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CONTROL AND MONITORING SUBSYSTEM OF AN UNMANNED AERIAL VEHICLE

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Abstract—*The object of the research is the unmanned aerial vehicle monitoring system, the data exchange protocol and the unmanned aerial vehicle control line. A study was conducted, based on the results of which the unmanned aerial vehicle protection protocol and criteria were selected. An algorithm has been developed that ensures the establishment of the fact that the received radio radiation belongs to the class of radio signals of unmanned aerial vehicle remote control systems with pulse-position and pulse-code modulations. The results of practical testing of possible solutions are presented and the results of the functioning of the developed communication components are given. The user interface was developed, and the hybrid data exchange protocol was implemented in software.*

Index Terms—Ground control station; data exchange protocol; control system; unmanned aircraft; control line; protection line; user interface.

I. INTRODUCTION

Recently, unmanned aviation has been rapidly developing. The development of unmanned aerial systems (UAS) based on unmanned aerial vehicles (UAVs) is currently carried out by almost all industrialized countries of the world. Until recently, UAVs had a military purpose, now the use of UAVs is effective both in military and civilian tasks, for example, in combating the consequences of emergencies, natural disasters, agricultural applications, reconnaissance and aerial photography.

The impetus for the development of unmanned aviation worldwide was the need for light, relatively cheap aircraft with high maneuverability characteristics and capable of performing a wide range of tasks. Unmanned aerial vehicles are successfully used in military operations around the world, and at the same time they successfully perform civilian tasks. Today, most of the existing unmanned aerial vehicles are piloted manually, using remote controls operating on radio channels.

When manually piloting UAVs, there are difficulties associated with pilot training, insufficient operating range, and weather restrictions. UAV control is the task of a well-trained professional. For example, in the U.S. Army, UAV operators become active duty Air Force pilots after a year of preparation and training. In many aspects, it is more difficult than piloting an aircraft and, as is known, most accidents of unmanned aircraft are due to pilot-operator errors and mechanical failures.

According to the official data provided for 2012, 70 unmanned aircraft crashed in the US Air Force.

II. GROUND CONTROL STATIONS OF UAVS

Unmanned aerial vehicle ground control station (GCS) is a land or sea control center that provides means of human control unmanned aerial vehicles (UAVs or "drones"). It can also refer to a missile control system within or above the atmosphere, but it is usually described as a Mission Control Center.

Main purpose:

1) Plan the mission – after receiving information about the UAVs environment and the details of the mission, the GCS performs the appropriate calculations to determine the trajectory of the course and the time frame of the maneuvers.

2) Provide navigation and positioning – the GCS reacts to changes in the environment in case of unforeseen situations during the flight of the UAV in relation to the planned trajectory.

3) Establish communication and data collection - during the mission, data from the UAV is transmitted to the GCS for their analysis and reporting to the operator.

The GCS supports network operation, and thanks to its architecture and compatibility with Ethernet, it can be easily and efficiently integrated into existing network systems, distributing the necessary information between users, for example, transmitting intelligence information from the GCS to the headquarters and receiving a combat mission from the headquarters [3].

Appointment:

- training of UAV and target load operators (TL), support of their skills and abilities in UAV piloting, navigation, operation of UAV systems and equipment in flight;

- carrying out objective supervision of floorings (Fig. 1).

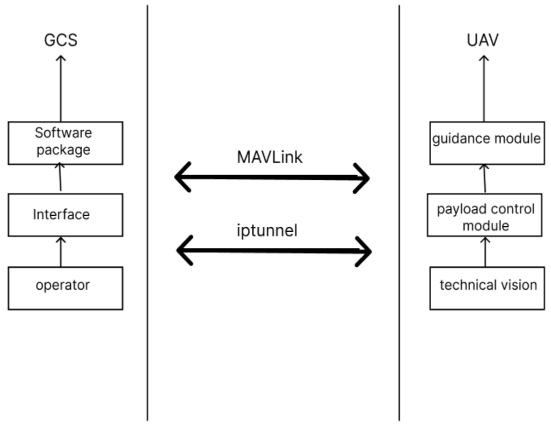

Fig. 1. Functional diagram of the UAV control subsystem

A. UAV Monitoring Subsystem

The protocol is designed for binary telemetry. It can be used for systems with limited resources and limited bandwidth of communication channels. It describes the interaction between the small unmanned aerial vehicle (SUAV) system and the ground control station (GCS), as well as their components.

A system has a unique ID, and each component within that system has its own unique ID. These IDs will be used for routing / addressing.

MavLink is the main communication protocol between GCS and UAV. It allows communication over various transport and physical layer protocols such as UDP and TCP, WiFi and Ethernet.

MavLink is also a binary serialization protocol, which means first converting the data into a sequence of bytes and then converting it back to data for the receiver. This quality makes the average message size of this protocol very low [1] due to high compression of the output data. Each MavLink v2 message consists of a header and a message body, weighing from 25 to 270 bytes. The messages themselves are divided into two main types [2]:

1) Status messages – sent from the UAV to the GCS and contain information about the position of the UAV, data from sensors and additional information required by the GCS.

2) Management messages – sent from the GCS to the UAV and contain requests for certain actions.

B. Problems that Arise with the Management and Security of UAVs

UAVs and drones are perceived as viable and vital information security threats. Many UAVs have serious design flaws and most of them are designed without wireless security protection and channel encryption.

Tendency to spoofing. Analysis of the configuration and flight controllers of UAV models with multiple rotors revealed many weaknesses. They are associated with telemetry links that transmit data to / from the drone via a serial port connection, especially due to the weak nature of the connection, which in most cases is not encrypted. Experiments performed have shown that with the help of GPS spoofing, information can be easily hijacked, changed or introduced [3]. This vulnerability in the data link allows interception and moonlighting, giving hackers full control over the drone.

Tendency to be infected with malware. Communication protocols are included in the UAVs to allow users to control drones with a wireless remote control such as tablets, laptops and mobile phones. However, this technique has proven to be dangerous, as it allows hackers to create a loopback TCP payload by injecting it into the drone's memory, which will covertly install malware on systems running at ground stations.

Tendency to interfere and intercept data. Telemetry channels are used to monitor vehicles and facilitate the transmission of information through open, unsecured wireless transmission, making them vulnerable to various threats. This includes data interception, malicious data entry, and alteration of pre-established flight paths. This allows many infected digital files (videos, images) to be installed and pasted from the drone to the ground station. Another vulnerability was discovered and associated with the UAV communication module, which uses wireless communication to exchange data and commands with the ground station [4].

Tendency to manipulation. Because drones fly pre-programmed and predetermined routes, manipulation can occur that can have serious consequences [5]. Ranging from hijacking high value cargoes to redirecting the UAV to deliver explosives, bioweapons, or other terrorist payloads via RF or GPS spoofing, allowing the attacker to gain control of the drone by sending out fake signals, or jamming its target to malfunction. · Tendency to technical problems. Many drones suffer from various technical problems. This includes application errors such as a connection failure between the user's device and the aircraft, causing it to either crash or take off. Other issues are related to the lack of a stable connection, especially for complex natural reasons; battery life, resulting in a very limited flight time before cooking again [6].

Prone to Wi-Fi interference. Drones can also be hijacked by sending a deauthentication process between the access point and the device controlling the drones, which can be done temporarily or permanently, such as interfering with the drones' intended frequency and luring it into connecting to a Wi-Fi hacker; this can be done by installing and configuring raspberry-pi to do this.

III. Statement of the Problem

In this work, we analyzed:

1) Structural features of the UAV.
2) Features of the Ground Control Station and its purpose.
3) The main subsystems for monitoring and controlling the UAV.
4) Features of UAV control and defense lines.
5) Existing problems of control and protection of the UAV control line.
6) Existing solutions to ensure the protection of the UAV control line.
7) Available solutions for UAV-Operator (GCS) interaction interface.

It was found that the existing solutions in the protection of the line of defense and the hierarchy itself the structure of the UAV-GCS complex needs improvement. The following problems were identified:

1) Standard data exchange protocols have significant insecurity due to the openness of the data package and small structure.
2) The solutions that provide the protection line of the control channel are largely outdated, and knowing the algorithm of the exchange line, you can easily sew your data packets into the structure of the UAV.
3) The system of internal software monitoring does not allow full data analysis, so it will be difficult to diagnose the system on the fly [7].
4) Most of the interfaces are difficult to learn and the more functionality the system has, the more time it takes for the operator to master the system.

Therefore, the following tasks were set in the further work:

- modernize the level of protection of the data exchange protocol, and write a software implementation of the protocol that will make the system more secure;
- to analyze the features of signal formation in remote control systems of drones;
- write a new algorithm for the line of protection that will allow the control line to receive more protection;
- develop a system by which it is possible (in the presence of an operator and a specialist) to quickly diagnose the state of the UAV and its systems (Software failures);
- to develop a light and maximally optimized UAV control interface, which will not have a heavy appearance and will be clear to use.

IV. Results

A. Improvement of the Signal Detection Algorithm of UAV Controls

The first stage of the algorithm is to check the energy feature S1. Checking other signs is carried out only when S1 = True, that is, the presence of any signal whose energy is sufficient for further analysis. Otherwise, a decision is made about the absence of any signal (including the signal of the UAV control systems) and the algorithm ends its work. Additionally, on this basis, the radio receiver can be rebuilt to analyze another part of the frequency range.

The second stage of the algorithm is to check the modulation feature S2, which is preceded by intermediate calculations: Fourier and Gilbert transform, selection of the modulating function (vector of the instantaneous frequency of the signal), filtering and automatic tuning to the dominant frequency of the signal. When S2 = True there is a case of a signal that, by the type of modulation, corresponds to the signal of the UAV control systems.

The third stage of the algorithm is to check the structural feature S3. When it is executed, the final decision is made on the availability (S = True) or absence (S = False) signal of UAV control systems in the received signal mixture.ystems

B. Software structure

The user interface is implemented through the Q_t toolkit, which is a cross-platform software development toolkit in the C++ programming language. Helps launch the program – on most modern operating systems, by simply compiling the program text for each operating system without changing the written code.

The product is used in complex projects. It is popular for development on the Android platform. But its use requires significant resources [8].

The project is divided into 3 main modules, this is the Interface implemented on the basis of the interpreted QTqml language, the software part where all the operations and action algorithms are described (the writing language is C++), and the server in which the UAV parameter transmission is simulated (Fig. 2).

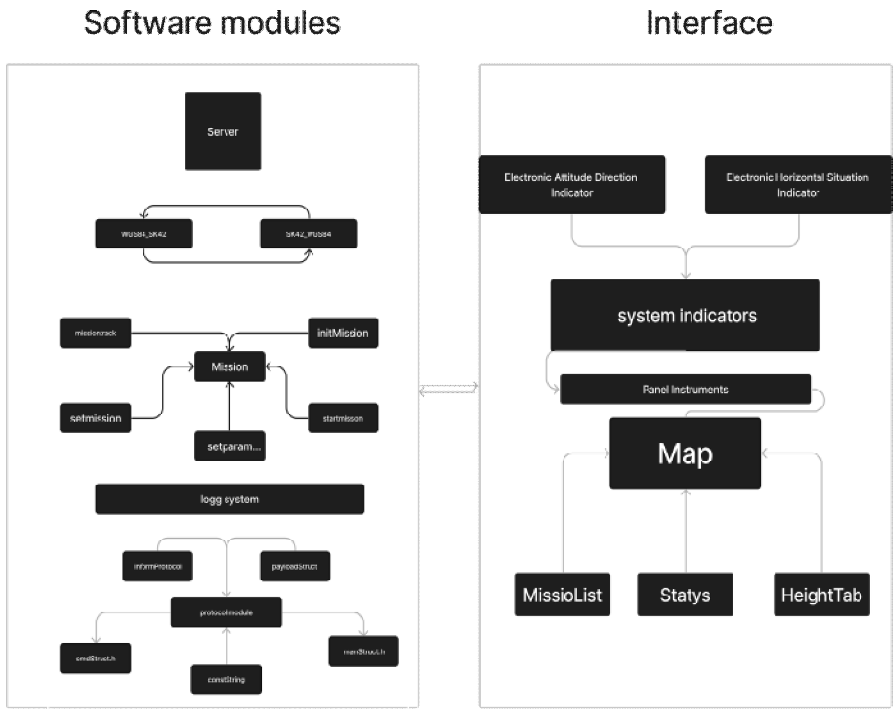

Fig. 2. Project architecture

C. User (Operator) Interface

Let's start with the main tools for displaying and visualizing UAV parameters, which is implemented as follows: in the left part of the graphical interface, we can observe all the necessary parameters that are used in modern piloting realities.

Two main digital instruments (QFlightinstruments) were taken as a basis:

- electronic Attitude Direction Indicator (EADI);
- electronic Horizontal Situation Indicator (EHSI).

As additional indicators, separate elements were added, which were also added manually:

- GPS coordinates;
- angular velocities;
- angles of orientation;
- latitude and longitude;
- delta controls;
- linear acceleration;
- BINS coordinates;
- magnetometer parameters;
- GPS course;
- velocity vectors by GPS.

The expanded parameters interface is shown in Figs 3 – 5.

In the lower part of the interface there are additional messages, namely Message and Warning, which serve as additional information for control operators.

Now you can go to the right part of the interface (map and additional options).

Fig. 3. Graphic implementation of UAV parameters monitoring

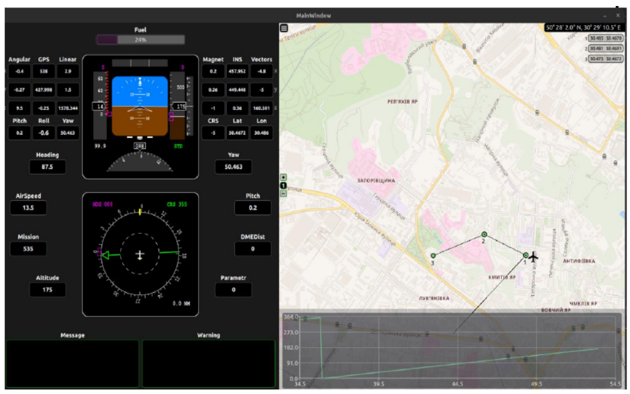

Fig. 4. Expanded interface of additional parameters

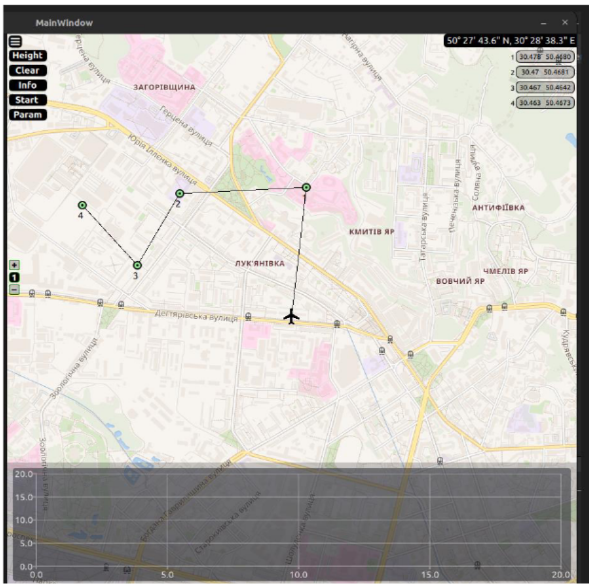

Fig. 5. Interface of the graphic position of the UAV on the map

This window contains:

- map;
- graph of dependence of speed and distance;
- route points (Missions);
- current location (Longitude, Latitude).

During the development of this interface, all the necessary indicators, cartographic subjects, a toolbar and dependency graphs were added, which will fully allow to have all the necessary and up-to-date information about the state of missions and UAV indicators.

D. Description of the Software Package

a) Logging system

Logs (log files) are logs that contain information about system operation and certain user actions.

Their purpose is to record the operations performed on the machine for later analysis of these operations for system improvement or system diagnostics.

Implementation of the logging system was a difficult task as it was not necessary to reboot the system by constantly writing and reading its parameters and errors. To optimize the entire process, it was decided to develop this system as follows:

- intercept the entire console of our program by redirecting the flow of information into a text stream (buffer);
- dynamic creation of directory and log files (.txt);
- each session, the flow of information is written to files;
- debugging proceeds with a frequency of 1000 Hz.

After the session ends, the file is saved and the buffer is cleared After checking the work, we came to the conclusion that such manipulations will allow us not to reboot the system and correctly keep the event log of our program.

b) Mission establishment subsystem

Having drawn up the data exchange protocol and missions, you can proceed to the software implementation, the structural diagram is shown in Fig. 6.

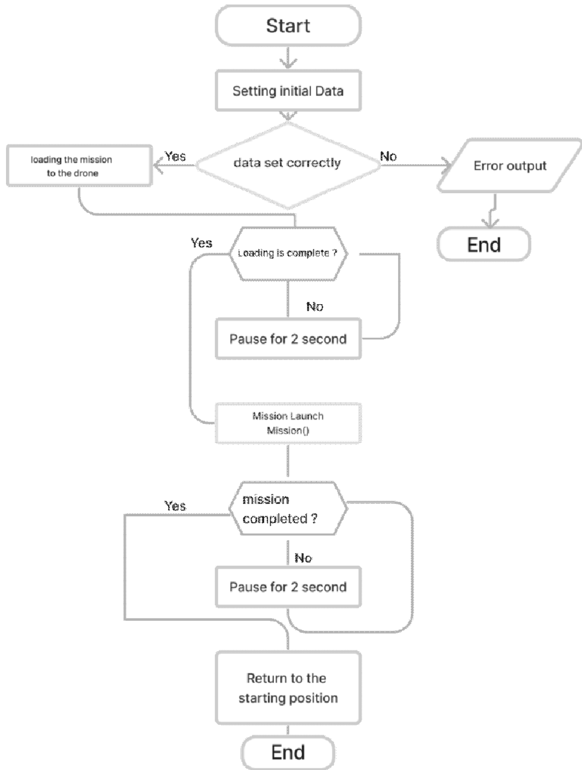

Fig. 6. Structural diagram of mission initialization

Any flight begins with the initialization of the initial parameters. Since we use our data packaging algorithm, which is a hybrid of the MavLink protocol and the created data structures (Fig. 6), which are multi-nested systems of identifiers, additional protection of our system against unauthorized access appears.

After each parameter initialization according to the developed transmission line protection algorithm, we include timers that check the delay and the correctness of identifiers, if everything is correct – the data is considered correct.

After the initial initialization, the mission is downloaded according to the same algorithm, after the NSU received a message about the mission being downloaded, it sends a coded check for the correctness of the data recording. When the responses to the messages are correct, the final ready-to-execute signal is sent.

During the mission execution process, it is possible to monitor all subsystems of the UAV and log logs (which in the future makes it possible to check all security protocols).

After completing the mission, the UAV sends a signal about the completion of the mission, the NSU sends a response in which it gives a mission log, according to which the UAV checks whether all the points of the mission have really been completed, if so, the UAV sends a message about the final status of the mission.

Next, the waiting protocol for further commands is started, if the waiting time exceeds the norm, the aircraft returns to the previously set landing point.

V. CONCLUSIONS

The Data Transfer Protocol was modified, all data is packed into structures, which allows you to bypass the payload check, which makes it possible to simplify and at the same time ensure reliable data transfer.

In the form of a software solution, an interface has been developed that fully performs the tasks of monitoring the control of the UAV. Elaboration of UAV control scenarios and those implemented in C++ code. A logging system has been implemented, which allows diagnosing the system at the end of the flight.

In the form of an algorithm, specific solutions and means of eliminating the weakness of the UAV defense line were proposed. And the algorithm, based on successive checks of the energy, modulation and structural features of the signal, suggests the possibility of automatically determining its frequency by the accompanying signal.

In general, a full-fledged UAV monitoring subsystem was made, which allows you to monitor the performance of the system and, in case of danger, take control of the operator.

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В. М. Синєглазов, А. О. Цьоба. Підсистема керування та моніторингу безпілотного літального апарату

У роботі досліджено систему моніторингу безпілотного літального апарату, протокол обміну даними та лінію керування безпілотним літальним апаратом. Розроблено підсистеми моніторингу та керування безпілотного

літального апарата, модернізовано захист лінії керування безпілотного літального апарата. Проведено дослідження, за результатами якого обрано протокол та критерії захисту безпілотного літального апарата. Розроблено алгоритм, який забезпечує встановлення належності прийнятого радіовипромінювання до класу радіосигналів систем дистанційного керування безпілотними літальними апаратами з імпульсно-позиційною та імпульсно-кодовою модуляціями. Наведено результати практичної перевірки можливих рішень та наведено результати функціонування розроблених комунікаційних компонентів. Розроблено інтерфейс користувача та програмно реалізовано гібридний протокол обміну даними.
Ключові слова: наземна станція керування; протокол обміну даними; система керування; безпілотні літальні апарати; лінія керування; лінія захисту; інтерфейс користувача.

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