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Automata and Continuous Logic

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Abstract: The review of works on application of continuous logic for the mathematical description of finite automata and digital devices is given. The simple and complex automata, automata with feedback and without feedback, deterministic and not deterministic automata are considered. The review is founded on Russian Publications.
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1. Introduction

The author has established in 1991 that operations of the continuous logic (CL) determined on an interval $C=[A,B]$: $a \vee b = \max(a,b)$ – disjunction, $a \wedge b = \min(a,b)$ – conjunction (the mark $\wedge$ frequently is not put), allow to describe in the analytical form dynamic processes in the circuits of digital finite automata. In 1972 the author has shown, that the quasiboolean algebra CL $\{C,\vee,\wedge\}$ is the adequate mathematics for the description of dynamics of the specified automata. Just, that with help of operations CL $\vee$ and $\wedge$ it is possible to express the moments of changes of a signal in any unit of the circuit of any automata, if the moments of changes of its input signals are known. This result has generalized and expanded results of Shannon, Nakashima and Shestakov (the conformity between Boolean algebra and statics of work of the circuits of automata without memory (relay-contact circuits), established in 1938–1941. On the basis of specified result the new science (analytical dynamics of finite automata) is developed. This science allows to find in the analytical form, to analyze and to synthesize dynamic processes in the circuits of automata of rather large complexity with enough complex input processes. There are today basic means for reception CL: description of work of systems in engineering, economy, biology, sociology, politology, for what these systems previously are simulated by the dynamic automata.

2. Model of Automata Without Memory

The most simply object in the considered theory – deterministic dynamic automata without memory, about an input-output ratio

$$y_k(t) = G_k[x_1(t),\ldots,x_n(t)], k=1,\ldots,m, \; x_i \in X, y_k \in Y. \tag{1}$$

In (1) $x_i(t)$ and $y_k(t)$ are input and output processes (respectively), X and Y are input and output alphabets (respectively), and the G_k are operators without memory. Such automata are realised as the asynchronous combinational circuit - a circuit from logic and inertial elements which do not have feedback. We usually take the alphabets $X = Y = \{0,1\}$, so input, output and internal processes in the circuit and its elements are binary. Each logic element i realizes on output an appropriate Boolean function of inputs $\{0,1\}^R \to \{0,1\}$. The inertial elements are delay and filter. The delay moves together the moment of change of input process on constant t and filter does not pass on output of change of input process with time lag less than t. The reaction $y(x)$ on an output of element (logic or inertial) on the given input processes $x_i(t)$, $i = 1,..., p$ is called as dynamic process in this element. The set of processes in elements of the circuit with processes working on its inputs $x_i(t)$, $i = 1,..., n$ is called as dynamic process in the circuit appropriate to these input processes. The task of calculation analysis of dynamics of the circuit consists in searching in the analytical form (analysis received) dynamic process in any of its units (in particular on outputs), if the analytical processes on its inputs are given. The basic method of calculation of dynamics of circuits is method of substitutions. It consists in splitting the circuit into consecutive steps by depth in one element and use of ratio "input processes – output process" of elements. Such ratios are rather simple for 1-input elements: inverter ($y = \bar{x}$), delay and filter. Let the input process write down as a sequence of impulses and pauses

$$x(t) = u(a_1, a_2)\bar{u}(a_2, a_3)...\tilde{u}(a_{m-1}, a_m), \quad u \in \{0,1\}, \tag{2}$$

The dynamic processes on the outputs of 1-input elements - inverter, delay and filter - in this format can be presented by sequences

$$\begin{aligned} &y_{inv}(t) = \bar{u}(a_1, a_2)u(a_2, a_3)...\tilde{u}(a_{m-1}, a_m), \\ &y_d(t) = u(a_1 + t, a_2 + t)\bar{u}(a_2 + t, a_3 + t)...\tilde{u}(a_{m-1} + t, a_m + t), \\ &y_f(t) = u[a_1, a_1 + (a_2 - a_1)I(a_2 - a_1 - t)]\bar{u}[a_2, a_2 + (a_3 - a_2) \times I(a_3 - a_2 - t)]... \\ &\quad ...\tilde{u}[a_{m-1}, a_{m-1} + (a_m - a_{m-1})I(a_m - a_{m-1} - t)]. \end{aligned} \tag{3}$$

For two-input elements these ratios are much more complex, and here CL plays the outstanding role. Let's find, for example, reaction of conjunction element (function $y = x_1 \wedge x_2$) on the input influences $x_1(t) = 0 \to 1_{t=a}$ (denoted by $1'_a$), $x_2(t) = 1 \to 0_{t=b}$ (denoted by $0'_a$). This reaction is equal to an impulse $1(a,b)$ with $a \ge b$ and constant zero with $b < a$ or, with use of a disjunction CL

$$1'_a \wedge 0'_a = \begin{cases} 1(a,b), & b \ge a \\ 0 = 1(a,a), & b < a \end{cases} \Bigg| = 1(a, a \vee b).$$

Other cases of simple influences in the conjunction element and also in the disjunction element (function $y = x_1 \vee x_2$) are similarly analysed

$$\begin{gathered} 0'_a \wedge 0'_b = 0'_{a \wedge b},\ 0'_a \vee 0'_b = 0'_{a \vee b}, 1'_a \wedge 1'_b = 1'_{a \vee b}, 1'_a \vee 1'_b = 1'_{a \wedge b}, \\ 1'_a \wedge 0'_b = 1(a, a \vee b),\ 1'_a \vee 0'_b = 0(b, a \vee b). \end{gathered} \tag{4}$$

Formulas (4) demonstrate us the convenience of the theory of Continuous Logic in the study of dynamics of logic elements.

3. Case of Complex Input Processes

If the input processes of logic elements have number strictly greater than 1, the formal methods are necessary for a calculation of their dynamic processes. The simplest of such methods is decomposition of input processes $x(t)$, $y(t)$ (for example, $x(t)$) to the two consecutive subprocesses $x_a(t)$ and $x_b(t)$; the last moment of change in $x_a(t)$ is called as a point of division. Further find reactions of elements $f_a(t)$ and $f_b(t)$ on partial input influences $\{x_a(t), y(t)\}$ and $\{x_b(t), y(t)\}$. If they aren't intersected in time, the reaction $f(t)$ of element on the given input influence $\{x(t), y(t)\}$ is calculated as a sequence of partial reactions $f_a(t)$, $f_b(t)$. The method of decomposition reduces the calculation of dynamic process in an element with the given input influences to a similar task with simpler influences. This method is applicable (that is f_a, f_b are not intersected) under condition: 1) of suitable choice of point of division (for conjunctor it is a point $0'_b$, for disjunctor is $1'_a$); 2) reductions of process $f_a(t)$ ($f_b(t)$) to normal on the right (normal at the left) form, where the expression of the moment of the ending (beginning) of process satisfies to some estimation from above of actual moment of the ending (estimation from below of actual moment of the beginning). By a method of decomposition it is possible to find an expression of dynamic processes in elements with input processes containing up to several changes. For example,

$$
\begin{aligned}
&0'_a \vee 1(b,c) = 0(a, a \vee b)1(-, a \vee c);\; 0'_a \vee 0(b,c) = 0(a \vee b, a \vee c);\\
&1'_a \vee 1(b,c) = 1(a \wedge b, c)0(-, a \vee c);\; 0'_a \wedge 1(b,c) = 1(a \wedge b, a \wedge c);\\
&0'_a \wedge 0(b,c) = 0(a \wedge b, c)1(-, a \vee c);\; 1'_a \wedge 1(b,c) = 1(a \vee b, a \vee c);\\
&1'_a \vee 0(b,c) = 0(a \wedge b, a \wedge c);\; 1'_a \wedge 0(b,c) = 1(a, a \vee b)0(-, a \vee c).
\end{aligned}
\tag{5}
$$

Using the formulas of a type (4) or (5) for dynamic processes in typical logic elements, it is possible to find dynamic processes in the simple circuits, and then to analyse them, writing down those conditions because of which the processes accept one or another form, and solving CL-equations and inequalities.

4. Model of Automata with Memory

Let's consider more complex object in the considered theory – deterministic automata with feedback, about an input-output ratio

$$
\left.\begin{aligned}
&y_k(t) = G_k[x_1(t),...,x_n(t), u_1(t),...,u_p(t)],\; k = \overline{1,m}\\
&u'_i(t) = u_i(t + t_i) = F_i[x_1(t),...,x_n(t), u_1(t),...,u_p(t)],\; i = \overline{1,p}
\end{aligned}\right|\; x_i \in X, y_k \in Y, u_j \in U. \tag{6}
$$

In (6) $x_i(t), y_k(t), u_j(t)$ – input, output and internal processes, X, Y and U – input, output and internal alphabets, $(G_1,...,G_m)$ and $(F_1,...,F_p)$ – operators without memory. Such automata is realized as the asynchronous circuit with memory having the logic block (some asynchronous combinational circuit) and the block of memory (p of delays $t_1,..., t_p$ working in parallel), and the logic block is surrounded with p feedbacks which are taking place from outputs of the logic block on its inputs through appropriate delays of the block of memory. In this circuit we now designate $x(t) = (x_1(t),..., x_n(t))$ - vector of input processes, $y(t) = (y_1(t),..., y_m(t))$ - vector of output processes, $u(t) = (u_1(t),...,u_p(t))$ – vector of processes on outputs of the block of memory (internal state of automata in moment t), $u(t+t)=(u_1(t+t),...,u_p(t+t))$ – vector of processes on inputs of the memory block, (following internal state of automata), $(x(t),u(t))$ and $(y(t),u(t+t))$ – vectors of processes on inputs and outputs of logic block (respectively). Usually $X=Y=U=\{0,1\}$, so all processes in the circuit are binary. The dynamic process in the circuit with memory is defined similarly to a combinational circuit. The task of calculation (analysis) of dynamics of automata with feedback consists in calculating in analytical form (analysis) of dynamic process in any unit (including on an output) appropriate circuit on the processes, given in the analytical form, on its inputs and its initial internal state. There are two basic methods of the calculation of dynamics of automata: 1) method of the equations of dynamics and 2) method of combinational modeling. The first method is realized as algorithm which consists of 4 steps: 1) drawing up under circuit of system of equations (6) rather than unknown processes $u_i(t), x_i(t)$; 2) the evaluation of the form in which is necessary to search for solution (for each unknown process probably some forms differ by complexity); 3) choice of the elementary form and simplification of system of equations; 4) solution of system of the equations. If the solution exists the working of algorithm is finished. Otherwise: going to step 3 and new choice of the form of unknown processes for further simplification. The second method is realized as following algorithm: 1) knowing an initial steady internal state $(u_1^0,...,u_p^0)$, input processes $x_1(t),...,x_n(t)$ and operators $F_1,...,F_p$ from the last p equations (6) by methods of calculation of dynamics of combinational circuits we find first initial sites $u_i'^1(t), i=\overline{1,p}$, processes $u_i'(t)=u_i(t+t_i)$ on inputs of the block of memory. These sites pass through the block of memory and taken the form $u_1^1(t)=u_1'^1(t)_{t_1},...,u_p^1(t)=u_p'^1(t)_{t_p}$, where the addition of t_i means the shift of process by t_i, and the process $u(t)=(u_1(t),...u_p(t))$ represent the first initial sites of evolution of internal state of automata; 2) similarly, knowing the first initial sites $u_1^1(t),...,u_p^1(t)$ of processes $u_1(t),...,u_p(t)$, input processes $x_1(t),...,x_n(t)$ and operators $F_1,...,F_p$, from the same equations (6), we find 2nd, longer initial sites $u_i'^2(t), i=1,...,p$ of processes $u_i'(t)=u_i(t+t_i)$ on inputs of memory block. Running memory block these sites become the second initial sites of process $u(t)$. They are taking following form: $u_1^2(t)=u_1'^2(t)_{t_1},...,u_p^2(t)=u_p'^2(t)_{t_p}$. The further steps (3, 4… etc) are similarly. As a result the sufficient initial site $u^n(t)=(u_1^n(t),...,u_p^n(t))$ of process of evolution of internal state of automata is received. From the first m equations (6) we find the appropriate initial site $y^n(t)=(y_1^n(t),...,y_p^n(t))$ output process of automata. The given algorithms allow to find dynamic processes in simple automata with the help of operations of CL, and then to analyze them, writing down states, with which the processes accept the necessary form, and solving the resulting equations and inequalities in CL. The calculation of dynamic processes in automata can be combined with their analysis, if the method of equations is used. It is necessary to take steps 2 and 3 of the algorithms of the given method to take into calculation the requirements to the form of processes.

5. Problem of Dimension

With the calculation and analysis of dynamic processes in complex automaton with very long (with large number of changes) input processes the problem of dimension arise. The solution of problem is based on canonical representation of input processes of circuits according to theorem: it is possible to present any process $(x_1(t),...,x_n(t))$ on n inputs of one-output non-inertial combinational circuit, with the operator G from (1) as symmetrical Boolean function, equivalent input set free (i.e. independent from the certain inputs) impulses $1(a^r,b^r), r=\overline{1,M}$, which are ordered linearly $1(a^1,b^1)\le ... \le 1(a^M,b^M)$. Here $a^r(b^r)$ is the moment of r-th (by linear order) changing like $0\to 1$ (or like $1\to 0$) in the set of input processes $x_1(t),...,x_n(t)$ and M is the total number of changes of each kind (number of impulses) in the specified set. By replacing input process by equivalent set of impulses, it is possible to break time for intervals with constant number of impulses in each interval and consequently with constant magnitude of output process $y(t)$. The complexity of splitting is $O(M^2)$. For a calculation of the process $y(t)$ it is necessary to find its magnitude in any one point of each interval. The influence on the combinational circuit can be presented in the analytical form. Indeed, if it is given by sequences

$$x_i(t)=1(a_{i1},b_{i1})0(-,-)1(a_{i2},b_{i2})...1(a_{im_i},b_{im_i}),\ i=\overline{1,n}, \tag{7}$$

that under the theorem are represented by equivalent set of free (i.e. independent from the certain inputs of combinatorial circuit) impulses of the kind of $1(a^r,b^r), r=\overline{1,M}$, $M=\sum_{i=1}^{n} m_i$, which moments of the beginning and ending are expressed through the moments of changes of processes (7) by the sequence of constructions named logic determinants:

$$a^r=\begin{vmatrix} a_{11} & \ldots & a_{1m_1} \\ \ldots & \ldots & \ldots \\ a_{n1} & \ldots & a_{nm_n} \end{vmatrix}^r, b^r=\begin{vmatrix} b_{11} & \ldots & b_{1m_1} \\ \ldots & \ldots & \ldots \\ b_{n1} & \ldots & b_{nm_n} \end{vmatrix}^r,\quad r=\overline{1,M},\ M=\sum_{i=1}^{n} m_i . \tag{8}$$

The determinants in (8) are functions $\left|a_{ij}\right|^r=\{a_{ij}\}\to a^r$. In the obvious form the determinants are expressed through the elements by operations of CL.

$$\begin{vmatrix} a_{11} & \ldots & a_{1m_1} \\ \ldots & \ldots & \ldots \\ a_{n1} & \ldots & a_{nm_n} \end{vmatrix}^r = \bigvee_{\sum_{i=1}^{n} i_s=n+r-1} (a_{1i_1}^{m_1}\wedge ... \wedge a_{ni_n}^{m_n}). \tag{9}$$

The analytical representation with the help of CL of input processes in the complex circuits with symmetrical function allows to receive the same representation for dynamic processes in such circuits. For it is enough to consider interaction of next free input impulses and to allocate the intervals in which the constant number of impulses works meaning that the magnitude of symmetrical function is completely determined by number of its arguments with individual magnitude equal to 1.

Let's find, for example, the reaction of disjunctor (function $y=x_1\vee x_2$) on a pair of input processes $x_1(t), x_2(t)$ of the kind (7) with $n=2$. We can replace these processes by an equivalent set of $1(a^r,b^r)$ impulses with a^r,b^r from (8). Now it is enough to consider the interaction of impulses: r-th and $r+1$-th, that gives such fragment of reaction of an element

$$y_r(t)=\begin{cases} 1(a^r,b^r)0(-,-)1(a^{r+1},b^{r+1}), & b^r<a^{r+1}, \\ 1(a^r,b^{r+1})\equiv 1(a^r,a^{r+1})0(-,-)...1(a^{r+1},b^{r+1}), & b^r\ge a^{r+1}. \end{cases}$$

We can greatly reduce the length of expression. For this transformation we can use the operation of conjunction of continuous logic and get

$$y_r(t) = 1(a^r, b^r \wedge a^{r+1})0(-,-)1(a^{r+1}, b^{r+1})\,. \tag{10}$$

According to (10), the required reaction $y(t)$ is a sequence of impulses $1(a^r, b^r)$, compressed by a rule $b^r \to a^{r+1} \wedge b^r$, $r = \overline{1, M}$, $M = m_1 + m_2$ and consequently no more intersected. So,

$$y(t) = 1(a^1, b^1 \wedge a^2)0(-,-)1(a^2, b^2 \wedge a^3)\ldots 1(a^{M-1}, b^{M-1} \wedge a^M)0(-,-)1(a^M, b^M),\ M = m_1 + m_2\,. \tag{11}$$

Other two- and multi-input logic elements and also any combinational circuits are similarly analyzed with symmetrical function. The formulas, got with it, of dynamic processes are a basis for analytical calculation of dynamics of the complex combinational circuits with nonsymmetrical functions, and also complex circuits with memory. Here the problem of dimension is overcame by logic determinants incorporating dimension of circuit and its input processes.

6. Not deterministic Automata Without Memory

Even more complex object – non-determiniscic automata without memory. It differs from deterministic automata by that the input-ratio (1) realizes in the alphabet $X = Y = \{0,1,\Theta\}$, where Θ is the uncertainty (the value between 0 and 1). In the non-deterministic circuit realizing such automata input, output and internal processes and elements are ternary in the alphabet $\{0,1,\Theta\}$. Each logic element realizes on output ternary function of inputs $\{0,1,\Theta\} \xrightarrow{R} \{0,1,\Theta\}$. Each such function f_i can output Θ, so it is an expansion of appropriate binary function F_i on the basis of some axioms. The calculation of dynamic processes in the non-deterministic circuits can be carried out by a method of substitutions, using the ratio "ternary input processes – output process" of elements. The ratios are revolving around: 1) replacements of ternary processes $x(t) \in \{0,1,\Theta\}$ by equivalent pair of binary processes – lower $\check{x}(t)$ and upper $\hat{x}(t)$ envelopes

$$\check{x}(t) = \begin{cases} 1, & x(t) = 1, \\ 0, & x(t) \in \{0,\Theta\}; \end{cases} \qquad \hat{x}(t) = \begin{cases} 0, & x(t) = 0, \\ 1, & x(t) \in \{1,\Theta\}; \end{cases} \tag{12}$$

2) calculation of elements and finding envelopes of their output dynamic process $y(t)$, for what are used an input-output ratios of envelopes' typical elements

$$\begin{aligned} &\overbrace{\bigvee_{i=1}^{n} x_i(t)} = \bigvee_{i=1}^{n} \check{x}_i(t), \quad \underbrace{\bigvee_{i=1}^{n} x_i(t)} = \bigvee_{i=1}^{n} \hat{x}_i(t), \\ &\overbrace{\bigwedge_{i=1}^{n} x_i(t)} = \bigwedge_{i=1}^{n} \check{x}_i(t), \quad \underbrace{\bigwedge_{i=1}^{n} x_i(t)} = \bigwedge_{i=1}^{n} \hat{x}_i(t), \\ &\underbrace{\overline{x(t)}} = \overline{\check{x}(t)}, \quad \overbrace{\overline{x(t)}} = \overline{\hat{x}(t)} \end{aligned} \tag{13}$$

and representation of a considered element as the circuit from typical elements; 3) transitions from the envelopes' input and output processes to processes of an element. It is also possible to conduct under calculation of dynamic processes in the not determined combinational circuits by a method of substitutions, manipulating envelopes' processes and passing to processes only after are found the envelopes of output process. With the help of the described technique it is possible to analyse different cases of the simple processes on the simple elements and circuits. For example, here is the set of equations which correspond to different simple combinations of values:

$$\begin{aligned}
&\Theta'_{1,a}0'_{\Theta,b} \wedge \Theta'_{1,c}0'_{\Theta,d} = \Theta'_{1,a\wedge c}0'_{\Theta,b\wedge d},\ \Theta'_{1,a}0'_{\Theta,b} \vee \Theta'_{1,c}0'_{\Theta,d} = \Theta'_{1,a\vee c}0'_{\Theta,b\vee d};\\
&\Theta'_{0,a}1'_{\Theta,b} \wedge \Theta'_{0,c}1'_{\Theta,d} = \Theta'_{0,a\vee c}1'_{\Theta,b\vee d},\ \Theta'_{0,a}1'_{\Theta,b} \vee \Theta'_{0,c}1'_{\Theta,d} = \Theta'_{1,a\wedge c}1'_{\Theta,b\wedge d};\\
&\Theta'_{0,a}1'_{\Theta,b} \wedge \Theta'_{1,c}0'_{\Theta,d} = \{I_1:(b, b\vee c);\ I_0:(-\infty, a),(a\vee d,\infty)\};\\
&\Theta'_{0,a}1'_{\Theta,b} \vee \Theta'_{1,c}0'_{\Theta,d} = \{I_1:(-\infty, c),(b\vee c,\infty);\ I_0:(d, a\vee d)\},
\end{aligned} \tag{14}$$

where I_a are intervals in which the reaction is equal a. Cases of complex processes and/or of complex circuits need the use of logic determinants.

7. Non-Determininistic Automata With Memory

The most complex objects of the considered theory are non-deterministic automata with feedback. They differ from deterministic automata by that input-output ratio (6) realizes in the alphabet $X=Y=U=\{0,1,\Theta\}$. The circuit realizing non-deterministic automata differs from the circuit of the deterministic automata by following facts: 1) in the non-deterministic automata logic blocks are non-deterministic circuits with the alphabet $X=Y=\{0,1,\Theta\}$; 2) blocks of memory have p parallelly working delays from time delays as intervals $t_1=[t_{11},t_{12}],\ldots,t_p=[t_{p1},t_{p2}]$. In the non-deterministic circuit with memory the input, output and internal processes and all elements are ternary and the alphabet is $X=Y=\{0,1,\Theta\}$, but the structure is the same as in the deterministic circuit. Therefore the methods of calculation and analysis of dynamic processes are here the same, and results are still expressed with the help of CL. But the preliminary transition from equations of non-deterministic circuit of rather ternary processes to the appropriate equations concerning their envelopes is necessary for these methods which are the binary processes. It raises the dimension of object and makes its calculation more complex.

8. Processes In Delay and Filter

One of the complex tasks of the automata dynamics is the calculation of nonlinear inertial elements (delay and filter) with interval temporary parameters. In a nonlinear delay the time of a delay depends on input change: $0\to 1$ or $1\to 0$ and is equal accordingly to $t_{01}=[t^1_{01},t^2_{01}]$ or, respectively, $t_{10}=[t^1_{10},t^2_{10}]$. In the nonlinear filter the time of filtration depends on the kind of signal (an impulse $0\to 1\to 0$ or a pause $1\to 0\to 1$) and is equal $t_1=[t^1_1,t^2_1]$ or $t_0=[t^1_0,t^2_0]$ (respectively). For the solution of this task the universal method of dedeterminization, suitable also for calculations of dynamic processes in not determined circuits is developed. It consists in the following: 1) determinization of the given ternary input processes and temporary parameters of inertial elements by overlapping the ends of intervals of uncertainty; 2) in the received determined circuit the calculation of dynamic processes by methods of calculation of these classes of the circuits (see items 2-5) will be carried out; 3) In the found determined (binary) dynamic processes dedeterminization is making, according to given not determined input processes of the circuit and temporary parameters of its elements, so the moments of changes of processes accept a kind of functions from intervals; 4) by function evaluation from intervals by rules of the interval analysis of the CL expression of all dynamic processes receive a final, obvious form.

9. Conclusion

More details on the questions, mentioned in the given review, are contained in generalizing works [1]–[12]. There is an extensive bibliography.

References

[1]. Roginskiy, V.N. (1975), *Basic of Discrete Automatics.* Moscow: Sviaz (in Russian).

[2]. Levin, V.I. (1975), *Introduction to the Dynamic Theory of Finite Automata.* Riga: Zinat-ne (in Russian).

[3]. Bochmann, D and Roginskiy, V.N. (1977), *Dinamische Processe in Automaten*. Berlin: Technik.

[4]. Levin, V.I. (1980), *Dynamics of Logic Devices and Systems.* Moscow: Energia (in Russian).

[5]. Levin, V.I. (1982), *Infinite-Valued Logic in Problems of Cybernetics.* Moscow: Radio i Swiaz (in Russian).

[6]. Levin, V.I. (1988, 1989), "Research of Dynamics of Discrete Automaton with Possible Uncertainty of Magnitude of Signals. I, II". *Cybernetics,* 6, 2.

[7]. Levin, V.I. (1989), "Models and Calculation of Dynamics of the Digital Circuits with the Short Certain Signals", *Electronic Modelling,* 1, 2.

[8]. Levin, V.I. (1989), "Calculation of Dynamics of the Digital Circuits with Memory with the Short Certain Signals", *Cybernetics,* 4.

[9]. Levin, V.I. (1992), "Calculation of Dynamic Processes in Discrete Automata with Uncertain Parameters with the Help of Not Determined Infinite-valued Logic", *Cybernetics and System Analysis*, 3.

[10]. Levin, V.I. (1995), *The Theory of Dynamic Automata*. Penza: University Publishing (in Russian).

[11]. Levin, V.I. (2003), "Methods of Continuous Logic in the Problems of *Control", Automation and Remote Control*, 3.

[12]. Levin, V.I. (2010), "Continuous Logic in Problems of Finite Automata", *Journal of Computer and Systems Sciences International*, 1.