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Development of Models and Algorithms for Studying Multi-Dimensional Systems with Latitude-Impulse Modulation

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Abstract. The paper deals with the development of mathematical models and algorithms for studying the dynamic characteristics of multidimensional discrete control systems with pulse-width modulation. The analysis of the existing methods for solving the problem has been carried out, as a result of which the paper proposes to consider the dynamics of a discrete system in the class of a system with a dynamic structure, which allows partitioning the dynamics of the system into linear sections based on the physical features of the operating modes of modulators with nonlinear modulation characteristics. The selection of a set of structural states in accordance with the moments of closure of transmission channels makes it possible to represent the original -dimensional nonlinear pulse-width system (PWS) in the form of a set of linear subsystems interacting with each other. In this case, the nonlinearity of the original system manifests itself through the time of pulse fixation determined according to the nonlinear law within each of the structural states. The proposed technique is distinguished by its simple implementation in the tasks of controlling technological processes using microcontrollers to identify and take into account the peculiarities of the control process in real objects.

INTRODUCTION

Pulse width modulator (PWM) systems are highly nonlinear systems. The use of these methods often leads to systems of partial differential equations or algebraic transcendental equations, the exact solution of which is impossible: if certain calculations are incorrect, there may not be a solution in principle; the use of numerical methods of solution with a large dimensionality of the resulting system, even when using the capabilities of modern computers, can give an absolutely unacceptable result.The known methods for analyzing the dynamics of this class of systems can be classified as methods using various recurrent procedures [1,2], methods based on the concept of the phase plane [3] and summary equations [4].

Despite the rich and long history of the issue, today there are vast subsets of systems that are either not covered by the known approaches or encounter fundamental difficulties when trying to study them. First of all, it should be noted such complex subclasses of systems as systems with non-standard modes of operation of latitude modulators.

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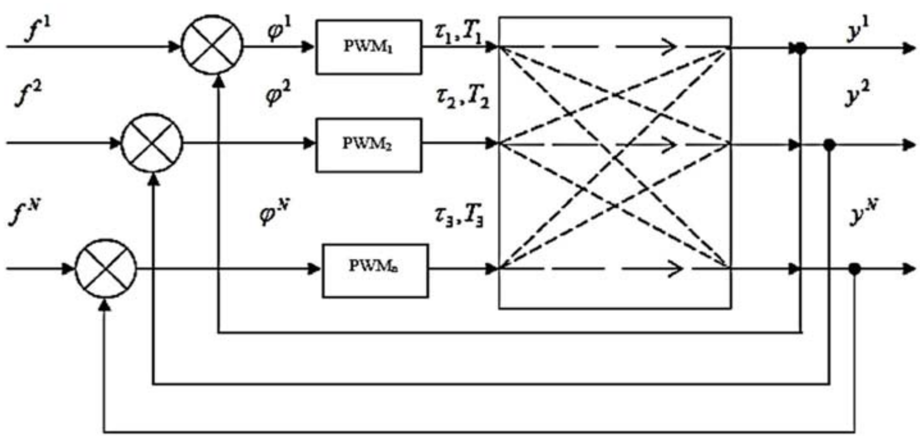
FORMATION OF THE PROBLEM

In multidimensional systems with autonomous modulators, the repetition periods of impulse elements can be very different. If we take into account that, in this case, the pulse durations at each of the variable intervals for each channel are determined depending on various nonlinear modulation characteristics, then the sources of difficulties in modeling such modes of operation of the pulse parts become clear. The considered circuit with pulse width modulation (PWM) (Figure 1a) consists of pulse width modulators (PWM) and a continuous linear part (LFC). The duration of the n -th pulse at the output of each modulator $PWM_i,\ i = 1,\ 2,...,\ N$ determined by the value of the error signal $e(nT_i)$, calculated at discrete times, i.e.

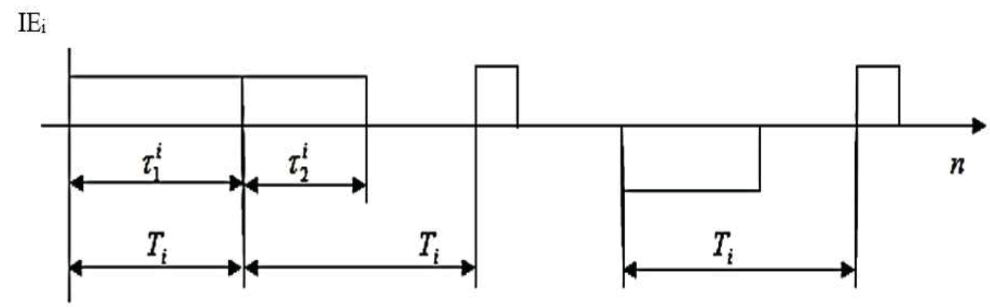
$$\tau_n^l = \begin{cases} \varphi^l\left[e(nT_l)\right] \, at \; \varphi^l\left[e(nT_l)\right] \le T_l, \\ T \qquad\qquad at \; \varphi^l\left[e(nT_l)\right] > T_{l,} \end{cases} \tag{1}$$

where T_l - output pulse repetition period PWM_l;

φ_l - PWM modulation response.



(a)



(b)

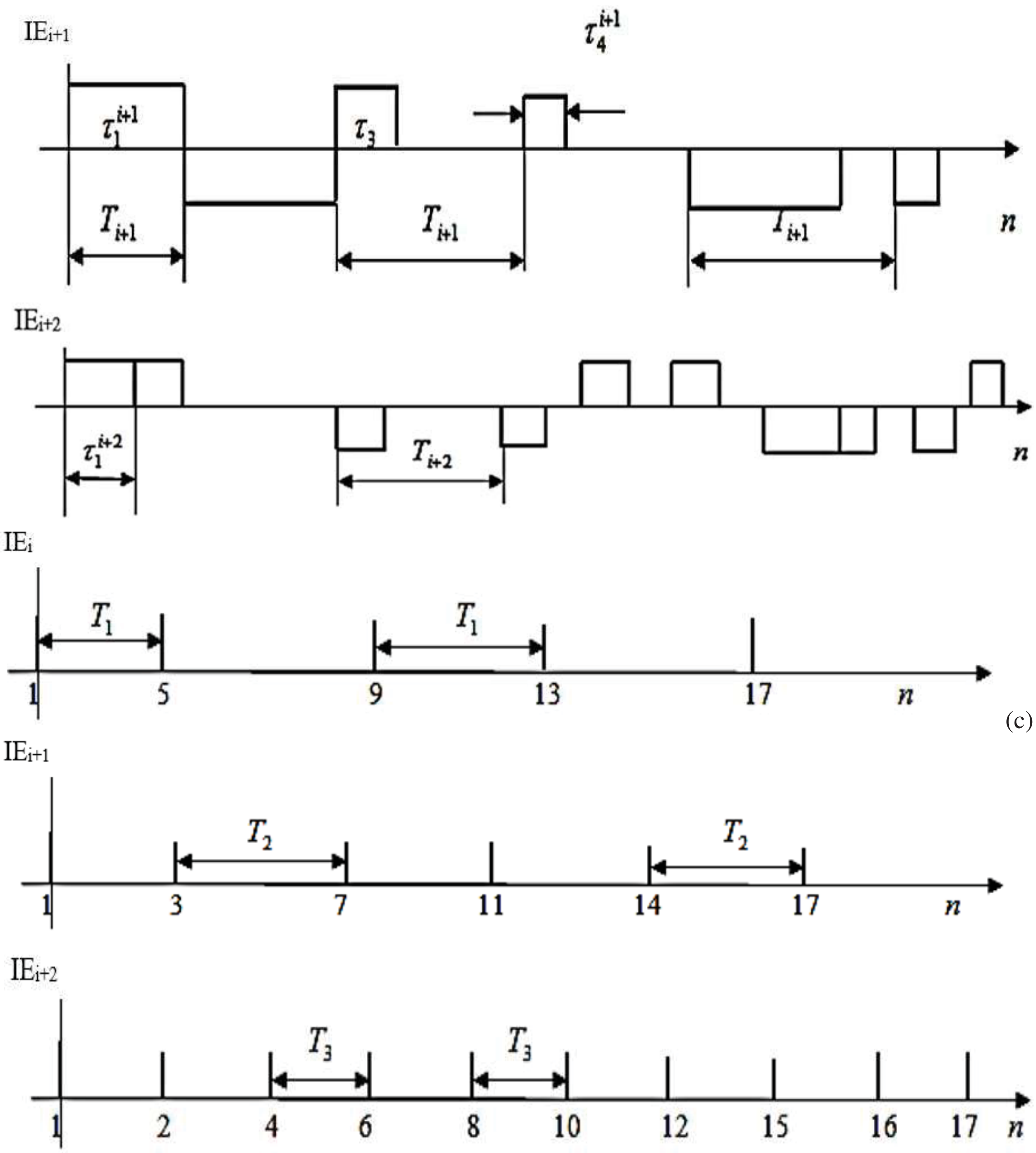


FIGURE 1. Block diagram and timing diagrams ShIS modulators

The physics of the system shows that it is closed only at moments of time $n1_i$ $n=1,2,3\ldots$. The rest of the time the circuit is open, and the process at its output can be defined as the sum of reactions caused by rectangular pulses of different durations and signs when they act on the linear continuous part.

The nonlinearity of the system is manifested in the fact that at the beginning of each interval with duration T_i the width of the pulses and their sign are determined in accordance with the modulation characteristic $\varphi^i, i=1,2,\ldots,N$ (figure 1 b,c).

Non-linearity and non-stationarity with such a representation scheme of the SIS are due to the fact that the forming links are described by non-stationary non-linear transfer functions of the form

$$\tilde{W}_i(p) = \frac{1 - e^{-p\frac{i}{n}}}{p}, \tag{2}$$

where τ_n^i - determined according to the non-linear modulation characteristic φ^j, nonstationarity $W_i(p)$ caused by the variability of the pulse duration, which in turn leads to variability of the parameters of the reduced continuous part of the system as a whole (figure 2). Note that, despite the nonlinearity and nonstationarity of PNP, within the framework of the selected structural states, it is linear and stationary. [5]. Selecting a set of structural states in accordance with the moments of closure of transmission channels allows us to represent the initial N - dimensional nonlinear ShIS in the form of a set of linear subsystems interacting with each other.

In this case, the nonlinearity of the original system manifests itself through the time of pulse fixation determined according to the nonlinear law within each of the structural states

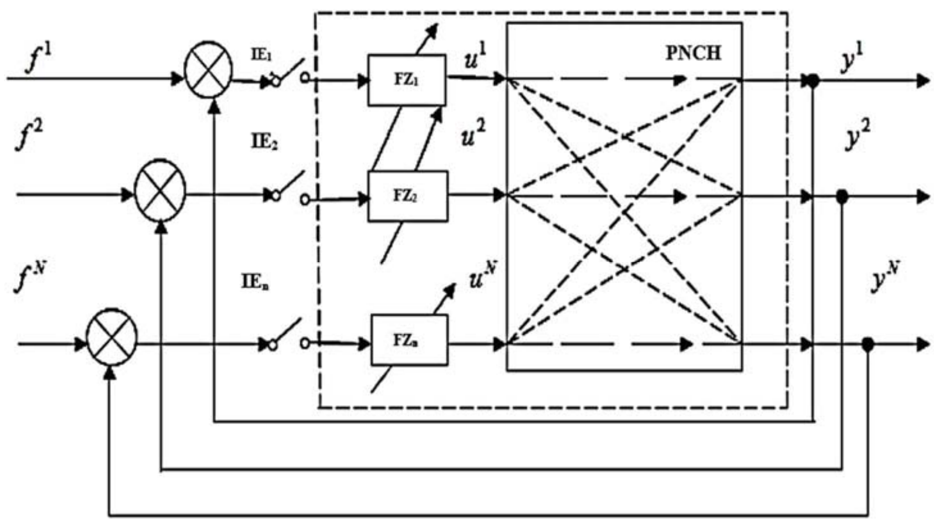


FIGURE 2. Equivalent circuit.

Identifying errors $e^i(jT^+)$ in a multidimensional SIS occurs as a result of comparing the input and output signals calculated at the moments in jT, preceding the moment of closure.

Forming links, where SIS in the interval greater than the closure period $T_i, i = 1, 2, \ldots, N$ should be classified as non-linear non-stationary links with transfer functions

$$\tilde{W}_i(p) = \frac{1 - e^{-p\frac{i}{n}}}{p}.$$

However, when considering the SIS as an SDS with a decomposition into separate structural states of the model of the forming links in the redistribution $jT < t < (\overline{j + 1T})$ are built from the simplest models using gears

$$\frac{1}{p}, \frac{B_i}{\left|e^i(jT_i^+)\right|}$$

Arcs take into account the effect of fixation and the form of the amplitude characteristic of the pulse-width element. Non-linearity is taken into account when determining τ_j^i at the moment of closure jT_i^+ according to non-linear modulation characteristic φ^j, and nonstationarity manifests itself through the variable duration of fixation τ_j^i at each interval of closure of system transmission channels. In the areas where there are no impulses, the models of the forming links are excluded from consideration. Consider an arbitrary separate channel N - measuring system with PWM [6].

Let's look at a specific example:

$$A(p) = \bar{p}\frac{1}{(p+0{,}5)}, \qquad \tau_j^i = \begin{cases} \left| e\,(T_r^+) \right| & for \ \left| e\,(jT_r^+) \right| < 1, \\ T & for \ \left| e\,(jT_r^+) \right| \geq 1. \end{cases}$$
$$f(t) = 1(t),$$

τ_j^r - pulse duration r-st the channel in j-st interruption period. In the interval $jT_r < i \leq jT_r + \tau_j^r$ the pulse height is

$$e = \begin{cases} +B^r \ for \ e\,(jT_r^+) > 0, \\ -B^r \ for \ e\,(jT_r) < 0, \end{cases}$$

SMA consists of two parts, the first corresponds to the presence of an impulse, the second reflects the processes in the transmission channel during a pause

From here we can determine

$$\frac{B^r}{p\left| e^r\,(0^+) \right|} e^r(0^+) = \frac{B^r}{p} signe^r(0^r)$$

or in general

$$\frac{B^r}{p\left| e^r\,(jT^+) \right|} e^r(jT^+) = \frac{B^r}{p} signe^r(jT^+). \tag{3}$$

We further denote

$$u^r(jT^+) = B^r signe^r(jT^+). \tag{4}$$

Determining the transfer between the corresponding variables, we obtain the design formula for calculating the reaction [7-10].

PRIMER SYNTHESIS OF MANAGERIAL ACTIONS IN THE PROPOSED METODS

Modeling of pulse-width modulators is, in essence, combined with modeling the forming links of an equivalent system. In addition, it is sufficient for each channel at each interrupt interval to calculate the pulse width from the modulation characteristic [11-14].

Taking into account the above and based on the generality of certain stages of the formation of models of multidimensional AIS and SIS, an algorithm for constructing a dynamic graph model of SIS can be formulated.

Algorithm 1

Adopted a uniform time base for repetition periods $T_1,\ T_2,...,T_N$ pulse width modulators $PWM_1,\ PWM_2,.....,PWM_N \cdot \tilde{\tau}_* = t^1 \cup t^2 \cup ... \cup t^N,$ where $t^i, i = 1, 2,...,N$ - the set of moments of closure of the SIS along i - му separate transmission channel.

2. The calculation of multidimensional SIS processes is carried out by calculating the processes in individual elements with their subsequent summation in accordance with the structure of the system and the mode of operation of pulse-width modulators $PWM_1,\ PWM_2,.....,PWM_N$ based on the following algorithm [15].

Algorithm 2

At each step of the calculations, starting from the first, errors are determined e^r, pulse duration τ^r and input signals u^r for everyone $r \in k = \{1, 2,...., N\}$.

Moments of time corresponding to the beginning or end of the impulses are marked on a single time scale [16-17]. The state vectors of the separate and cross channels are determined by the relations

$$\vec{X}^r(t_k) = \left[\vec{A}_u^r(t_k^r - t_{k-1}^\alpha) \vee \vec{A}_n^r(t_k^r - t_{k-1}^\alpha)\right]\vec{X}^r(t_{k-1}^\alpha); \tag{5}$$

$$\vec{X}^{rk}(t_k) = \left[\vec{C}_u^{rk}(t_k^r - t_{k-1}^\alpha) \vee \vec{C}_n^{rk}(t_k^r - t_{k-1}^\alpha)\right]\vec{X}^{rk}(t_{k-1}^\alpha); \tag{6}$$

In (5), (6) the matrices $\vec{A}_u^r$, C_u^{rk} are used if at time t_{k-1} there were pulses at the inputs r -st and k -st separate channels. Otherwise, the calculation of state vectors is carried out on the basis of matrices $\vec{A}_n^r$, $\vec{C}_n^{rk}$

The output coordinates of the system are determined

$$y^r(t_k) = x_1^r(t_k) + \sum_{\substack{j=1 \\ j \neq r}}^{N} x_1^{rj}(t_k), \tag{7}$$

where $x_1^r(t_k) \in \vec{X}^r(t_k)$, $x_1^{rj}(t_k) \in \vec{X}^{rj}(t_k)$.

Go to point 1 of the algorithm for the time t_{k+1}.

It is convenient to present the calculation results in tabular form, where the time of occurrence of events, structural states and values of variables characterizing the dynamics of the intermediate, input and output coordinates of the system are noted.

CONCLUSION

Computational models for calculating transient processes of continuous-discrete systems with PWM have been developed, which are distinguished by the simplicity of implementation in computers and take into account the modes of operation of modulators.

A method is proposed for formalizing a discrete system in the class of a system with a dynamic structure, which makes it possible to describe the dynamics of the system by a linear transfer function.

An algorithm for calculating the response of a discrete system, with according to the structural states of the system and the modes of operation of the modulators.

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