DOI: https://doi.org/10.15407/kvt217.03.005

HUBSKY O.M., PhD Student,
https://orcid.org/0009-0004-3106-2770
e-mail: aleksey.gubsky@gmail.com
International Research and Training Center for Information
Technologies and Systems of the National Academy of Sciences of Ukraine
and Ministry of Education and Science of Ukraine,
40, Acad. Glushkov av., 03187, Kyiv, Ukraine

ANALYSIS OF USER INTERFACES FOR GROUND CONTROL STATIONS OF UNMANNED AERIAL VEHICLES

Introduction. *In the modern world, software (SW) is updated daily, particularly for ground control stations (GCS) of unmanned aerial vehicles (UAVs). These systems ' user interfaces (UI) ensure operator interaction with the drone, flight control, mission planning, and real-time data acquisition. These interfaces must be functional, convenient, and intuitive, allowing operators to perform their tasks effectively. Examining global experience allows for an evaluation of existing systems and the identification of areas for improvement. Important aspects include creating intuitive UIs to prevent information overload, ensuring situational awareness, adapting to extreme conditions, and integrating with other systems. The use of virtual and augmented reality technologies, as well as artificial intelligence, can enhance the functionality and convenience of GCS. Such analysis will help in creating safe, efficient, and reliable systems for UAV control.*

The purpose of the paper *is to investigate and conduct a comprehensive analysis of existing user interfaces of software for UAV ground control stations, focusing on their functional capabilities and ease of use.*

Methods. *The following methodological tools were used: concepts of intellectualization of information technologies, the theory of intelligent control, the methodology of building autonomous systems, decision-making theory, and artificial intelligence theory.*

Results. *A review of global experience in user interface development was conducted. The UIs of each of the studied software were analyzed, and their functional capabilities were assessed, identifying their strengths and weaknesses. Comparative tables of interface products were compiled based on their functional capabilities and UI usability levels. Generalized recommendations were prepared for creating a unified interface that combines the best features of existing solutions and addresses their shortcomings.*

Conclusions. *The analysis of GCS UI design for UAVs showed that all systems have strengths and weaknesses. The UI of the Mission Planner software has the most extensive* *capabilities, but it also requires improvement. Future development should add roles for military pilots and operators, develop a more intuitive and user-friendly interface that meets user needs, and simplify SW settings. For working in extreme conditions, the interface needs to be optimized. Enhancements in data visualization will help make information clear and easy to understand, which is critically important in fast-paced and dangerous situations.*

Keywords: *user interface, ground control station, UAV, virtual reality, augmented reality.*

INTRODUCTION

In today's world, many drone manufacturers have created different software solutions, each with its unique ground control station (GCS) user interfaces. These are essential for unmanned aerial systems (UAS), enabling operators to control the drone, plan missions, and gather real-time data. Modern GCS user interfaces are highly functional, user-friendly, and intuitively designed, allowing operators to work efficiently. This review aims to examine the key components and features of GCS user interfaces and study global experiences in designing UAS user interfaces. Such analysis will assess the functionality and usability of existing software and identify areas for improvement.

When reviewing the user interfaces of ground control stations for unmanned aerial vehicles (UAVs), we encounter various challenges that can impact the efficiency and safety of UAV operations.

The UAV operator must monitor many parameters simultaneously, a complex task, especially during emergencies when information overload can reduce operational efficiency. Therefore, creating an intuitive user interface is crucial. At the same time, ensuring a sufficient level of situational awareness for the pilot-operator is essential, as shortcomings in this area can lead to accidents.

Modern user interfaces must be adaptable for use in various conditions, including extreme temperatures, rain, and other weather conditions. Additionally, in wartime conditions, they must be resilient to physical damage. When studying global design experiences, it is important to consider integration with other military and civilian systems.

Furthermore, exploring innovative implementations in user interfaces is necessary, particularly the use of virtual reality (VR) and augmented reality (AR) technologies, which enhance operator situational awareness. The analysis of user interfaces should also consider the applications of artificial intelligence (AI), which, when combined with AR, promises to enhance the functionality and usability of ground control stations in the future.

This analysis of worldwide control systems aims to help address the challenges faced by GCS user interface developers, ensuring the safe, efficient, and reliable operation of both individual UAVs and large unmanned aviation complexes.

OBJECTIVES

The goal of this article is to analyze the current user interfaces of ground control station software for unmanned aerial vehicles, focusing on their functionality and usability.

ANALYSIS OF THE FEATURES OF THE CONSTRUCTION OF EXISTING USER INTERFACES FOR DRONE CONTROL STATIONS

Experience in building user interfaces of drone control stations. The literature review highlights significant progress in unmanned aerial systems, particularly ground control stations for UAVs. User interfaces of these systems are crucial for ensuring UAV efficiency and safety. Recent studies focus on optimizing UI design, enhancing usability, improving situational awareness, and adapting to extreme conditions. This section analyzes and compares existing user interfaces for ground control stations to identify directions for further development and improvement.

The review begins with article [1], which emphasizes providing operators with essential information about risk assessment to enhance situational awareness and safety. The study compares the usability of two graphical user interfaces, exploring how users interact with different information display styles. Feldman's usability scale was proposed, and the analysis of complex tasks, such as risk assessment and prioritization, was conducted for workload and response time. The results offer insights applicable to the analysis of existing UIs in the present study.

In contrast to the general approach of the previous article, the authors of article [2] focus on understanding the impact of three primary control interface methods (line-of-sight, video recording, and first-person view) on flight performance, situational awareness, and perceived mental workload. The research compares traditional control UIs and first-person view (FPV) control. It highlights the problem of increased mental workload and lower situational awareness compared to traditional methods. Given the rapid advancement of technologies, it is essential to reassess these results when analyzing modern UIs.

One fundamental criterion for evaluating UI performance is usability in human-machine interaction. Users with low technological experience require simple interfaces that support recognition rather than recall. Article [3] examines creating a natural user interface that mimics "natural" sensorimotor embodied interaction with the environment. This paper compares the usability of a new interface based on eye-tracking and hand gesture recognition with a traditional interface (keyboard) for the distal control of a drone flying in a virtual environment. Natural UI is a new direction for UAV control, making it interesting to explore how similar ideas are implemented in specific software and the prospects for further development in designing new universal GCS and their UIs.

In article [4], researchers from the USA examine the issues of creating intuitive gesture-based user interfaces. Precise remote control of robotic devices requires simple, intuitive, and reliable control interfaces. A control method relying on upper body movement was applied, allowing inexperienced pilots to outperform those using manual control tools with traditional UI. Although the study's results are promising, the developers note that drone control was only tested on relatively smooth waypoint trajectories. Thus, it is essential to consider that complex trajectories with sharp directional changes may not be such successful. In our study, these results should be viewed as interesting but not requiring immediate implementation in UIs. Additionally, the sample size was small and lacked diversity, consisting mainly of young university students.

Article [5] presents a study on using a natural user interface, where an intuitive control method is achieved through body gestures. The Robot Operating System was used for project control and management of various components. While the proposed idea found experimental implementation, the design ideas for organizing the UI under this new method were not thoroughly explored, leaving ample room for analyzing human-system interaction features.

UAV missions in urban areas or over long distances offer new opportunities for UAV operators but often carry potential risks, including obtaining permissions from authorities. Almost always, when discussing UAV operations in cities or over long distances, there is a need to support the mission planning process. Article [6] presents the development of an interactive representation of operational parameters on maps to accelerate the planning process for large-scale missions. The results are particularly interesting due to the extensive feedback collected, allowing for the creation of a broad repository of risks. Although the study investigated the impact of operational parameters on safety and identified some risks, it would be interesting to supplement the list with previously unidentified risks in our analysis and suggest approaches to address them.

When addressing mission definition and flight automation tasks, there is a need for a system that performs measurements for discrete infrastructure inspections using UAVs, particularly multirotor drones [7]. Therefore, when developing the UI, a multi-purpose mission definition system architecture should be employed to facilitate the definition of flight missions for various types of automated operations using visual tools. This would overcome the limitations of basic tools provided by drone manufacturers and provide users and pilots with a shared operational perspective.

The UI of the proposed in the article system supports automated operations for various UAV autopilots and sensors. The tool defines a set of pre-defined primary inspection modes that help easily determine parts of a large number of mission operations. Although real-time telemetry and sensor visualization are possible, the system requires significant improvements and modifications for universal application with drones from different manufacturers. The study also presented a unique type of 3D flight simulation, but it does not guarantee that the proposed visual information is exactly what the operator needs at each stage of the flight.

Overview of available interfaces. A user interface, or human-machine interface [8], for ground control stations in UAV operations, refers to the graphical and interactive components that allow users to control and manage UAVs. Figure 1 shows an example of the hardware implementation of a UAV ground control station user interface.

Here are the key elements typically found in the user interface of GCS software:

Flight Data Display: The UAV control system provides users with access to real-time telemetry data, including altitude, speed, GPS coordinates, battery status, and signal strength. Position indicators display roll, pitch, and yaw, offering detailed information about the current flight status.

Map Interface: The map interface provides a live map showing the UAV's current location. It includes overlays with waypoints and mission planning, as well as visualizations of geofences and no-fly zones, which are critical for safe flight management.

Fig. 1. Presentation of the interface of the UAV ground control station

Mission Planning Tools: The system offers tools for setting waypoints, flight paths, and mission parameters. These tools allow users to edit and save mission plans for future use, ensuring flexibility and convenience in flight planning.

Video Streaming: The system supports live video streaming from the UAV's camera(s), allowing users to monitor the flight in real time. Options for recording and replaying videos are also available, which are useful for post-flight analysis.

Alert Elements: Real-time alerts about battery status, signal loss, obstacles, and other critical issues ensure a high level of safety during flight. Audio and visual notifications help users quickly respond to potential problems.

Settings and Configuration: Users have access to various settings for the UAV and the ground control station. Calibration tools for sensors and controllers ensure system accuracy and reliability.

Data Logs: The system provides access to flight logs and telemetry data visualization, allowing for detailed flight analysis. Data export options enable further analysis, which is essential for scientific research and technology improvement.

Control Elements: Users can control the UAV using a virtual joystick or control buttons for manual flight control. Additionally, the system supports automated commands for takeoff, landing, and waypoint navigation, significantly simplifying the control process.

DJI pilot and DJI GO

DJI Pilot and DJI GO are two distinct ground control applications created by DJI for managing their drones. These apps offer flight control, camera control, and flight data monitoring, making them essential tools for DJI drone operators. (Fig. 2)

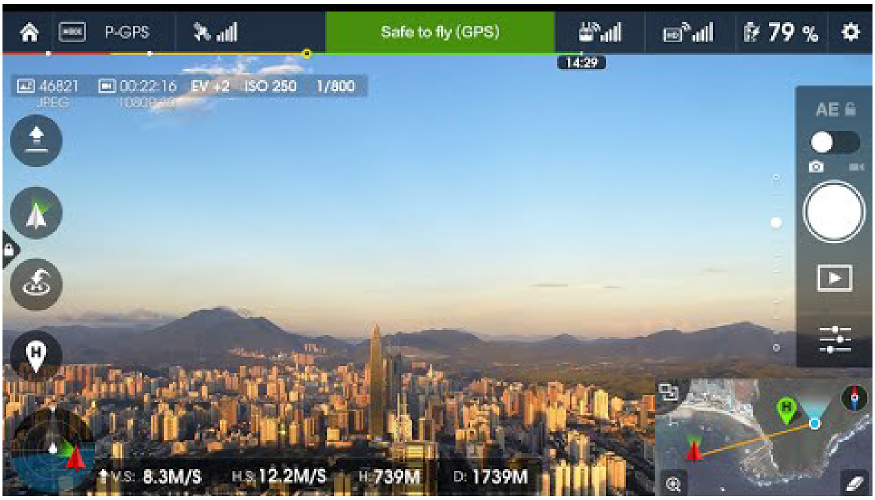

Fig. 2. DJI Pilot / DJI Go software user interface

DJI Pilot [9] is a specialized app designed for DJI's business and industrial drones, such as the Matrice 300 RTK and Matrice 30 series. This app offers a clear telemetry data display, easy access to mission planning tools, and a customizable dashboard. DJI Pilot's interface is modern and intuitive, making it convenient for professional users. Its optimized structure ensures high usability, allowing quick drone deployment and effective flight control. DJI Pilot also supports real-time video streaming, enabling operators to receive visual information during flight and store and analyze flight data for later use.

DJI GO [10] is a comprehensive app providing full flight control and camera settings for DJI drones like the Mavic, Phantom, Inspire, and Osmo series. Its simplified interface features basic controls for camera and flight operations, making it suitable for users of all skill levels. The DJI GO interface resembles consumer mobile apps, making it user-friendly for hobbyists and beginners. The app allows easy control of the drone's camera, video, and photo capture, as well as editing and sharing directly from the app. This makes DJI GO ideal for those who do aerial photography for fun or small projects.

Both DJI Pilot and DJI GO apps include flight data storage and analysis capabilities, allowing operators to keep flight logs, view flight paths, analyze telemetry data, and use that data to improve future missions. A notable advantage is the integration with other DJI programs for further data processing and analysis.

Cybersecurity is increasingly important in the field of drone use. A study [11] showed that DJI software can collect and analyze data not only from drones but also from remote controls. This includes information about the pilot's account, the specific drone, connection timestamps, the pilot's location, the drone's flight path, and content captured during flights. This data is critical for ensuring operational security and protecting confidential information.

In summary, DJI Pilot and DJI GO are powerful tools for controlling DJI drones, each with unique features designed for different user categories. They provide high functionality, ease of use, and integration with other DJI products, making them indispensable for both professional and amateur drone operators.

QGroundControl

QGroundControl is open-source software [12] for ground control stations, compatible with various drones. It offers mission planning, flight control, and telemetry monitoring, providing a comprehensive range of features for drone operations. From flight control and mission planning to aircraft configuration and real-time data display, QGroundControl addresses all aspects of drone control. Its cross-platform compatibility, open-source code, and support for multiple flight stacks make it a versatile tool for both professional and amateur UAV users (Fig. 3).

Developed by an open-source community, QGroundControl allows users to modify and improve the software freely according to their needs. It offers advanced flight planning, including the ability to automate mission planning and replanning in real-time. This feature is handy for increasing vehicle autonomy and reducing operator workload.

One of QGroundControl's main features is real-time telemetry, enabling users to receive and analyze flight data directly during flight. Its support for different types of UAVs makes the software extremely flexible and versatile for various tasks and operations.

While QGroundControl's interface is functional, it may not be as polished as DJI's apps. However, its high level of customization allows experienced users to optimize the program for their specific needs. This aspect makes QGroundControl particularly appealing to those requiring advanced features and capabilities for specialized tasks.

The usability of QGroundControl can be considered average; it is best suited for advanced users and those needing sophisticated features. Beginners might find the interface complex, but experts in UAVs will find its capabilities invaluable.

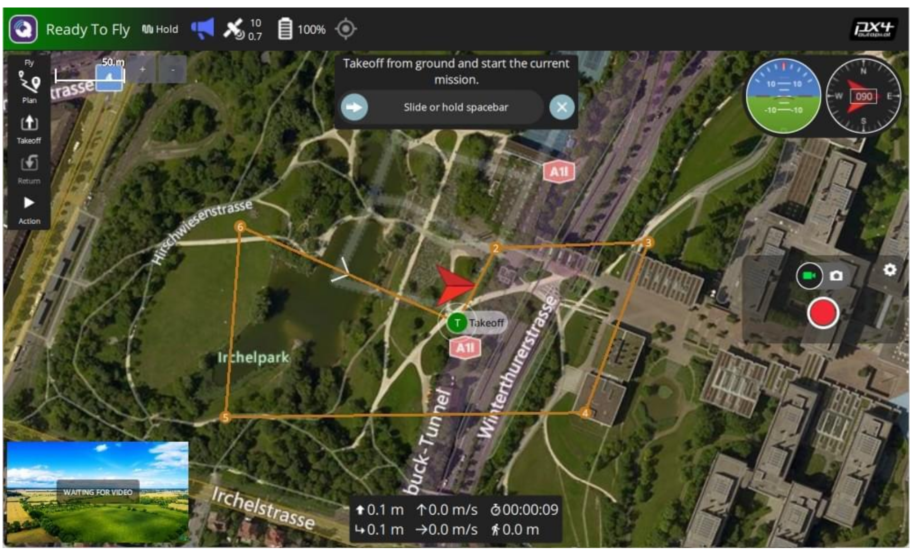

Fig. 3. QGroundControl software user interface

A significant achievement in the field of UAVs is the automation of mission planning and replanning in real-time, which is very useful for enhancing vehicle autonomy and reducing operator workload. The article [13] discusses automated mission planning systems in terms of building a human-machine interface that facilitates the operator's work, utilizing the capabilities of QGroundControl and the modeling environment.

UGCS (Universal Ground Control Software)

UGCS (Universal Ground Control Software) is a robust solution developed by SPH Engineering for the professional planning and control of unmanned aerial vehicle (UAV) missions [14]. This software supports a wide range of UAV platforms and autopilots, making it suitable for organizations of all sizes, from single operators to large enterprises with UAV departments. (Fig. 4)

UGCS is known for its powerful features, including extensive mission planning, 3D mapping, real-time telemetry, and automation scripts. These features enable users to efficiently plan and execute complex missions efficiently, ensuring high accuracy and reliability. The 3D mapping and real-time telemetry capabilities, in particular, give operators a comprehensive view of the situation, allowing them to make informed decisions during missions.

The UGCS interface is professional and detailed, with a focus on advanced features. It provides a high level of control and flexibility, which is especially crucial for professional use. The usability of UGCS can be rated as medium to high, although it is intended for users with significant training and experience. New users may need some time to learn all the features and capabilities.

One of the standout features of UGCS is its support for photogrammetric and complex LiDAR surveys. This includes Lidar area and Lidar corridor tools, which enable high-precision measurements over large areas. The photogrammetry tool simplifies the mission planning process by allowing users to create and execute photogrammetry missions with just a few clicks.

Fig. 4. UGCS (Universal Ground Control Software) user interface

UGCS also supports the import of custom altitude data and offers a terrain tracking mode that provides optimal flight paths in areas with challenging terrain. This feature allows drones to automatically adjust their altitude based on the topography, which is essential for maintaining a consistent distance to the ground during LiDAR surveys and improving data quality [15].

Other key features of UGCS include the ability to combine multiple photogrammetry areas into one route, the option to optimize survey lines for each area separately, and the option to use a “dual grid” option to enhance point cloud quality in urban and densely vegetated areas. This greatly improves the quality of the final orthomosaic, which is important for accurate geodetic and cartographic work.

Overall, UGCS offers advanced planning tools that, through automatic calibration and terrain tracking, allow UAV operators to conduct LiDAR surveys more efficiently. Using UGCS can reduce the time spent planning LiDAR flights by up to three times compared to manual methods, significantly boosting productivity and operational efficiency.

Pix4Dcapture

Pix4Dcapture is a free drone flight planning software by Pix4D designed for optimal 3D mapping and modeling [16]. This software allows users to plan and control drone flights using only a mobile device, making the process very convenient and accessible for users of various levels. (Fig. 5)

The main feature of Pix4Dcapture is the ease and speed of planning a mission for aerosolization. The program's interface is simple and clean, focused on photogrammetry missions, making it ideal for users familiar with mapping applications. The program provides high usability, allowing operators to quickly get acquainted with its functionality and use it effectively.

Fig. 5. Pix4Dcapture software user interface

Location	Area Surveyed (ha)	Georeferencing Method	Cameras Total/Aligned	Key Points per Images	Dense Cloud (nbr Points)	Orthomosaic, DSM Resolution (cm)
KEKEC	3.4	BBA_traditional	135/135	65,326	45,662,559 (327.6/m^3)	2.4
		BBA_PPK			45,754,260 (323.16/m^3)	
KRNICA	9.6	BBA_traditional	659/659	69,863	159,285,721 (836.51/m^3)	2.5
		BBA_PPK			165,097,231 (756.25/m^3)	
MANGART	7.4	BBA_traditional	368/368	72,809	100,688,038 (1635.12/m^3)	2.2
		BBA_PPK			106,209,704 (1707.94/m^3)	

Fig. 6. Results of photogrammetric processing of Pix4D software for different locations and methods of georeferencing. [17]

A key feature of Pix4Dcapture is its integration with the Pix4D software package, offering a seamless transition from data collection to processing and analysis. This enables users to create accurate 3D models and mapping products. The program also includes specialized plans for capturing specific objects, such as cell towers and power lines, simplifying the process and ensuring high-quality data.

The Pix4Dcapture interface supports the automatic downloading of digital terrain models, including terrain detection. This feature provides optimal flight paths in areas with complex terrain, crucial for creating accurate maps and models. Additionally, Pix4Dcapture allows the import of custom altitude data and offers a terrain tracking mode, enabling drones to automatically adjust their altitude based on terrain, maintaining a constant ground distance during shooting and improving data quality.

Studies have shown [17] that the results of photogrammetric processing of data collected using Pix4Dcapture demonstrate high accuracy and quality. Drone image post-processing modules for 3D surface modeling were compared, and Pix4Dmapper proved to be one of the best tools for creating 3D models [18]. Although the algorithmic output from Pix4D is sometimes complemented by other programs for accurately modeling local elevations such as trees or buildings, it provides an excellent 3D perspective for tasks like golf course mapping. (Fig. 6)

Overall, Pix4Dcapture is a powerful and convenient tool for planning and executing aerial missions. Its integration with other Pix4D programs, simple interface, and automatic flight height adjustment has made it indispensable for professionals in cartography and 3D modeling.

Mission Planner

Mission Planner is an open-source ground control station software primarily used for ArduPilot-based drones [19]. It includes mission planning, flight control, and telemetry data analysis. Although designed specifically for ArduPilot vehicles, mission planning systems generally provide optimized schemes for military operations across various military systems, typically featuring input, core databases, and decision-making modules to support command and control. (Fig. 7)

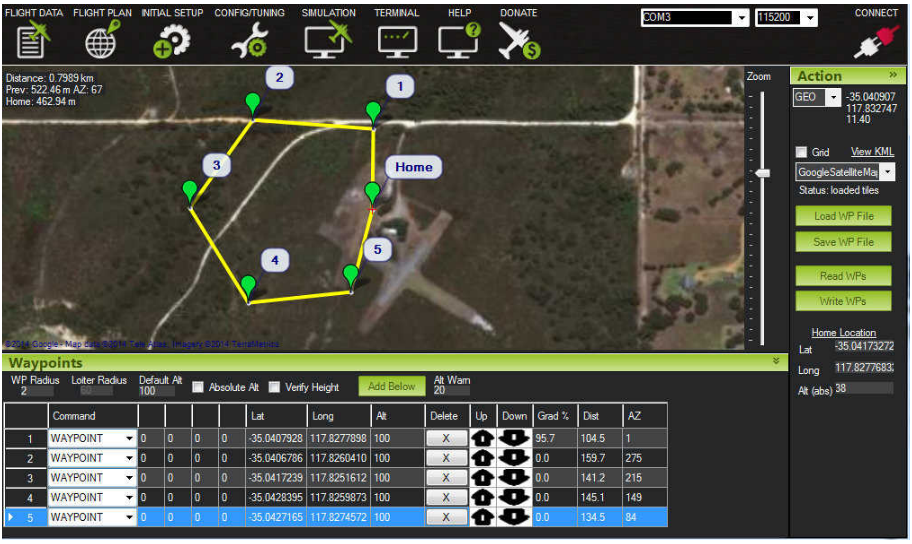

Fig. 7. Mission Planner software user interface

Developed by the ArduPilot community, Mission Planner offers a comprehensive set of tools for mission planning, UAV configuration, and monitoring. Users can create detailed flight plans, configure various drone parameters, and monitor performance in real time. One of Mission Planner's main advantages is its versatility, allowing for a wide range of tasks, from simple drone setup to complex military operations.

The Mission Planner interface is complex and feature-rich but has a steep learning curve [20]. Beginners will need time to master all the functions, but advanced users will appreciate its power and flexibility, allowing customization to meet specific needs. The ease of use ranges from low to average, as effective use requires a good understanding of UAV principles and operational processes.

The user interface must consider not only the functional aspect but also modularity, scalability, and interoperability. The article proposed the architecture of a heterogeneous multitasking mission planning system based on a robotic operating system and the Mission Planner user interface [21]. The future widespread use of robotics and autonomous systems is anticipated, especially for missions requiring coordination and cooperation between multiple robots.

Mission planning remains a human task, but the development of artificial intelligence raises the issue of joint human-AI mission planning. The article discusses new AI-based methods that effectively transfer information from AI to operators [22], supporting their mission planning workflow. The approach involves viewing the human-operator and AI system as a single unit with a common cognitive system, allowing for better identification of key information to create the most effective mission plan jointly.

Mission Planner is a powerful tool for professional use, especially in military and complex civilian operations. Its versatility, advanced planning, data analysis capabilities, and potential for AI integration make it indispensable for UAV operators who require high levels of control and precision.

COMPARATIVE ANALYSIS OF USER INTERFACES OF GROUND CONTROL STATION

In this section, we will conduct a comparative analysis of several popular UAV ground control station interfaces. Our main goal is to identify their strengths and weaknesses and pinpoint the most effective solutions for future improvements. We will examine aspects such as design intuitiveness, functionality (including customization options, support for various usage scenarios, and operator situational awareness), and usability.

This comparative analysis will help us to understand how different systems meet user needs in various operating conditions and will guide further innovation in the field of UAV ground control stations.

It's important to note that all UI GCS UAVs (specifically, DJI Ground Station Pro, ArduPilot Mission Planner, and UGCS) support real-time telemetry transmission, which is a key function. This feature allows operators to receive current data about the drone's flight, such as altitude, speed, position, battery status, and other critical parameters. It enables quick responses to change flight conditions and informed decision-making, aligned with mission tasks and safety considerations.

Design of User Interfaces

The user interface design for ground control stations of unmanned aerial vehicles, developed by various companies, adheres to standard rules and shares fundamental design elements. These typically include a main screen with maps and flight plans, panels with telemetry, video streams from drone cameras, controllers, data analysis tools, and emergency functions. The key principles in designing our user interfaces are intuitiveness, ease of use, situational awareness, and adaptability to various conditions.

Simplicity and Intuitiveness. DJI Go features a colorful and user-friendly interface with large icons and easy access to main functions, making it appealing to beginners. DJI Pilot is also intuitive but caters more to professional use, offering more technical data on the screen. Pix4Dcapture provides a simple and user-friendly interface for quick setup and mission launch.

Technicality and Flexibility. QGroundControl and Mission Planner have a more technical interface with numerous settings and options, which can be challenging for beginners but very useful for advanced users. UGCS also targets professional users with a comprehensive set of tools for detailed mission planning and analysis. While the UGCS interface is more complex, it offers significant control and flexibility for experienced operators.

Maintaining a balance between providing all necessary flight and device information without overloading the UAV operator's screen is crucial in UI design. This challenge is further complicated by the need to integrate advanced features like augmented and virtual reality.

The continual evolution of interfaces, considering technological advancements in artificial intelligence for function automation, also requires attention. This is important both to preserve the functionality of the human-machine system and to reduce the workload on human operators.

Functionality of User Interfaces

Missions Planning. All programs offer mission planning but with varying levels of detail. DJI Pilot and DJI Go enable you to create a straightforward and efficient flight plan by setting waypoints, altitude, and speed. QGroundControl and Mission Planner provide advanced mission customization, including autopilot calibration and setup. UGCS excels in 3D flight planning and supports various drone types, making it ideal for complex missions. Pix4Dcapture specializes in aerial photography, allowing you to plan for high-quality image collection for further processing.

Real-Time Monitoring. All apps offer real-time monitoring, tracking the drone's position, speed, altitude, and battery status. DJI Pilot and DJI Go are user-friendly and present essential data. QGroundControl and Mission Planner provide more technical data and customizable information displays. UGCS offers advanced monitoring, including simultaneous control of multiple drones. Pix4Dcapture focuses on the quality of collected data for mapping tasks, providing basic monitoring.

Camera and Sensors. DJI Pilot and DJI Go support camera and sensor control, enabling you to take photos, and videos, and collect data. QGroundControl and Mission Planner also support a wide range of sensors, making them suitable for professional tasks. UGCS integrates with various sensors, including specialized industrial add-ons. Pix4Dcapture is centered on aerial photography, providing camera control for 3D modeling data collection.

Security and Alerts. All apps include safety features and alerts, such as low-battery, lost-communication, or approaching-obstacle notifications. DJI Pilot and DJI Go offer an intuitive and easy-to-understand interface. QGroundControl and Mission Planner provide more technical capabilities that may require a deeper understanding of the system. UGCS offers advanced transmission for complex missions, while Pix4Dcapture prioritizes safety during aerial photography.

Ease of use

Ease of use is one of the main features that characterize UI. DJI Pilot is optimized for quick deployment and ease of use, offering a high level of usability. DJI Go is designed for general users, hobbyists, and beginners, providing very high usability. QGroundControl is suitable for advanced users who need advanced features but offers average usability. Mission Planner, despite its power, has low to average usability due to its complex interface. UGCS offers medium to high usability as it is intended for professional use with extensive training and experience. Pix4Dcapture is highly user-friendly, especially for mapping and surveying applications.

Based on the analysis, two comparative tables were compiled: a functionality comparison table (Table 1) and a comparative table of interface usability (Table 2).

All the programs considered have unique features that make them suitable for different usage scenarios. DJI Pilot and DJI Go offer convenience and ease of use for a wide range of users. QGroundControl and Mission Planner provide powerful tools for professional use and flexible customization. UGCS stands out with its support for many types of drones and the ability to work with multiple devices. Pix4Dcapture specializes in aerial photography and is particularly useful for mapping tasks.

Table. 1. *Comparative table of functional capability*

Software	Platform	UAV Support	Mission Planning	3D Mapping	Photogrammetry	Automation (Scripts)	Customization
DJI Pilot	Mobile	DJI	Yes	No	No	Yes	No
DJI Go	Mobile	DJI	Limited	No	No	No	No
QGroundControl	Mobile/ Desktop	Various	Yes	Yes	Yes	Yes	Yes
Mission Planner	Desktop	Various	Yes	No	No	Yes	Yes
UGCS	Desktop	Various	Yes	Yes	Yes	Yes	Yes
Pix4Dcapture	Mobile	DJI, Parrot, etc.	Yes	Yes	Yes	Limited	No

Table. 2. Comparative table of interface usability

Software	Design	Features	Usability
DJI Pilot	Modern and intuitive, designed for commercial users	Clear display of telemetry data, easy integration with DJI drones	High; optimized for quick deployment and operation
DJI Go	User-friendly, similar to mobile apps	Simplified interface with basic control elements	Very high; designed for general users
QGroundControl	Functional, less polished than DJI apps	Advanced flight planning, real-time telemetry, support for various UAVs	Medium; suitable for experienced users
Mission Planner	Complex and multifunctional, but with a steep learning curve	Comprehensive toolset for mission planning and telemetry	Low to medium; powerful but requires knowledge and experience
UGCS	Professional, highly detailed with a focus on mission planning	Extensive mission planning, 3D mapping, real-time telemetry	Medium to high; designed for professional use
Pix4Dcapture	Designed for photogrammetry and 3D mapping with a user-friendly interface	Photogrammetry and 3D mapping capabilities, integration with Pix4D software	High; easy to use for mapping and photogrammetry tasks

Analysis of Strengths

Versatility And Variety Of Functions. All apps offer both basic and advanced features for drone control, including mission planning, real-time monitoring, camera and sensor management, and flight data analysis tools. This versatility allows users to select the program that best fits their needs.

Intuitiveness And Ease Of Use. Programs like DJI Go and Pix4Dcapture have simple, intuitive interfaces that are accessible even to beginners. This lowers the entry barrier and helps users quickly master the basic functions.

Enhanced Functionality For Professionals. Programs such as QGroundControl, Mission Planner, and UGCS provide detailed setup and support for complex missions, giving professionals full control over drones and allowing them to adapt to specific tasks.

Security And Alerts. All the reviewed programs offer high levels of security, providing users with warnings about critical situations, such as low battery or communication loss. This helps reduce risks during flights.

Areas for Improvement

Unification Of Interfaces. Each application has unique characteristics, but the lack of a unified approach to interface design can make it difficult for users to switch between different applications. Developing more standard interfaces could simplify the learning process and reduce errors.

Reduction Of Technical Complexity. Programs like QGroundControl and Mission Planner have very technical interfaces that can be challenging for beginners. Reducing technical complexity or providing more intuitive learning tools could make these programs more accessible to a wider range of users.

Compatibility Improvements. While most apps support a wide range of drones and sensors, there are occasional issues with compatibility or integration of new devices. Continuous software updates to support new drone models and sensors could greatly enhance the user experience.

Enabling Collaborative Drone Missions: Programs such as UGCS already support the operation of multiple drones simultaneously. Extending this functionality to other platforms could open up new opportunities for complex missions and projects that require the coordination of multiple drones.

Optimizing Productivity. Some programs consume significant system resources, affecting their performance on less powerful devices. Optimizing the software for better performance could provide a smoother experience across platforms.

Disadvantages of Mission Planner

Let's focus on the user interface of Mission Planner, which, despite its powerful functionality, has several significant shortcomings that reduce its effectiveness compared to other popular UAV control programs like QGroundControl and DJI Go.

One of the main issues is the complexity of the user interface. The program is overloaded with numerous options and settings, making it difficult to master, especially for beginners. Compared to the more intuitive and user-friendly interfaces of QGroundControl and DJI Go, Mission Planner feels outdated and cumbersome. This creates barriers for new users, who may spend considerable time learning the basic functions of the program.

Another issue is its excessive versatility. While it can be used for a wide range of tasks and different types of UAVs, such as multicopters, fixed-wing, and VTOL, this versatility makes it difficult to adjust for specific tasks. Users face additional challenges when trying to quickly adapt the program for particular tasks. The interface tries to cater to the needs of different UAV types, leading to overload and difficulty in use. In military operations and intelligence contexts, where quick response and precision are essential, these limitations can be critical. Compared to DJI Go, which is optimized for specific usage scenarios, Mission Planner requires more time and effort to set up.

Another significant problem with Mission Planner is its performance in extreme environments, such as combat operations or military intelligence. In these situations, the software must ensure reliability and speed, including readiness for potential failures or loss of communication. For instance, if the UAV is intercepted by enemy electronic warfare (EW), the operator may lose contact with the device. Mission Planner lacks convenient and fast tools to switch to an autonomous "radio silence" mode, which is crucial in a military setting. Additionally, customizing UAV functions for military needs is often complex and requires deep technical knowledge.

Thus, despite its powerful functionality, Mission Planner has significant shortcomings in user experience, versatility, and ease of use in extreme environments. These issues make it a less attractive choice compared to programs like QGroundControl and DJI Go, especially for beginners and in critical situations.

DISCUSSION OF THE RESULTS

An overview of the world experience in the development of user interfaces was made. The user interfaces of each of the studied software tools were analyzed and their functional capabilities were evaluated, and their strengths and weaknesses were determined. Comparison tables of interface products were compiled according to their functionality and the level of usability of their user interfaces. Generalized recommendations have been prepared for the creation of a unified interface that would combine the best features of existing solutions and eliminate their shortcomings.

Recommendations for improving the efficiency of using the Mission Planner software and meeting the needs of users may involve introducing several important changes. Firstly, adding the roles of military pilots and operators to the list of users. This will allow for consideration of the specific needs of these roles and provide appropriate functionality. Secondly, developing a more intuitive and user-friendly interface that will meet the needs of users.

Equally important is simplifying the software configuration by introducing templates for specific tasks. This will significantly reduce setup time and reduce the likelihood of errors. Similarly, it is necessary to optimize the interface for operation in extreme conditions, such as combat or military reconnaissance, by providing quick access to key functions. Finally, the data visualization should be improved to make it more understandable and easy to interpret, which is critical in fast-paced and dangerous situations.

CONCLUSIONS

An analysis of user interface designs for ground control stations of unmanned aerial vehicles revealed that all systems have their strengths and weaknesses. The Mission Planner software was identified as having the greatest potential for functionality and improvement, though it also requires enhancements.

For further development and the creation of a new universal user interface, it is recommended to include the roles of military pilot and operator. This addition would address the specific needs of these roles and provide appropriate functionality. Developing a more intuitive and user-friendly interface is essential to meet user needs. Simplifying software setup through task-specific templates will reduce setup time and minimize errors.

In extreme conditions, such as combat operations or military intelligence, optimizing the interface to provide quick access to key functions is crucial. Enhancing data visualization will make information clear and easy to interpret, which is vital in fast-moving and dangerous situations.

Overall, improving user interfaces will increase the efficiency and safety of UAV operations, offering a tool that is better adapted to real operating conditions.

REFERENCES

1. Feldman, J., Costedoat, G., Martin, L., Gujral, V. (2023). Usability of pre-flight planning interfaces for Supplemental Data Service Provider tools to support Uncrewed Aircraft System Traffic Management. Tareq Ahram and Waldemar Karwowski (eds) Application of Emerging Technologies. *AHFE (2023) International Conference*. AHFE Open Access, vol 115. AHFE International, USA. http://doi.org/10.54941/ahfe1004333
2. Merrell, Thomas William. Evaluation of Consumer Drone Control Interface (2018). https://corescholar.libraries.wright.edu/etd_all/1929
3. Di Vincenzo M, Palini F, De Marsico M, Borghi AM, Baldassarre G. (2022). A Natural Human-Drone Embodied Interface: Empirical Comparison With a Traditional Interface. *Front. Neurorobot* https://doi.org/10.3389/fnbot.2022.898859
4. Miehlbradt J, Cherpillod A, Mintchev S, Coscia M, Artoni F, Floreano D, Micera S. (2018). Data-driven body-machine interface for the accurate control of drones. *Proc Natl Acad Sci USA*. https://doi.org/10.1073/pnas.1718648115
5. B.A. Yam-Viramontes, D. Mercado-Ravell. Implementation of a Natural User Interface to Command a Drone. 2020 *International Conference on Unmanned Aircraft Systems (ICUAS)*, Athens, Greece, 2020, pp. 1139–1144, https://ieeexplore.ieee.org/stamp/tamp.jsp?tp=&arnumber=9836056&isnumber=9835714 https://doi.org/10.1109/ICUAS48674.2020.9213995
6. B. Rakotonarivo, N. Drougard, S. Conversy, J. Garcia. Supporting drone mission planning and risk assessment with interactive representations of operational parameters. 2022 *International Conference on Unmanned Aircraft Systems (ICUAS)*, Dubrovnik, Croatia, 2022, pp. 1091–1100, https://doi.org/10.1109/ICUAS54217.2022.9836056
7. Besada JA, Bergesio L, Campaña I, Vaquero-Melchor D, López-Araquistain J, Bernardos AM, Casar JR. (2018). Drone Mission Definition and Implementation for Automated Infrastructure Inspection Using Airborne Sensors. Sensors (Basel). *Sensor Networks* https://doi.org/10.3390/s18041170
8. Roth R. E. (2017). User Interface and User Experience (UI/UX) Design. The Geographic Information Science & Technology Body of Knowledge (2nd Quarter 2017 Edition), John P. Wilson (ed.) https://doi.org/10.22224/gistbok/2017.2.5
9. https://www.dji.com/global/downloads/djiapp/dji-pilot
10. https://www.dji.com/global/downloads/djiapp/dji-go-3

11. Lee, S.; Seo, H.; Kim, D. Digital Forensic Research for Analyzing Drone Pilot: Focusing on DJI Remote Controller. *Sensors*. 2023, 23, 8934. https://doi.org/10.3390/s23218934
12. http://qgroundcontrol.com/
13. Ramirez-Atencia, C.; Camacho, D. Extending QGroundControl for Automated Mission Planning of UAVs. *Sensors*. 2018, 18, 2339. https://doi.org/10.3390/s18072339
14. https://www.sphengineering.com/flight-planning/ugcs
15. https://www.yellowscan.com/knowledge/drone-flight-planners-the-continuing-integration-of-lidar-and-uavs/
16. https://www.pix4d.com/product/pix4dcapture/
17. Žabota, B.; Kobal, M. Accuracy Assessment of UAV-Photogrammetric-Derived Products Using PPK and GCPs in Challenging Terrains. *Search of Optimized Rockfall Mapping. Remote Sens*. 2021, 13, 3812. https://doi.org/10.3390/rs13193812
18. Hinge, Lars, Gundorph, J., Ujang, Uznir, Azri, Suhaibah, Anton, François, Rahman, Alias. (2019). COMPARATIVE ANALYSIS OF 3D PHOTOGRAMMETRY MODELING SOFTWARE PACKAGES FOR DRONES SURVEY. ISPRS – International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. XLII-4/W12. 95-100. https://doi.org/10.5194/isprs-archives-XLII-4-W12-95-2019
19. https://ardupilot.org/planner/docs/mission-planner-overview.html
20. Hirschmann W.B., Profit from the Learning Curve, ISBN 9780000641076, 1964, Harvard Business School Reprint https://books.google.com.ua/ ooks?id=5UGiPQAACAAJ
21. Dwiyasa, F., Lim, MH., Kang, P., Foo, RX., Teo, SW.J. (2020). Heterogeneous Multi-robot Mission Planning for Coordinated Tasks Execution. Nagar, A., Deep, K., Bansal, J., Das, K. (eds) *Soft Computing for Problem Solving* 2019. Advances *in Intelligent Systems and Computing*, vol 1139. Springer, Singapore. https://doi.org/10.1007/978-981-15-3287-0_13
22. Kane, S., Moody, V., Harradon, M. (2021). Towards Incorporating AI into the Mission Planning Process. In: Degen, H., Ntoa, S. (eds) Artificial Intelligence in HCI. HCII 2021. Lecture Notes. *Computer Science*, vol 12797. Springer, Cham. https://doi.org/10.1007/978-3-030-77772-2_14

Received: 27.05.2024

Губський О.М., аспірант,
https://orcid.org/0009-0004-3106-2770
e-mail: aleksey.gubsky@gmail.com

Міжнародний науково-навчальний
центр інформаційних технологій
та систем НАН України та МОН України,
просп. Акад. Глушкова, 40, 03187, Київ, Україна

АНАЛІЗ ІНТЕРФЕЙСІВ КОРИСТУВАЧА НАЗЕМНИХ СТАНЦІЙ КЕРУВАННЯ БЕЗПІЛОТНИМИ ЛІТАЛЬНИМИ АПАРАТАМИ

Вступ. *У сучасному світі щоденно оновлюється програмне забезпечення (ПЗ), зокрема для наземних станцій управління безпілотними літальними апаратами (БпЛА). Перед їхніми інтерфейсами користувача (ІК) постають задачі забезпечення взаємодії оператора з дроном, контролю польоту, планування місій та отримання даних в реальному часі. Ці інтерфейси повинні бути функційними, зручними та інтуїтивно зрозумілими, щоб оператори могли ефективно виконувати свої завдання. Дослідження світового досвіду дає змогу оцінити наявні системи та визначити області для вдосконалення. Важливими аспектами є створення інтуїтивних ІК для запобігання перевантаженню інформацією, забезпечення ситуаційної обізнаності, адаптація до екстремальних умов та інтеграція з іншими системами. Використання* *технологій віртуальної та доповненої реальності, а також штучного інтелекту, можуть підвищити функційність та зручність наземних станцій керування (НСК). Такий аналіз допоможе створювати безпечні, ефективні та надійні системи для керування БпЛА.*

Мета статті *— дослідити і провести комплексний аналіз наявних інтерфейсів користувача програмного забезпечення наземних станцій керування БпЛА, з фокусом на їх функційних можливостях та зручності використання.*

Методи. *Застосовано такі методологічні інструменти: концепції інтелектуалізації інформаційних технологій, теорію інтелектуального керування, методологію побудови автономних систем, теорію прийняття рішень, теорію штучного інтелекту.*

Результати. *Було зроблено огляд світового досвіду розроблення інтерфейсів користувача. Проаналізовано ІК кожного з досліджуваних ПЗ та надано оцінку їх функційних можливостей, визначено їхні сильні та слабкі сторони. Було складено порівняльні таблиці інтерфейсних продуктів за їх функційними можливостями та рівнем юзабіліті ІК. Підготовлено узагальнені рекомендації для створення уніфікованого інтерфейсу, який би поєднував найкращі риси існуючих рішень та передбачав усунення їх недоліків.*

Висновки. *Аналіз дизайну ІК НСК для БпЛА показав, що всі системи мають сильні та слабкі сторони. Найширші можливості має ІК ПЗ Mission Planner, однак і він також потребує вдосконалення. Для подальшого розвитку слід додати ролі військового пілота та оператора, розробити більш інтуїтивний та зручний інтерфейс, який відповідатиме потребам користувачів, та спростити налаштування ПЗ. Для роботи в екстремальних умовах потрібно оптимізувати інтерфейс. Вдосконалення візуалізації даних допоможе зробити їх зрозумілими та легкими, що є критично важливим у швидкоплинних і небезпечних ситуаціях.*

Ключові слова: *інтерфейс користувача, наземна станція керування, БпЛА, віртуальна реальність, доповнена реальність.*