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JUSTIFICATION OF CONTROL SYSTEM TYPES OF UNMANNED AERIAL VEHICLE FOR CIVIL AVIATION

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Abstract

Objective: *The problem of unmanned aerial vehicle control systems is a complicated issue which requires consideration of the tasks and applications of unmanned aerial vehicles. The typology of control systems combination for civil unmanned aerial vehicle is suggested and justified.* ***Methods:*** *The methodology of the research was based on application of the varieties of the experts method for rationale of the variants of control system combinations for a specific type of unmanned aerial vehicle and the morphological analysis was used to generate the variants of control system combinations.* ***Results:*** *The causes that lead to discrepancies in types of control systems for civil unmanned aerial vehicle are revealed. Compliance between remote radio control application and type of feedback signal are considered. Based on morphological analysis method, 25 variants of combined unmanned aerial vehicle control systems are suggested.* ***Discussion:*** *Regulatory, substantive and technical components of basic unmanned aerial vehicle control systems are considered. The practical experience of the development by Scientific Production Center of Unmanned Aviation "Virazh" is used to demonstrate the applicability of findings.*

Keywords: automatic control system; civil unmanned aerial vehicle; morphological analysis; remote radio control.

1. Introduction

It is well known that the basis of flight route compliance by the Civil Unmanned Aerial Vehicle (CUAV) is the flight carried out according to the flight plan developed in advance. The flight plan on uses the straight line segments connected through the points, which are called Route Turning Points (RTP). This ensures congruence of task performance for patrolling, surveillance or other aerial works (are entitled to route type) with the objects and the actual position of the UAV in the airspace over the object. [1].

Modern technical means of radio control, radio programming, automation, satellite air navigation support of flight revealed a whole layer of various Control Systems (CS) that allow the UAV perform very complicated tasks in the air.

In general, CS can be categorized into two basic groups of systems. The first group is called Remote Radio Control System (RRCS). The second large group includes Automatic Control Systems (ACS). There are formed the relationships between the group elements which eventually generate a particular type of UAV CS. For example «Ikarus» CS for small UAVs is a combination of RRCS with telemetry and video support [2].

Today there is no unity in the definition of UAV CS type, taking into account the known basic systems. The reason for this, in our opinion, is the contradiction which emerged as a result of rapid development of microelectronics and programming and the natural need for appropriate, new synthesis of UAV CS.

2. Analysis of the latest research and publications

The Air Code of Ukraine identifies CUAV as "the aircraft intended for the flight without a pilot on board, where the flight management and control is performed by a special control station located outside the aircraft" [3].

Circular № 328 ICAO expressly states that "in order to ensure the integration of the UAV application in the general airspace on common airfields, the pilot that is responsible for the flight of UAV is required. Pilot can use the appropriate equipment, such as autopilot, which helps to perform the pilot's duties, but under no circumstances, in the foreseeable future the responsibility of the pilot will be transferred to the technology" [4].

In fact, these regulatory documents emphasize that the UAV CS must provide its remote control in the first place. ACS is rather a desirable option, but not the main one. However, the practice of modern UAV flight proves that its manual piloting for a long time (5-10 hours) is associated with a significant overload for the external pilot (herein the authors introduce the name "*operator*" instead of the conventional name "*pilot*") and, similar to the piloted aviation there exists the need of automation of the piloting process.

3. Aim of the research

The main aim is justification of Civil Unmanned Aerial Vehicle CS types.

The specified task can be completed through the availability of UAV control system devices that can provide remote, automatic and combined UAV control.

It is known that modern Remote Radio Control (RRC) is industrially implemented in the form of the merged and dispersed systems. The merged RRC is the most common system which looks like a handheld transmitter (a remote control with two short handles – manipulators) produced by "Hi-Tec", "Futaba", etc. [5]. Accordingly, its receiving part is on board of the UAV. The dispersed system is less widespread. This system combines the output spools of the standard transmitter connected to the remote amplifier and a remote antenna to increase the range of communication. Sometimes the manipulators and the transmitter itself are structurally separated. Often, instead of handles-manipulators used a standard three-axis joystick.

4. Research results

Analysis of modern UAV RRC revealed the significant difference in their functions. For example, in UAV "Tango" uses the "pure" radio control link "Futaba", whereas the control system of UAV "Orbiter" provides feedback in the form of telemetry link from on-board sensors [6]. Obviously, such a difference in the functions of RRC is motivated by the tasks/applications that are set for the RRC. Eventually, the only restriction for this issue is the question of flight within the optical sight or beyond it.

Flight beyond the optical sight via radio control system is possible only if there is a certain type of feedback. Today among the technically implemented systems telemetry, terrain video image and virtual model of the area are able to provide feedback.

Given this, remote control of UAV could be typed as follows (Table 1).

Table 1

Compliance between RRC application and type of feedback signal

RRC type	Application	Type of feedback signal
D1	within the optical sight	none
D2	beyond the optical sight	telemetry
D3	beyond the optical sight	telemetry + real video image
D4	beyond the optical sight	telemetry + virtual video image
D5	beyond the optical sight	telemetry + real video image + virtual video image

The result of the analysis also revealed a great variety in the functions of automatic control [7]. The simplest variant of automation is the automation of the flight at the level of such basic function as auto maintenance of speed, flight altitude and position in space between the RTP's, which are assigned "manually" ("simple" autopilot). However, today there are UAV control systems, which allow perform the flight task from the start to finish with the certain freedom of choice for the whole trajectory or its segment [8]. It is obvious that there are some intermediate types of AC in between of the first simplest and the last most difficult examples of automation.

If the first system of AC is taken as basic variant of ACS, then while adding some options to the basic variant in order to expand the range of its functions, the above mentioned types of UAV ACS can be represented in the following form of Table 2.

As shown in Tables 1 and 2, the generalized variants of remote radio control and automatic control systems of UAV can be formalized according to the identified types of CS. Each these variants can be considered as an independent type of CS. But usually when real UAV CS is analyzed, it can be noted that in the "pure" form, CS are used only in UAVs limited by the specific requirements. Thus, the systems of D1 type are used for sports and for scientific purposes. Systems of D2-D5 type are limited by time of continuous piloting by an external pilot [8]. The more widely spread variants in military application are A2 and A3 types of AC, only in the class of short range UAV (5-15 km range) and small UAV (5 - 20 kg takeoff weight [9].

For CUAVs within the class of above 20 kg, the more suitable variant are the combined CS with prioritization of RC and automation, while support of the accuracy compliance of planned the route is carried out through the usage of automation. Such a practical variation implies the idea of certain amount of correspondence between the RRC and CS types suggested in Tables 1 and 2.

Table 2

Compliance of type and functions of different ACSs

Type of AC	Functions of ACS
A1	Automatic control of speed, altitude and position in space between RTPs defined "manually" («simple» autopilot)
A2	Route automatic control («simple» autopilot + flight program)
A3	Route automatic control, automatic take-off and landing («complex» autopilot + flight program)
A4	Route automatic control («complex» autopilot + flight program + subprograms archive of «behavior» on the route)
A5	Route automatic control with independent choice of movement "scenarios" on its segments («complex» autopilot + flight program + subprograms archive of «behavior» on the route + elements of artificial «intelligence»)

To obtain variants of CS combinations, presented in Tables 1 and 2, morphological analysis method was used [10].

The morphological matrix, in this case, is a symbolic entry of remote and automatic control systems variants represented as:

D1	D2	D3	D4	D5
A1	A2	A3	A4	A5

In order to generate a certain number of variants of combined CS it is necessary to multiply the amount of RC systems variants by the amount of AC systems variants, i.e.:

$Y_k = D_{ns}A_{ns}$

$$D_{ns}A_{ns} = \begin{cases} 1 if n = 1,\dots,5;\ s = 1,\dots,5;\ s \in Z \\ 0\ otherwise \end{cases}$$

$\sum Y_k = 25$

We respectively obtain 25 variants of combined UAV CSs. Every combination should contain the element "D" and the element "A", for example, D2A3, D5A4, etc. Through detailed analysis of every variant, which is carried out using one of the experts method, for example, the method of synectics or "brainstorming", the accuracy of selecting a CS combination for a particular UAV type can be confirmed or denied. Let us consider the variant D2A3, used in "Bird Eye 400", while «Predator RQ -1» uses a D5A4 combination of systems.

It should be added that the basic variants of CS taken from Tables 1 and 2 are self-sufficient and appropriate to control UAVs in the specified part, so these variants can be used independently.

Table 3 shows the complete list of variants for the combination of systems «D» and «A».

Table 3

Variants for the combination of systems «D» and «A» and their designation

№ var	Designation	№ var	Designation
1	D_1A_1	13	D_3A_3
2	$D_1 A_2$	14	D_3A_4
3	$D_1 A_3$	15	D_3A_5
4	$D_1 A_4$	16	D_4A_1
5	$D_1 A_5$	17	D_4A_2
6	$D_2 A_1$	18	D_4A_3
7	$D_2 A_2$	19	D_4A_4
8	D_2A_3	20	D_4A_5
9	D_2A_4	21	D_5A_1
10	D_2A_5	22	D_5A_2
11	D_3A_1	23	D_5A_3
12	D_3A_2	24	D_5A_4
		25	D_5A_5

Based on the obtained variants for the combination of systems «D» and «A» some variants for individual UAVs and Unmanned Aviation Systems (UASs) can be defined. These variants were developed and are in operation at Scientific Production Center of Unmanned Aviation (SPCUA) «Virazh» (*Reference needed*). The following UAVs and UASs are considered:

1. *M-7V5 "Sky Patrol"* (Fig. 1) [11]. This UAV uses D5A3 system combination, since the flights performed it performs are not limited by optical sight. Telemetry, real time video images transmitted from onboard cameras is utilized. The software ensures formation of the virtual video image in accord to the UAV position on the route. Application of the ACS on the route, automatic launch and landing are planned.

Fig. 1 UAV M-7V5 «Sky Patrol»

2. *M-6-3 «Zhayvir»* (Fig. 2) [12] and *M-10 «Oko 2»* (Fig. 3) [13]. Unmanned Aviation Complexes (UACs) uses D3A3 system combination, since the flights not limited by optical sight.

Fig. 2 UAC M-6-3 «Zhayvir»

Telemetry, real time video images transmitted from onboard cameras is utilized.

Fig. 3 UAC M-10 «Oko 2»

Application of the ACS on the route, automatic launch and landing are planned.

5. Conclusions

1. The main reason that leads to ambiguity in typology of CUAV CSs is the contradiction between the need to ensure operation of CUAVs of different weight classes in common airspace and the absence of structures and composition of CSs, respective to these weight classes.

2. Due to significant overload of the external pilot of CUAV when "manually" piloting the UAV for a long period of time (5-10 hours) there is a need to automate the process.

3. ICAO regulations and the Air Code of Ukraine states that CUAV is, in the first place, a "remotely piloted aircraft", so the automatic control is rather a desirable option, but not the main one.

4. Basic UAV CSs are entitled to two groups; the first group is remote radio control systems and the second group is the automatic control systems. Some relationships are formed between the elements of the groups that eventually produce a particular type of UAV CS.

5. To obtain specific combinations of the basic UAV CS variants the method of morphological analysis was used.

6. In the future, for a detailed analysis of the specific variant of UAV CS the experts methods, for example, synectics or "brainstorming" can be employed.

7. Selected analysis of the RRC and AC for some UAV and UAC was conducted. The UAVs and UACs were developed and are in operation by SPCUA «Virazh». UAV M-7V5 «Sky Patrol» uses the variant of system combination D5A3. D3A3 variant of system combination is applicable for UAC M-6-3 «Zhayvir» and UAC M-10 «Oko 2».

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Обґрунтування типів систем керування безпілотними повітряними суднами цивільної авіації

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Мета: Проблема систем керування безпілотних повітряних суден є складним питанням, яке потребує розгляду завдань і застосування безпілотних повітряних суден. Запропоновано і обґрунтовано типологію комбінації систем керування безпілотними повітряними суднами цивільної авіації. **Методи:** Методологія дослідження ґрунтується на застосуванні різновидів методу експертних оцінок для обґрунтування варіантів комбінацій системи керування для конкретного типу безпілотного повітряного судна, застосований морфологічний аналіз для генерування варіантів комбінацій систем управління. **Результати:** Розкрито причини що приводять до різночитання у типізації систем керування безпілотними повітряними суднами цивільної авіації. Розглянуто відповідність між застосуванням дистанційного радіокомандного керування та типом зворотного зв'язку. На базі методу морфологічного аналізу запропоновано 25 варіантів комбінованих систем керування безпілотними повітряними суднами. **Обговорення:** Розглянуто нормативну, змістовну та технічну складові базових систем керування безпілотних повітряних суден. Для демонстрації застосовності результатів використано практичний досвід розробки Науково-виробничого центру безпілотної авіації «Віраж».

Ключові слова: безпілотне повітряне судно цивільної авіації; дистанційне радіокомандне керування; морфологічний аналіз; система автоматичного керування.

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Обоснование типов систем управления беспилотными воздушными судами гражданской авиации

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Цель: Проблема систем управления беспилотных воздушных судов является сложным вопросом, который требует рассмотрения задач и применения беспилотных воздушных судов. Предлагается и обоснована типология комбинации систем управления для беспилотных воздушных судов гражданской авиации. **Методы:** Методология исследования основана на применении разновидностей метода экспертных оценок для обоснования вариантов комбинаций системы управления для конкретного типа беспилотного воздушного судна и применен морфологический анализ для генерирования вариантов комбинаций системы управления. **Результаты:** Раскрыты причины, приводящие к разночтению в типизации систем управления беспилотными воздушными судами гражданской авиации. Рассмотрено соответствие между применением дистанционного радиокомандного управления и типу обратной связи. На базе метода морфологического анализа предложено 25 вариантов комбинированных систем управления беспилотными воздушными судами. **Обсуждение:** Рассмотрены нормативная, содержательная и техническая составляющие базовых систем управления беспилотных воздушных судов. Для демонстрации применимости результатов использован практический опыт разработки Научно-производственного центра беспилотной авиации «Вираж».

Ключевые слова: беспилотное воздушное судно гражданской авиации; дистанционное радиокомандное управление; морфологический анализ; система автоматического управления.

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