Improving the management quality of the process control in the food and agricultural industries

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Abstract. The work focuses on analyzing the modern process control systems in the food and agricultural industries for improving management quality. Computer simulation of the control systems with a network channel for transmitting information was carried out for various volumes of data buffers for system elements. The subject of the investigation is to study the effect of data buffering on the quality of process control for systems with a limited buffer volume for data packets. It is assumed that the transmission of a data packet over a network channel during the quantization period is carried out with a given probability. If the data packet from the digital sensor is not transmitted in one quantization cycle to the controller, then it is placed in the sensor buffer. When data is transmitted over the channel, all packets from the sensor buffer are transferred to the controller buffer. The controller processes the incoming data from the buffer sequentially – one packet per quantization cycle. For simulate such situations, it was proposed to use the corresponding developed random processes. The innovation of the developed simulation models is in the fact that the development of the simulation models is based on modelling the time gap of the information data stream. Modelling the functioning of the network control system was carried out in the Simulink environment of the Matlab system.

1. Introduction

The development of technologies in the food and agricultural industries is in the field of knowledge of industrial engineering, which is the tool for creating innovative technologies. The introduction of the innovation involves the implementation of the pairing of equipment, regulatory, measuring, information systems, by eliminating technical contradictions between the functioning and control of the process flow [1]. For measure the parameters of technological processes, it is recommended to use integrated sensors [2]. They adapt well with modern microcontrollers and allow using the digital networks for data transfer. Such data transmission channels have many features – random delays and queues [3-8]. Such transmission channels are called network channels, and systems are called Networked Control System (NCS) [9, 10]. It is shown that random delays have a significant impact on the quality of process control [9, 10].

Simulation modelling is used for analyzing the modes and quality of control in systems using stochastic data transmission channels. This circumstance requires the use of methods and approaches, both control theory and communication theory. This fact significantly complicates the analysis, modelling and synthesis of such control systems [7, 11-13].
To coordinate data transfer rates in communication lines and smooth out short-term overloads in data transfer channels, buffer memory of network devices is used. And its size influences the number of lost packets on the network. But it is also engaging the assessment of the impact of buffer size on the quality of regulation.

In [14, 15], the analysis of data transmission time in distributed networks with competing for access to the network channel was performed. The results of the analysis showed that the exponential distribution law could satisfactorily describe the data transmission time. In [14, 15], an attempt is made to compensate for the loss of data packets with a limited buffer volume by duplicating data. However, the influence of the buffer volume on the quality of control of the system has not been considered.

This work is aimed to analyze the influence of the volume of the data packet buffer on the quality of process control. For achieving this goal, simulation models have been developed that allow analyzing the control quality process for various sizes of network device buffers.

The innovation of the developed simulation models is in the fact that the development of the simulation models is based on modelling the time gap of the information data stream.

2. Methods
Modelling the functioning of the network control system was carried out in the Simulink environment of the Matlab system. The developed scheme of the control system uses a network data channel between the sensor and the controller. At the same time, network devices can have buffer modules (sensor – output buffer, controller – input).

This system works as follows. The digital sensor reads the output signal of the regulatory object at the moments of quantization of the output of the regulatory object. If the channel is "open," then the digital sensor immediately transfers the scan data to the controller. If the channel is "closed," i.e., the data transmission is not possible during the quantization cycle \( T_0 \), then the data packet is placed in the buffer (if any) if it is not filled. Otherwise, the data is lost. Thus, if the channel is "closed" for a long time, for several quantizations steps \( T_0 \), then in the buffer (if any) of the sensor there be an appropriate number of data packets. It is assumed that as soon as the network channel is "open," i.e., data transmission through it become possible, all data packets from the sensor buffer be moved to the controller buffer.

The controller sequentially processes the incoming data from the sensor: at time \( t = kT_0 \) only one data packet is processed, which arrived first, the rest are in the queue. The volume of the sensor and controller buffers are considered limited and the same in volume. It is assumed that the sensor and controller operate synchronously: the sensor and controller are quantized with the same quantization cycle \( T_0 \) and at the same time \( t = kT_0 \). The controller produces a regulatory effect according to a specific law. The regulatory action from the controller is transmitted to the actuator at time \( t = kT_0 \).

It is assumed that the characteristics of the digital sensor and actuator do not influence the process of regulating the system. Therefore, we assume that the digital sensor and actuator correspond to inertia fewer elements with a unity gain.

A direct current motor (servo drive) is selected as the object of regulation. A discrete proportional-integral-differential regulator (PID-regulator) is used as a controller.

As an example, Figure 1 shows a simulation scheme for modelling a system without the buffer elements for data packets.

The simulation of the network control system (Fig. 1) was carried out under the assumption that the data packets in the system are not lost, except for the case of artificially organized losses. There are no buffers for the data packets in the discrete controller and digital sensor.
The mode of operation of this system can be described as follows:

1. If the channel "closing" time does not exceed the quantization cycle $T_0$, then the data from the digital sensor is transferred to a discrete controller and is taken into account when generating the regulatory action.

2. If the channel "closing" time exceeds the quantization cycle $T_0$, the data from the digital sensor be lost, and the previous data from the digital sensor be used for generating a regulatory action in the discrete controller.

The modules are provided on this scheme:

1. the formation of a discrete random process $\xi_k$ "closing-opening" of the network channel;
   $$\xi_k = \xi(kT_0) = \begin{cases} 1, & \text{channel closed} \quad \text{probability} p; \\ 0, & \text{channel open} \quad \text{probability} q = 1 - p. \end{cases}$$
   For this purpose, a random number generating unit having a proportional distribution is used. The probability of $p$ is defined by setting the corresponding value in the controlled switch Switch.

2. To implement the operation of "closing-opening" the channel, the Interval Test and Enabled Subsystem 1 blocks are used.

   The Interval Test block is used for generating the control signal “1” to the Enabled Subsystem 1 block when the signal is “0” at the output of the Switch block.

   When the channel is “closed”, the Enabled Subsystem 1 block saves the previous signal at its output.

**Figure 1.** Scheme of a simulation model of a control system without a buffer for data packets
3. Results
The numerical results of the study are presented in the form of graphs of transients of the network control system (Figures 2 - 4).

Here: $P$ is the probability of channel “closure”; $T_0$ - quantization cycle, s; $N$ - buffer volume, pcs.

Figure 2 shows a comparison; the transients of the control system at $P = 0.2$. Figure 2a shows that the system has a buffer for data packets with a capacity of $N = 1$. Figure 2b shows that the system has a buffer for data packets with a capacity of $N = 0$. As can be seen from the graphs presented, even with a relatively small probability of channel "closure", the presence, though it is small, of the buffer volume for data packets leads to a slight deterioration in the quality of the transient control process: the transient process time increases from 0.1 to 0.2 s.

![Graph a) N=1](image1)

![Graph b) N=0](image2)

**Figure 2.** Transient process: $P = 0.2$; $T_0 = 0.01$s

Figure 3 shows, in comparison, the transients of the control system at $P = 0.4$. Figure 3a shows that the system has a buffer for data packets with a capacity of $N = 3$. Figure 3b shows that the system has...
a buffer for data packets with a capacity of \( N = 0 \). From the graphs presented, it can be seen that if there are buffers in the elements of the system, the quality of control is unsatisfactory: overshoot increases from 0 to 37%; transient time increases from 0.1 to 0.5 s; there is a significant oscillation of the transition process.

\[ a) \ N=3 \]

\[ b) \ N=0 \]

**Figure 3.** Transient process: \( P = 0.4; \ T_0 = 0.01 \ s \)

Figure 4 shows, in comparison, the transients of the control system at \( P = 0.6 \). Figure 4a shows the system has a buffer for data packets with a capacity of \( N = 5 \); Figure 4b shows the system has a buffer for data packets with a capacity of \( N = 0 \). From the graphs presented, it can be seen that if there are buffers in the elements of the system, the control quality is even more unsatisfactory: overshoot increases from 5 to 75%; transient time increases from 0.2 to more than 1 s; a transient oscillation arises close to the self-oscillating regime.
Figure 4. Transient process: $P = 0.6$; $T_0 = 0.01$ s

Figure 5 shows the transient process of the network control system at $P = 0.9$ and $N = 0$. Figure 5a is a transient process in the time interval of up to 1 s, and Figure 5b - in the time interval of up to 10 s. From the analysis of the transient in Figure 5a, we can conclude that the control system, although it does not have satisfactory quality indicators, is stable. However, an analysis of the transition process of this system over a more extended period (Figure 5 b) shows that the quality of control of such a system is unsatisfactory.
3. a) N=0.

3. b) N=0

Figure 5. Transient process: P = 0.9; T_o = 0.01 s

4. Conclusion
The developed simulation models allow analyzing the quality of control systems using network stochastic data transmission channels, such as digital networks, and to assess the impact of the size of the buffer device on the quality of transients. The examples considered show that a network control system without a buffer device with small probabilities of channel "closure" provides the best quality of the transition process. However, with an increase in the probability of channel "closure", the control system without a buffer device may lose stability.

The developed simulation models are distinguished by the fact that the basis of their development is the modelling of the time gap of the information data stream. Compared with the well-known approaches of mathematical modelling of network control systems [16], the obtained models allow studying a broader class of such systems – systems whose elements have buffers for storing data packets.
The practical value of the developed simulation models is that they can be used in the design of new network control systems, as well as in the modernization of systems that are already used in practice.

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