Bulgarian Academy of Sciences. Space Research Institute.
Aerospace Research in Bulgaria. 23, 2009, Sofia

AUTOMATED CONTROL SYSTEM FOR UNMANNED COMBAT AIR VEHICLE

Valentina Tsekova

Rakovski Defence and Staff College, Defence Advanced Research Institute
e-mail: valsof20@hotmail.com

Abstract

A type of automated control system (ACS) for unmanned combat air vehicle (UCAV) is suggested. ACS framework is synthesized out of its block diagram. The diagram and the equations enclosed to them could be used for basic calculations and researches of ACS for unmanned air vehicle.

Introduction

One of the earliest created UCAV is the unmanned plane, controlled by operators. In this case, the operator follows the target and the unmanned air vehicle (UAV) evaluates the deviation between the plane and the target. If there is any diversion, the operator gives command to the plane to eliminate it. In this type of control, the operator takes a very big psychophysical load on himself [1,3,4,5], commensurable with the load of pilots, because of the very limited time and the need to evaluate quickly and precisely the changing situation, when controlling an air vehicle with pronounced inertia. This is why UAV operator selection was similar to pilot selection and their education was long and expensive. The possibility of a hit in the target for this UAV was very low and usually less that 0.5.

Notwithstanding the above-mentioned difficulties in operator-controlled UAVs, they have been used widely, mostly for striking small and mobile targets and objects as tanks, command posts, ground radars, etc., which have less dynamics than UAV.

The abundant available literature on control systems provides no thorough research of the ACS for air vehicles nor states any issues for their synthesis. ACS high noise stability, the possibility to reach high probability for hitting, especially for low contrasted targets, and the comparatively low price for single used board equipment substantiate their wide use, especially in light UAV. That is why their research is interesting not only in the theoretical aspect, but is also of practical value, which is underlined by the possibility for streamlining the control system for reconnaissance UAV, developed and produced in Bulgaria.

Block-Diagram of ACS for UAV

As mentioned above, UCAV operators take a very big psychophysical load upon themselves during the flight to the target. ACS has been developed in order to reduce that load. After the operator identifies the target and turns the UAV in its direction, he just keeps a marker (label, color point, etc.) on it on his monitor screen till the strike. During that time the microprocessor systems are calculating the deviation of the UAV from the target and turn it in such way that its longitudinal axis sticks always through it.

The diagram of ACS for UCAV is shown in Fig. 1.

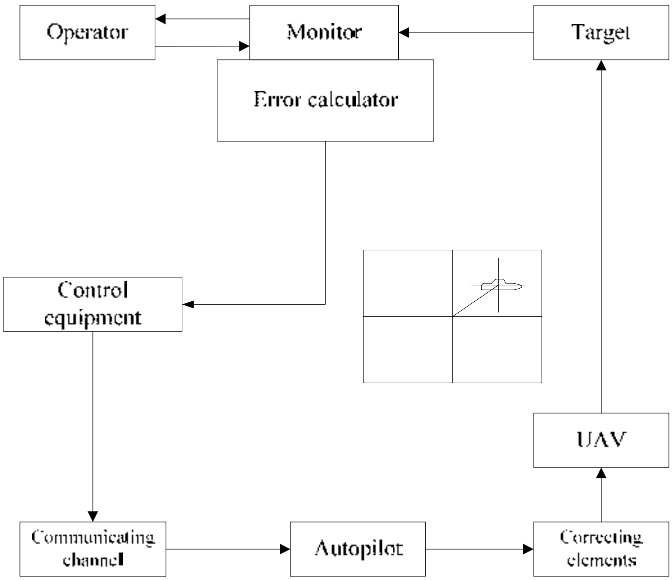

Fig. 1. Block Diagram of ACS for UCAV

It is synthesized on the base of the following control algorithm. After the choice and identification of the target, the operator integrates the longitudinal axis of the board system for air observation (usually television camera or infrared one) with the UAV longitudinal axis. Thus, the target view is centralized on the screen of the monitor and at that very moment the operator marks this position by a marker. When the UAV's longitudinal axis deviates from the target, its view moves out of the centre of the monitor screen. Then the operator indicates again the target by the marker and thus he shows the deviation of the center, i.e. indentifies the deviation of the desired value. Based on this error the error calculator determines the UAV's deviation from the kinematics path and issues the respective signal to the control equipment. It produces correcting signals which reach the UAV auto pilot via the communicating channel. The latter sends the correcting signals which divert the air vehicle correcting elements (the steering wheel) in the direction of the issued command. As a result of the wheel's deviation, the UAV starts to change its flight path until the commands stop, i.e. until the target view is back in the center of the monitor.

The essential difference between the ACS whose operation algorithm was explained above, and the systems controlled manually by operators, from automation point of view, lies in the operator's elimination from the control cycle. Regarding ACS - he has to cover only the target view on the monitor screen and all the decisions are taken by the dedicated and universal computers. This elimination of the operator from the control cycle increases abruptly control quality and the system's efficiency as the psychophysical load on him decreases significantly.

Structural Diagram of ACS for UCAV

The ACV for UAV is a device complex. Together with the operator, these devices measure the target and UAV coordinates and, depending on the adopted law on targeting, the produces commands, which keep the flight to the kinematic pathway. In this process, the plane could be considered as an element of the control system – a generalized correcting element which eliminates the measured error.

The description of the UAV (the airplane) as an element of the automation is presented in the available abundant literature on plane control, e.g. [2], where their longitudinal and cross motion is presented in details. The integration of the function of the UAV on the angle of arrival θ with the angle of alternation of the horizontal wheel δ_x could be expressed by:

(1) $$W_{\theta}^{\delta_x}(p) = \frac{k_{\theta}^{\delta_x}}{T_{\theta}p\,(T_{\alpha}^2 p^2 + 2\xi_{\alpha}p + 1)},$$

Where

(2) $$k_{\theta}^{\delta_x} = \frac{a_{\omega z1}^{\delta_x}}{a_{\theta}^{\theta}\, a_{\omega z1}^{\omega z1} - a_{\omega z1}^{\vartheta}}$$

is factor of the angle of arrival to the angle of alternation of the horizontal steering wheel;

(3) $$a_{\omega z1}^{\delta_x} = \frac{1}{J_{z1}} M_{z1}^{\delta_x}$$

where J_{z1} is the plane moment of inertia in relation to the axis O_{z1};

(4) $$M_{z1}^{\delta_x} = m_{z1}^{\delta_x} \frac{\rho V^2}{2} S_k b_a$$

is the plane moment of pitch;

(5) $$m_{z1}^{\delta_x} = f(\alpha, \beta, M, \delta_x)$$

is dimensionless factor; β – angle of resistance; $M = V_в/a$ – Mah's figure; a – local sonic velocity;

(6) $$\overline{\omega_{z1}} = \frac{\omega_{z1} l_k}{2V_в}$$

is dimensionless angular velocity of the UAV around the axis O_{z1}; ω_{z1}=dα/dt – angular velocity of the plane around the axis O_{z1}; $l_к$ – UAV wing-span; $V_в$ – UAV air velocity; ρ – air density; $S_к$ – wing area; b_a – middle aerodynamic chord;

(7) $$a_{\omega z1}^{\vartheta} = \frac{1}{J_{z1}} M_{z1}^{\alpha}$$

ϑ – angle of pitch; $\alpha = \vartheta + \theta$ – angle of attack;

(8) $$M_{z1}^{\alpha} = m_{z1}^{\alpha} \frac{\rho V_{в}^{2}}{2} S_k b_a \,;$$

(9) $$a_{\theta}^{\theta} = \frac{1}{m(t)V_{в}} (-P - Y^{\alpha} + G \sin\theta) \,;$$

m(t) – variable airplane mass; P – traction of engine;

(10) $$Y^{\alpha} = C_{y}^{\alpha} \frac{\rho V_{в}^{2}}{2} S_k \alpha$$

is lifting force; G = m(t)g – UAV gravity force;

(11) $$a_{\omega z1}^{\omega z1} = \frac{1}{J_{z1}} M_{z1}^{\omega z1}$$

is UAV angular velocity around the axis O_{z1};

(12) $$M_{z1}^{\omega z1} = m_{z1}^{\omega z1} \frac{\rho V_{в}^{2}}{2} S_k b_a$$

is UAV moment of rotation around the axis O_{z1};
$T_{\theta} = 1/a_{\theta}^{\vartheta}$ – time constant of the plane to the alteration of its path;

(13) $$a_{\theta}^{\vartheta} = \frac{1}{m(t)V_{в}} (P + Y^{\alpha}) \,;$$

(14) $$T_{\alpha} = \frac{1}{\sqrt{a_{\theta}^{\theta} a_{\omega z1}^{\omega z1} - a_{\omega z1}^{\vartheta}}}$$

is time constant of the plane to the angle of attack;

(15) $$\xi_{\alpha} = \frac{-a_{\theta}^{\theta} - a_{\omega z1}^{\omega z1}}{2\sqrt{a_{\theta}^{\theta} a_{\omega z1}^{\omega z1} - a_{\omega z1}^{\vartheta}}}$$

is damping ratio of the UAV variation to the angle of attack.

The linear deviation of the plane trajectory strike from the target is as follows:

$$x = V_ц \tau (\lambda_ц + \varepsilon_ц) + r(\varepsilon_ц + \varepsilon_c), \quad (16)$$

where: $V_ц$ – the target velocity; $\lambda_ц$ – the angle between the target velocity vector and the visual axis of TV system; r – radius vector; $\varepsilon_ц$ – the diversion of the target screen image from the monitor center, converted into angle measure; ε_c – the angle between the longitudinal plane axis and the line which connects the UAV with the target; $\tau = \tau_c + \tau_{опер}$, where τ_c is time constant of UAV and $\tau_{опер}$ – time constant of the operator.

Equation (16) shows that the linear deviation of the plane trajectory strike from the target is a sum of two parts, whereas in real tactic conditions the first part is smaller than the second one. Therefore, the ACS functional diagram will be synthesized only by the second part. It is shown in Fig. 2.

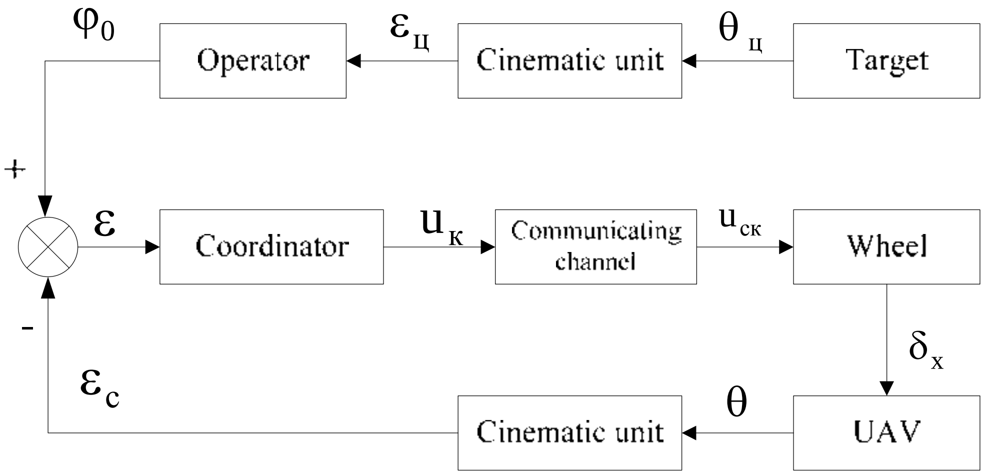

Fig. 2. Functional Diagram of ACS for UCAV

The functional diagram above shows that, as a result of the target trajectory deviation (the angle $\theta_ц$), the operator observes the deviation of the angle of error $\varepsilon_ц$ on the monitor and moves the marker to the converted angle φ_0, so as to cover the target's visualization. The angle φ_0 is incoming (coordinating) signal for the coordinator. The coordinator is formed by the error calculator and the control system shown in Fig. 1. It creates the load

$u_к$, which comes to the steering wheels of the plane (correcting elements) via the communicating channel. They divert into angle δ_x, according to which UAV switches over to a new trajectory, whose angle of arrival is θ. This angle is transformed into angle ε_c by the kinematic unit. The deviation of the angle θ will continue until the equality $\varepsilon = \varphi_0 - \varepsilon_c = 0$ is reached. This equality is an idealization and usually in the stated regime $\varepsilon \rightarrow 0$.

The angle ε_c will change, if any deviation of the plane from its kinematic trajectory occurs. After that, the equality $\varepsilon = 0$ will be broken and the coordinator will send a command to the UAV, so that it is restored to the initial trajectory.

The structural diagram of ACS for UCAV could be designed using the functional diagram (Fig. 2), as shown in Fig. 3.

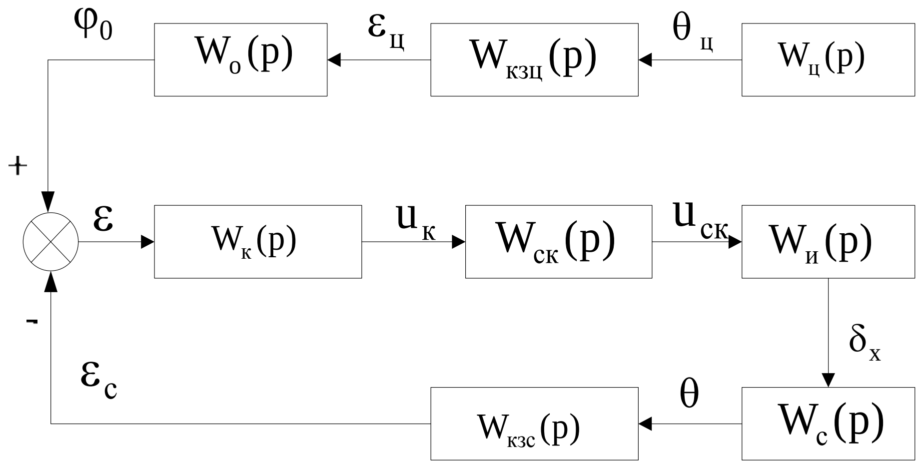

Fig. 3. Structural Diagram of ACS for UCAV

The closed loop control system (without the operator) is of some interest from theoretical point of view. Using the known characteristics of the units, which are part of it, it could be shown in Fig. 4. The following symbols are used: $W_к(p)$ – indefinite transmission function of the coordinator; $K_{ск}$ – factor of the communicating channel; $K_и/p$ – transmission function of the correcting elements (the wheels); $K_\theta^{\delta x}/T_\theta p$ – transmission function of the UAV and $K_{кзс}/p$ – transmission function of the kinematic unit of the unmanned plane.

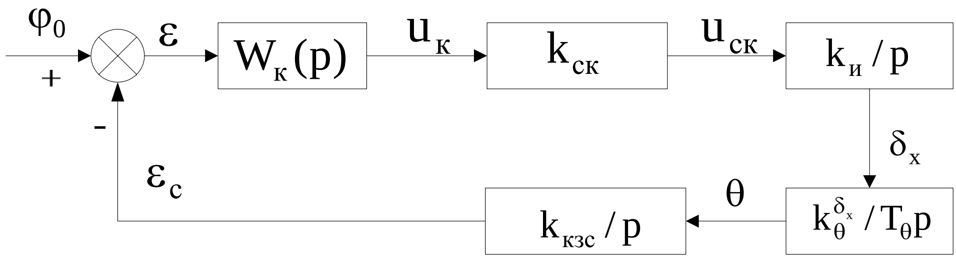

Fig. 4. Structural Diagram of Closed Loop ACS for UCAV

Only the main parameters of the single units of the control system are taken into consideration in the description, as the influence of the small-valued second-order parameters has been ignored. Actually, the influence of the pure delay has been ignored, which could be recognized for the time constants, whose values are 5–10 times smaller than $1/\omega_c$.

Conclusions

The structural diagram, shown in Fig. 4 shows that the closed part of the ACS for UCAV is structurally unstable – there are three integrated units. Therefore, some special measures for its correction have to be taken. The easiest way to make this correction is by using classical automation methods. The transmission function of the coordinator should be considered as transmission function of consecutive correcting elements and should have such parameters and structure, so that the closed system has some previously defined characteristics as:

(17) $$W_k(p) = \frac{W_ж(p)}{W(p)},$$

where $W_ж(p)$ is the previously desired function of the open loop control system and

(18) $$W(p) = W_{СК}(p)W_И(p)W_C(p)W_{КЗС}(p).$$

When the automation set is used, for example the method of logarithmic characteristic, the preliminary function of the coordinator $W_к(p)$ could be determined and some requirements could be applied to it – for example to optimize the control system in general.

References

1. Б о д н е р В. А. Оператор и летательный аппарат, М.: Машиностроение, 1976.
2. Г л а г о л е в А. Н., М. Я. Г о л ь д и н о в, С. М. Г р и г о р е н к о. Конструкция самолетов, М.: Машиностроение, 1975.
3. Е л и с е е в А. А., А. А. О в о д е н к о, Управление движущимися объектами, М.: Мир книги, 1994.
4. Инженерная психология в применении к проектированию оборудования, разработано и составлено Обединеным координационным комитетом сухопутных, военно-морских и военно-воздушных сил США, М.: Машиностроение, 1971.
5. Н а з а р о в А. И. Изучение сенсомоторных реакции и двигательных навиков, кн. Инженерная психология М.: МГУ, 1964.

АВТОМАТИЗИРАНА СИСТЕМА ЗА УПРАВЛЕНИЕ НА БОЕН БЕЗПИЛОТЕН ЛЕТАТЕЛЕН АПАРАТ

В. Цекова

Резюме

Предложен е един тип автоматизирана система за управление (АСУ) на боен безпилотен летателен апарат (БЛА). Като е използвана блоковата схема на АСУ е синтезирана структурната й схема. Схемите и уравненията към тях могат да се използват за първоначални разчети и изследвания на АСУ на БЛА.