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Analysis of logic-time characteristics of subsystem supply functioning hardware elements of unmanned aerial vehicles

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Abstract. To obtain the logical and temporal characteristics of the model of control loop process variable, an analysis of the subsystem hardware of the autonomous unmanned object onboard control system was conducted. The problem of time delays in the information transmission from the primary converter to the control element in automated process control systems is considered as equivalent of the subsystem of the onboard control system of an autonomous unmanned object. At present, there are no methods for estimating the effect of time delays of an information signal on the response time of a control loop, which leads to inefficient use of system resources. The increased time interval between the change in the process variable and the control effect can also lead to negative consequences. Parametric identification of individual nodes with subsequent compilation of a closed loop model by a separate parameter is selected as a tool for system analysis.

1. Introduction
As an object of research, we will consider unmanned aircraft (UA) which belong to the class of autonomous unmanned objects for which it is critically important to evaluate the log-time characteristics of the hardware elements of the onboard control system (OCS) from the point of view of management and operation. During OCS operation process the probability of destabilizing influences occurrence is high (for example, a strong lateral wind or ascending induction currents). Late response of the automatic control system of OCS leads to a loss of stability and, as a consequence, a drop of OCS. Knowing the delays, occurring in the automatic stabilization control loop, it becomes possible to properly...
compensate, due to the formation of an advanced control action. During the determination of log-time characteristics, nodes and communication protocols are identified, creating the greatest delays in the passage of the signal which can cause emergency situations leading to negative consequences, such as: damage to equipment or damage to human health and the environment. [1] Often this is due to the late reaction of the on-board software (OBS) namely the software subsystem for the changes in the critical parameters. The reason for this is the lack of a methodology for analyzing log-time characteristics. The current level of development of technical systems makes it necessary to solve both theoretical and practical problems of identifying the state of individual elements of the system and channels of information transfer. However, when studying structurally complex objects it is not rational to analyze the entire volume of information about the system. At the current automation level, the amount of information about the system being studied is excessive, whereas in critical processes only a limited number of control loops participate. A systematic approach to the development of a mathematical model represents a unified approach to the description of the whole path of transformation and transmission of information, starting with the primary transducer, perceiving a continuous measured value, and ending with digital information processing devices and control devices [2]. To analyze rationally only the contours of automatic regulation of critical parameters Both at the design stage and in the existing OCS. The list of critical parameters is determined individually for considered process. Each loop of automatic regulation of the critical parameter is considered individually.

The characteristic features of the identification problem in this case are connected with the presence of feedback which establishes a causal relationship between the output of the object and the input control action on the object. The use of passive identification methods in these conditions without taking into account the influence of feedback leads to incorrect results or causes ambiguity in the solution of the identification problem, which in turn leads to the need of use a parametric identification algorithm that takes into account the influence of the feedback. [3].

2. Analysis of the structural diagram of the OCS subsystem
Let us introduce the concept of "Signal Flow Map" which means the complete path that will pass the signal formed by the primary converter.

Based on the structural scheme of the OCS subsystem (figure 1), we can divide the map of each signal into two parts:

- Regulatory map of signal passing (RMS) which includes devices and networks from the primary converter to the actuator, the passage of which leads to an increase in the response time of the control loop;
- Informative map of signal passing (IMS) which includes other devices and networks, intended for processing, storage, display and transmission of a signal, which do not affect the response time of the control loop [4].

![Controller level](image1.png)

**Figure 1.** General structural scheme of the OCS subsystem.
Based on this, the object for analyzing the log-time characteristic is a regulatory map of signal passing (RMS).

As a result of the RMS analysis we will get the following:

- The disadvantages of the loop automatic control of technological process are revealed on design stage (inadequate communication protocol, low-speed device, not optimized network configuration, etc.);
- To prevent possible emergencies, changes to the existing OCS subsystem have been made;
- Functional dependencies, between the admissible values of the critical parameters and the reaction time of the system which can be compensated by OCS subsystem without the occurrence of negative consequences, are defined.

The Composition of the RMS may be varied, and may include a different number of devices and networks.

According to the type of signal formation at the output of primary converters, it can be divided into two groups.

1. Converter without electronic digital nodes with continuous signal generation. Signal on its kind may be analog or discrete.

   \[ T_{pt.set} = 0 \text{ s}, \]

   where \( T_{pt.set} \) is a primary transducer output signal settling time, s.

2. Transducer with electronic-digital signal conditioning units. The signal at the output by genus can be either digital, or analog or discrete, but its change occurs with some delay, which occurs as a result of processing and forming a signal in the electronic unit:

   \[ T_{pt.set} = T_{ips} + T_{eb} \]

   where \( T_{ips} \) is transient process time of the sensor, s; \( T_{eb} \) – electronic block delay time, s.

   Electronic block delay time is determined by the formula (2)

   \[ T_{eb} = t_d + \tau, \]

   where \( t_d \) – damping time, s; \( \tau \) – sensor cycle time, s.

   Channel poll or output of information are produced one after the other. Thus, the signal delay time in DACS (\( T_{dacs} \)) will be determined by the formula (3):

   \[ T_{dacs} = N_{nch} \cdot T_{nch}, \]

   where \( N_{nch} \) – number of channels, psc; \( T_{nch} \) – one channel polling time, s.

   All channels are Sequential ed simultaneously, respectively \( T_{dacs} = T_{pol} \), where \( T_{pol} \) - channel polling time, s.

   All information on delays is available in the documentation for a particular device.

   The data exchange protocol can be divided into:

   1. Sequential type polling protocols Master/Slave. Sequential poll of slave devices is carried out by one master device (such as protocol Modbus). In protocols of this type, the main factor of the delay in the exchange of information is the number of connected slave devices.

   To calculate the delays that arise in the protocol of exchange, it is necessary to know:

   \( N_{dacs} \) – number of connected slaves, psc; \( T_{que} \) – query time, s; \( T_{sil} \) – pause time after the poll cycle, s; \( T_{dacs.res} \) – response time of the connected device, s; \( P_{coll} \) – collision probability.
2. Protocols with fixed time for information transfer. In protocols of this type the master device opens a "window" for receiving data. Reception time is strictly fixed. This protocol is applied to the real-time system. To calculate the delays in this type of protocol, it is necessary to know:

Tres – duration of information reception, s; P – priority of the signal under consideration; Tsil – time delay between the «windows» of receiving information, s.

The priority of the considered critical parameter is considered as the highest one, which ensures the priority transfer.

3. Protocols with equal participants in the network [5]. All devices on the network with this type of protocol have the right to initiate data transmission themselves.

If in the network all devices have equal priority, this will lead to constant collisions and loss of information, which is unacceptable for most automatic control systems.

When prioritizing, low priority devices can never transmit information due to a large information flow from devices with a higher priority.

3. Programmable logic controller (PLC)
Information processing time and signal issuance time for each controller are described in the technical documentation. However, it can vary depending on the law of regulation for the investigated parameter and the load on PLC at given time. Tplc – time of information processing and signal issuance, s.

4. Servo unit (SU)
Servo unit response time is the elapsed time since the appearance of the signal at its input, to the start of movement of the regulating body. Delays can be created by the electronic signal processing unit of the SU. Tsu – servo unit response time, s.

When analyzing each component which is part of the RMS, parameters can be added to the existing formulas that affect the passage of the signal. All information about the delays available at a particular node is described in the technical documentation for communication devices / protocols.

The reaction time of the control loop of the critical parameter is a variable value within the predicted range from Tmin to Tmax, where Tmin.

5. Calculating example of the RMS
For an example of a RMS calculation, let us take the air pressure control loop in a closed system.

Having distinguished the RMS from the general structural scheme, we will describe each of its elements.

We will define parameters for calculating the settling time of the output signal: Ttps – transient process time of the sensor, s; td – damping time, s; τ – sensor cycle time, s (channel update time), s.

Ttps for this data unit is 100 ms, parameter td set to 200 ms, the channel update time is 100 ms:

\[ T_{pt.set} = 100 + 200 + 100 = 400 \text{ ms} \]

Let us display on the timeline the cycle of operation of the primary converter (figure 2).

![Figure 2. Working cycle of intelligent pressure data unit.](image-url)
Device for communication with the object has 6 analog inputs. According to the wiring diagram, the primary converter is connected to the first channel: the channel poll method – sequential; the number of channels is 6, the channel polling rate is 100 ms/channel (Tnch = 100):

\[ T_{\text{sys}} = N_{\text{ch}} \times T_{\text{nch}} = 6 \times 100 = 600 \, \text{ms}. \]

Let us display received information graphically (figure 3).

![Figure 3. DACS working cycle.](image)

Based on the protocol documentation ModBUS RTU, as well as the parameters of the studied network, we will determine the quantities required for the calculation:

- Number of slaves connected to one network (since the poll is sequential) \( N_{\text{dacs}} = 3 \) psc;
- Query time, defined by protocol parameters \( T_{\text{que}} = 100 \, \text{ms} \);
- Response time of the connected device, is determined by the network settings (in Modbus protocols the average response time of the slaves is 0.25 s) \( T_{\text{ans}} = 200 \, \text{ms} \);
- Pause after polling cycle, is determined by the network settings \( T_{\text{sil}} = 100 \, \text{ms} \).

Let’s represent polling cycle of the slaves on the considered RMS timeline (figure 4).

![Figure 4. Polling cycle of the slaves.](image)

The processing time and the generation of the output signal time depend on software, which is entered / will be entered in PLC. Regulated cycle time of the program is within 0.05–0.15 s. If we make an analysis of the existing RMS, this parameter is a specific quantity and is known. In case of analysis of the projected OCS, for calculation accepted both the minimum and maximum values.

\[ T_{\text{cpu}_{\text{min}}} = 50 \, \text{ms}; \]
\[ T_{\text{cpu}_{\text{max}}} = 150 \, \text{ms}. \]

According to the wiring diagram, the actuator is connected to the second channel.
At the set data rate 9600 bod, read speed of registers is \( T_{\text{read}} = 100 \, \text{bd} \).
Also according to the specification, a pause of at least 40 ms before processing of the next command is required. \( T_{\text{pause}} = 40 \, \text{ms} \).

We represent cycle of output signals forming on the timeline. (figure 5).
Since SU takes a unified signal, in its composition an electronic unit is present, which includes ADC, normalizing processing unit, DAC, which imposes certain delay to the signal. $T_{\text{su min}} = 1 \text{ ms}$ and $T_{\text{su max}} = 10 \text{ ms}$.

However, in order to calculate, for example, limit value of the critical parameter, it is necessary to take into account the time of the full stroke of the output shaft, equal to 20 s.

6. Calculation of the maximum passing time of the signal on the regulatory map

Let us compile the graphs of the cycles of the maximum duration of operation of all devices and protocols of the RMS in question.

We will draw up the graphs of the cycles of the maximum uptime of all devices and protocols of the considered RMS (figure 6), shifting them relative to each other so that the signal delay at each node is maximal [6].

The order of the graphs is built according to the logic of the signal passage:
- Change in the value of the critical parameter;
- Cycle of operation of the primary converter;
- Working cycle of DACS1;
- Data transfer cycle for ModBUS RTU;
- Cycle of processing and forming of signal in PLC;
- Data transfer cycle for ModBUS RTU;
- Cycle of processing and transmission of a control signal to DACS3;
- Working cycle of servo unit;
- Change in the value of the critical parameter.
7. Analysis of the results
During this particular RMS analysis, the maximum reaction time of the system for the change in the critical parameter was calculated (4570 ms).

In order to understand whether this control loop meets the requirements, it is necessary to draw up a mathematical model of the emergency situation, at which the critical parameter will vary with the greatest possible speed. We take the reaction time of the system as the sum of the maximum time value and safety margin equal to 20%.

\[ \text{Trs.max} = 5484 \text{ ms}. \]

Example: due to the jamming of the ballast fittings, an uncontrolled pressure set in the system has begun (0.7 atm/s). Assignment value 5 atm (P_{initial}=5). The maximum allowable pressure in the system 12 atm (P_{max}=12). Based on the data, we get:

\[ \text{Trs} = \frac{(12-5)}{0.7}=10 \text{ s}. \]

Consequently, the reaction time of the system to change this parameter should not exceed 10 s, otherwise, the technological equipment will be destroyed.

From the inequality 5.484<10 we conclude, that the analyzed control loop of the critical parameter satisfies the requirements.

Let us consider the case when the analyzed RMS does not satisfy the safety conditions of the object. Suppose that an uncontrolled pressure set in the receiver occurs at a speed of 1 atm/s:

\[ \text{Trs} = \frac{(12-5)}{1}=7 \text{ s}; \]

5.484>7 s.

Analyzed control loop of the critical parameter does not satisfy the safety requirements.

8. Conclusion
In the present work the calculation of the reaction time of the control loop was carried out, as well as analysis of the regulatory map of signal passing for the presence of shortcomings and satisfaction of the conditions of stability (safety) under the given operating conditions. Based on obtained data, it was concluded that it is necessary to structure the loop control analyzing process by time delays and to obtain a technique for restructuring the automatic control loop in order to achieve the required reaction time of the system. The obtained evaluation of the logic-temporal characteristics of the model clearly demonstrates the existing inertia of interaction between the elements of the subsystem of the onboard control system of an autonomous unmanned object, the subject of interaction of which are signals and data. It should be noted that the analyzed model has a number of assumptions, because the physical elements of the model have specific overall-weight characteristics, however, on the whole, the model and the obtained logic-temporal characteristics do not negate the presence of inertia of interaction.

Thus, to assess the effect of subsystems and their hardware on the on-board software and hardware interfaces of the onboard control complex, there is a need to build models of autonomous unmanned object onboard control system subsystem, including unmanned aircrafts, taking into account overall-weight characteristics of its physical elements, followed by an evaluation of the logic-temporal characteristics, arises.

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