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# ESTIMATION OF REMOTE UNMANNED AERIAL VEHICLES CONTROL DELAYS

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*The causes of delays in the control circuit of remote unmanned aerial vehicles are considered. The necessity of taking into high-speed performance, memory and capacity of digital hardware facilities, realizing the system of autonomous remote control is substantiated.*

**Keywords:** delay, the system of autonomous remote control.

**Introduction.** Remote unmanned aerial vehicles (UAV) are currently the dynamically developing systems, which are used in various sectors of civil economy. They are used increasingly for protection problems of large agricultural and forest areas, environmental monitoring.

The main feature of UAV is realized – an interactive control only in cooperation of the UAV with a ground control station and its central element-the human operator. UAV is of course an automatic aircraft, designed to fly on a given route and maintain its orientation in space without human intervention, but at the same time it is ready to respond immediately to control actions of the human operator.

The high importance, the responsibility of actions, and the unique properties of a man in non-standard conditions, with imperfection and distortion of information, involve the using of the control channels, including the human operator. A perspective solution, which allows using advantages of a human effectively, is the using of systems with virtual control circuit, which immerses a pilot in an artificial environment, in which he generates control commands for the aircraft, which are adjusted through a feedback system. Despite of the clear obviousness of solutions, there is a number of challenges, which are associated with the creation of autonomous remote control system (ARCS). One of these challenges is the emergence of significant time delays in the control circuit [1]. Therefore, in this work we investigate the causes of delays in the complex UAV.

**Statement of the problem.** It is known that in communication systems, as well as in television systems there are lags, which cause an appearance of phase distortions in the telecontrol system, moreover delays are a destabilizing factor, which breaks the synchronous work of control system [2].

In this case it is necessary to consider the possibilities of registration of arising delays in the problem statement of analysis and synthesis of ARCS.

**Control system structure.** Let us consider a simplified block diagram of the control system of UAV, shown in figure.

Let us start with the onboard equipment, which is significant for management. These are the following devices:

– an onboard computer, the informational centre of UAV;

– a receiver of command control channel (CCC) and synchronized with it (for opportunity of ranging) a transmitter of radio and coordinates metration (RCM).

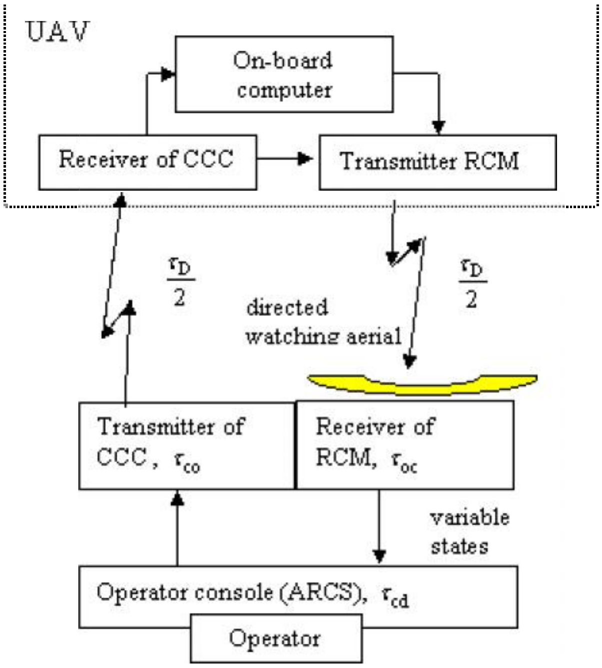
Ground Equipment:

– a directional tracking antenna with a receiver of RCM for measurement of the range and azimuth of UAV;

– transmitter CCC;

– operator console (ARCS).

For simplicity all auxiliary equipment is excluded from the scheme, such as encoders, decoders, radio channel encoders and decoders.




Simplified block diagram of the control system of UAV

On-board computer is a hard analog-digital circuit, which performs certain operations with incoming digital and analog signals, and directly controls UAV. Thus, we exclude it from the consideration, because delays, arising in the board circuit, can be neglected.

**Communication and control systems.** The time of delay, arising in the circuit of UAV, will be mainly determined by the time of information transmission by links of digital computer of ground communication station and support equipment. It can be represented by the following formula:

$$\tau = \tau_D + \tau_{oc} + \tau_{cd} + \tau_{co}. \quad (1)$$

where $^{2}{}_{\mathrm{D}}$ – is the delay time of the reflected signal, associating with a range of target by ratio [2]

$$\tau_D = \frac{2D}{c},$$

where $D$ – is a range of target; $c$ – is a propagation of electromagnetic waves; $\tau_{cd}$ – is a delay of a computer, which is associated with the computational cost of the production control actions (that takes place, for example, when there are bulky matrix operations in the calculation of control actions on low-speed, low memory and low bit digital devices); $\tau_{oc}$ – is a delay in the transmission channel “object-regulator”, which manifests itself in features of channel measurement results of the state variables and / or an output object’s account to the control device (for example, because of the limited bit data path or limited bit data memory and speed of an analog-to-digital converter in the remote control system, or because of organization characteristics of the transfer of information); $\tau_{oc}$ – is a delay in the transmission channel “regulator-object”, which is associated with features of the channel of action transfer from the control device to an object (for example, because of the limited bit data path or limited bit data memory and speed of digital-to-analog converter in the remote control system, or because of the organization of the information transfer).

If the human operator makes control action instead of a computing device, it is also necessary to consider the time of his reaction in (1) instead of $\tau_{cd}$ . In the technical literature linear models of the human operator are well studied, and they can be submitted as a link of delay, which varies over time and generally can range from 0,15 to 0,25 s [3].

Note that last three terms of equation (1) are the information time-lag, which also depends on the structure and organization of data collection and computation. The same algorithm, organized in different ways, can cause different time delays in the system and lead to different measures of control quality.

**Models of data channels from UAV to the control device and from the control device to the UAV.** Transmission of information about the object to the controller occurs by the data channel, which we call the transmission channel of vector of state variables (CTVSV). For transfering control actions from the regulator to the control object the data channel is used , which we call the transmission channel of control actions (CTCA).

Call the transmission channel of vector of state variables in this case consists of data devices, and ancillary devices (transmission error correction devices and encoders). Call the transmission channel of control actions also consists of data devices and ancillary devices.

Basing on the results of work on the theory of digital transmission [4; 5], as well as of work on the digital transmission technique [5 – 7], and taking into account the fact that model of the control system is constructed considering the limited speed, memory and bit hardware, we can specify the following features of CTVSV and CTCA, which affect on the quantity of the information delay in communication links.

**Call the transmission channel of vector of state variables and call the transmission channel of control actions.** Call the transmission channel of vector of state variables transfers each element of the state vector **x[s]** in the form of $k_{\mathrm{CTVCSV},i}$ – bit binary code combinations, containing $k^{\mathrm{inf}}_{\mathrm{CTVCSV},i}$ informational and $k^{\mathrm{ver}}_{\mathrm{CTVCSV},i}$ checking bits, where $i = 1, ..., n$. Call the transmission channel of control actions, respectively, transfers elements of the vector control actions **u[s]** in the form of $k_{\mathrm{CTCA},j}$ – bit binary code combinations, containing $k^{\mathrm{inf}}_{\mathrm{CTCA},j}$ informational and $k^{\mathrm{ver}}_{\mathrm{CTCA},j}$ checking bits, where $j = 1, ..., r$. Both codes may be redundant (correction, they contain extra bits, the number of which is $k^{\mathrm{ver}}_{\mathrm{CTVSV},i} > 0$ for CTVSV and $k^{\mathrm{ver}}_{\mathrm{CTCA},j} > 0$ for CTCA) and non-redundant (primary, do not contain extra bits, $k^{\mathrm{ver}}_{\mathrm{CTVSV},i} = 0$ for CTVSV and $k^{\mathrm{ver}}_{\mathrm{CTVSV},j} = 0$ for CTCA). For the considered model (see figure) and metered parameters of technology (speed, memory, capacity) for CTVSV and CTCA it is important the maximum capacity in one cycle, the number of simultaneously transmitted bits.

**The transmission time of the state vector and the transmission time of control actions.** The transmission time of the state vector $\Delta_{vs}$ and the transmission time of control actions $\Delta_c$ depend on the way of the transfer organization.

In addition, the transfer time depends on the used methods of the accuracy of the information transfer (for example, the method of detection and correction by redundant codes, the method of repeated transfer of redundant or non-redundant code, transmission method with acknowledgment information, etc.). In general, the transfer time of the state vector $\Delta_{vs}$ can be represented by the following function

$$\Delta_{vs} = f_1\left(n, k^{\mathrm{inf}}_{\mathrm{CTVCSV},i}, k^{\mathrm{ver}}_{\mathrm{CTVCSV},i}, \rho_1\right),$$

where $n$ is the number of state variables, $k^{\mathrm{inf}}_{\mathrm{CTVCSV}}$, $k^{\mathrm{ver}}_{\mathrm{CTCA}}$ is the total amount of informational and checking bits in the state vector, $\rho_1$ is the number of repetitions of the transfer of the state vector.

The function of time transfer of control actions vector $\Delta_c$ has a form

$$\Delta_c = f_2\left(r, k^{\mathrm{inf}}_{\mathrm{CTCA}}, k^{\mathrm{ver}}_{\mathrm{CTCA}}, \rho_2\right),$$

where $r$ is the number of control actions, $k^{\mathrm{inf}}_{\mathrm{CTCA}}$, $k^{\mathrm{ver}}_{\mathrm{CTCA}}$ is the total amount of information and checking bits in the control actions vector, $\rho_2$ is the number of repetitions of the transfer of the control vector.

The time of transmission vectors depends on their dimension, the number of repetitions transmission, rate of information and verification (transmit redundancy) bits and their number, as well as the transmission pauses between reps (they depend on the speed and operation of the receiving and transmitting devices). In organizing the transfer with acknowledgment $\Delta_{\mathrm{vs}}$ and $\Delta_{\mathrm{c}}$ they will also depend on the speed of transmission of acknowledged signals and pauses between sending acknowledged signals and data bits.

Quantities $\Delta_{vs}$ and $\Delta_c$ may vary within a wide range (for example, if there are strong interferences in the communication channels, the number of repetitions of a particular program (as well as the total time) can be very large).

For the considered model (see figure) and metered parameters of hardware, speed of data transmission is important. Speed of CTVSV will be expressed in the number of delay cycles $\tau_{oc}$, and CTCA will be expressed in the number of cycles delay $\tau_{co}$.

If CTVSV has time to pass the required vector of state variables from the object to the controller at the same time, then $\tau_{oc} = 0$, otherwise the number of cycles of delay equals to the nearest maximum integer value of the ratio transmission time of the state vector $\Delta_{vs}$ to the sampling interval $\Delta t$

$$\tau_{oc} = \max\left\{\frac{\Delta_{vs}}{\Delta t}\right\}.$$

For CTCA $\tau_{co} = 0$, if it manages to pass the necessary vector of control inputs from the controller to the object at the same time, or the number of cycles of delay equals to the nearest maximum integer value of the ratio transmission time of control actions vector $\Delta_c$ to the sampling interval $\Delta t$.

$$\tau_{co} = \max\left\{\frac{\Delta_c}{\Delta t}\right\}.$$

**Delays of memory.** The amount of memory of CTVSV and CTCA, as well as their capacity, indirectly affects the speed of data transfer and depends mainly on the organization, location and data flow control.

Call the transmission channel of vector of state variables and CTCA transmit instantaneously variables of state and control actions, received in discrete time moments [5; 6].

**Features of calculation CTVSV and CTCA.** Listed features of CTVSV and CTCA must be taken into account while creating ARCS in the following way: there is a possibility to set the bit as the total number of data bits $k_{\text{CTVCSV}}^{\text{inf}}$ and $k_{\text{CTCA}}^{\text{inf}}$, the number of bits of numbers is represented in the software $k_n$, the number of repetitions of transmission $\rho_1$ and $\rho_2$, and also time of full transmission $\Delta_{vs,i}$ of one set of information and check bits, considering the amount of memory of CTVSV and CTCA, is arranged of the transmission and other channels features. Parameters "*n*" – the number of state variables, – and "*r*" – the number of control actions – are defined in the general formulation of the problem (in the formation of the ARCS). Thus, the total transmission time of the state vector is defined in a software system as

$$\Delta_{vs} = \Delta_{vs,i}\left(\frac{nk_n}{k_{\text{CTVCSV}}^{\text{inf}}}\right)\rho_1.$$

where the ratio $\left(\frac{nk_n}{k_{\text{CTVCSV}}^{\text{inf}}}\right)$ is calculated as the maximum integer number, and the total transmission time of control actions vector is defined as

$$\Delta_c = \Delta_{c,i}\left(\frac{rk_n}{k_{\text{CTCA}}^{\text{inf}}}\right)\rho_2.$$

where the ratio $\left(\frac{rk_n}{k_{\text{CTCA}}^{\text{inf}}}\right)$ is calculated as the maximum integer number.

As we can see from this study, only place of reducing delays, which are encountered in management channel, is an optimization of the computing device, computational resources on the development of control actions. Choosing the perfect technical base, faster computing facilities with more memory, more powerful communication channels will also cause a delays reduction, but will also more expensive.

**Conclusions.** From this study of the causes of the delays in the control circuit in UAV, we can select only one approach, which can reduce delays in the control circuit. This approach implies the search of the effective organization of information management and calculation algorithms, the synthesis of control systems, taking into account the information lag, and with the participation of the operator in the control circuit – the development and optimization of the training programs on management of UAV, in order to reduce the response time of the operator while performing tasks.

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**Оцінка затримок, що виникають під час керування дистанційного безпілотного літального апарату**

Розглянуто причини затримки у ланцюзі керування дистанційного безпілотного літального апарату. Обгрунтовано необхідність підвищення швидкодії ємності пам’яті цифрових елементів, що реалізують систему автономного пульта дистанційного керування.

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**Оценка задержек возникающих при управлении дистанционного беспилотного летательного аппарата**

Рассмотрены причины задержки в цепи управления дистанционного беспилотного летательного аппарата. Обоснована необходимость повышения быстродействия емкости памяти цифровых элементов реализующих систему автономного пульта дистанционного управления.