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METHOD OF SYNTHESIS OF DIGITAL CONTROLLER FOR UAV AUTOMATIC CONTROL SYSTEM

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Introduction

Unmanned aerial vehicles (UAV) have become an important tool in many areas due to their versatility, accuracy and technological capabilities. This has led to the rapid development of technologies for creation and deployment of UAVs. The development of UAVs opens up new opportunities for the military sector and expands the scope of their civilian application in such industries as: oil and gas industry, transport, construction, energy, agriculture, communications, etc. Therefore, nowadays the task of creating new unmanned aerial vehicles (UAVs) of various purposes and configurations is an extremely relevant and promising research topic. The effectiveness of UAV task performance is largely determined by the ability of the automatic control system (ACS) to perform its functions [1-3].

Thus, the quality and reliability of the automatic control system (ACS) will depend on [4-6]:

- control accuracy: the ACS must ensure accurate following of the given route, execution of maneuvers and stabilization of the vehicle in difficult conditions. This is critical for reconnaissance, cargo and military UAVs;
- autonomy: a higher level of autonomy (artificial intelligence algorithms, event prediction) allows performing complex missions without active operator intervention;
- adaptability: the ACS must take into account changes in environmental conditions and adapt the behavior of the UAV in accordance with these changes.

The quality of the operation of the UAV's ACS depends on many factors, the key of which is the selection and adjustment of the correction device. The correction device is the main element that increases the accuracy, stability, speed and reliability of the ACS operation. Its usage allows to significantly improve the efficiency of UAV task performance and adaptation to complex and changing conditions.

Taking into account the development of computing hardware, digital correction devices (digital controllers), calculation of which is carried out according to analog mathematical models, became widespread [7].

Usage of digital controllers in UAV systems is an urgent task for the following reasons [7, 8]:

- digital controllers allow to provide high accuracy of UAV control, which is critical when performing complex maneuvers and tasks.

- digital controllers can be adjusted and adapted to different flight conditions and tasks. This allows you to quickly react to changes in the environment and increase the overall efficiency of the UAV.
- digital controllers are easily integrated with other digital systems on board of the UAV, such as navigation systems, communication systems, data processing systems, sensor systems, etc.
- the reliability of controls is critical for the safety of UAV and the avoidance of emergency situations. Digital controllers can include systems of automatic detection and correction of errors, which increases the overall reliability of the control system.
- digital controllers allows the application of complex control algorithms, such as adaptive, optimal and intellectual methods, which increases the overall efficiency and autonomy of the UAV.

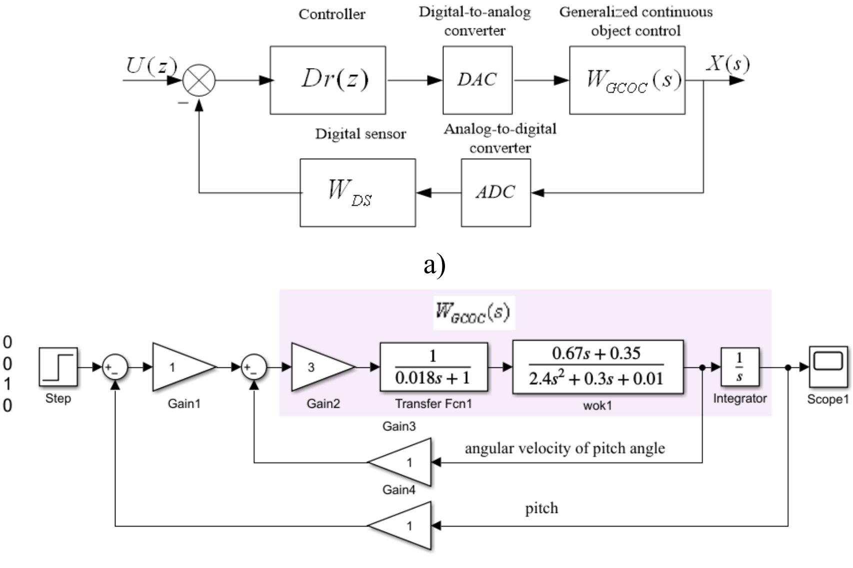
Therefore, the synthesis of digital controllers is a key stage in the development of modern UAV control systems, which ensures their reliability, accuracy and efficiency in the conditions of real operational tasks, and the adjustment of controller parameters is an urgent scientific task.

In this article a method for synthesizing a digital controller for pitch angle control system of an aircraft-type UAV based on the use of the desired transfer function method.

Problem Statement

The solution of the problems of automatic control of the UAV flight is carried out by separate circuits of automatic control systems. Angular movement control circuits are designed to control and stabilize the angular position of the aircraft, which is characterized by the angles of roll, pitch and yaw. Angular movement control circuits and altitude stabilization circuits are traditionally called autopilots [1, 8]. As the initial data, we will consider the pitch angle circuit. The pitch autopilot provides control and stabilization of the angular position of the aircraft, deflecting the corresponding control surfaces. These controls create control moments relative to the transverse axis, changing the pitch angle. To develop a mathematical model of the automatic control system of pitch angle of the UAV, standard mathematical models of the longitudinal movement of an aircraft-type UAV were used in the work [1, 8].

Based on the selected typical mathematical model of the UAV and its parameters [1], the transfer functions of all elements included in the structural diagram were determined. The structural diagram of the automatic control system of pitch angle of the UAV and its simulated mathematical model are shown in fig. 1.



a)

b)

Fig. 1. Structure of the pitch angle ACS a– block diagram of the ACS, b-imitation model of the ACS

The simulated mathematical model of the UAV (fig. 1, b) consists of the following blocks: Gain1 – a digital controller, presented by a proportional link; Gain2 – a power amplifier, Transfer Fnc1 – a transfer function of the servo drive; Transfer Fnc2 – a transfer function that connects the pitch angular velocity and the elevator deviation; Gain3, Gain4 – transfer functions of the pitch angular velocity sensor and pitch angle, presented by proportional links The automatic control system of pitch angle (Fig. 1) includes two control loops: the inner loop – angular velocity control loop; the outer loop – pitch angle control loop. The ACS ensures that the UAV's specified pitch angle is achieved through the interaction of these two control loops, changing the elevator deviation angle, which allows the UAV to achieve the required position [9, 10].

Modern UAV automatic control systems uses digital controllers due to their high accuracy, flexibility of adjustment and ability to adapt to various flight conditions. The presence of the digital controllers in the system allows you to carry out the optimal transient responses without overregulation for a finite and minimal time. To obtain such a process in the system, it is necessary to determine the required transfer function of the digital controller.

This paper proposes a method for synthesizing a digital controller for the longitudinal movement control system of an aircraft-type UAV based on the use of the desired transfer function method.

Problem Solution

The synthesis of a digital controller using the desired transfer function method consists in finding the structure and parameters of the digital controller and the desired transfer function of a closed-loop digital ACS [7].

The method of synthesizing a UAV pitch angle digital ACS controller based on the use of the desired transfer function method is as follows:

1. At the first stage, the polynomial equation of the controller synthesis is calculated in the general form.
2. At the second stage, the polynomial equation of the synthesis is constructed in the form that ensures the given quality of the control object control process.
3. At the third stage, the coefficients of the digital controller are synthesized.

Move on to the reviewing these stages.

Stage 1. To determine the polynomial equation of synthesis, we find the transfer function of the generalized continuous control object (GCCO). To do this, consider the structure of the mathematical model of the ACS presented in Fig. 1, a, in which the open part is a serial connection of the controller and the generalized continuous control object (GCOC). The generalized continuous object of control according to Fig. 1, b, is a serial connection of the power amplifier and the servo drive and the dynamic model of the UAV.

The corresponding transfer function of the generalized continuous control object presented in Fig. 1, b will have the form

$$W_{GCOC}(s) = \frac{2{,}01s+1{,}05}{2{,}4s^3+0{,}3s^2+0{,}01s}. \qquad (1)$$

Let us define the transfer function of a closed-loop ACS (fig. 1, b) for the output signal, which will have the following form:

$$H_X(s) = \frac{X(s)}{U(s)} = \frac{D(s)\cdot W_{GCOC}(s)}{1+D(s)\cdot W_{GCOC}(s)}. \qquad (2)$$

Let us assume that the transfer function of the closed-loop ACS for the output signal is equal to the desired one desired $H_X(s) = H_{XD}(s)$.

Then the transfer function of the controller, i.e., the automatic control algorithm, can be calculated by the formula

$$D(s) = \frac{1}{W_{GCOC}(s)} \cdot \frac{H_{XD}(s)}{1-H_{XD}(s)}. \qquad (3)$$

Let us represent $W_{GCOC}(s)$ in the form of zeros and poles:

$$W_{GCOC}(s) = \frac{P_0(s)}{Q_0(s)} \cdot e^{-\tau_0 s}, \qquad (4)$$

where $P_0(s)$, $Q_0(s)$ – polynomials with respect to a variable s, τ_0 – nominal delay that exists in the control object and depends only on the physical principle of functioning of this object (in this model τ_0=0).

Let us perform the operation of factoring polynomials $P_0(s)$, $Q_0(s)$, that is, we represent them in the form and represent the desired transfer function of the closed-loop ACS $H_{XD}(s)$ and $1-H_{XD}(s)$ respectively in the form:

$$H_{XD}(s) = A(s)\cdot\frac{M(s)}{G(s)}\cdot e^{-\tau_D s}$$

$$\text{and } 1-H_{XD}(s) = B(s)\cdot\frac{N(s)}{G(s)}, \qquad (5)$$

where $A(s)=P_{0+}(s)\cdot P_{0-}(s)$, $B(s) = = Q_{0+}(s)\cdot Q_{0-}(s)$, $M(s), N(s)$, $G(s)$ – polynomials with respect to a variable s; τ_D – desired delay.

Substituting equations (4), (5) into expression (3), we obtain the transfer function of the regulator in the general form

$$D(s) = \frac{Q_{0+}(s)}{P_{0+}(s)}\cdot\frac{Q_{0-}(s)}{P_{0-}(s)}\cdot\frac{A(s)}{B(s)}\cdot\frac{M(s)}{N(s)}e^{-(\tau_D-\tau_0)s}, \quad (6)$$

which should have been obtained during the execution of this stage of the method.

Substitute the expression for $H_{XD}(s)$ into the expression for calculating $1-H_{XD}(s)$ and obtain the polynomial equation for the synthesis of the controller transfer function in the general form

$$G(s) = A(s)\cdot M(s) + B(s)\cdot N(s), \quad (7)$$

which should have been obtained during the execution of this stage of the method.

Stage 2. Factorize the polynomials of the numerator and denominator of the transfer function of the generalized continuous control object.

$$W_{GCOC}(s) = \frac{P_0(s)}{Q_0(s)}\cdot e^{-\tau_0 s} = \frac{2{,}01s+1{,}05}{2{,}4s^3+0{,}3s^2+0{,}01s}\cdot e^{-0s},$$

$$P_0(s) = P_{0+}(s)\cdot P_{0-}(s) = (2{,}01s+1{,}05)\cdot 1;$$

$$Q_0(s) = Q_{0+}(s)\cdot Q_{0-}(s) = (2{,}4s^2 + 0{,}3s^1+0{,}01)s. \qquad (8)$$

Substituting the obtained expressions (8) into equation (6), we write down the generalized transfer function of the controller

$$D(s) = \frac{2{,}4s^2+0{,}3s^1+0{,}01}{2{,}01s+1{,}05}\cdot\frac{s}{1}\frac{A(s)}{B(s)}\cdot\frac{M(s)}{N(s)}\cdot 1.$$

The polynomials A(s), B(s), M(s), N(s) are set in such a way that the expression for calculating the transfer function of the regulator D(s) has a simple form and, at the same time, the transfer function D(s) could be physically implemented: $B(s)=s$, $A(s) = 1$, $M(s)=m_0$ and $N(s)=n_1\cdot s+n_0$.

The polynomial synthesis equation takes the form

$$G(s) = 1\cdot m_0 + s\cdot(n_1\cdot s+n_0). \quad (9)$$

To ensure the stability of the closed control loop and the ability to uniquely solve the polynomial synthesis equation, we assume that

$$G(s) = (s+a)^2|_{a=2} = s^2+4s+s.$$

Using the polynomial synthesis equation (9), we find the unknowns m_0, n_2, n_1, n_0 by the method of undetermined coefficients:

$$s^2+4s+4 = 1\cdot m_0 + n_1\cdot s^2 + n_0\cdot s \rightarrow$$
$$\rightarrow \left\{\begin{matrix} m_0 = 4 \\ \\ n_1 = 1 \\ n_0 = 4 \end{matrix}\right\}.$$

Let us find the generalized transfer function of the controller

$$D(s) = 4\cdot\frac{2{,}4s^2+0{,}3s+0{,}01}{(2{,}01s+1{,}05)(s+4)}.$$

Stage 3. Based on the generalized transfer function of the controller, we will find a discrete model of the digital controller. The discrete model of the DC can be obtained from the continuous model using various methods such as the method of triangles, the method of trapezoids and other methods, which are given in the works [foreign, Landau, and another article].

It should be noted that the determination of the transfer functions of the DC for systems with a control object of the third order and higher is a labor-intensive task. Therefore, in this work, it is proposed to use the special function c2d of the computer mathematics system MATLAB to determine the discrete model of the digital controller and selected discretization step T = 0,05 c.

As a result of applying the special function c2d, we obtain the transfer function of the digital controller

$$Dr(z) = 4 \cdot \frac{1.194z^2 - 2.333z + 1.14}{z^2 - 1.793z + 0{,}7965}.$$

Computer mathematical model of the pitch angle ACS with a synthesized digital controller and the results of computer modeling are shown in fig. 2, 3.

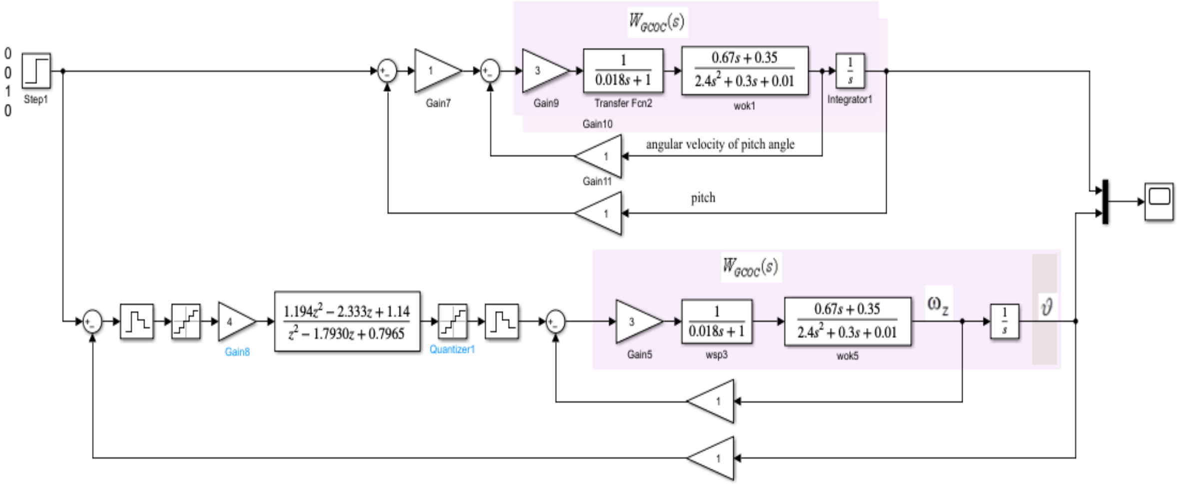


Fig. 2. Computer mathematical model of pitch angle ACS with a synthesized digital controller

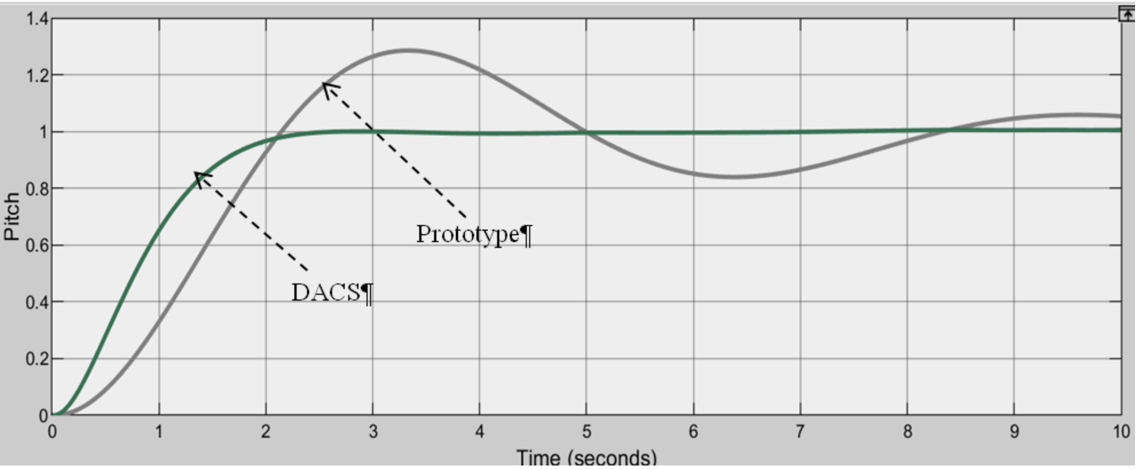


Fig. 3. Results of computer simulation

Conclusion

Based on the results of simulation modeling, it can be concluded that the proposed method for synthesizing a digital controller allowed to improve the quality of the transient response, namely, to ensure the smoothness of the transient response, reduce overshoot and the time of the transient response, which is critically important for the accuracy of UAV flight control.

Since the main indicators of the quality of the pitch angle automatic control system in a steady state are the accuracy of stabilization of the given parameter, and the results of simulation modeling showed that the steady state operation of the automatic control system fully satisfies the requirements for the automatic control system of the UAV, this indicates the feasibility of using the proposed method for synthesizing digital controllers for such systems.

The synthesized digital controller can be integrated into the software or hardware of the UAV automatic control system.

The proposed method can be used to design digital controllers for automatic control systems of any type of UAV.

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METHOD OF SYNTHESIS OF DIGITAL CONTROLLER FOR UAV AUTOMATIC CONTROL SYSTEM

In this article the method for synthesizing a digital controller for an unmanned aerial vehicle (UAV) automatic control system is proposed. The suggested method is simple to use and enables rapid parametric tuning of the digital controller for a specific loop of the UAV automatic control system. The synthesized digital controller can be integrated into the software or hardware of the UAV automatic control system. The proposed method can be used to design digital controllers for automatic control systems of any type of UAV.

***Keywords**: UAV; optimal control; digital controller; control system.*

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МЕТОД СИНТЕЗУ ЦИФРОВОГО РЕГУЛЯТОРА ДЛЯ СИСТЕМИ АВТОМАТИЧНОГО КЕРУВАННЯ БПЛА

В даній статті запропоновано метод синтезу цифрового регулятора для системи автоматичного керування БПЛА. Запропонований метод є простим у використанні і дозволяє виконувати за короткий час параметричне налаштування цифрового регулятора для окремого контуру системи автоматичного керування БПЛА. Синтезований цифровий регулятор можна інтегрувати у програмне або апаратне забезпечення система автоматичного керування БПЛА. Запропонований метод може використовуватись для проектування цифрових регуляторів для систем автоматичного керування БПЛА будь-якого типу.

***Ключові слова**: БПЛА; оптимальне керування; цифровий регулятор; система керування.*