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EVALUATION OF USER INTERFACES OF VARIOUS FLIGHT CONTROLLERS FOR UAV

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Summary. *Planning a flight task by a remote pilot is a very important stage in the process of preparing a flight of an unmanned aerial vehicle. The smallest mistakes made at the same time can lead to irreparable consequences for both the UAV and others. The number of remote pilot errors can be reduced by reducing the speed of flight task planning. However, in actual operation, this can slow down flight preparation and, as a result, reduce the efficiency of the process as a whole. Among other things, the speed of flight planning is influenced by the user interface itself, which is a means of communication between the remote pilot and the machine – the on-board flight controller It is known that human-machine communication interfaces are very diverse, but in general they should contribute to the smooth and error-free entry of the input information into the memory of the machine (flight controller), which will later serve as a guide for the machine in its actions. At the same time, there is insufficient evidence to apply quantitative interface assessments (assessments of means, rules and methods and techniques) to already known flight controllers.*

The paper presents the results of the analysis and research of the user interfaces of two flight controllers according to the criteria of ease of data entry during planning, the total number of operations during the planning of all flight stages, and the amount of work performed within each operation, as well as the level of visualization (display) of information on the monitor of the ground control station of the unmanned aerial vehicle. Relative weighting factors based on rating methods were applied to each of the mentioned criteria. After taking into account the results of the evaluation, the ratings of such dispatchers as Pixhawk and Veronte were established.

Key words: *remote pilot; speed and quality of flight task planning; flight controller interfaces; ground control station; main screen; controller operating modes; interface evaluation criteria; weight coefficients of the i-th criterion.*

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Accepted termsand abbreviations:FC – flight controller; UAV – unmanned aerial vehicle; TP – turning point of the route; LSW – a line of the set way; SFT– software; PC – personal computer; RN – runway; MS – main screen; RP – remote pilot; GCS – ground control station.

Introduction. When planning a flight task, the RP encounters objective and subjective difficulties that reduce the speed of task planning or lead to errors.

The objective ones include the ambiguous statement of the flight task by the customer; insufficient awareness of the crew about the weather conditions on the route; poor location of the ground control station; delays in the initialization of existing digital communication lines and the corresponding difficulties in transferring the flight task (repeated manipulations are required to download the task) and other objective reasons.

Subjective difficulties may be insufficient qualification of the RP and the unsatisfactory state of his health, unacceptable current cartographic support, unforeseen system failures in the ground control computer, etc. [1].

The purpose of the work and the task. The aim of the work is to establish the dependence of the speed and quality of flight task planning on simplicity, as well as the availability of using the interfaces of different flight controllers.

Solution of problem. For the correctness of the study, the comparison of the accessibility and ease of use of interfaces was carried out under the condition that there is a complete current cartographic support, the full technical readiness of the unmanned aerial vehicle to perform the task, approximately the same qualifications of remote pilots and with the same type of flight task.

The criteria for evaluating the interfaces were taken as follows:

- convenience of entering data for planning;
- total number of operations during planning;
- the amount of work performed within each operation;
- level of visualization (display) of information on the monitor.

The first to be compared was the interface of the well-known ground control station «Mission Planner», which is used for widespread FCs such as «APM» and «Ardupilot Pixhawk» of various modifications [2].

These FCs are open source, which gives the community ample opportunity to modify the firmware [3].The second example for comparison was the interface of the ground control station for FC type «Veronte Autopilot» [4]. The «Veronte» flight controller differs from the previous ones in that it has closed code, ie the built-in software can be changed only by the manufacturer (except for the options that are responsible for the current settings required by the user).

Flight planning using the Mission Planner interface. The «Mission Planner» flight planning and control station is a software and hardware complex consisting of a PC and downloaded «Mission Planner» software of the required versions. Visualization of the current parameters of the UAV (Fig. 1) takes place on one monitor screen, called the MS.

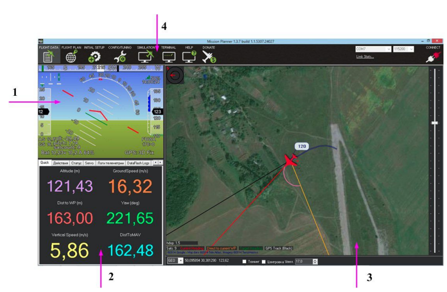

Figure 1. General view of the main screen of the station «Mission Planner» (window «Flight data»):
1 – aviahorizon zone; 2 – window of flight parameters;
3 – flight card; 4 – «Menu» panel

In two cases studied, automatic take-off planning, cruising flight and automatic landing planning were analyzed.

Planning of automatic flight of UAV by means of station «Mission Planner» occurs as follows. Automatic takeoff is implemented by entering the values of specific parameters (Fig. 2), visualized by the list [5]:

TKOFF_ACCEL_CNT	1		1 10
TKOFF_ALT	50	m	0 200
TKOFF_DIST	200	m	0 500
TKOFF_FLAP_PCNT	0	%	0 100
TKOFF_LVL_ALT	20	m	0 50
TKOFF_LVL_PITCH	15	deg	0 30
TKOFF_PLIM_SEC	2	s	0 10
TKOFF_ROTATE_SPD	0	m/s	0 30
TKOFF_TDRAG_ELEV	0	%	-100 100
TKOFF_TDRAG_SPD1	0	m/s	0 30
TKOFF_THR_DELAY	2	ds	0 127
TKOFF_THR_MAX	0	%	0 100
TKOFF_THR_MINACC	0	m/s/s	0 30
TKOFF_THR_MINSPD	0	m/s	0 30
TKOFF_THR_SLEW	0	%/s	-1 127
TKOFF_TIMEOUT	0	s	0 120

Figure 2. List of parameters to be filled in for automatic take-off planning

Next you need to determine the coordinates of the base (the position of the ground control station); for the first route point the point marked «TKOFF» is chosen [6].

Creating a flight task for cruising mode with the help of the station «Mission Planner» is divided into several steps. To implement step № 1 you need:

- assign the 1st TP(turning point of the route) near the point with the coordinates of the GCS;
- in the command selection window for the selected 1st TP, select the «TKOFF» property via the Waipoint list (Fig. 3).

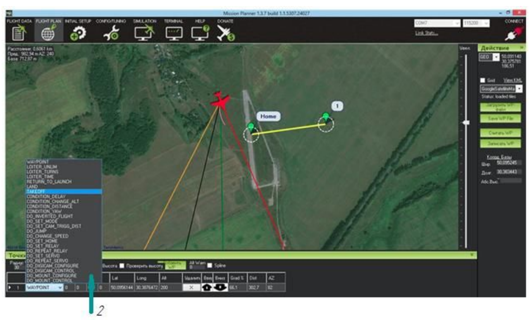

Figure 3. Drawing up a flight plan (step No. 1): 1 – point of the first TP;
2 – drop-down menu of TP parameters for design; «Home» – route point «base»

The second step (step № 2) requires:

– to assign to the 1st TP the parameter of the set pitch angle for take-off, and also to assign to the parameter «Alt» the height to which the UAV should rise before the start of movement on the TP № 2;

– assign the following TP, which are necessary for the implementation of the flight (Fig. 4).

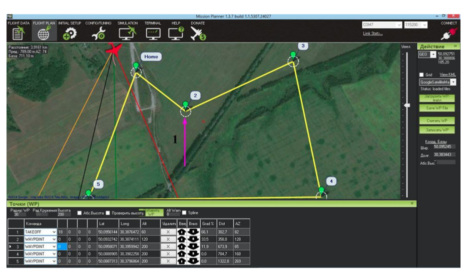

Figure 4. Drawing up a flight plan (step No. 2) for assigning the necessary intermediate waypoints:
1 – height setting for TP 2; 2 – turning points of the route TP3 – TP5

To perform automatic landing, you must fill in the list of parameters presented in Fig. 5.

LAND_ABORT_DEG	0
LAND_ABORT_THR	0
LAND_DISARMDELAY	20
LAND_FLAP_PERCNT	0
LAND_FLARE_ALT	3
LAND_FLARE_SEC	5
LAND_OPTIONS	0
LAND_PF_ALT	10
LAND_PF_ARSPD	0
LAND_PF_SEC	6
LAND_PITCH_CD	100
LAND_SLOPE_RCALC	2
LAND_THEN_NEUTRL	0
LAND_THR_SLEW	0
LAND_TYPE	0
LEVEL_ROLL_LIMIT	5

Figure 5. List of parameters to be filled in for automatic landing planning

The third stage is the adjustment of the flight task, which is performed as follows:

– the correctness of the entered data is checked for each TP, especially in cases of different heights and complex lines (broken, circular, elliptical, etc.);

– the absence of a preliminary flight plan in the flight controller is checked (the «Clear task» is performed);

– after the complete introduction of the flight task and its approval, it is necessary to execute «Save the WP file». To load a flight task on board the UAV, you must click «Save TP» (Fig. 6).

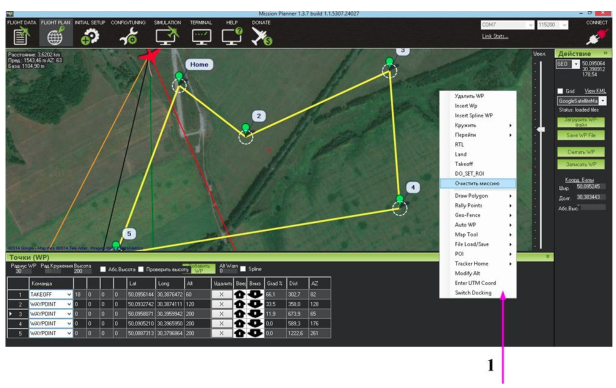

Figure 6. Drawing up a flight plan (step № 3): 1 – menu for loading and recording a flight task on board

The onboard FC has «manual», «semi-automatic» and «automatic» operating modes. Accordingly, the next step is to set the GCS «Mission Planner» mode «automatic» (Fig. 7).

Figure 7. «Actions» window: 1 – button to set the required control mode

In the process of planning a flight task in automatic mode using the software «Mission Planner», the total number of required keystrokes on the keyboard (mouse) is about 40 times.

Flight planning using the «Veronte Autopilot» station interface. The flight plan is formed in the menu «Mission»; it is necessary to choose the onboard FC in order to keep the plan on board the UAV(Fig. 8).

Figure 8. «Veronte» onboard FC selection menu

Then you need to open the menu to create a flight plan for a particular aircraft; in Fig. 9 shows the tool for its creation [7].

Figure 9. Tools for creating a flight plan in the onboard FC «Veronte Air»

The takeoff of the aircraft consists of several stages and is planned in the menu «Takeoff» (Fig. 10).

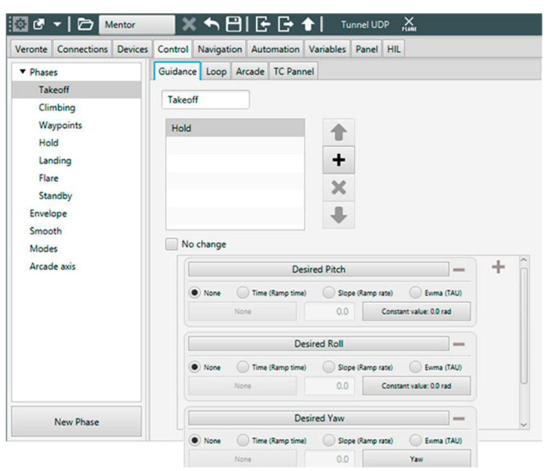

Figure 10. Menu for creating a takeoff plan

Stage № 1 – takeoff (Fig. 11) begins with planning to control the engine to exit idling at maximum speed, i.e. at maximum thrust during takeoff.

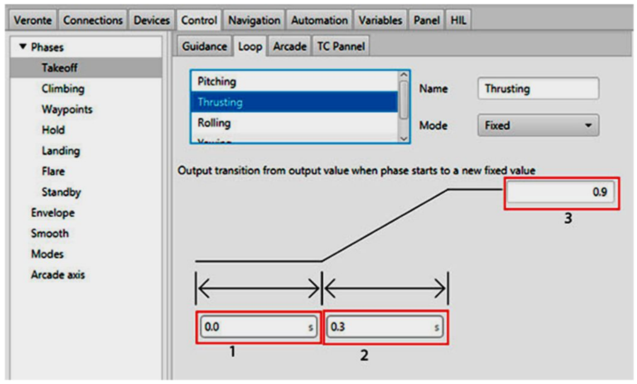

Figure 11. Basic commands for planning the engine operation mode during takeoff run

To plan the rise (Fig. 12) you need to open the tab «Climbing»: planning is to assign values to the following parameters:

- Line attraction – creating a lifting line;
- Set limit acceleration – setting the limit acceleration;
- Set speed – speed setting;
- Route – choose the direction of travel on the route;
- Flight-path angle – setting the angle of the rise trajectory.

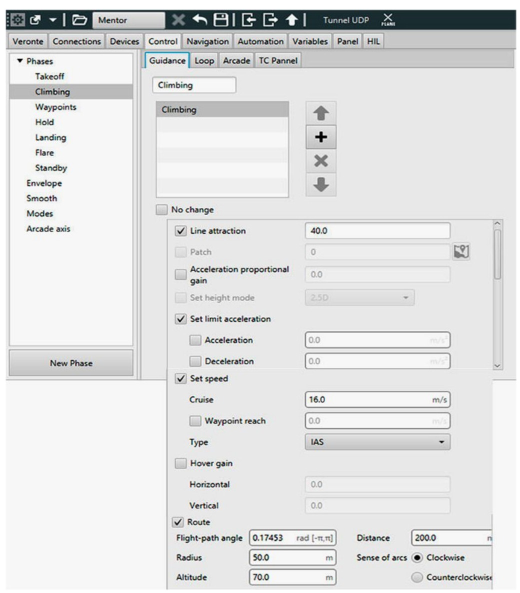

Figure 12. Parameters programmable for the implementation of automatic control of aircraft lift

If necessary, to complete the lifting phase programming, you can additionally set the radius of the trajectory of the circle performed by the aircraft after takeoff and the distance from the end of the ascent to the beginning of the circular trajectory, as well as the height to be reached during takeoff.

To create a waypoint – TP, you need to open the tool «newwaipoint» (Fig. 13).

Figure 13. Toolbar to create a new point

To manually change the coordinates of the points, you must double-click on the point; the display for entering parameters will appear (Fig. 14).

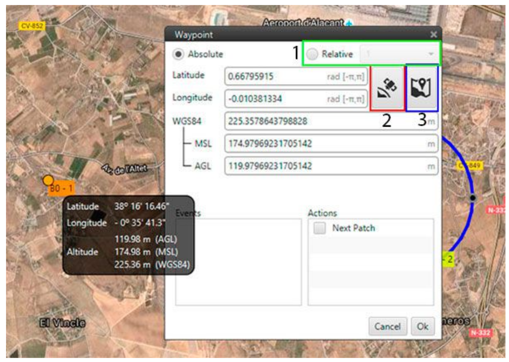

Figure 14. Method of creating a new point (turning point of the route)

To move the obtained route points you just need to «drag» them with the cursor. Planning and implementation of automatic landing requires opening the appropriate tab (Fig.15).

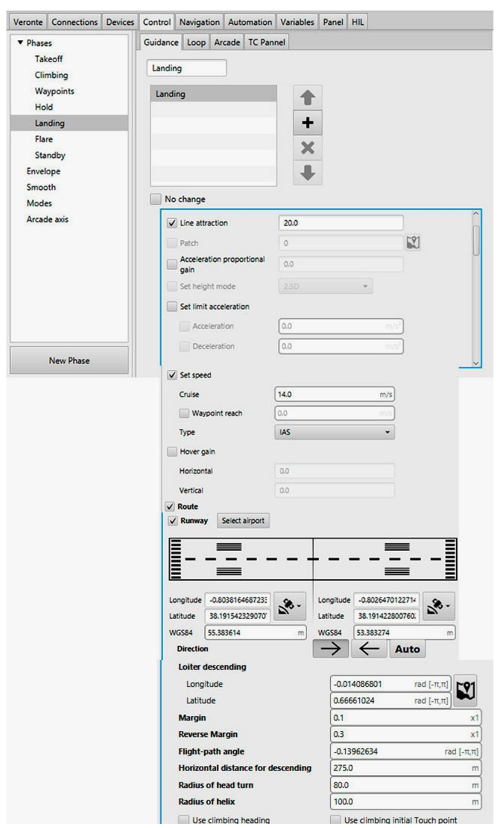

Figure 15. Bookmark «automatic landing»

Due to the fact that the approach to the runway of a particular airport may require additional maneuvering, the software contains the appropriate tools. Figure 16 shows the use of the following additional commands: «Spiral radius» – spiral radius; «Radial turn of the head» and «loiter rejecting» – waiting on the descent.

Figure 16. Tools for additional maneuvering of the UAV before its arrival on the runway

Criteria for evaluating interfaces. Among other criteria for evaluating the user interfaces of different flight controllers for UAV, this paper uses the criteria of ease of data entry for planning, criteria for the total number of operations and the amount of work performed within each operation, and the level of visualization (display) of information on the monitor .

Ease of data entry for planning. Thisparameter characterizes the time spent searching in the interface of the cell that contains the window for entering data when planning a flight. It is known that certain interfaces have only the so-called «drop-down list» of parameters from which to select the necessary. Other interfaces have specially designed "drop-down windows" in which the parameters that need to be changed are in a certain order and do not take time to search for them. Accordingly, the latter will be given preference and the score should be higher. For this criterion, the weighting factor is 0.5. The grade is set from 1 to 10; more user-friendly interface has a higher rating.

Total numberof operations. This parameter characterizes the number of clicks on the manipulator that must be performed to fully plan the flight task. The lower need for clicks allows you to evaluate the interface of this flight controller and vice versa: with increasing need for additional clicks, the quality of the interface decreases. The criterion of the total number of clicks has a weighting factor of 0,3. The total number of transactions is estimated from 10 to 1; while the greater the number of required operations is assigned a lower score.

The amount of work performed within each operation. This paragraph refers to the need for additional work to obtain the final value of a parameter in relation to its inclusion in the flight plan. For example, finding and entering geographical coordinates requires much more work than entering the speed of detachment of the aircraft from the runway. The weighting factor of this criterion is equal to 0,2. Evaluation of the criterion in the range from 4 to 1; an increase in the volume of a particular transaction leads to a decrease in valuation.

When entering planning data, it is much more convenient to have additional visualization, which helps to clarify, for example, the position of a particular TP on the map. In addition, coded commands make it much more difficult for staff to understand their content. Interfaces with commands that are written in a clear way, such as «Climbing», «radius turn», etc., have a significant advantage. This criterion is assigned a relative weighting factor of 0,1; evaluation of the criterion in the range from 1 to 4. Thus, the better visualized interface is assigned a higher score.

In the table. 1 shows the value of the relative weight of the criteria for evaluating the user interfaces of different flight controllers for UAV.

Table 1

Summary table of the relative weight of the criteria for evaluation

№	Parameter name	The relative weight of the criterion
1	Ease of data entry for planning	0,5
2	Total number of operations	0,2
3	The amount of work performed within each operation	0,1
4	The level of visualization (display) of information on the monitor	0,1

Estimates were calculated using the direct placement method. It is known that the sum of the coefficients of all weights must be equal to [8, 9]:

$$\sum_{i=1}^{n} k_i = 1, \quad (1)$$

wherek_i – are of the coefficients of weightsthe of the i-th criterion.

The specific assessment of the i-th criterion was obtained as follows:

$$\mathrm{O}_{\mathrm{i}.cr.} = k_i \times \mathrm{B}_{nv.cr.}, \quad (2)$$

where $\mathrm{B}_{nv.cr.}$ – dimensionless numerical value of the i-th criterion.

The input data for the calculation of scores by criteria are given in Table 2.

Table 2

Data for calculating estimates of flight controller interfaces

The name of the controller	«Ardupilot Pixhawk»	«Veronte Autopilot»	The relative weight of the criterion
Parameter name	Evaluation by criterion		
Ease of data entry for planning	6	10	0,5
Total number of operations	4	8	0,2
The amount of work performed within each operation	2	4	0,1
The level of visualization (display) of information on the monitor	2	4	0,1

The total score of the specific interface was obtained as follows:

$$\sum \mathrm{O}_{\mathrm{i}.cr.} = \mathrm{O}_{i.1} + \mathrm{O}_{i.2} + \mathrm{O}_{i.3} + \mathrm{O}_{i.4}$$

In the Table 3 shows the results of calculations of total estimates of criteria for evaluating the interfaces of different flight controllers.

Table 3

Evaluation results and rating of interfaces of various flight controllers

The name of the controller	«Ardupilot Pixhawk»	«Veronte Autopilot»
Total valuation	4,2	7,4
Rating	2	1

Conclusions. From the point of view of the content component of the interfaces of different flight controllers, it can be stated that for planning the flight of unmanned aerial vehicles in automatic mode, their interfaces are very similar and contain approximately the same number of input or changed parameters. A significant difference between them is that some are built on the principle of «drop-down window», ie have specially designed windows in which the parameters that need to be changed are in «one window» in a certain order.Others are based on a «drop-down list», where the parameters are summarized in a list.

The application of the method of rating evaluation of flight controller interfaces allowed to quantify such criteria as ease of data entry for planning and the total number of operations in planning, the amount of work within each operation and the level of visualization (display) of information on the monitor.Based on the generalization of quantitative characteristics, a rating was obtained, which can be used to subjectively assess the future speed and quality of flight task planning with one or another interface.

It is established that preference will be given to interfaces with «drop-down windows», such as «Veronte Autopilot», which requires much less time to find the parameters that need to be changed.Interfaces with drop-down lists, such as «Ardupilot Pixhawk», are much simpler to set up, but increasing the speed of flight task planning can lead to planning errors. In addition, denoting commands in the form of abbreviations, such as «TKOFFACCELCNT» etc., is likely to lead to additional errors and reduce the speed of scheduling tasks.

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ОЦІНКА КОРИСТУВАЦЬКИХ ІНТЕРФЕЙСІВ РІЗНИХ ПОЛЬОТНИХ КОНТРОЛЕРІВ ДЛЯ БПС

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Резюме. *Планування польотного завдання дистанційним пілотом є дуже важливим етапом у процесі підготовки польоту безпілотного повітряного судна. Найменші помилки, допущені при цьому, можуть призвести до непоправних наслідків як для самого безпілотного повітряного судна, так і для оточуючих. Кількість помилок дистанційного пілота можна зменшити за рахунок зниження ним швидкості планування польотного завдання. Однак у реальній експлуатації це може уповільнити підготовку до польоту і, як наслідок, знизити ефективність процесу виконання польотного завдання в цілому. Крім усього іншого, на швидкість планування польоту впливає сам інтерфейс користувача, який є засобом зв'язку між дистанційним пілотом і машиною – бортовим польотним контролером. Відомо, що людино-машинні комунікаційні інтерфейси дуже різноманітні, але в цілому вони повинні сприяти безперешкодному та безпомилковому уведенню в пам'ять машини (польотного контролера) вхідної інформації, яка в подальшому буде служити орієнтиром для машини в її діях. У той же час, недостатньо доказів щодо застосування кількісних оцінювань інтерфейсу (оцінювань засобів, правил і методів та способів) для вже відомих польотних контролерів.*

Наведено результати аналізу та дослідження інтерфейсів користувача двох польотних контролерів з відкритим та закритим кодами, за критеріями простоти введення в них даних під час планування, сумарної кількості операцій під час планування всіх етапів польоту та обсягу виконаної роботи в рамках кожної операції, а також рівня візуалізації (відображення) інформації на моніторі наземної станції керування безпілотним повітряним судном. До кожного із зазначених критеріїв були застосовані відносні вагові коефіцієнти на основі рейтингових методів. Після врахування результатів оцінювання були встановлені рейтинги для таких польотних контролерів, як Pixhawk та Veronte.

Ключові слова: *дистанційний пілот, швидкість та якість планування польотного завдання, інтерфейси польотних контролерів, наземна станція керування, головний екран, режими роботи контролера, критерії оцінювання інтерфейсів, вагові коефіцієнти і-го критерію.*

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