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Short communication

Modeling of data acquisition systems using the queueing theory

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ABSTRACT

This paper describes the features of a data acquisition system modeling based on queueing theory method. The main elements of the studied data acquisition system structure are sample hold amplifiers and dual-slope analogue digital converters. In case of the threshold control of technological facilities parameters, alarm signals in the system input are presented as a flow of customers with the Poisson intensity distribution. A converting time of these alarms in analogue digital converters depends on signal levels and is described by an exponential distribution. In this case we present the data acquisition system as the Markov model of the multichannel queueing system with a limited queue. This modeling method may help the data acquisition system structure to adapt to characteristics of input signals and features of communication lines in an output of system.

1. Introduction

The continually growing flow of information provided by systems that are used to control technological processes, monitor environmental conditions, test industrial facilities and support scientific research presents increasing challenges in terms of equipment and maintenance costs, as well as timing of information delivery [9,14]. Data acquisition systems (DAS), comprising a set of hardware for sampling, conversion, storage and primary processing of input analogue signals received from sensors installed, for example, at industrial facilities, offer an approach towards the optimisation of information flows [19,20]. Enhanced efficiency of information processing can be achieved by data compression given an accurate DAS functional model. This model is to be based on a detailed analysis of input information and should take into account required output indices and DAS configuration features. DAS input is connected to measuring channels, including sensors, DAS output is connected to communication channels via discrete switch.

Initial attempts to compress data files involved an identification of redundant information by adaptive signal sampling over time intervals [10]. Taking this approach, the selection of the most informative signal samples can be performed provided the approximation error reaches a threshold value. However, the elimination of redundant samples leads to nonuniform sampling intervals and, therefore, to nonuniform communication channels. Moreover, such data compression can only be realised by a DAS equipped with a sensor activity analyser. It is obvious that the DAS structure becomes too involved, since each sensor needs its own analogue digital converter (ADC).

A method for the adaptive commutation of signal sources was developed by Takayama and Kariya [16]. According to this approach, a converter receives a signal only from that sensor whose current approximation error is maximal during sampling. For this method to be implemented, one ADC per all sensors is generally sufficient. However, this approach has a number of disadvantages. Firstly, the system efficiency is largely dependent on how accurately the approximation error for the signal functions in each channel is calculated. Secondly, the ordinariness requirement is violated when the sampling frequency is reduced. Finally, the communication channel is loaded nonuniformly at the exit from the DAS.

This paper proposes a DAS model having an optimal amount of structural elements based on queuing theory. The flow of customers in the queuing system is represented by the signals from those controlled parameters that cross a threshold level. We introduce a Markov model of DAS based on a multichannel queuing system [3,15]. In this model, ADCs represent service centres and

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sample hold amplifiers (SHA) represent queuing nodes. We suggest using a dual-slope integrating ADC, whose reliable qualities are described in Ref. [7]. The optimal number of DAS elements is calculated taking capacity requirements and queuing time into account [2,4]. The model provides a sufficiently high compression of the input information avoiding significant hardware costs.

2. Description of DAS modeling method

The purpose of this chapter is to describe a sequence of DAS modeling using queuing theory. Proposed DAS is intended to process telemetry alarms in industrial sensor networks. Such signals u_i are generated in random moments when controlled parameter x crosses a threshold level x_{Π} (Fig. 1).

Alarm signals, transmitted by sensors of facilities to DAS in random moments, are presented as a queue [11]. Customer service is performed as analogue digital conversion [5]. This modeling method was selected in order to determine analytical dependence of technical parameters of DAS elements and queuing system indicators. Modeling results allow optimizing amount of structural elements that provides harmonizing output indexes of system and capacity requirements of communication channels.

Dual-slope integrating ADCs are mostly used in telemetry because of their accuracy and stability [12].

The elements of dual-slope ADC in classical scheme can be distributed in two DAS subsystems: capacitor C, operational amplifier and key belong to SHA subsystem, the other elements, including comparator zero (SZ), belong to ADC subsystem (Fig. 2).

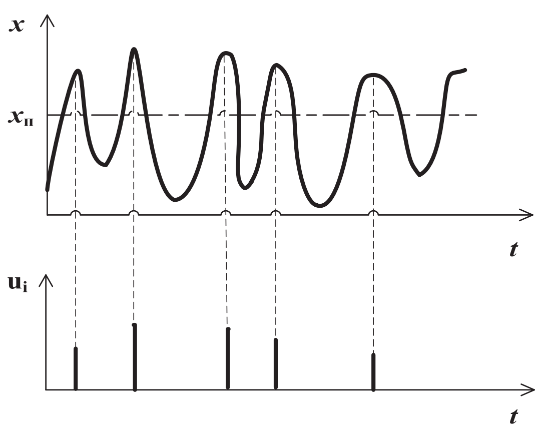

Fig. 1. Alarm forming in DAS input.

Analog switch (AS-1) provides connection of sensors with output voltage U_x (threshold amplitude) to free SHA. Capacitor of this SHA charges during fixed for all sensors time t_1, connecting to level comparator. Analog switch AS-2 connects output of SHA with charged capacitor to input of SZ of free converter with simultaneous connection of the second SHA input to common negative reference voltage source $-U_{dis}$. In the phase of the capacitor discharge count pulses are formed with a constant speed during the time t_{dis} in the amount, proportional to the input voltage.

Operation of switches can be controlled by Field-Programmable Gate Array (FPGA).

Here GCP is the generator of the counting pulses, DS is the discrete switch.SHA can have several modes according to a voltage in the capacitor:

1) without voltage
2) capacitor charge by the input signal voltage
3) standby mode (voltage storage)
4) capacitor discharge by free ADC.

Distribution of functions of SHA and ADC provides fast process of the signal without overcomplicating DAS structure.

Main idea is to model DAS as the queuing system with n measuring channels represented by ADCs and the queue limited by m SHAs [6]. The service time t_{serv} corresponds to the time of capacitor discharge t_{dis}. As reported previously, the time t_{dis} of telemetry alarm signals is proportional to amplitude of threshold level of controlled parameters and has exponential Poisson distribution. Therefore, DAS is classified as a classical M/M/n/m Markov model [8,22].

A failure probability of customer service is determined if all n ADCs and m SHAs are occupied [1,17]:

$$p_{n+m} = \left[\left(\frac{\lambda}{\mu}\right)^{n+m} / n^m n!\right] p_0, \tag{1}$$

where λ is the average arrival rate; $\mu = 1/\bar{t}_{dis}$ is the average service rate of a single service; $\bar{t}_{dis}$ is the average time of capacitor discharge by free ADC;

$$p_0 = \left(\sum_{j=0}^{n} \frac{\lambda^j}{\mu^j j!} + \frac{(\lambda/\mu)^{n+1}}{n \cdot n!} \cdot \frac{[1-(\lambda/\mu n)^m]}{(1-\lambda/\mu n)}\right)^{-1} \tag{2}$$

is the probability that the server is idle.

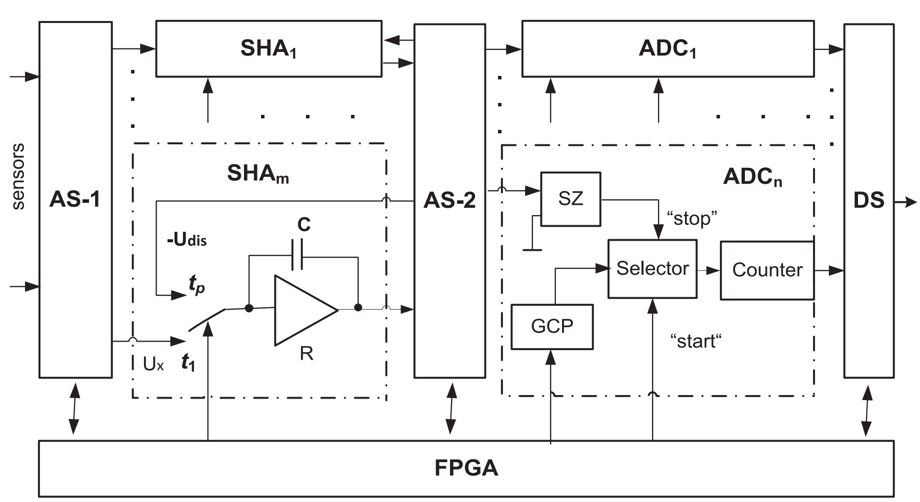

Fig. 2. Decomposition of dual-slope ADC scheme in multichannel DAS structure.