4. calculate data to ensure the safe work of designers
5. calculate production costs, as well as prepare a report-rationale for the economic side of the project

List of graphical material (with precise indication of mandatory drawings);

This degree project contains 51 figures and tables

Recommended basic literature:

1. Bekisheva A.I. Guidelines for the implementation of the economic part of the thesis for bachelors of specialty 5B0703 - Information Systems - Almaty: AUES; 2013. –24 s.
2. Inozemtsev D.P. Unmanned aerial vehicles: Theory and practice // Automated technology for research and design, 2013. No. 2. - S. 50-54.
3. Pavlushenko M., Evstafiev G., Makarenko I. UAV: history, application, threat of spread and development prospects. M., "Human Rights", 2005.

Consultants for work with indication of the relevant section

Section	Consultant	Date	Sign
Life safety	Begimbetova A.S	16.05.2020	
Economic part	Tuzelbayev B.I	18.05.2020	

SCHEDULE

Of degree project preparation

№	Title of section, list of issues to be developed	Deadline for submission to instructor	Note
1	The main part	29.01	
2	Technical part	05.03	
3	Software part	15.05	
4	Life safety	05.05	
5	Feasibility study for the project	31.05	
6	Conclusion	09.06	

Date of issue of the assignment « 20 » 01 2020 year

The head of department Chigambayev T.O.
(sign) (Surname and initials)

Supervisor: Balbayev G.K.
(sign) (Surname and initials)

The assignment for execution is accepted by: Suleimenov A.B.
(sign) (Surname and initials)

Аңдатпа

Дипломдық жоба арнайы мақсаттарға арналған автономды ұшқышсыз ұшу аппаратын (ҰҰА) жасауға арналған. Бұл аппарат объектілерді қашықтықтан бақылауға және аймақты бақылауға арналған болашақ ҰҰА үшін негіз бола алады.

Құрылымдық және функционалдық сызбалар көрсетілді, осы сызбалардың негізінде автономды ұшақтың прототипі әзірленді және модельденді. Прототип INAV Configurator бағдарламасында реттеуден өтіп құрылды. Ұшу миссиялары және ұшу нүктелері арқылы автономияны жүзеге асырудың жолдары анықталды.

Жұмыстың құрылымы кіріспеден, бес бөлімнен, қорытындыдан және әдебиеттер тізімінен тұрады.

Аннотация

Дипломный проект посвящен разработке автономного беспилотного летательного аппарата (БПЛА) для специального назначения, который станет основой для автономных БПЛА используемых в целях дистанционного осмотра объектов и патрулирования.

Были показаны структурные и функциональные схемы, на основе этих схем была реализована разработка и моделирование прототипа автономного летательного аппарата. Настройка и прошивка прототипа была выполнена в программе INAV Configurator. Были найдены пути реализаций автономности посредством полетных миссий при помощи путевых точек.

Структура работы предоставлена введением, пятью разделами, заключением и списком литератур.

Annotation

The graduation project is dedicated to the design of an autonomous unmanned aerial vehicle (UAV) for special purposes, which will become the basis for autonomous UAVs used for remote inspection of objects and patrols.

Structural and functional diagrams were shown; on the basis of these diagrams, the development and modeling of a prototype autonomous aircraft was implemented. The prototype was configured and flashed in the INAV Configurator program. Ways of realizing autonomy through flight missions using waypoints were found.

The structure of the work is provided by the introduction, five sections, conclusion and list of literature.

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Introduction

The changing nature of military operations of possible future wars is associated with the rapid technological formation of all types of weapons, a significant improvement in their tactical and technical effectiveness, aimed at increasing the accuracy of destroying targets, destructive capabilities and speed of delivery of military equipment. Currently, according to new physical principles, the weapon modernization process is accelerating. All this led to the fact that in the second half of the 20th century - the beginning of the 21st century, the main feature of the war was the redistribution of roles in various areas of armed confrontation.

In modern military conflicts, a generalized principle can be seen - the main efforts of the warring parties are not focused on the battle of the advanced units, but on the enemy's fire at ultimate ranges from aerospace directions. The combination of reconnaissance satellites, long-range high-precision weapons and modern information technologies into a single information-reconnaissance-navigation-strike system allows a highly developed state in military-technical terms to achieve a quick victory in military conflicts of various intensities and types without serious losses in one "high-precision battle". The revealed regularity of such military conflicts shows that wars of industrially developed states begin with a massive missile and air strike, in the first echelon of which the latest models of high-precision unmanned weapons are involved. The purpose of such a strike is the destruction of the economy and the most important vital objects of the state, violation of state and military control, counter-force defeat of strategic nuclear forces.

Like most scientific inventions, the first drone was built specifically for military purposes. Historical analysis of unmanned projects shows that they did not suddenly appear. They began their work during the First World War. In the 1930s, the first example of a remote-controlled aircraft appeared; in the 1940s, a long-range nuclear warhead, the first cruise missile in 1950, and drones were used as scouts in the 1960s. In the 1970s, work began to study the influence of unmanned aerial vehicles, in 1980 on the use of cruise missiles, strategic ground, sea and space, in the 1990s, drones were used for long-term monitoring as part of a reconnaissance-strike complex. In the 2000s, combat drones, which can strike ground targets, began to develop [1].

However, truly, the breakthrough of UAVs in the 20th century was in 1933, which is formally considered the founder of all subsequent developments. It was this year that British military engineers first developed unmanned aerial vehicles, which, incidentally, were reusable. The project was named "DH.82B Queen Bee" and was a restored version of the "Fairy Queen" biplane, which was radio-controlled from afar. Moreover, this unmanned ship is designed to become a distracting target aircraft for future aces and anti-aircraft gunners. "DH.82B Queen Bee" served in the British Air Force from 1934 to 1943.

You can quite reasonably talk about the prospects for the development of unmanned aerial vehicles. For single-use UAVs, this is increasing the accuracy of hitting the target, increasing flight range, achieving hypersonic speeds, ensuring a high probability of overcoming air defense and missile defense on a theater of war, creating conventional warheads with high damaging effects, expanding the range of

targets, and the ability to adjust the flight mission during flight , the associated use of a one-time UAV for reconnaissance.

1 The main part

1.1 Setting objectives for implementation in a graduation project

The main goal of the thesis is the creation of an autonomous unmanned vehicle. To achieve the main goal, it is necessary to solve several of the following tasks:

- analyze the world experience in using an automated system in UAVs;
- choose a flight controller that provides the most acceptable flight conditions;
- chart the flight management process;
- calculate data to ensure the safe work of designers;
- calculate production costs, as well as prepare a report-rationale for the economic side of the project.

1.2 Analysis of the use of regulators of automated quadcopter control systems

The use of unmanned aerial vehicles (UAVs) is becoming increasingly popular due to the important advantages in the existence of this type of aircraft technology [2, 3]: the cost of training pilots and flights, as well as ongoing maintenance costs, are reduced. This is especially important when motor circuits are used, which eliminates the need for highly qualified technical assistance for servicing the drone [2].

The multidirectionality of unmanned aerial vehicles allows them to be used to solve various problems: geodetic surveys, monitoring of transport infrastructure, energy and pipeline facilities, compilation of cadastral maps, determination of mineral extraction and calculations of bulk cargo, writing maps and plans of territories, rescue, reconnaissance and military operations, detection of forest fires, aerial photography, etc. The possibility of using UAVs without crew on board allows you to remove the restrictions on the use of drones in the most critical, dangerous and harmful conditions for human life and health.

1.2.1 The classification of the use of various types of drones.

The classification of the use of various types of drones is shown in figure 1.1, the specifics of each type of application is determined by their technical capabilities. Let's just look at the difference between unmanned aerial vehicles of an airplane and a helicopter type [2].

The weight efficiency of the first type of drone is low, due to two main reasons. The first reason is that in the absence of a runway, equipment in take-off and landing modes experiences significant overload, which requires a maximum reduction in structural rigidity and weight.

The second reason is the typical characteristics of large UAVs that use a runway. Usually this is far from the actual use of the aircraft. This means that drones take a long time to reach the field of application, so the amount of fuel required for the flight is very large. It also reduces the possible weight of useful aircraft equipment. Another disadvantage of unmanned aerial vehicles of the aircraft type is that they limit the flight speed to no lower than a certain value, and there is no flight state like hovering [3].

Table 1.1 - Simplified classification of UAVs

UAV classification			
By control method	By design type	By size and weight	By designation
Uncontrolled	Aircraft type	«Micro»	Intelligence
Automatic			Target designation
Remotely piloted	Helicopter type	«Mini»	Remote monitoring and surveillance systems
		medium	strike
		heavy	Multi-purpose

Helicopter drones also have their limitations, but for many tasks their use is preferable. A typical problem solved on the basis of unmanned aerial vehicles is the monitoring of various objects. The most popular domestic and foreign researchers among typical rotary-wing UAVs are quadcopters, the appearance of which is shown in figure 1.1.

The quadcopter is a four-rotor helicopter. A distinctive feature of it from a helicopter is the formation of lift and flight stability with each rotor involved.

Quadcopter is a complex duplicating device with unmodeled dynamics, subject to the influence of external influences [3, 4]. The task of controlling a quadcopter is interesting from a scientific and practical point of view, which leads to significant interest in this topic. The functionality of the proposed solution is considered by various authors, which will be described in the following paragraphs.

Despite the development of modern methods of control theory (TAU) and as a result, PI, PD, PID controllers obtained on their basis are often used in robots. The disadvantages and advantages of these regulatory bodies are well known [4,5]. Based on PI, PD, PID regulators control systems to solve the problem of providing stable flight of the quadcopter, do not provide the required quality, due to the fact that to calculate this parameter it is required to obtain an extremely complex accurate mathematical model of the object of control and disturbances.

1.2.2 The advantages of using the fuzzy logic apparatus.

The advantages of using the fuzzy logic apparatus are the possibility of using intuitive information, expert experience about OS, and the absence of the need for an accurate mathematical model (MM). As a minus, we can consider the iteration of the process of formation of regulators, i.e. the need to select a number of parameters. This is caused by low requirements for information security of control objects, for which fuzzy regulators are synthesized.



Figure 1.1 - The appearance of the quadcopter

The use of the fuzzy logic apparatus today for automation tasks is permissible by two methods. The first is to design a classifier of environments that defines the tasks of the functioning of the system. The second method is the most conservative and is based on the direct regulation of the variables of the control object. Despite the noted differences, these methods are similar to each other.

Figure 1.2 shows the structure of the regulators, presented by various creators, in order to control the flight progress of the quadcopter [6, 7]. briefly analyze the characteristic features of each of them.

The controller shown in figure 1.2, a, [7] consists of four equivalent fuzzy controllers that produce a single control (U) and correction factors according to each of the variables: angles pitch (Pitch), yaw (Yaw), rotation (Roll) (ΔU) according to PID-like law. The calculation of the final control actions for each of the quadcopter motors is performed in the “Agregation” block by summing the values of the regulator outputs.

The feature of the controller shown in Fig. 1.2, b [8] is that it implements forecasting and control at the same time. The controllers FLC_z , FLC_ψ generate control actions U_z , U_ψ directly on the basis of the input values of the controller Z , \dot{Z} , ψ , $\dot{\psi}$. The FLC_x , FLC_y controllers classify situations based on the input of the controller, \dot{X} , \dot{Y} and produce the required values for pitch angle (θ_d) and rotation (ϕ_d), which are subsequently used to form input signals for FLC_θ , FLC_ϕ . The considered controllers carry out PI similar sub-control.

In addition to the structures of regulators shown in figure 1.2, there are others. Due to the fact that fuzzy controllers are synthesized in the absence of MM, the current lack of generally accepted methods for mathematical analysis of fuzzy controllers makes it impossible to say that the solutions obtained on their basis will be the best [9].

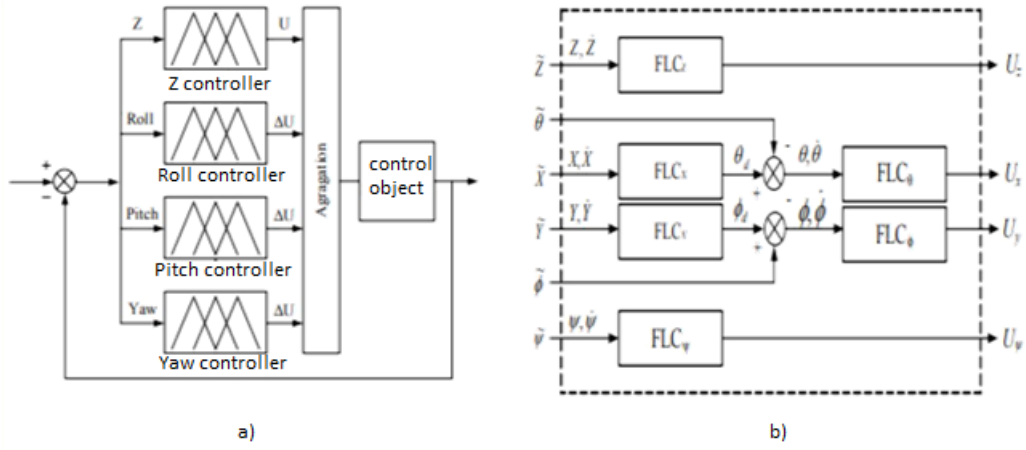


Figure 1.2 - Fuzzy controllers

1.2.3 Artificial neural networks

Artificial neural networks (ANNs) are some alternative for creating intelligent control systems for fuzzy controllers. The application of ANNs to solve control problems is different: they have every chance of being used as an apparatus for emulating, evaluating, modeling the parameters of OS, directly regulating. The interest in the ANN as a base for the organization of control concepts is determined by their ability to function with fuzzy, inaccurate information, which is characteristic of numerous technical OS, also quadcopters [10]. Another good quality of ANN is the ability to create on their basis of robust regulators with significant flexibility to changes in the characteristics of the opamp and the environment, the noise of the sensors. This ensures a significant increase in the accuracy of the controller and expands the range of its practical application in comparison with the classic PID, PI, PD.

The features of ANNs make it possible to carry out composite, nonlinear communications based on them. When designing controllers, the described property simplifies the synthesis of the control system, since the implementation on the basis of the ANN of interconnected control systems does not require the designer specific numerical knowledge about the mutual influence of internal quantities. As a minus, it is possible to indicate the need for a certain number of iterations of the synthesis of the regulator, the great dependence of the development process on the intuition of the designer, the need to obtain training samples in advance, which in itself is a difficult task.

The presence of the ability of dynamic adaptation provides the opportunity to often use ANNs as the basis of self-adjusting regulators [11]. The possibility of flexible adjustment and versatility make it possible to use the ANN as a powerful tool in the hands of the designer. The creation of similar control concepts requires special assumptions, for example, the presence of an idealized mathematical model that provides the ability to establish the desired behavior of the op-amp. The complexity of the practical application of ANNs lies in the huge number of architectures available and the inability to preliminarily note which of them is more suitable for solving a practical problem. The problem is solved by different methods, for example, by conducting experiments with a further choice or on the

basis of expert research. Often, for the purpose of application, the direct distribution ANS, perceptrons are used as the basis of the regulator. In order to ensure that the dynamics of the object are taken into account, special restraining components are introduced into the network structure. There are examples of successful use of other networks, such as recursive ones.

Modern trends in the development of management concepts consists in combining several techniques within the framework of one regulator. This makes it possible to acquire extremely diverse and interesting solutions and is explained by the fact that the formation of multi-purpose controllers with static settings that are suitable for all operating modes of the op amp and provide high-quality control is almost impossible.

1.3 The use of UAVs for various purposes around the world and the development of new directions for the development of this area

Depending on the size and embedded programs, quadcopters have different purposes. Hence the various options for their application. The largest and most serious models are used in the army - they are equipped with fixed wings and require short runways. There are units that are used for geographic survey of the area, the fight against poaching and for meteorological purposes. Smaller drones use vertical take-off and landing technology. And very, very tiny models run from the palm of your hand.

Goods delivery. A number of large trading and postal companies have seriously considered investing in the development of drones involved in the delivery of parcels, mail, medicines, and food. The delay in launching such projects lies only in some technical problems in the conditions of dense urban development, as well as the interaction of drones with aircraft in the free zone. Drone Courier is shown in figure 1.2.



Figure 1.2 – Delivery drone

Journalism assistant. Events on the battlefield, large-scale events, sports can now be observed online, which increases the degree of consumer confidence in information and takes modern journalism to a new level. The digital age has made major changes to the nature of journalism and the evolution of information

dissemination. You can stay at the forefront of collecting and submitting information using a quadrocopter. The concept of “unmanned journalism” allows you to give viewers multimedia news content in real time.

Considering how and what can be done with the help of this device, the Association of Photographers of America together with the Google News Laboratory presented an innovative program for training journalists to use drones. The Drone Journalism School created by them considers not only the collection of information, but also pays great attention to the ethical and legal issues of mass communication data.

Transportation of medicines. Quadrocopters deliver blood, transplants, vaccines to patients in underdeveloped countries - Rwanda, Tanzania, Papua New Guinea. It is this area of use of quadrocopters that is most demanded and appreciated by physicians.

The use of devices in emergency situations proved their indispensability after the earthquake in Haiti in 2012, the typhoon in the Philippines and other regions where the infrastructure was completely destroyed. The leader in saving people and delivering medicine using drones is California-based Zipline, which works closely with Doctors Without Borders. One prototype is shown in figure 1.3.

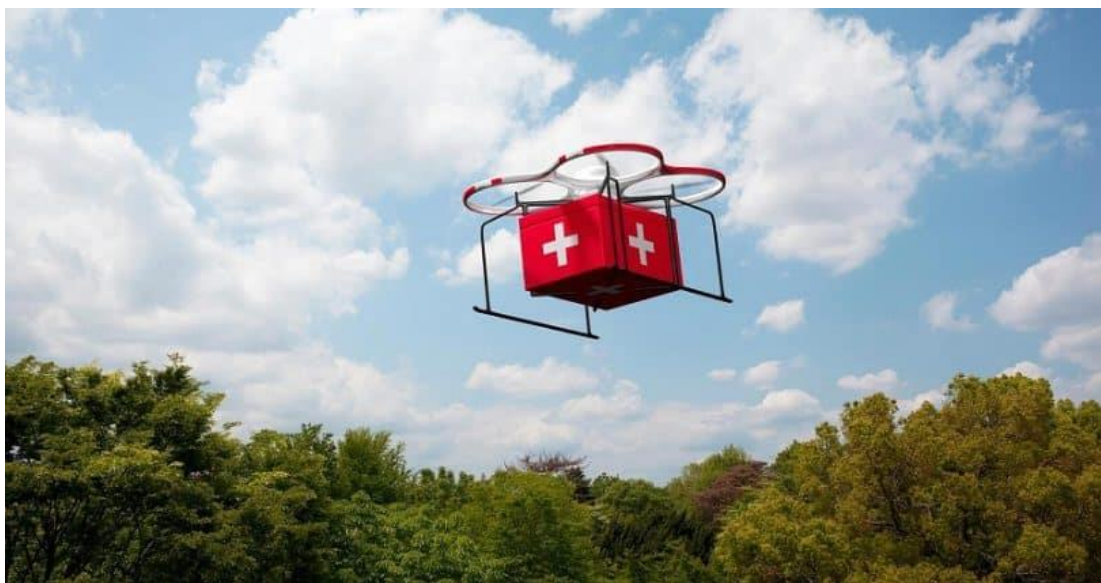


Figure 1.3 – Medical drone

Wildlife watching. Monitoring of the animal population, determination of their habitat on the scale of large geographical areas becomes possible with the advent of an unmanned inspection system. According to experts, drones are the safest, most environmentally friendly and inexpensive alternative to manned aircraft.

Quadrocopters, which can shoot in several modes, (DJI Spark) can be used in extreme situations, in large areas, without unnerving the animals and without breaking their rhythm of life. With their help, researchers monitor the behavior of penguins in Antarctica, the movement of humpback whales off the coast of Chile, observe bird flights, and monitor the migration routes of elephants in India. Using photo and video material, scientists have found habitats of wild animals that are on the verge of extinction, and can prevent their death.

Disaster relief. Unmanned aerial vehicles will help with technological disasters, when humanitarian workers cannot gain access to disaster areas. They will assess the damage caused by accidents at industrial enterprises, railway accidents with dangerous goods, terrorist acts, determine the degree of contamination of large areas with chemical or nuclear waste, and provide assistance to victims.

So, in 2011, during the tsunami in Japan, the building of the Fukushima nuclear power plant was damaged. A whole army of drones evaluated the situation and the degree of destruction of the station. These devices participated in monitoring the radiation threat, and monitored the spread of radiation to other territories. One of these drones is shown in figure 1.4.



Figure 1.4 – Disaster assessment drone

Help to farmers. In agriculture, drones equipped with thermal imagers measure plant growth. Multispectral sensors allow the farmer to monitor the application of irrigation, fertilizers and pesticides in the required places. They can also monitor the health of crops, their infection with fungal or bacterial infections.

In addition, the fields can be cultivated using drones in complex geographical landscapes, spraying fertilizers in those places where the plane cannot reach. Using ultrasonic sonar technology, spray drones accurately carry out the spraying procedure, avoiding the risk of excessive application of chemicals. Figure 1.5 shows a farmer drone.



Figure 1.5 – Farm drone

National Border Protection. The use of drones to protect state borders is popular and effective. Such drones can be equipped with face and license plate recognition systems of cars, thermal imagers, technology for intercepting phone calls. It is very convenient for preventing and responding to incidents at the border. In addition, it is a convenient way to control the situation in inaccessible border areas. With the help of drones, border guards can track smugglers, drug dealers and prevent illegal border crossings in difficult areas. One of the solutions for observing the state border using a drone is shown in figure 1.6.



Figure 1.6 – drone border guard

Crime control. The safety of police officers has increased significantly with the use of quadcopters (DJI Phantom 4 PRO). Effective use of drones is especially advisable in the following cases:

- Traffic accident analysis. Pictures from the drone's camera record all the details of the accidents, the urgency of calling medical services, the route to the scene;

- Crowd monitoring. Large events, concerts, sports, parades are usually accompanied by a huge number of people. Drones provide an opportunity to assess the threat, regulate the passage of the crowd along paths that do not allow crowding, to see foreign objects;

- Inspection of bombs. Examination of suspicious packages or bags can be carried out using a drone to assess the initial threat and decide on the degree of danger;

- Tracking criminals in the dark. The presence of thermal imagers on the drone's camera helps the police to pursue criminals, guided by data from the drone. Figure 1.7 shows one of the solutions for the police.



Figure 1.7 – Drone for police

2 Technical part

2.1 Mathematical description of the quadcopter model

In this chapter, much attention will be paid to mathematical description of the quadcopter model, which will be used later for analysis and the principle of operation of the quadcopter, and more specifically: kinematics and driving dynamics; forces acting on UAVs; simplifying assumptions mathematical expressions. Based on these data, we can analyze the principles of SU..

Each of the engines creates traction and torque. For to compensate for the moments of rotation, a pair of engines 1 and 3 rotate clockwise, and rotors 2 and 4 - counterclockwise (see. fig. 2.1). Thereby moments created by a pair of engines 1 and 3 are compensated by moments the other pair - 2 and 4.

The movement of the quadcopter is made by changing speeds engine rotation. To change the roll (ϕ), increase the angular rotational speed of engines 1 and 2, and also reduce rotational speed 3 and 4. Pitch (θ) is changed in the same way. Changes yawing is more difficult: engine rotation speed increases 1-3 and the rotation speed 2-4 decreases. Changing the angular velocity of two screws (pairs of screws) is necessary in order to maintain overall traction, created by 4 screws unchanged.

Accepted Assumptions:

- a) the quadcopter is symmetrical about the x and y axes;
- b) the quadcopter frame and its screws are absolutely rigid;
- c) each engine is located at the end of the rod;
- d) the thrust created by each screw is perpendicular to the x-y plane.

To describe the position and movement of the quadcopter in space will use inertial and associated CO, therefore it is necessary to describe the transformation from one coordinate system to another.

The use of several COs is necessary for the following reasons:

- a) Newton's equations of motion are derived relatively motionless inertial reference system. However, movement is most easily described in associated CO;
- b) aerodynamic forces and moments are also most easily described in associated CO;
- c) airborne UAV sensors receive information regarding bound CO [12].

Figure 2.1 shows an image of an inertial system coordinates with vectors x, y, z, relative to which the bound quadcopter coordinate system. Euler angles used in bound CO - roll angle - ϕ , pitch angle - θ and yaw angle - ψ .

Figure 2.1 also shows the positive directions of rotation. quadcopters along the axes. The connection between the two RMs is carried out using rotation matrices [13], which is a supercomposition of three matrices rotation around each axis:

$$R = \begin{vmatrix} c\theta c\psi & s\phi s\theta c\psi - c\phi s\theta & c\phi s\theta c\psi + s\phi s\psi \\ c\theta s\psi & s\phi s\theta s\psi + c\phi c\psi & c\phi s\theta s\psi - s\phi c\psi \\ -s\theta & s\phi c\theta & c\phi c\theta \end{vmatrix} \quad (2.1)$$

In order to avoid cumbersome expressions for the functions sin and cos abbreviations s and c were introduced respectively.

Motors 1-4 are DC electric drives, rotation which is transmitted to the screw

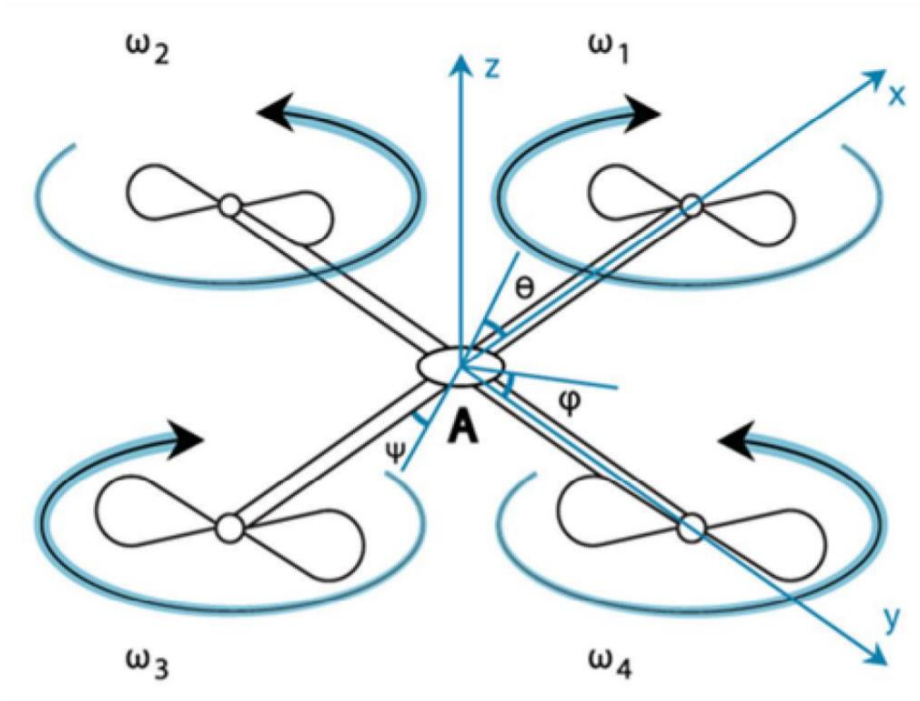


Figure 2.1 - Reference systems and direction of rotation

through the gearbox. Figure 2.2 shows the equivalent circuit of the armature of the electric motor (Armature circuit) and shaft [14].

In this model, the input voltage U is applied to the ED armature, and the output is the shaft rotation speed \dot{c} . Anchor and shaft are considered absolutely rigid. Also in this model, viscous friction (b) is taken into account - the friction moment is proportional to the shaft rotation speed.

ED parameters:

- Jr - moment of inertia of the shaft, $\text{kg} \cdot \text{m}^2$;
- b - coefficient of viscous friction, $\text{N} \cdot \text{m} \cdot \text{s}$;
- Ke - coefficient of electromotive force (EMF), $\text{V} \cdot \text{s} / \text{rad}$;
- Kt - engine rotation moment, $\text{N} \cdot \text{m} / \text{A}$;
- R - electrical resistance of the circuit, Ohm ;
- L - inductance, GN .

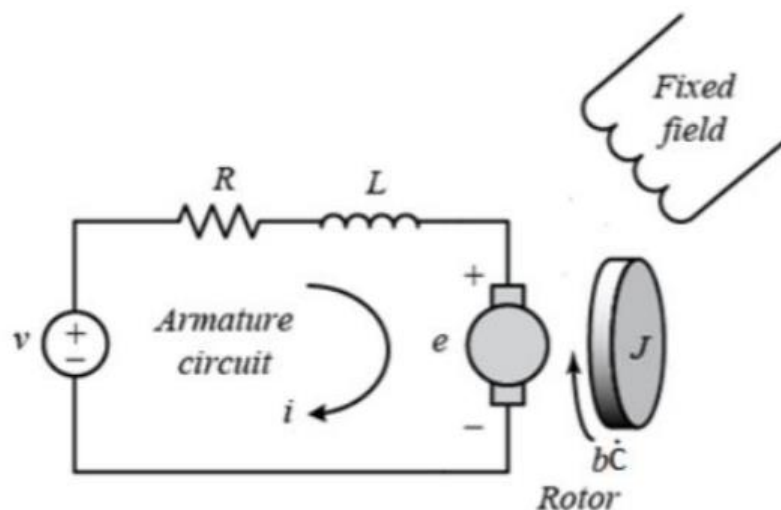


Figure 2.2 - Electric drive scheme

In general, the torque generated by the engine is proportional armature current and magnetic field strength. Assume that the magnetic field is not changes, then the rotation moment is proportional to the current in the armature circuit:

$$M = K_t i. \quad (2.2)$$

Self-induction occurring in the circuit is proportional to speed shaft rotation and is connected with it by a coefficient K_e :

$$e = K_e \dot{c}. \quad (2.3)$$

Based on Newton's 2nd law and Kirchhoff's law of stresses, we we can write the following system:

$$\begin{cases} J_r \times \ddot{c} + b \times \dot{c} = K_t i \\ L \frac{di}{dt} + R_i = U - K_e \dot{c} \end{cases} \quad (2.4)$$

Knowing the engine speed, we can find the thrust that quadcopter propellers develop:

$$F = C_T \rho A (c R_{rad})^2, \quad (2.5)$$

Where C_T – traction coefficient;

ρ – air density;

A – area of the disk that the propeller forms;

R_{rad} – rotor radius [12].

The equation describing the motion of a quadrocopter in inertial reference frame has the form [15]:

$$\begin{bmatrix} \ddot{x} \\ \ddot{y} \\ \ddot{z} \end{bmatrix} = \frac{1}{m} \left(\sum_{i=1}^4 F_i \right) R \bar{e}_3 + (g_r(z) - g) \bar{e}_3, \quad (2.6)$$

Where \ddot{x} , \ddot{y} , \ddot{z} – accelerations along the respective axes,

m – total mass of the quadcopter,

F_i – forces created by the i -th engine,

$\bar{e}_3 = [0 \ 0 \ 1]^T$ – vector column with which to describe only movement along the z axis;

$g_r(z)$ – the effect of the earth, it is supposed to be unknown;

g - gravity acceleration.

The system of equations describing the motion of a UAV in a coupled system coordinates [3]:

$$\begin{aligned} \ddot{\phi} &= \frac{l(F_2 - F_4)}{J_1}, \\ \ddot{\theta} &= \frac{l(F_3 - F_1)}{J_2}, \end{aligned} \quad (2.7)$$

$$\ddot{\Psi} = \frac{l(F_1 - F_2 + F_3 - F_4)}{j_3},$$

where $\ddot{\Phi}$, $\ddot{\Theta}$, $\ddot{\Psi}$ are accelerations of rotation around the axes x, y, z, respectively;

l – distance from the center of the frame to the engine;

J_1, J_2, J_3 – moments of inertia with respect to the x, y, z axes, respectively;

ρ is the scaling factor.

In order to simplify (2.6) and (2.7), we introduce the following variables:

- u_1 – resulting normalized traction;

- u_2, u_3, u_4 – control variables for roll, pitch and yaw respectively.

These variables will be used as input impacts.

$$\begin{aligned} u_1 &= \frac{(F_1 + F_2 + F_3 + F_4)}{m}, \\ u_2 &= \frac{l(F_2 - F_4)}{j_1}, \\ u_3 &= \frac{l(F_3 - F_1)}{j_2}, \\ u_4 &= \rho \frac{l(F_1 - F_2 + F_3 - F_4)}{j_3}, \end{aligned} \quad (2.8)$$

Then (2.6) and (2.7), taking into account (2.8), can be written as:

$$\ddot{x} = u_1(\cos\phi \sin\theta \cos\psi + \sin\phi \sin\theta), \quad (2.9)$$

$$\ddot{y} = u_1(\cos\phi \sin\theta \cos\psi + \sin\phi \sin\psi), \quad (2.10)$$

$$\ddot{z} = u_1 \cos\phi \sin\theta - g - g_r(z), \quad (2.11)$$

$$\ddot{\Phi} = u_2 l, \quad (2.12)$$

$$\ddot{\Theta} = u_3 l, \quad (2.13)$$

$$\ddot{\Psi} = u_4 l. \quad (2.14)$$

Introduce the vectors:

- $x = [x \ y \ z \ \phi \ \theta \ \psi]^T$,

- $u = [u_1 \ u_2 \ u_3 \ u_4]^T$.

Then (2.9) - (2.14) in matrix form can be written as:

$$\ddot{x} = f(x) + g(x)u + f_r(x), \quad (2.15)$$

Where

$$\begin{aligned}
f(x) &= [0 \ 0 \ -g \ 0 \ 0 \ 0]^T, \\
f_r(x) &= [0 \ 0 \ -g_r(z) \ 0 \ 0 \ 0]^T, \\
g(x) &= \begin{bmatrix} \cos\phi\sin\theta\cos\psi + \sin\phi\sin\theta & 0 & 0 & 0 \\ \cos\phi\sin\theta\sin\psi + \sin\phi\sin\psi & 0 & 0 & 0 \\ \cos\phi\cos\theta & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}
\end{aligned}$$

Note that the resulting system is not fully controllable: we cannot directly affect the x and y coordinates.

Often the mathematical model of the control object (OS) does not accurately describe the OS itself; it is often impossible to take into account possible disturbances. The engineer's task is to ensure a high level of reliability of the control system, despite these deviations in the description of the model and in conditions of limited uncertainty. Many robust methods have been developed for this, one of which is the sliding control method. SUs using this method are called variable structure systems (SPS). The main advantage of the sliding control mode is that it is possible to choose the so-called sliding or switching plane along which the system will move. It is so named for the following reason: if the trajectory of the system moves above this plane, the proportional coefficient has one sign, but as soon as the trajectory is under the selected plane, the coefficient will change the sign to the opposite. An important point here is the choice of this same plane. In the process of operation of the control system, its structure is constantly changing - moving from one to another - which is the name of the ATP [16].

As mentioned above, the quadcopter is not a complete system controllable. In order to start the synthesis of the regulator, it is necessary complement the original system so that the matrix g becomes square and, as corollary reversible. To do this, you need to enter two auxiliary variables: u_5 and u_6 . In this way, we circumvented the problem of incomplete manageability of the system. Then we write (2.15) as:

$$\ddot{x} = f(x) + G(x)U + f_r(x), \quad (2.16)$$

where $G(x) = [g(x), g_s]$;

$U = [u^T, u_s^T]^T$;

$v = g_s u_s$;

$g_s = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix}^T$ – constants;

$v = [u_5 \ u_6 \ 0 \ 0 \ 0 \ 0]^T$ – member required for compensation entered variables.

Now that the matrix G (x) is square, we can find the inverse [15]:

$$g^{-1} = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{l} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{l} & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix}. \quad (2.17)$$

In this case, we assume that the angles vary slightly.

As mentioned above, the trajectory of the system can be stabilize with a slider. To do this, we choose a plane $s = 0$ that would provide the desired dynamic properties. To do this, we introduce the error vector:

$$e = x - x_d, \quad (2.18)$$

where $x_d = [x_d, y_d, z_d, \phi_d, \theta_d, \psi_d]$ – desired system state vector.

Then the slip plane is defined as:

$$S = [s_1, s_2, s_3, s_4, s_5, s_6]^T = \dot{e} + Ke, \quad (2.19)$$

where, $K = \begin{bmatrix} k_1 & \dots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \dots & k_6 \end{bmatrix}$ – diagonal matrix with positive elements.

A non-linear controller will be used in the work, due to the complexity of the control object and the task we set. For the synthesis of nonlinear controllers often the second (direct) Lyapunov method is used. He says that if there exists a positive definite function $L(x)$, and its derivative $\dot{L}(x)$ negatively defined, then the selected equilibrium position is stable [15]. However, we are interested in one of the consequences of this theorem. It talks about that if the conditions of the second Lyapunov method are satisfied, then there asymptotically stable sliding mode [15]. So, if we if we can choose the Lyapunov function, then we prove the stability of our slip mode.

In order to get rid of the nonlinearities in (2.13), we need introduce an estimate of the values of v and $f_r(x)$, which we denote by \hat{v} and $\hat{f}_r(x)$ respectively. And introduce the following variables:

- $\tilde{v} = v - \hat{v}$;
- $\tilde{f}_r(x) = f_r(x) - \hat{f}_r(x)$.

Let the Lyapunov function have the form:

$$L = \frac{1}{2} S^T S + \frac{1}{2} \tilde{v}^T \Gamma \tilde{v} + \frac{1}{2} \tilde{f}_r(x)^T \Omega \tilde{f}_r(x), \quad (2.20)$$

where Γ and Ω positive diagonal matrices.

Multiplying the row vector by the matched column vector, we get the sum of the product of the elements. Consider the term $\frac{1}{2} S^T S$ from (2.20):

$$\frac{1}{2} \begin{bmatrix} S_1 & S_2 & S_3 & S_4 & S_5 & S_6 \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \\ S_3 \\ S_4 \\ S_5 \\ S_6 \end{bmatrix} = \frac{1}{2} (s_1^2 + s_2^2 + s_3^2 + s_4^2 + s_5^2 + s_6^2). \quad (2.21)$$

The resulting sum is always positive (complex numbers are not considered). Then the remaining members are also always positive, so as \tilde{v} and $\tilde{f}_r(x)$ are also column vectors, and the elements of the diagonal matrices are non-negative. Thus, the selected Lyapunov function is positive definite.

Suppose that v and $f_r(x)$ change slowly enough so that

$$\tilde{v} \cong -\hat{v} \text{ и } \tilde{f}_r(x) = -\hat{f}_r(x).$$

Next, we need to find the time derivative of the Lyapunov function. In general terms, it will be written as:

$$\dot{L}(\tilde{S}, \tilde{v}, \tilde{f}_r(x)) = \frac{dL(\tilde{S}, \tilde{v}, \tilde{f}_r(x))}{d\tilde{S}} * \frac{d\tilde{S}}{dt} + \frac{dL(\tilde{S}, \tilde{v}, \tilde{f}_r(x))}{d\tilde{v}} * \frac{d\tilde{v}}{d\tilde{S}} + \frac{dL(\tilde{S}, \tilde{v}, \tilde{f}_r(x))}{d\tilde{f}_r(x)} * \frac{d\tilde{f}_r(x)}{dt} \quad (2.22)$$

$$\frac{d\tilde{f}_r(x)}{dt} = S^T \dot{S} + \tilde{v}^T \Gamma \dot{\tilde{v}} + \tilde{f}_r(x)^T \Omega \dot{\tilde{f}}_r(x).$$

Derivative S : $\dot{S} = \ddot{e} + Ke = \ddot{x} - \ddot{x}_d + Ke$ Knowing \ddot{x} , we can substitute this expression in (2.22), we obtain:

$$\dot{L} = S^T [f(x) + G(x)U - \ddot{v} + \tilde{f}_r(x)\ddot{x}_d + Ke] + \tilde{v}^T \Gamma (-\dot{\tilde{v}}) + \tilde{f}_r(x)^T \Omega \dot{\tilde{f}}_r(x). \quad (2.23)$$

In order to make the derivative of the Lyapunov function negative certain we choose the control action:

$$U = G^{-1}(x)[f(x) + \hat{v} - \tilde{f}_r(x) + \ddot{x}_d - Ke - \text{diag}[c_1, c_2, \dots, c_6] \text{sign}(S)]. \quad (2.24)$$

Substituting (2.22) into (2.23) we obtain:

$$\dot{L} = \tilde{v}^T [-S - \Gamma \dot{\tilde{v}}] + \tilde{f}_r(x)^T [S - \Omega \dot{\tilde{f}}_r(x)] - C^T |S|, \quad (2.25)$$

where, $C = [c_1 \ c_2 \ c_3 \ c_4 \ c_5 \ c_6]^T$ – column vector of input coefficients.

Now we can define the previously introduced variables u_5, u_6 , and also evaluate the unknown perturbation $g_r(z)$:

$$\dot{\tilde{v}} = [\dot{e}_x + k_1 e_x \dot{e}_y + k_2 e_y \ 0 \ 0 \ 0 \ 0]^T, \quad (2.26)$$

$$\hat{f}_r(x) = [0 0 \dot{e}_z + k_3 e_z + k_3 e_z 0 0 0]^T. \quad (2.27)$$

If the vector $C = [c_1 \ c_2 \ c_3 \ c_4 \ c_5 \ c_6]^T$ positive and, given (2.26) and (2.27), we have:

$$\dot{L} = -C^T |S| < 0. \quad (2.28)$$

Equation (2.28) suggests that there is an asymptotically stable sliding mode for the selected controller [15].

Since we cannot directly control the x and y states from the inputs, it is necessary to enter the desired coordinates that would allow us to change these states. These coordinates are roll - changes the position along the y axis and pitch - changes the position along the x axis. Mathematically denote them as [14]:

$$\phi_d = \dot{e}_y + k_\phi e_y. \quad (2.29)$$

$$\theta_d = \dot{e}_x + k_\theta e_x. \quad (2.30)$$

2.2 Description of the construction of the quadcopter and the details of the quadcopter

Quadcopters are represented by a variety of different forms, but all of them are united by four rotors. Despite the apparent symmetry, it is necessary to distinguish where the quadcopter is in front (shown by the arrow in figure 2.3). Here, as with radio-controlled car models: with the “forward” command, the quadcopter does not fly where the pilot is looking, but where the imaginary “nose” of the quadcopter is directed. Front screws or beams of the same color can partially help to solve this problem.

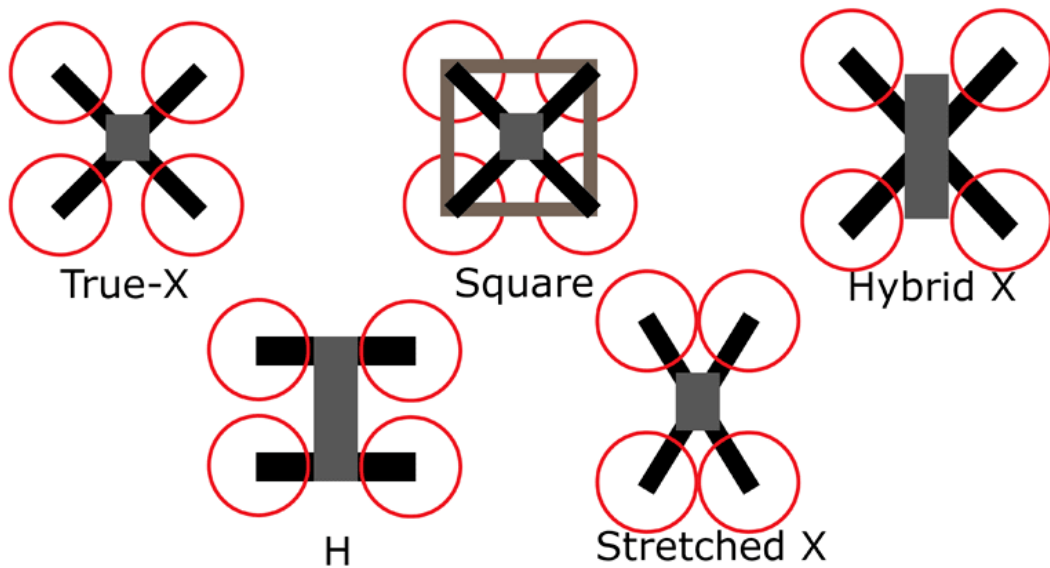


Figure 2.3 - Types of quadcopters

In this project, a quadcopter will be constructed on a frame of the "X" shape. Each design has its own advantages and purpose. In addition to quadcopters, there are other multicopters. Figure 2.4 is a diagram showing how the quadcopter is arranged inside. The pitch, roll and yaw angles (pitch, roll, yaw) are the angles by which it is customary to determine and set the orientation of the quadcopter in space. Sometimes the word “angle” is omitted and they simply say: pitch, roll, yaw. Quadcopter flight in the required direction is achieved by changing these three angles. For example, to fly forward, the quadcopter should lean due to the fact that the rear motors spin a little more than the front ones.

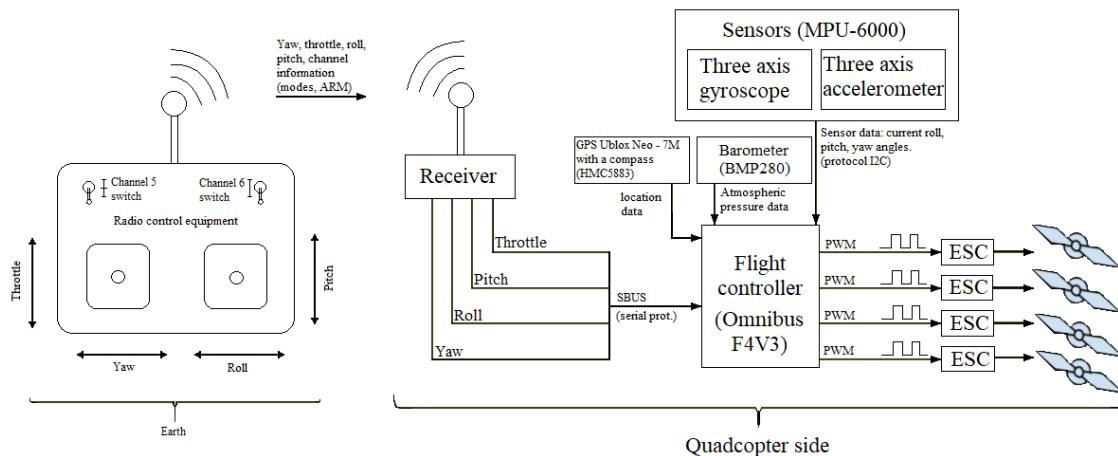


Figure 2.4 - Schematic representation of the operation of the quadcopter

Quadcopter gas is the arithmetic mean between the speeds of rotation of all motors. The more gas, the greater the total thrust of the motors, the stronger they lift the quadcopter up. Usually measured as a percentage: 0% - the motors are stopped, 100% - rotate at maximum speed. Hanging gas is the minimum gas level that is necessary so that the quadcopter does not lose altitude. Gas, pitch, roll, yaw - if it is possible to control these four parameters, then it is possible to control the quadcopter. They are also sometimes called control channels. In order to fully control the quadcopter, we need at least 4 control channels, the receiver I use has 10 channels, which provides complete control over the quadcopter.

The direction of rotation of the screws is not chosen randomly (see fig. 2.5).

If all the motors rotated in one direction, the quadcopter would rotate in the opposite because of the moments created. Therefore, one pair of opposing motors always rotates in one direction, and the other pair - in

another one. The effect of the appearance of moments of rotation is used to change the yaw angle: one pair of motors starts to rotate a little faster

another, and now the quadcopter slowly turns to face us:

- LFW - left front clockwise rotation (left front, clockwise rotation)
- RFC - right front counter clockwise rotation (right front, counterclockwise rotation)
- LBC - left back counter clockwise rotation (left back, counterclockwise rotation)
- RBW - right back clockwise rotation (right back, clockwise rotation).

The speed of the motors is controlled by the flight controller. Typically, this is a small board or box with many inputs and outputs.

There are a huge number of different controllers with a different set of features, different firmware, different tasks. The generalized task of the flight controller is several tens of times per second to carry out a control cycle which includes: reading sensor readings, reading control channels, processing information and issuing control signals to motors to execute pilot commands.

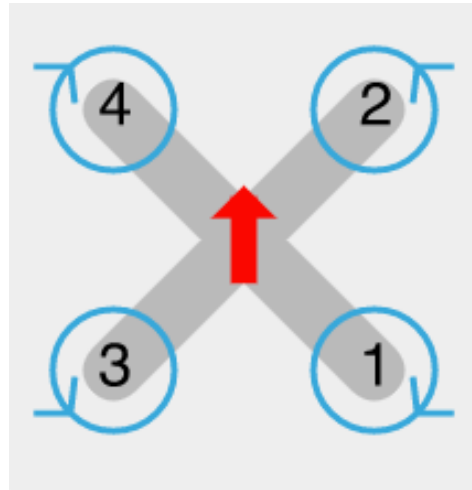


Figure 2.5 - Image of the directions of rotation of the quadcopter propellers

The accelerometer measures acceleration, the gyroscope measures angular velocity. Thanks to them, the flight controller recognizes the current pitch, roll and yaw. These sensors are built-in to the flight controller, but are external.

Multicopter motors consume large currents, so the flight controller does not directly control them, but through special hardware drivers called speed controllers (ESC). These regulators are powered by the main on-board battery, a control signal is received from the controller, and at the output they have three wires (A, B, C) that directly go to the motors.

To command the motor to rotate at maximum speed, the controller must send pulses of 2 milliseconds duration, alternating with a logic zero of 10 to 20 milliseconds duration. A pulse duration of 1 millisecond corresponds to a motor stop, 1.1 ms - 10% of the maximum speed, 1.2 ms - 20%, etc. In practice, the duration of zero does not play any role, only the duration of the pulse itself is important.

In addition to the program for the flight controller, another program is needed: the flight controller configuration interface. Most often, it is a PC program that connects to the flight controller via USB and allows the user to configure and check the flight program, for example: start calibration of the radio, adjust the stabilization parameters, check the operation of the sensors, set the flight route on the map, determine the behavior of the multicopter when the signal is lost and much more.

The flight controller continuously receives commands from the ground: “roll of 30 degrees”, “roll of -10 degrees”, “roll of 0 degrees (keep the horizon)”; its task is to perform them as quickly and accurately as possible with the help of motors, taking into account: wind, uneven distribution of the weight of the quadcopter,

uneven wear of the motors, inertia of the quadcopter, etc. Thus, the flight controller must continuously solve the problem of what rotation speed to apply to each motor, taking into account the current value of the angle of heel and the required. It all depends on the computing capabilities of a particular hardware. On Arduino, it is possible to fit one iteration of the processing and control cycle in 10 milliseconds. This means that once every 10 milliseconds the readings of the angles of the quadcopter will be read, and on their basis control signals will be sent to the motors. These 10 milliseconds are called the regulatory period. It is clear that the smaller it is, the more often and more accurately regulation occurs.

3 Software-design documentation

3.1 Configuring the flight controller.

In this part, the commands for configuring the quadrocopter firmware will be explained. The firmware of the flight controller has the basic settings for the available sensors, but the sensors need proper calibration. For proper flight, you need full tuning of the flight controller. The firmware of the controller was performed through the INAV Configurator. Further configuration of the flight controller is made in the CLI of this program, which is a kind of text interface.

Figure 3.1 shows the command setting values for calibrating the gyroscope, accelerometer, barometer and compass. Correct calibration of these sensors is important for quadrocopter flight. The accelerometer and gyroscope are responsible for the position of the quadrocopter in space, they serve to stabilize the UAV. The barometer, by the method of measuring atmospheric pressure, determines the height of the quadrocopter, and helps it to maintain the set altitude in ALTHOLD mode.

A compass is needed to control the quadrocopter using GPS. In autopilot mode, which will be used during autonomous flight on flight missions to control UAVs, GPS will be based on compass readings. Also, before setting the values, models of sensors that were installed or connected to the flight controller were selected, the corresponding commands are also shown in the figure.

```
# set looptime = 500
looptime set to 500
# set gyro_hardware_lpf = 256HZ
gyro_hardware_lpf set to 256HZ
# set gyro_lpf_hz = 110
gyro_lpf_hz set to 110
# set gyro_lpf_type = PT1
gyro_lpf_type set to PT1
# set gyro_stage2_lowpass_hz = 250
gyro_stage2_lowpass_hz set to 250
# set gyro_stage2_lowpass_type = PT1
gyro_stage2_lowpass_type set to PT1
# set dynamic_gyro_notch_enabled = ON
dynamic_gyro_notch_enabled set to ON
# set dynamic_gyro_notch_q = 200
dynamic_gyro_notch_q set to 200
# set acc_hardware = MPU6000
acc_hardware set to MPU6000
# set acczero_x = 76
acczero_x set to 76
# set acczero_y = -6
acczero_y set to -6
# set acczero_z = 153
acczero_z set to 153
# set accgain_x = 4108
accgain_x set to 4108
# set accgain_y = 4065
accgain_y set to 4065
# set accgain_z = 4014
accgain_z set to 4014
# set mag_hardware = HMC5883
mag_hardware set to HMC5883
# set magzero_x = 92
magzero_x set to 92
# set magzero_y = 1
magzero_y set to 1
# set magzero_z = -74
magzero_z set to -74
# set baro_hardware = BMP280
baro hardware set to BMP280
```

Figure 3.1 - Commands for calibrating sensors

Figure 3.2 shows the settings of the radio receiver for communication with the flight controller. A command is given to set the SBUS protocol for a receiver, which is a serial data protocol.

```
# set receiver_type = SERIAL
receiver_type set to SERIAL
# set min_check = 1050
min_check set to 1050
# set serialrx_provider = SBUS
serialrx_provider set to SBUS
```

Figure 3.2 - Radio receiver settings

In figure 3.3, the command sets the idle speed of the motors, the values are indicated as a percentage of power.

```
# set throttle_idle = 22.000  
throttle_idle set to 22.000
```

Figure 3.3 - Idle speed setting

Figure 3.4 shows the values set for tuning the PID controller. Tuning the PID controller is important for UAV flight stability, as it reads data from sensors and adjusts engine rotation for optimal flight.

```
# set mc_p_pitch = 47  
mc_p_pitch set to 47  
# set mc_i_pitch = 20  
mc_i_pitch set to 20  
# set mc_d_pitch = 40  
mc_d_pitch set to 40  
# set mc_p_roll = 47  
mc_p_roll set to 47  
# set mc_i_roll = 20  
mc_i_roll set to 20  
# set mc_d_roll = 40  
mc_d_roll set to 40  
# set mc_p_yaw = 100  
mc_p_yaw set to 100  
# set mc_i_yaw = 60  
mc_i_yaw set to 60
```

Figure 3.4 - PID Values

Figure 3.5 shows the PID settings for flight in navigation modes.

```
# set nav_mc_pos_z_p = 40  
nav_mc_pos_z_p set to 40  
# set nav_mc_vel_z_p = 70  
nav_mc_vel_z_p set to 70  
# set nav_mc_pos_xy_p = 25  
nav_mc_pos_xy_p set to 25  
# set nav_mc_vel_xy_p = 20  
nav_mc_vel_xy_p set to 20  
# set nav_mc_vel_xy_i = 10  
nav_mc_vel_xy_i set to 10  
# set nav_mc_vel_xy_d = 60  
nav_mc_vel_xy_d set to 60
```

Figure 3.5 - PID settings for navigation mode.

Figure 3.6 shows the command that sets the height value in RTH mode.

```
# set nav_rth_altitude = 500  
nav_rth_altitude set to 500
```

Figure 3.6 – Height adjustment at RTH.

On figure 3.7 you can see command for smoothness in navigation mode Controls smoothness of navigation control (0-9). 0 gives legacy behaviour, non-zero values give increasing smoothness in navigation mode.

```
# set nav_fw_control_smoothness=4
nav_fw_control_smoothness set to 4
```

Figure 3.7 – Command to set the smoothness in autopilot mode.

For remote viewing of objects or patrolling the terrain, we need software in which you can create flight missions, for this task I will use the MWPtools program as in this program you can create complex missions with additional flight point settings.

This program is for Linux, so to use it on Windows, we need auxiliary programs. In order to install MWPtools we need the following:

Install the base cygwin package using the graphical installer from Cygwin.com. Cygwin is a large collection of GNU and Open Source tools which provide functionality similar to a Linux distribution on Windows.

Install a few (additional) packages git, wget and gzip.

Open the cygwin terminal

Fetch and make executable the apt-cyg script:

-wget <https://rawgit.com/transcode-open/apt-cyg/master/apt-cyg>

install apt-cyg /bin

Clone the mwp repository:

-git clone --depth 1 <https://github.com/stronnag/mwptools>

Install all the dependencies in one hit:

-apt-cyg install \$(zcat mwptools/docs/cygwin-example-packages.txt.gz)

Build mwp:

-cd mwptools

-make && make install # no sudo in Cygwin

In order to run the program, use the following command

-docs/mwp.bat

At run time, you need to have started the a X server. For this I used MobaXterm.

Figure 3.8 shows an example of flight missions in the MWPtools program.

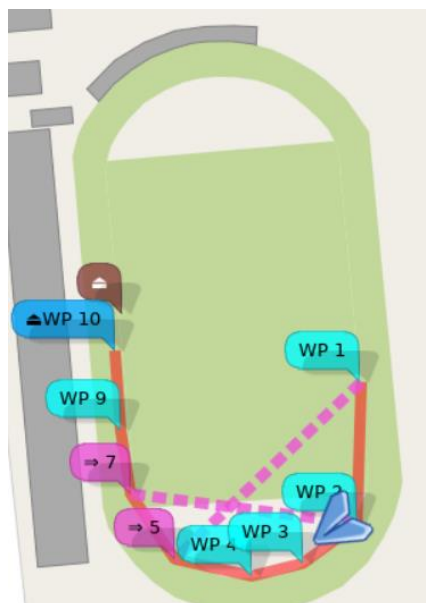


Figure 3.8 – Example of flight mission.

The following example illustrates the WAYPOINT, JUMP, and RTH types:

Mission points 6 and 8 are JUMP; they have no location as they affect the current location (the previous WP) and cause an action.

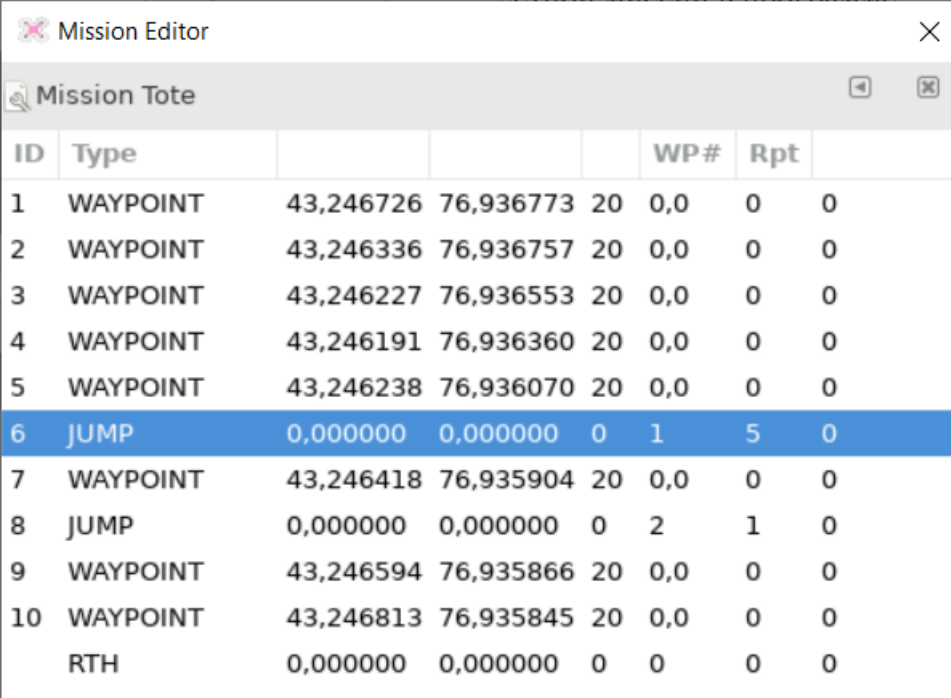
After WP 5 (JUMP at 6), the vehicle will proceed to WP 1 (parameter1 = 1); it will do this twice (parameter2 = 5). Then it will proceed to WP 7.

After WP 7 (JUMP at 8), the vehicle will proceed to WP 2 (parameter1 = 2); it will do this once (parameter2 = 1). Then it will proceed to WP 9.

The second JUMP (8) will cause the first jump (6) to be re-executed.

Mission point 10 is RTH. The UAV will return “home”. (to take-off point)

Figure 3.9 provides the settings for each of the points.



ID	Type				WP#	Rpt	
1	WAYPOINT	43,246726	76,936773	20	0,0	0	0
2	WAYPOINT	43,246336	76,936757	20	0,0	0	0
3	WAYPOINT	43,246227	76,936553	20	0,0	0	0
4	WAYPOINT	43,246191	76,936360	20	0,0	0	0
5	WAYPOINT	43,246238	76,936070	20	0,0	0	0
6	JUMP	0,000000	0,000000	0	1	5	0
7	WAYPOINT	43,246418	76,935904	20	0,0	0	0
8	JUMP	0,000000	0,000000	0	2	1	0
9	WAYPOINT	43,246594	76,935866	20	0,0	0	0
10	WAYPOINT	43,246813	76,935845	20	0,0	0	0
	RTH	0,000000	0,000000	0	0	0	0

Figure 3.9 – Waypoints parameters.

The number of iterations of the Jump functions is selected by the user, also if you specify -1 in the number of repetitions, the cycle will be infinite.

3.2 Description of the main functional links of the quadcopter

Omnibus F4V3 - This controller allows you to receive telemetry data and fly in automatic mode with setting the flight path of your multicopter.

Flexible firmware allows you to program the controller for any quadcopter. These flight controllers are one of the most affordable on the market, and also have decent functionality for their low cost.

OmnibusF4 flight controllers allow you to turn any radio-controlled aircraft, multicopter and even a boat or car into a fully autonomous unmanned model capable of completing missions along given routes with GPS coordinates. What is the advantage of this flight controller? To answer this question, first of all, we will describe its main characteristics. Omnibus has an axial gyroscope, accelerometer and high-precision barometer. It is also equipped with a stabilization system with the possibility of aerial acrobatics, the function of holding the position by GPS, flying by points and returning to the starting point. Also, this controller has the

ability to use an infrared sensor to bypass obstacles. Figure 3.10 shows the logic inputs, outputs.

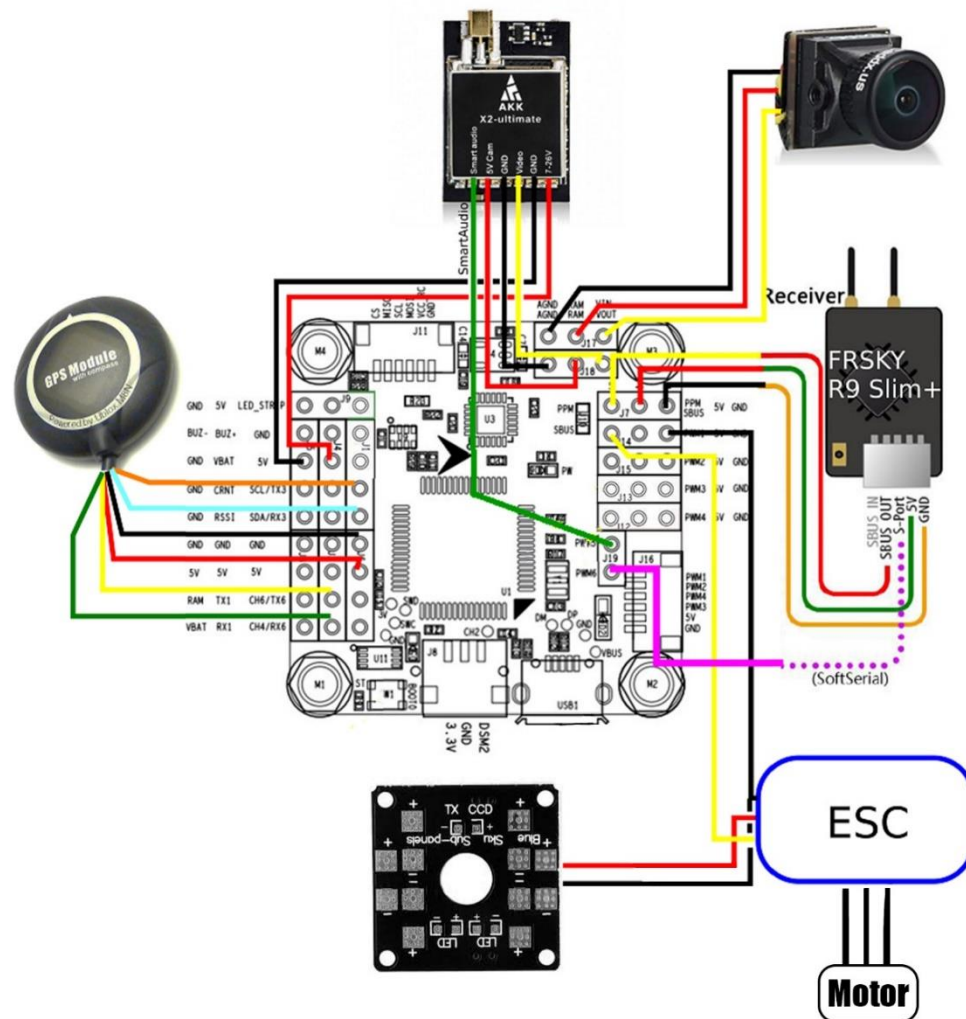


Figure 3.10 - Description of inputs and outputs of the flight controller and module connection diagram.

Omnibus F4V3 Flight Controller.

The functions of the flight controller include:

- stabilization of the model in the air;
- holding the model's position in the air using a GPS antenna;
- autopilot at given points with GPS coordinates;
- transfer of navigation information to the pilot using OSD and / or telemetry;
- security - return to take-off or auto-landing at emergency situation.

For the implementation of various goals, various flight controller operating modes can be used, such as:

- stabilization (Horizon) - holding the horizon;
- hold height (AltHold);
- RTH (Return-to-Home) - return to the starting point;
- NAV WP - execution of a given route in automatic mode (Flight by points);
- acro - acrobatics;

- NAV POSHOLD - fixation in the air and hold the set position according to GPS data;

- land - automatic landing;

- simple and super simple - light and super light flight, suitable for.

Motors are controlled by PWM using speed controllers (ESC). They also support radio communications and telemetry from the side, many frames and configurations of flying and ground devices, battery level sensor. Omnibus flight controller is compatible with many PWM and PPM radio receivers signals and receivers supporting serial protocols (for example, SBUS (FRSKY)). It has a terrific real-time support for telemetry data. This controller also has support for a memory card for automatic data recording and flight log recording (BlackBox).

Brushless motors were used in the work, in figure 3.11 The principle of operation of this type of motors is shown. How do they differ from collector?

The heavy and sparking unit - the collector - requiring maintenance, is removed from the engine design. The design of the engine is greatly simplified. The engine is lighter and more compact. Significantly reduced switching losses, since the contacts collectors and brushes are replaced by electronic keys. As a result, we get electric motor with the best efficiency indicators and power indicator per kilogram of dead weight, with the widest range of variation rotation speed.

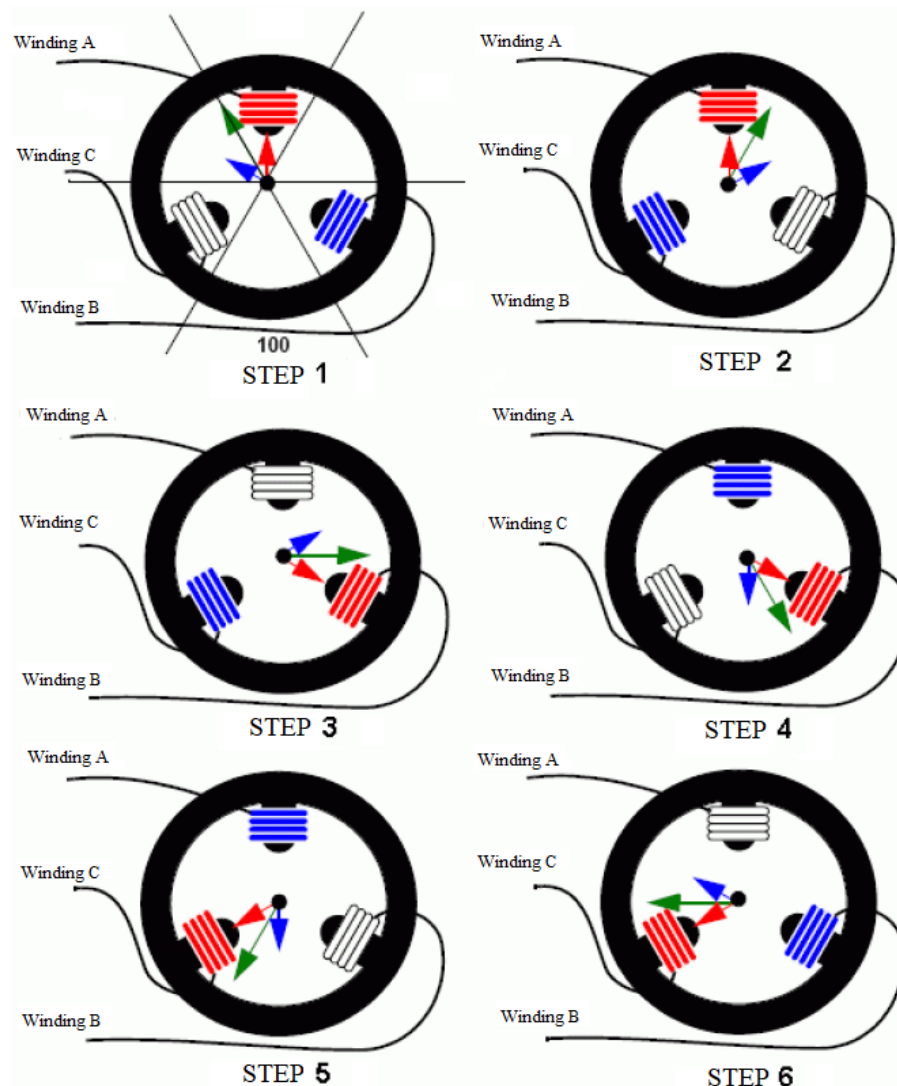


Figure 3.11 - A graphical description of the 6 functional stages of the motor

so much ... This function prevents the motor from gaining more than the specified number of revolutions, some controllers exceeding this value at idle start to fail, causing significant inrush currents - the motor begins to jerk sharply. This effect is not a malfunction of the motor or controller.

Internal resistance - the total resistance of the power keys of the controller, excluding wires. The more powerful the controller, the less its internal resistance. As a rule, the resistance of the wires is comparable to the internal resistance of the controller and contributes up to 30% of losses.

The pulse frequency of the controller - as a rule, is 7-8 KHz. For "advanced" controllers, the control frequency can be programmed to other values - 16 and 32 KHz.

The FrSky Taranis Q X7 radio set with the FrSky R-XSR receiver is designed to control glider, aircraft and helicopter models. The control panel Taranis Q X7 is made in a convenient and very thin (compared to similar models) case. It is powered by 4 AA batteries, which led to a significant reduction in weight, while the range of the equipment is 1500 - 2000 meters. The appearance of the radio control equipment is shown in figure 3.13.



Figure 3.13 - Taranis Q X7 control equipment

The radio control equipment FrSky Taranis Q X7 has the following characteristics:

- Designed for airplanes, helicopters and gliders;

- Support for 16 channels;
- Power: 6 ~ 15V (2-3S LiPo, or any other power source)
- Frequency: 2.4G;
- Current consumption: 210mA (RF modules + backlight);
- Operating temperature: from -10 to + 45 °C;
- Black and white LCD screen with backlight: 128 * 64;
- Logging flight data in real time (blackbox);

Six-channel receiver FS-A6 has high sensitivity

105dBm and works stably in the range of supply voltage from 4V to 6V.

With dimensions of 45x23x9 mm, its weight is only 13 grams.

FrSky R-XSR receiver specifications:

- Operating voltage range: 4 ~ 10 V;
- Number of channels: 16CH (1-16CH from the SBUS channel, 1 ~ 8CH from the CPM channel) - radio range: AFHDS 2.4Ghz;
- power supply: 4.0V - 6.5V;
- dimensions: 45x23x9 mm;
- weight: 1.5g.

Figure 3.14 shows the appearance of the receiver FrSky R-XSR.



Figure 3.14 - Radio receiver for 16 channels FrSky R-XSR

Lithium-polymer batteries are compact and have good current efficiency. The battery is equipped with power and balancing connectors. Products are intended for use in all types of radio-controlled models. When using the battery, you should not allow the discharge of any of the three batteries below 3V, since this can lead to a decrease in the electric capacity of the battery, and it is dangerous to overcharge the battery as it can swell and ignite. Appearance is shown in the figure 3.15.



Figure 3.15 – Li-Pol accumulator battery

The lithium-polymer battery used in the work has the following characteristics:

- number of battery cans: 3
- capacity: 2200 mAh;
- voltage: 11.1 V;
- current output: 35C.

The NEO-7 series is a stand-alone GPS / GNSS module with a system of processing navigation protocols (GPS, GLONASS, Galileo, QZSS and SBAS) of exceptional performance. The NEO-7 series has a high sensitivity to satellite signals and a minimum detection time, while having a small-sized case, convenient for mounting on a printed circuit board. At maximum sensitivity, the NEO-7 series has low power consumption. NEO-7M is optimized for low-cost applications, and NEO-7N represents better performance and easy RF integration. The form factor of NEO modules enables simple migration from previous generations of NEO modules. Based on the above, this module is well suited to the needs of the project.

Features:

- amplifier MAX2659ELT +;
- 56 channels of reception;
- the presence of indication diodes;
- built-in 3V battery;
- ceramic antenna 25x25x2 mm;
- frequency: 10 Hz - GPS, 1 Hz - GLONASS;
- non-volatile I2C EEPROM memory;
- preset port speed 38400 baud;
- Built-in SBAS correction system (WAAS, EGNOS, MSAS);
- Support for GPS L1 C / A, GLONASS L1 FDMA, QZSS L1 C / A and Galileo E1B / C.

Specification:

- Weight: 28g;

-Size: 60 x 11.5 mm;
-Cable length: 250 mm.
The module is shown in the figure 3.16.



Figure 3.16 – Ublox Neo-7M GPS module

4 Feasibility Study for the Project

4.1 Technical and economic UAV development justification

The aim of this diploma is the development of autonomous UAV for special purposes.

It is necessary to develop a prototype autonomous UAV that can fly along a given route and using the control panel. The purpose of this part of the diploma is to analyze and verify the development process of the above UAV for the appropriateness and calculation of the total costs at the development stage

In the technical and economic part of the diploma project, the following indicators will be calculated for payback analysis:

- investments for project development, tenge;
- equipment costs, tenge;
- assembly of a quadrocopter, tenge;
- transport services, tenge;
- purchase of materials, tenge;
- software development, tenge.

4.2 Calculation of capital investments for the implementation of the project

To calculate capital investments, we use the formula:

$$K = K_{pr} + K_{eq} + K_{as} + K_{tr} + K_m + C_n, \quad (4.1)$$

where K_{pr} - capital investment in the development of the project, tenge;

K_{eq} - equipment costs, tenge;

K_{as} - capital investments for the assembly of a quadrocopter, tenge;

K_{tr} - capital investments in transport services, tenge;

K_m - capital investments for the purchase of materials, tenge;

C_n - capital investments for software development, tenge.

Project development costs are calculated by the formula:

$$K_{pr} = Z_{pf} + Z_c + Z_{ob} + Z_o, \quad (4.2)$$

where K_{pr} - project costs, tenge;

Z_{pf} - general payroll fund for developers, tenge;

Z_{st} - deductions for social tax, tenge;

Z_{se} - special equipment, tenge;

Z_o - overhead, tenge.

The total payroll of developers (Z_{pf}) is calculated as the sum of the main and additional wages according to the formula:

$$Z_{pf} = Z_s + Z_{as}, \quad (4.3)$$

where Z_s - the basic salary, tenge;

Z_{as} - additional salary, tenge.

The project involves 2 people. Project participants and their salaries are presented in the table 4.1.

Table 4.1 - Basic salary for system development

№	The name of the stages	Performers (by category)	Labor input (person / day)	Official salary (tenge)	Cost 1 person / day. (tenge)	Salary (tenge)
1	Development of technical specifications	Design engineer	2	186000	6000	12000
2	Technical Proposal	Design engineer	1	186000	6000	6000
3	Draft design	Design engineer	1	186000	6000	6000
4	Development of working documentation	Supervisor	2	232500	7500	15000
		Design engineer	1	186000	6000	6000
5	Engineering analysis	Design engineer	1	186000	6000	6000
6	Checking Results	Supervisor	1	232500	7500	7500
		Total	9			58500

Thus, with the consistent implementation of all the stages of work listed in table 1, the total duration of the one-time work will be 9 working days. Additional salary of employees, which takes into account illness, holidays and other unforeseen circumstances (on average 10% of the basic salary):

$$Z_d = Z_s \times N_a / 100, \quad (4.4)$$

where N_a - the coefficient of additional salaries of developers.

$$Z_d = 0,1 \times 58500 = 5850 \text{ (tenge)}.$$

According to formula 3, the wage fund will be:

$$Z_{pf} = 5850 + 58500 = 64350 \text{ (tenge)}.$$

The deductions for the unified social tax are calculated based on the employee's salary and make up 9,5% (Article 358 para. 1 of the Tax Code of the Republic of Kazakhstan):

$$Z_s = (Z_{pf} - PC) \times 9.5\%, \quad (4.5)$$

where PC - contribution to the Pension Fund in the Republic of Kazakhstan, which is calculated by the formula:

$$PC = Z_{pf} \times 10\%, \quad (4.6)$$

So,

$$PC = 64350 \times 0,1 = 6435 \text{ (tenge).}$$

$$Z_{st} = (64350 - 6435) \times 0.095 = 5501.93 \text{ (tenge).}$$

The cost of special equipment for experimental work is 91200 tenge (table 4.2).

Table 4.2 - Costs of special equipment

№	Name of materials	Quantity, pcs	Price, tenge	Cost, tenge
1.	A computer	1	80000	80000
2.	Screwdriver	2	350	700
3.	Soldering kit	1	9500	9500
	Total			91200

Overhead costs make up 30% of the salary:

$$Z_o = 0,3 * 64350 = 19305 \text{ (tenge).}$$

Thus, according to formula 2, the cost of developing research will be:

$$K_{pr} = 64350 + 5501.93 + 91200 + 19305 = 180356.93 \text{ (tenge).}$$

Capital investments in equipment amount to 102800 tenge. The list of necessary equipment is presented in table 4.3.

Table 4.3 - List of equipment necessary for the implementation of the project

Name of equipment	Quantity, units	Price per unit, tg	Cost including VAT, tg	Cost without VAT, tg
Housing	1	7300	7884	7300
Propellers, ESCs and Motors	4	11250	48600	45000
Remote Control	1	20000	21600	20000
Battery	1	16000	17280	16000
Flight Controller		14500	15660	14500
Total			111024	102800

To calculate the capital investment for the assembly, we use the formula:

$$K_{as} = K_{eq} \times 10\%, \quad (4.7)$$

In this way,

$$K_{as} = 102800 \times 10\% = 10280 \text{ (tenge)}$$

Capital investments in transport services are calculated by the formula:

$$K_{tr} = K_{eq} \times 5\%, \quad (4.8)$$

So,

$$K_{tr} = 102800 \times 5\% = 5140 \text{ (tenge)}.$$

Capital investments in materials necessary for the implementation of the project are presented in table 4.4

Table 4.4 - Material Costs

№, п/п	Name of materials	Quantity, pcs	Price, tenge	Amount, tenge
1.	Solder	1	1500	1500
2.	Rosin	1	100	100
3.	Soldering Acid	1	400	400
4.	Connecting wires	10	10	100
5.	Ethanol	2	200	400
6.	Lacquer	5	135	675
	Total			3165

Costs (C_n) for software development can be found by the formula:

$$C_n = Z_{pf} + Z_{st} + P_d + P_e + P_o, \quad (4.9)$$

where Z_{pf} is the general payroll fund for developers, tenge;

Z_{st} - deductions for social tax, tenge;

P_d - depreciation costs of equipment, tenge;

P_e - electricity costs, tenge;

P_o - overhead expenses, tenge.

The size of the payroll fund for developers (Z_{fot}) is calculated according to formula 3.3. In order to calculate the basic salary of the contractor, we use the formula:

$$Z_s = t_p \times Z_{ds}, \quad (4.10)$$

where t_p - the complexity of software product development, person-days;

Z_{ds} - daily salary of the developer, (tenge).

Total labor costs are calculated as the sum of the composite labor costs according to the formula:

$$t = t_d + t_a + t_w + t_{de} + t_{doc}, \quad (4.11)$$

where t_d - time spent on the task description, person / hour;

t_a - compilation of the program algorithm, person / hour;
 t_w - time spent writing a program, person / hour;
 t_{de} - time allotted for debugging software on a PC, person / hour;
 t_{doc} - time spent on the development of documentation, person / hour.

The conditional number of operators in the task program is determined by the formula:

$$Q = q \times c, \quad (4.12)$$

where Q is the conditional number of operators;
 q - estimated number of operators depending on the type of task;
 c - coefficient taking into account the novelty and complexity of the program.
 Let us select the coefficient q according to table 4.5.

Table 4.5 - The values of the coefficient q

Task type	Coefficient of measurement of the coefficient
Accounting tasks	from 1400 to 1500
Operational management tasks	from 1500 to 1700
Planning tasks	from 3000 to 3500
Multivariate tasks	from 4500 to 5000
Complex tasks	from 5000 to 5500

Since in this project we consider flight control with a remote control, we take the q coefficient equal to 1500.

Further, in order to determine the coefficient c , the first thing is to choose a group according to the degree of novelty:

- Group A - the development of fundamentally new tasks;
- Group B - development of original programs;
- Group C - development of programs using standard solutions;
- Group D - a one-time standard task.

The program will be written in a high-level language using standard algorithms. Now, based on table 4.6, we determine the coefficient c equal to 1.08.

Table 4.6 - Labor calculation factors

Programming language	Difficulty group	Degree of novelty				Coefficient B
		A	B	C	D	
High level	1	1,38	1,26	1,15	0,69	1,2
	2	1,30	1,19	1,08	0,65	1,35
	3	1,20	1,10	1,00	0,60	1,5

Thus, $Q = 1500 \times 1.08 = 1620$ (teams).

After this, it is necessary to determine the time spent on creating the software at each stage:

- a) to is taken upon the fact: $t_o = 24$ (person / hour).
- b) we find t_a by the formula:

$$t_a = Q / (50 \times K), \quad (4.13)$$

where K is a coefficient taking into account the qualifications of a programmer (table 4.7).

Table 4.7 - Programmer qualification factors

Experience	Qualification ratio
Up to two years	0,8
2-3 years	1
3-5 years	1,1-1,2
5-7 years	1,3-1,4
More than 7 years	1,5-1,6

In this way,

$$t_a = 1500 / (50 \times 0,8) = 37,5 \text{ (person / hour)}.$$

b) t_w we find by the formula:

$$t_w = Q \times 1,5 / (50 \times K), \quad (4.14)$$

Thus, according to formula 14:

$$T_w = 1500 \times 1,5 / (50 \times 0,8) = 56,25 \text{ (person / hour)}.$$

c) t_{de} is determined by the formula:

$$t_{de} = Q \times 4,2 / 50 \times K, \quad (4.15)$$

According to formula 3.15:

$$t_{de} = 1500 \times 4,2 / 50 \times 0,8 = 157,5 \text{ (person / hour)}.$$

d) t_{doc} , is taken upon the fact and is (from 3 to 5 days for 8 hours):

$$t_{doc} = 24 \text{ (man / hour)}.$$

Based on the formula 3.11:

$$t = 24 + 27.27 + 46.9 + 114.54 + 24 = 299,25 \text{ (hour)}.$$

Thus, the time spent on creating software is 299.25 hours or 37.4 people / day. The daily wage is determined based on the monthly salary of the developer and the number of working days in the month (on average, 22 working days can be accepted). Information on the employees involved in the development is presented in table 4.8.

Table 4.8 - Information on the employees involved in the project.

Specialist - Contractor	Number of persons	Salary per month, tenge
Design engineer	1	126000
Total		126000

The results of the calculation of basic wages are presented in table 4.9.

Table 4.9 - Summary results of the calculation of the costs of the basic wage

Name of the content of work	Executor	Labor input, norm-hour	Salary per hour of work	Salary amount
1	1	8	750	6000

The basic salary is calculated by the formula:

$$Z_s = t_p \times Z_{ds}, \quad (4.16)$$

where t_p - the complexity of software product development, person-days;
 Z_{ds} - daily salary of the developer, tenge (table 4.9).

Thus,

$$Z_s = 37.4 \times 6000 = 224400 \text{ (tenge)}.$$

Additional salary (Z_d) is calculated by the formula 4.4:

$$Z_{ds} = 224400 \times 0.1 = 22440 \text{ (tenge)}.$$

Thus, the payroll is:

$$Z_{pf} = 224400 + 22440 = 246840 \text{ (tenge)}.$$

Social tax is calculated using the formula 4.5.

Where pension contributions is calculated by the formula 4.6.

So,

$$PC = 246840 \times 10\% = 24684 \text{ (tenge)}.$$

In this way,

$$Z_{st} = (246840 - 24684) \times 9.5\% = 21104.8 \text{ (tenge)}.$$

Depreciation costs are calculated using the formula:

$$P_d = \frac{C_{equip} \times Na \times n}{100 \times 12 \times t} \quad (4.17)$$

where Na is the depreciation rate (25%);

C_{equip} - the initial cost of equipment (tenge);

n - time of use of a personal computer (days);

t is the number of working days in a month.

$$P_d = \frac{81200 \times 0,25 \times 37,4}{100 \times 12 \times 22} = 28,8 \text{ (тенге)}.$$

Electricity costs are calculated by the formula:

$$P_e = M \times l \times T \times C \text{ kWh}, \quad (4.18)$$

where P_{com} - power of the computer, kW;

l - load factor (0.8);

C kWh - the cost of 1 kWh of electricity, tenge / kWh;

T - time, hour.

In this way,

$$P_e = 0.08 \times 0.8 \times 235.71 \times 17.81 = 268.7 \text{ (tenge)}.$$

Overhead costs (P_H) make up 20% of the basic salary:

$$P_o = 224400 \times 20\% = 44880 \text{ (tenge)}.$$

Thus, according to formula 4.9, the software development costs will be:

$$C_n = 246840 + 21104.8 + 28.8 + 268.7 + 44880 = 313122.32 \text{ (tenge)}.$$

Thus, according to formula 4.1, the total amount of capital investment for the project without VAT is equal to:

$$K = 102800 + 10280 + 5140 + 3165 + 180356.93 + 313122.32 = 614864.25 \text{ (tenge)}.$$

4.3 Calculation of the economic efficiency of the project

Evaluation of the economic efficiency of the project is based on the indicator of comparative economic efficiency according to the formula:

$$E_{ef} = P - C \times E, \quad (4.19)$$

where E is the expected annual economic effect, tenge;

P - price when selling the device, tenge,

C - capital investments, tenge;

E - normative coefficient of economic efficiency of capital investments, which is determined by the formula:

$$E = \frac{1}{T_s}, \quad (4.20)$$

where T_s is the standard payback period for capital investments, which is 15 years. Thus, according to formula 4.20:

$$E = \frac{1}{15} \approx 0,06$$

The price will be equal to 150,000 tenge.

Based on the expected formula 4.19, the economic effect (E) will amount to 113108.15 (tenge). The coefficient of economic efficiency of capital costs is calculated by the formula:

$$E_p = \frac{P}{C}, \quad (4.21)$$

where E_p is the coefficient of economic efficiency of capital costs;
P - price when selling the device, tenge;
C - capital investments to create a system, tenge.

$$E_p = \frac{150000}{614864.25} \times 100\% = 24,4\%.$$

The payback period of capital investments is calculated by the formula:

$$T_p = \frac{1}{E_p} \cdot E_p, \quad (4.23)$$

and is:

$$T_p = \frac{1}{0,244} = 4,1 \text{ (year)}.$$

The summary results of the calculation of the economic efficiency of the project are presented in table 4.10

Table 4.10 - Indicators of economic efficiency

Indicators	
Capital investments, tenge	614864.25
Expected economic effect, tenge	113108.15
Coefficient of economic efficiency, %	24,4
Payback period, year	4,1

5 Life safety section

For assembly and flashing a four-screw UAV, a room of size 10x5x2.5 m is used. It is necessary to assess the severity of labor and calculate ventilation. Two work places should be organized for engineers. The layout of the room is shown in figure 5.1.

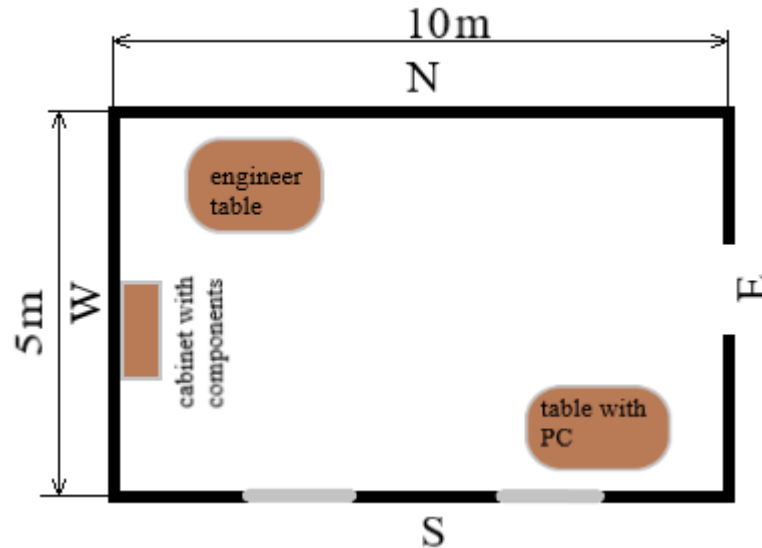


Figure 5.1 – Rooms layout.

5.1 Ventilation calculation

Table 5.1 - Categories of work on energy consumption of the body

Work type	Category	The energy consumption of the body, J / s (kcal / hour)	Work characteristic
Light physical	1	< 138	It is made sitting and does not require physical stress.

Regardless of the periods of the year, the microclimatic parameters in the room do not exceed the established permissible values: summer temperature +24 °C, winter temperature +22 °C.

Table 5.2 - Optimum microclimate parameters

Work period	Work category	T, °C	Air speed, m / s, no more
Cold	1	22-24	0,1
Warm	1	23-25	0,1

Initial data:

City: Almaty;

Room parameters (L x W x H), m: 10 x 5 x 2.5;
 Information on the equipment: qty 2 pcs .;
 Power R_{ob} , kW / h 2; Efficiency η 0.8;
 Light source data: power. $N_{os.ust.}$, W / m² 2 75;
 Type of light source: luminesc. Lamps;
 Number of employees: male 1 female 1;
 Windows: number 2 area 1 window, m² 1,5 location "S";
 Type of blinds: wood binding, slight pollution;
 Estimated time of day, hours: 12-13;
 Indoor temperature, °C: in summer 24 in winter 22;
 Type of work position: sitting.

In premises for various purposes, mainly heat loads occur that occur outside the room (outdoor); as well as thermal loads occurring inside buildings (internal). External heat loads are represented by the following components: - heat gain or heat loss as a result of the temperature difference outside and inside the building through walls, ceilings, floors, windows and doors.

- the temperature difference outside the building and inside it in the summer is positive, as a result of which there is an influx of heat from outside to inside the room; and vice versa - in winter this difference is negative and the direction of heat flow changes;

- heat from solar radiation through glazed areas; this load manifests itself in the form of perceived heat;

- heat gain from infiltration.

Depending on the time of year and time of day, external heat loads can be positive. Heat gain and heat loss as a result of the temperature difference are determined by the formula:

$$Q_{\text{оргЗима}} = V_{\text{пом}} \cdot X_o \cdot (t_{\text{Врасч}} - t_{\text{Нрасч}}), W \quad (5.1)$$

where $V_{\text{пом}}$ – room volume, m³:

$$V_{\text{пом}} = 10 \cdot 5 \cdot 2.5 = 125 \text{ m}^3; \quad (5.2)$$

X_o - specific thermal characteristic, W / m³ °C:

$X_o = 0.42 \text{ W / m}^3 \text{ °C};$

$t_{\text{Нрасч}}$ - outdoor temperature (parameter A).

$t_{\text{Calculation}}$ - internal temperature, is selected taking into account comfortable conditions or technological requirements for production processes.

For the warm season:

$Q_{\text{орг}} = 0 \text{ kW}.$

For the cold season:

$t_{\text{Нрасч}} = - 25 \text{ °C}$

$t_{\text{Врасч}} = 22 \text{ °C}$

$$Q_{\text{орг}} = 125 \cdot 0.42 \cdot 47 = 2467.5 \text{ W}$$

The excess heat of solar radiation, depending on the type of glass, is absorbed by up to 90% of the medium, the rest is reflected. The maximum thermal load is

achieved at the maximum level of radiation, which has direct and scattered components. The radiation intensity depends on the width of the terrain, time of year and time of day. Heat from solar radiation through glazing is determined by the formula:

$$Q_p = (q^I F_0^I + q^{II} F_0^{II}) \cdot \beta_{c.3} \quad (5.3)$$

where q^I, q^{II} – heat fluxes from direct and diffused solar radiation, W / m²;
 F_0^I, F_0^{II} – areas of the light opening irradiated and non-irradiated with direct solar radiation, m²;

$\beta_{c.3}$ – heat transfer coefficient.

According to table $\beta_{c.3} = 0.15$ (for shutter-blinds, 90 degrees with a load of wooden plates).

In the absence of external shading visors, ribs, etc., for the period of glazing irradiation with the sun, when its rays penetrate through the window into the room $F_0^I = F_o; F_0^{II} = 0$:

$$Q_p = q^I F_o \cdot \beta_{c.3} = (q_{BII} + q_{BPI}) \cdot K_1^C \cdot K_2 \cdot \beta_{c.3} \cdot n \cdot S_o, \text{ Wt} \quad (5.4)$$

$q_{BII}; q_{BPI}$ – heat fluxes from direct scattered radiation, W / m². According to latitude of 44 ° N in the afternoon at 12-13 o'clock at the location of the South:

$$q_{BII} = 288 \text{ W / m}^2;$$

$$q_{BPI} = 85 \text{ W / m}^2;$$

$$F_o = n S_o = 2 \cdot 1,5 = 3 \text{ m}^2 - \text{area of the light opening} \quad (5.5)$$

(n - the number of windows; S_o – the area of 1 window);

K_1 - coefficient of dimming glazing with bindings (K_1^C - for irradiated openings).

According to $K_1^C = 0.46$;

K_2 - glazing contamination coefficient.

According to $K_2 = 0.95$ (pollution is negligible).

Then:

$$Q_p = (288 + 85) \cdot 0.46 \cdot 0.95 \cdot 0.15 \cdot 3 = 73.4 \text{ Wt}$$

Internal loads in residential, office or service-related premises are mainly composed of heat:

- emitted by people;
- emitted by lamps and lighting, household appliances;
- emitted by computers, printers, photocopiers, etc.;

In industrial and technological premises for various purposes, additional sources of heat can be: heated production equipment, hot materials, including liquids and various kinds of semi-finished products, products of combustion and chemical reactions.

Heat input from people depends on the intensity of the work performed and the parameters of the surrounding air. The heat generated by a person consists of tangible (explicit), that is, transmitted into the air of the room by convection and

radiation, and latent heat spent on the evaporation of moisture from the surface of the skin and from the lungs.

According to table in the summer at 24 °C, only one man emits apparent heat of 67 watts, and the total - 102 watts. A woman emits 85% of the heat of an adult male. Then the apparent heat in the room will be:

$$Q_{\text{л}}^{\text{a}} = 67 \cdot 1 + 67 \cdot 1 \cdot 0.85 = 123,95 \text{ Wt.}$$

And the release of total heat:

$$Q_{\text{л}}^{\text{o}} = 102 \cdot 1 + 102 \cdot 1 \cdot 0.85 = 188,7 \text{ Wt.}$$

According to table in winter at 22 °C one man emits apparent heat of 76 W, and the total - 102 W. A woman emits 85% of the heat of an adult male. Then the apparent heat in the room will be:

$$Q_3^{\text{a}} = 76 \cdot 1 + 76 \cdot 1 \cdot 0.85 = 140,6 \text{ Wt.}$$

And the release of total heat:

$$Q_3^{\text{o}} = 102 \cdot 1 + 102 \cdot 1 \cdot 0.85 = 188,7 \text{ Wt.}$$

Heat from lighting devices, office equipment and equipment is calculated as follows. The heat supply from the lamps is determined by the formula:

$$Q_{\text{ocb}} = \eta \cdot N_{\text{ocb}} \cdot F_{\text{пол}} \text{ Wt} \quad (5.6)$$

where η is the coefficient of conversion of electric energy into heat (for fluorescent lamps $\eta = 0.5 - 0.6$);

N_{osv} - installed lamp power ($N = 75 \text{ W} / \text{m}^2$);

F_{floor} - floor area:

$$F_{\text{floor}} = 10 \cdot 5 = 50 \text{ m}^2 \quad (5.7)$$

Then:

$$Q_{\text{ocb}} = 0.5 \cdot 75 \cdot 50 = 1875 \text{ Wt} .$$

The heat generated by production equipment is determined by the formula:

$$Q_{\text{o6}} = N_{\text{yct}} \cdot K \quad (5.8)$$

$$Q_{\text{o6}} = 0.65 \cdot 0.75 \cdot 75 = 36.56 \text{ kWt} .$$

Heat inflows arising from office equipment is 30% of the equipment's capacity:

$$Q_{\text{opr}} = 0.65 \cdot 0.75 \cdot 0.3 = 0.15 \text{ kWt.}$$

Based on the calculations we make the balance of heat in the room:

$$Q_{изб} = Q_p + Q_{Л}^{\text{я}} + Q_{осв} + Q_{об} + Q_{опг} + Q_{опг} \text{ kWt} \quad (5.9)$$

Summer:

$$Q_{изб} = 73.4 + 123,95 + 1875 + 36560 + 150 + 0 = 38.799 \text{ kWt.}$$

Winter:

$$Q_{изб} = 73.4 + 140,6 + 1875 + 36560 + 150 + 2467.5 = 41.267 \text{ kWt.}$$

Since the heat balance for summer is greater than the winter heat balance, we calculate the heat stress of the air according to the formula:

$$Q_H = \frac{Q_{изб.зима} \times 860 \text{ kcal}}{V_{ном} \text{ m}^3} \quad (5.10)$$

$$Q_H = \frac{41.267 \times 860}{125} = 283,9 \text{ kcal/m}^3$$

At $Q_H > 20 \text{ kcal / m}^3$, $\Delta t = 8^\circ \text{C}$,

Determination of the amount of air required to enter the room:

$$L = \frac{Q_{изб} \times 86 \text{ m}^3}{C \times \Delta t \times \gamma \text{ hour}} \quad (5.11)$$

$$L = \frac{41.267 \times 86}{0.24 \times 8 \times 1.206} = 1532,7 \text{ m}^3/\text{hour}$$

where $C = 0.24 \text{ kcal / (kg } ^\circ \text{C)}$ is the heat capacity of air,

$\gamma = 1.206 \text{ kg / m}^3$ - specific gravity of the supply air.

Determination of air exchange rate:

$$n = \frac{L}{V_{ном}} \text{ hour}^{-1} \quad (5.12)$$

$$n = \frac{1532,7}{125} = 12,3 \text{ hour}^{-1}$$

Based on the data obtained, we choose an air conditioner with top air supply MHB-96HR.

Its technical characteristics are given in table 5.3.

Table 5.3 - The main technical characteristics of the air conditioner company Midea model MHB-96HR.

Sizes, mm	power, kWt			weigh t kg	air consumpti on, m ³ /h	Steam consumpt ion, kg / h
	of cold	compres sor	electric heater			
1740x700x450	9.6	2.9	2.2	150	Min: 1940 Max: 1400	2

5.2 Methodology for assessing the severity of the labor process

The severity of the labor process is evaluated by a number of indicators expressed in ergometric quantities characterizing the labor process, independently from the individual characteristics of the person participating in this process.

The main indicators of the severity of the labor process are:

- physical dynamic load;
- mass of lifting and moving cargo manually;
- stereotypical labor movements;
- static load;
- working pose;
- body inclinations;
- moving in space.

When performing work related to uneven physical loads on different working days (shifts), classifying working conditions (subclass) of working conditions according to the severity of the labor process (except the mass of the lifted and transported cargo and the slopes of the body employee) is carried out according to average indicators for 2 - 3 working days (shift). The mass of the load lifted and moved by the employee manually and body tilts are estimated at maximum values.

Physical dynamic load. The assignment of working conditions to a class (subclass) of working conditions by severity labor process during physical dynamic load is carried out by determining the mass of the cargo (parts, products, tools), manually moved by the employee during each operation, and distance movement of goods in meters. After that, the total operations on the transfer of goods by the employee during the working day (shift) and the value of the physical dynamic load ($\text{kg} \times \text{m}$) is determined during working day (shift). When working due to both regional and total physical activity during the working day (shift) associated with the movement of goods at various distances, the total mechanical work for a working day (shift) [28].

The mass of the lifted and transported cargo manually. To determine the total mass of cargo transported during every hour of the working day (shift), the weight of all goods per working day (shift) sums up. Regardless of the actual length of the working day (shift) the total mass of cargo per working day (shift) is divided by the number of hours working day (shift). In cases where the employee moves the goods manually as from the working surface and from the floor, indicators are summarized. If working the surface moved a larger load than from the floor, then the resulting value it should be compared with this indicator, and if the greatest the movement was made from the floor - then with an indicator of the total mass of the cargo in hour when moving from the floor. If from a working surface and from a floor if an equal load moves, the total mass of the load is compared with indicator of displacement from the floor.

Stereotypical labor movements. The assignment of working conditions to a class (subclass) of working conditions by severity labor process when an employee performs stereotypical workers movements and local load (involving the muscles of the hands and fingers) carried out by counting the number of movements of the employee for 10 - 15 minutes, determine the number of his movements in 1 minute and calculate the total number employee movements during the time during which

this work is performed (multiplication by the number of minutes of the working day (shift) during which work in progress).

The assignment of working conditions to a class (subclass) of working conditions by severity labor process when an employee performs stereotypical workers movements and regional pressure (when working with predominant participation muscles of the hands and shoulder girdle) is carried out by counting their number for 10 - 15 minutes or in 1 - 2 repeated operations, several times per working day (shift). After estimating the total number of operations or lead time work determines the total number of regional movements per worker day (shift).

Static load. The assignment of working conditions to a class (subclass) of working conditions by severity labor process with static load associated with retention by a cargo worker or by the application of efforts, carried out by the multiplication of two parameters: the weight of the cargo or the value of the holding effort and retention time. The assignment of working conditions to a class (subclass) of working conditions by severity labor process under static load associated with cargo retention or by the application of efforts, taking into account a certain predominant load: on one arm, on two arms or involving muscles body and legs. If during the execution of work 2 or 3 of the specified above the type of static load, they should be summed up and the total the value of the static load correlate with the prevailing indicator load.

Work posture. The assignment of working conditions to a class (subclass) of working conditions by severity labor process, taking into account the working position of the body of the employee carried out by determining the absolute time (in minutes, hours) stay in a particular working position, which is set on based on timing observations for the working day (shift). Thereafter calculated residence time in relative terms (as a percentage of 8-hour working day (shift), regardless of its actual duration). The time spent in the working position is determined by adding the time work of the worker in a standing position and the time of his movement in space between objects with a radius of not more than 5 m. If, by the nature of the work, workers the employee's positions are different, then assigning working conditions to a class (subclass) working conditions when exposed to the severity of the labor process, taking into account the working the body position of the worker should be carried out according to the most typical working pose for this work [28].

Tilts of the body. The assignment of working conditions to a class (subclass) of working conditions by severity the labor process taking into account the slopes of the body of the employee for the working day (shift) is determined by their direct calculation per unit time (minute, hour). Next, the total number of slopes of the body of the employee for all the time the work is done or their quantity is determined for one operation and is multiplied by the number of operations per shift.

Moving in space. The assignment of working conditions to a class (subclass) of working conditions by severity labor process when moving an employee in space carried out taking into account such horizontal movement and (or) vertical, due to the technological process, during the working day (shift) and is determined on the basis of counting the number of steps per working day (shift) and step length measurements. The number of steps per working day (shift) is determined using a

pedometer placed in an employee's pocket or secured to his belt (in time for regulated breaks and lunch break pedometer must be laid out of an employee's pocket or removed from his belt). The male step in the production environment is on average 0.6 m, and female - 0.5 m. Moving the worker vertically in space consider its movement on stairs or inclined surfaces, angletilt more than 30 ° from the horizontal. For workers whose labor function involves moving to space both horizontally and vertically, these distances it is necessary to summarize and compare with that indicator, the value of which was bigger.

Overall assessment. The general class (subclass) of working conditions is established by indicator the severity of the work process having the highest class (subclass) working conditions. In the presence of two or more indicators of the severity of labor a process for which working conditions are classified as subclass 3.1 or 3.2 harmful working conditions, class (subclass) of working conditions according to the severity of the labor process increases by one degree. The assignment of working conditions to classes (subclasses) of working conditions in terms of the severity of the labor process [28].

Table 5.4 - Physical dynamic load - units of external mechanical work per shift, kg / m

The severity of the labor process	Class (subclass) of working conditions			
	optimal	permissible	harmful	
	1	2	3.1	3.2
With a regional load (with predominant involvement of the muscles of the hands and shoulder girdle) when moving cargo to a distance of 1 m:				
for men for women	before 2 500 before 1 500	before 5 000 before 3 000	before 7 000 before 4 000	more than 7 000 more than 4 000
With a total load (involving the muscles of the arms, body, legs):				
when moving cargo at a distance of 1 to 5 m				
for men for women	before 12 500 before 7 500	before 25 000 before 15 000	before 35 000 before 25 000	more than 35 000 more than 25 000
when moving cargo to a distance of more than 5 m				
for men for women	before 24 000 before 14 000	before 46 000 before 28 000	before 70 000 before 40 000	more than 70 000 more than 40 000

Table 5.5 - The mass of the lifted and transported cargo manually, kg

The severity of the labor process	Class (subclass) of working conditions			
	optimal	permissible	harmful	
	1	2	3.1	3.2
Lifting and moving (one-time) gravity during alternation with other work (up to 2 times per hour):				
for men for women	before 15 before 5	before 30 before 10	before 35 before 12	more than 35 more than 12
Lifting and moving gravity continuously during a shift (more than 2 times per hour):				
for men for women	before 5 before 3	before 15 before 7	before 20 before 10	more than 20 more than 10
The total mass of goods transported during each hour of the working shift:				
from the work surface				
for men for women	before 250 before 100	before 870 before 350	before 1 500 before 700	more than 1 500 more than
from the floor				
for men for women	before 100 before 50	before 435 before 175	before 600 before 350	more than 600 more than 350

Table 5.6 - Stereotypical labor movements, number per shift

The severity of the labor process	Class (subclass) of working conditions			
	optimal	permissible	harmful	
	1	2	3.1	3.2
With local load (involving the muscles of the hands and fingers):				
	before 20 000	before 40 000	before 60 000	more than 60 000
Under regional pressure (when working with predominant participation muscles of the hands and shoulder girdle):				
	before 10 000	before 20 000	before 30 000	more than 30 000

Table 5.7 - Static load - the value of the static load per shift during load retention, application of force, kg / s

The severity of the labor process	Class (subclass) of working conditions			
	optimal	permissible	harmful	
	1	2	3.1	3.2
With one hand:				
for men for women	before 18 000 before 11 000	before 36 000 before 22 000	before 70 000 before 42 000	more than 70 000 more than 42 000
With two hands:				
for men for women	before 36 000 before 22 000	before 70 000 before 42 000	before 140 000 before 84 000	more than 140 000 more than 84 000
With the participation of the muscles of the body and legs:				
for men for women	before 43 000 before 26 000	before 100 000 before 60 000	before 200 000 before 120 000	more than 200 000 more than 120 000

Table 5.8 - Work posture regarding work shift

Class (subclass) of working conditions			
optimal	permissible	harmful	
1	2	3.1	3.2
Loose comfortable pose with the opportunity shift workers body position (sitting, standing). Being in standing position 3 to 40% of the time work shift.	Periodic up to 25% of the time work shift being in uncomfortable pose 3 and (or) fixed pose 5. Being in standing pose to 60% of the time work shift.	Periodic to 50% of the time work shift being in uncomfortable pose and (or) fixed pose; periodic to 25% of the time work shift stay in forced pose 4. Being in a standing position before 80% of the time shifts. Being in sitting position 4 without breaks from 60 up to 80% of the time shifts.	Periodic more than 50% working time shifts being in uncomfortable pose and (or) fixed pose; periodic more than 25% working time shifts forced stay pose. Finding in a standing pose more than 80% shift time. Being in sitting pose without breaks over 80% of the time shifts.

Table 5.9 - The inclinations of the housing forced more than 30°, the number per shift

Class (subclass) of working conditions			
optimal	permissible	harmful	
1	2	3.1	3.2
before 50	51 - 100	101 - 300	over 300

Table 5.10 - Displacements in space due to the process during the work shift, km

Class (subclass) of working conditions			
optimal	permissible	harmful	
1	2	3.1	3.2
Horizontally:			
before 4	before 8	before 12	over 12
Vertically:			
before 1	before 2,5	before 5	over 5

Table 5.11 – measurement results

Characteristic factor	Name factor	Actual value	Min value	Max value	Class conditions labor
Physical dynamic load (units of external mechanical shift work, kg · m)	regional - cargo movement up to 1 m	400	315	400	1
	general – cargo movement from 1 to 5 m	None	None	None	1
	general - cargo movement more than 5 m	None	None	None	1
Mass lifted androaming manually cargo (kg)	when alternating with another work constantly	1,2	1,2	1,2	1
	during the shift total weight	1,2	0,8	1,2	1
	for each shift hour:	10,8	7,2	10,8	1

Table 4.11 - continuation

Stereotypical labor movements (qty)	local load	14000-15000	12000 – 13000	16000 - 17000	1
	regional load	6000 - 7000	5000 - 6000	8000 - 9000	1
Static load (kgf · s)	with one hand	before 11 000	before 11 000	before 11 000	1
	with two hands	before 22 000	before 22 000	before 22 000	1
	involving the body and legs	None	None	None	1
Work pose		70% sitting	67% sitting	80% sitting	3.1
Housing tilts (quantity per shift)		before 50	before 50	before 50	1
Moving to space (km)	horizontally	before 4	before 4	before 4	1
	vertically	before 1	before 1	before 1	1

Conclusion

As a result of the graduation project, skills were obtained in research and analysis of the operation of aeronautics. The main types of quadrocopters are considered. The methods of designing and studying movements are studied. The quadrocopter system was investigated, which in the future can be used for the purpose of remote inspection of the terrain and its patrolling, which is relevant in the territory of the Republic of Kazakhstan. In the course of the work, the main criteria for selecting parts for installation were indicated. A prototype quadrocopter is designed, which has an automated control system and monitoring of the main characteristics (voltage, current, power). As a result of the work, the technical and economic costs for the creation of UAVs, for the configuration of the required software were calculated. As a result of economic calculation, we can conclude that the payback time of investments in the described quadrocopter is acceptable. Since the benefit is designed for the prospect of long-term use. Moreover, the quadrocopter has much more advantages in local application, in comparison with the same winged UAVs. An analysis of the general microclimate during work on the design of the system was also carried out, and an analysis of the severity of working conditions was made. The analysis showed that working conditions are safe for workers and are within optimal values.

List of abbreviations

UAV - unmanned aerial vehicle;
TO - theater of operations;
TAC - theory of automatic control;
CO - control object;
MM - mathematical model;
PID controller - proportional-integrating-differentiating controller;
ANN - artificial neural networks;
CS - control system;
EM - electric motor;
SVS - systems with a variable structure;
UPS - uninterruptible power supply;

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