Application of computer simulation models in the study of the impact of data buffering on the quality of control in network systems

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Abstract. The work focuses on the computer simulation modeling of the control system with the network channel of information transmission. We have studied the impact of data buffering on the quality of control for the systems with a limited volume buffer for data packets. It has been expected that the data packet transmission over the network channel for the quantization period is carried out with a given probability. If the data packet from the digital sensor is not transmitted in one quantization tact to the controller, it is placed in the sensor buffer. During data is transmitted over the channel, all packets from the sensor buffer are transmitted to the controller buffer. The controller processes incoming data from the buffer sequentially—one packet per quantization tact. To simulate such situations, it was proposed to use the appropriate developed random processes. The novelty of the developed simulation model lies in the fact that in the basis for the development of this model is accepted the modeling of the time gap of the information flow of data. Simulation of the network control system operation was carried out in the environment Simulink of Matlab system.

1. Introduction

Modern industrial systems of automatic (ACS) are a complex hierarchical information structure that uses different means of data processing and different standards of data transmission. This is especially true for critical important objects [1]. Analysis of the functioning parameters of such systems and their calculation is represent a difficult task, as data transmission channels with random delays and queues are often used [2-6]. Digital networks act as such transmission channels. Such transmission channels got the name network channels, and systems - networked control systems (NCS) [7]. It is shown that random delays have a significant impact on the quality of regulation.

Simulation modeling is used to analyze the modes and quality of functioning of systems using stochastic data transmission channels [8]. This requires the use of methods and approaches, both control theory and communication theory. This fact significantly complicates the analysis, modeling and synthesis of such control systems [5, 9-11].

To match data rates in communication lines and smooth short-term overloads in data channels, buffer memory of network devices is used. Her size influences the number of lost packets on the
network. But it is also interesting the assessment of the impact of buffer size on the quality of regulation.

In works \cite{12, 13} the analysis of data transmission time in distributed networks with competing access to the network channel is conducted. The results of the performed analysis showed that the data transmission time can be satisfactorily described by the exponential distribution law. However, the question of influence of buffer volume has not been considered. An attempt is made to compensation for the loss of data packets at a limited volume of buffer by duplicating the data. Herewith the impact of buffer volume the quality of system management has not been considered.

The aim of this work is to develop of a simulation model that enable an analysis the process quality of control at different buffer sizes of the network device.

The novelty of the developed simulation model lies in the fact that the basis for the development of this model is accepted the modeling of the time of rupture of the information flow of data.

2. Methods

The modeling of the functioning of the network control system operation it was conducted in the environment Simulink of Matlab system. The developed scheme (figure 1) of the control system uses a network channel of data transmission between the sensor and the controller. In this case, network devices have buffer modules (sensor – output buffer, controller – input).

This system works as follows. The digital sensor reads the output signal of the regulation object \( y(t) \) at time \( t = kT_0 \), where \( T_0 \) is the quantization tact by the digital sensor of the regulation object output. If the channel is "open", the digital sensor immediately transmits the \( y(kT_0) \) data to the controller. If the channel is "closed", that is, data transmission on it is not possible during the quantization tact \( T_0 \), the data packet is placed in the buffer, if it is not filled, otherwise, the data are lost. Thus, if the channel will be "closed" for a long time during of several quantization tacts \( T_0 \), that in the buffer of the sensor the corresponding number of data packets will be located. We will assume that as soon as the network channel will be "open", i. e. data transmission over it becomes possible, and all data packets from the sensor buffer will be moved to the controller buffer. The controller sequentially

![Figure 1. Control system with network communication channel and buffers for data packet: \( u(t) \) - regulating impact on the object of regulation, \( y(t) \) - output signal of the control object, \( y_k \) - data from the sensor, \( r_k \) - setting impact, \( u_k \) - control action on the execution device.](image_url)
processes the data from the sensor: at the time of \( t = kT_0 \), only one data packet is processed, which came first, the rest are in the queue. The volume of the sensor and controller buffers is considered to be limited and same in volume. It is assumed that the sensor and the controller work synchronously: quantization of the sensor and the controller is carried out with the same quantization tact \( T_0 \) and at same point in the time of \( t = kT_0 \).

The controller produces a control action \( u(kT_0) \) according to a certain law, taking into account of set impact \( r(kT_0) \) and the data obtained from the sensor \( y(kT_0) \). The control action \( u(kT_0) \) is transmitted on the execution device at times \( t = kT_0 \). The regulating impact on the object of regulation \( u(t) \) is realized by executive device. In the future, discrete variables such as \( y(kT_0), u(kT_0), r(kT_0) \) and others will be represented as: \( y_k, u_k, r_k \) to simplify the recording. It is assumed that the characteristics of the digital sensor and executive device do not effect on the regulation process of system. Therefore, accept that the digital sensor and executive device correspond to non-inertial elements with a one gain coefficient.

![Scheme of simulation model of control system with limited volume buffers for data packets.](image)

**Figure 2.** Scheme of simulation model of control system with limited volume buffers for data packets.

A direct current motor (servo drive) was chosen as the object of regulation. A discrete proportional-integral-differential regulator (PID-regulator) is used as a controller. The block diagram of the simulation model presented in figure 2 includes a number of modules and is described by equations (1)-(4). On this scheme provides modules.
1. Formation of a discrete random process $\xi_k$ of "closing-opening" of a network channel:

$$
\xi_k = \xi(kT_0) = \begin{cases} 
1, & \text{channel closed - probability } p; \\
0, & \text{channel open - probability } q = 1 - p. 
\end{cases}
$$

(1)

With this purpose, the block of formation of a random number having a uniform distribution is used. The probability is set by setting the appropriate value in the controlled switch “Switch”.

2. Formation of the numerical value of the closing time of the transmission channel in quantization tacts. With this purpose, a discrete random process is formed:

$$
\varepsilon_{k+1} = (\varepsilon_k + 1) \cdot \xi_k;
$$

(2)

where $\varepsilon_k$ is the number of serial quantization tacts of the "closure" of the network channel at the time $t = kT_0$.

An integrating block is used to implement this random process. So far $\xi_k = 1$, the output of the integrator increases, if $\xi_k = 0$, then the output of the integrator is reset. The condition of such transition is set in the controlled switch “Switch”.

3. The formation of a discrete random process:

$$
\varepsilon_k^{\max} = \varepsilon_k \cdot \left[ \varepsilon_k - N \right] + N \cdot (1 - \left[ \varepsilon_k - N \right]);
$$

(3)

where $\varepsilon_k$ is the value of the "closing" time of the network channel in the quantization tacts at the time $t = kT_0$; $\left[ \varepsilon_k - N \right]$ – function (value 1 if $\varepsilon_k \geq N$, otherwise 0). The value of this random process is not less than N. The “MinMax” block is used to implement this random process.

4. The formation of the time of information flow gap in the quantization tacts. With this purpose, a discrete random process is formed:

$$
\zeta_k^p = \varepsilon_k^{\max} - N.
$$

(4)

If there is absent rupture of information flow, the value is $\zeta_k^p = 0$.

At the moment when there is a rupture of the information flow, the value $\zeta_k^p$ begins to increase. The numerical value $\zeta_k^p$ is equal to the rupture time of the information flow in quantization tacts.

5. The formation of the constant time delay in the feedback circuit $\tau_N = NT_0$ is implemented using block “Transport Delay”.

6. The formation of the time of information flow gap. With this purpose, the “Enabled Subsystem” and “Variable Time Delay” blocks are used. If the "closing" time of the network channel in the control system exceeds the delay time $\tau_N = NT_0$, for example, on m the tacts $T_0$, there is a gap of the information flow. In this case, the “Enabled Subsystem” block receives a signal to pass a signal through it to the “Variable Time Delay” block. The delay time on this block is increased to the value $\tau_m = mT_0$. After the delay time $\tau_m$ is set, the “Enabled Subsystem” block is closed, the signal at its output corresponds to the value of this delay, and on the input - to the zero value. The interval of the time of setting this value on this block corresponds to the time of information flow gap. During this period of time, on the block the “Transport Delay” was received a signal having a value until moment the delay change. In order to correctly simulate the effect of the information flow gap, the delay time $\tau_m = mT_0$ in the “Variable Time Delay” block must be during the time $t = NT_0$. During this time, all "old packages" must to leave a buffer of the regulator. They will have a lag the time $\tau = (N + m)T_0$. After that, the delay time in the “Variable Time Delay” block is reset and the system goes by jump to...
work with the delay \( \tau_N = N\tau_0 \). In this case, part of the data is lost. To simulate this sequence of actions, the scheme uses “Transport Delay 2” and “Variable Time Delay 2” blocks. The actions of these blocks correspond to the actions of the corresponding “Transport Delay” and “Variable Time Delay” blocks. As a result, non-zero signal from the output of the “Enabled Subsystem block” will enter its control input via \( t = (N + m)\tau_0 \). This will reset the delay time in the “Variable Time Delay” and “Variable Time Delay 2” blocks. And the system will continue to work with the delay \( \tau_N = N\tau_0 \).

3. Research results

Numerical results are presented as a graphs of transitional process (figure 3, 5) and graphs of information about the operation of system (figure 4, 6) (the state of the channel, the number of packets in the buffers of the sensor and the controller and the presence of a gap in the information flow). Here: \( P \) – the probability of «closure» of the channel; \( T_0 \) is the tact of quantization; \( N \) is the buffer volume.

Analysis of the transition process when the buffer size is 5 packets (figure 3) shows that the control system with these parameters is sustainable, although the time of the transitional process insufficiently large - more than 1 sec. Reregulation is more than 60 %.

The figure 4 shows the time when the channel is "closed" - signal value "1", and when the channel is "open" - signal value "0". The "closing" time of the channel is shown by the number of quantization tacs. In case of exceeding the number of data packets in the controller buffer, there is a gap of the information flow. Herewith the data packets from the digital sensor are lost. On figure 4 shows the time rupture of information flow in the quantization tacs. Rupture the information flow leads to an increase in the delay time in the control system by the amount of rupture time of the information flow. However, the delay time in the networking system of control does not exceed the value of \( \tau_N = N\tau_0 \).

There are cases when the buffer overflows for data packets (figure 4). In this case, there is a loss of data packets which come from the digital sensor. These losses are accompanied by a gap of the information flow.

![Figure 3. The transition process: probability of «closure» of the channel \( P=0.6 \); tact of quantization \( T_0=0.01 \); buffer volume \( N=5 \).](image-url)
Figure 4. Information about the operation of system: probability of «closure» of the channel \( P = 0.6 \); tact of quantization \( T_0 = 0.01 \); buffer volume \( N = 5 \).

Analysis of the transitional process at the buffer size is 3 packets (figure 5) shows that as the buffer volume decreases, the control system remains stable. At the same time, the time of the transitional process is significantly decreases and is approximately 0.5 seconds. However, it should be noted that the transitional process still has a rather large reregulation – about 35 %.

In general, it should be noted that the decrease in the buffer volume has led to an improvement in the quality of the transitional process of the network system of control - the regulation time has decreased and the reregulation of the transitional process has decreased.

In this there are noted cases when the buffer overflows for data packets (figure 6). In this case, there is a loss of data packets which come from the digital sensor. These losses are also accompanied by gap of the information flow. During the time of transitional process, there were two rupture of the information flow – as with the buffer size a volume of 5 data packets. However, the second gap of the information flow in this case is longer lasting.
4. Conclusion
The developed simulation model allows conduct an analysis the quality of regulation of the regulator which use network stochastic data channels and to evaluate the impact of the size of the buffer device on the quality of transients in automatic control systems. On the example shows that increasing the buffer size does not always increase the quality of management.

The developed simulation model is differed by the fact that the basis for the development of this model is based on the simulation of the time of rupture of the information flow of data.

In comparison with the known approaches of mathematical modeling of network systems of control [14], the obtained model allows us to research a wider class of such systems - systems whose elements possess the buffers for storing data packets.

The practical value of the developed simulation model is that it can be used in the design of new network systems of control, as well as and when the modernization of systems, already used in practice.
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