CONDUCTING A SYNTHESIS OF A DIGITAL AUTOMATON FOR AN AUTOMATED FIREFIGHTING SYSTEM

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Introduction

The model of a digital automaton (CA) of an automated firefighting system with input and output signals induces a one-to-one mapping of the set of commands in the input signals (the input command mapping) into the set of commands in the output signals. In this article we consider the stages of solving the problem of synthesizing automata by the mappings induced by them.

According to the developed algorithm (Fig. 1), when selecting the states, one should take into account such recommendations as:

– the correspondence of the set and the initial set;
– the choice of the next state is made according to the ascending order after each PROCESS block;
– before each DECISION block, after each line adjacency point, which indicates the transition direction [1].

Refinery accident and fire analysis

According to the developed functioning algorithm decided that the scheme of the CA model of the automated fire protection system (AFS) will include 14 states, where $a_0$ – the initial state [2].

All 14 states of digital automaton will be encoded by four-bit binary numbers (Tables 1–3). The memory block, in this case, will be a four-bit parallel register on D-triggers, because storage of each bit of the binary code will use one trigger [3, 14].

Based on the developed algorithm of functioning of the digital automaton ASFT we build a graph [4]. The state of the device in the graph will depend proportionally on the values of the vertices (vertices of the graph). The vertices of the graph of the ASPT CA model are connected by arcs, which show the direction of transition. At the top of the arcs we write transition conditions and output signals [5, 11, 12].
Fig. 1. Algorithm of automatic fire extinguishing system operation at an industrial facility

Table 1

| State of the machine       | Status deciphering                                      |
|----------------------------|---------------------------------------------------------|
| $a_0$                      | Fire detectors are in standby mode.                     |
|                            | APT system in standby mode                              |
| $a_1$                      | 1 fire detector is in Fire mode.                        |
|                            | The sounders are on                                    |
| $a_2$                      | The fire detectors are in standby mode.                 |
|                            | The sounders are switched off.                          |
|                            | The ASFT system is in ERROR mode                       |
| $a_3$                      | CA corrects an error with the system                    |
| $a_4$                      | The sounders are switched on.                           |
|                            | Supply and exhaust ventilation is switched on.          |
|                            | The ASPT system is in Fire mode                        |
| $a_5$                      | The fire is extinguished                                |
| $a_6$                      | After fire suppression, the CA resets the alarms and restarts the ASFT |
| $a_7$                      | CA launches ASE and ASPT                                |
| $a_8$                      | CA corrects system error                                |
| $a_9$                      | 1 fire detector was triggered                           |
| $a_{10}$                   | Button for manual start of fire extinguishing is pressed |
| $a_{11}$                   | One of the loops is broken                              |
| $a_{12}$                   | The 2nd fire detector is triggered                      |
| $a_{13}$                   | There is a fire in the premises                        |
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**Table 2**

| State of the machine | Binary code |
|----------------------|-------------|
|                      | $Q_4$ | $Q_3$ | $Q_2$ | $Q_1$ |
| $a_0$                | 0     | 0     | 0     | 0     |
| $a_1$                | 0     | 0     | 0     | 1     |
| $a_2$                | 0     | 0     | 1     | 0     |
| $a_3$                | 0     | 0     | 1     | 1     |
| $a_4$                | 0     | 1     | 0     | 0     |
| $a_5$                | 0     | 1     | 0     | 1     |
| $a_6$                | 0     | 1     | 1     | 0     |
| $a_7$                | 0     | 1     | 1     | 1     |
| $a_8$                | 1     | 0     | 0     | 0     |
| $a_9$                | 1     | 0     | 0     | 1     |
| $a_{10}$             | 1     | 0     | 1     | 0     |
| $a_{11}$             | 1     | 0     | 1     | 1     |
| $a_{12}$             | 1     | 1     | 0     | 0     |
| $a_{13}$             | 1     | 1     | 0     | 1     |

**Table 3**

| Go to | D |
|-------|---|
| 0 → 0 | 0 |
| 0 → 1 | 1 |
| 1 → 0 | 0 |
| 1 → 1 | 1 |

Read the graph as follows: the automaton is in the initial state $a_0$, then under the signal from the fire detector it changes its state to $a_1$, with this transition the output signals must be formed $y_1, y_3, y_6$. This is followed by a transition $a_2$ to the state with the formation of output signals $y_1, y_3, y_6$. From the state $a_2$ to $a_3$, then to $a_4$. From the state $a_4$ the transition to the state $a_5$, or $a_8$ [5] is possible. The $a_5$ automaton enters the state if the external condition (fire is detected) $x_1$ is 1 ($x_1$) with issuing of $y_1, y_3, y_4$ control signals, and the automaton $a_8$ enters the state if the same signal is 0 ($\bar{x}_1$), etc.

After constructing the graph, fill in the table of functions of the vertices of the graph. Using this table you can write functions for any number of variables (Fig. 2). After that it is necessary to analyze it carefully in order to simplify (minimize) it, because the tabular method does not give an opportunity to obtain in perfect disjunctive normal form (DNF) for outputs the minimal disjunctive normal form (MDNF) or the minimal conjunctive normal form (MCNF) [6]. In this case it will be enough to apply the gluing law to some expressions [7, 8].

On the transition column of the digital automaton of the automated integrated firefighting system let's fill in the table 4. Example for the first line: The initial state, which is coded as “0000”, changes to the state with the code “0001”. This transition is unconditional. We see that $Q_4=0$, $Q_3=0$, $Q_2=0$, $Q_1=0$, and in the new state $Q_4=0$, $Q_3=0$, $Q_2=0$, $Q_1=1$ [6]. According to the table of D-trigger transitions $Q_4=0$, $Q_3=0$, $Q_2=0$, $Q_1=1$, to get $D_1$, it is necessary to supply 1 to the input in the column...
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$D_2, D_3, D_4$ “Trigger Control Signals”, and to supply 0 to the others, at this transition the signals are formed $y_1, y_5, y_6$. All the following lines are completed in the same way.

Fig. 2. Transition graph of the digital automaton of the automated integrated firefighting system

According to the table of functioning of the digital automata graph of AISPT we make analytical expressions in the SDNF for output signals $y_1, y_2, y_3$, and also signals of control of triggers $D_4, D_3, D_2, D_1$. The perfect disjunctive normal form of the function is a disjunction of elementary conjunctions [7, 15].

The output signal $y_1$ will be generated if the automaton is in state $a_0$, or in $a_1$, or in $a_3$, or in $a_5$, or in $a_7$, or in $a_9$, and the sign $a_4$ $x_3 = 1$, or in state $a_9$ and the sign $x_4 = 0$. Similarly the functions for other output signals and trigger control signals are written [10, 13].

**Table 4**

| Functioning of the graph of the digital automaton ASPT |
|-------------------------------------------------------|
| $y_1 = a_0 \lor a_1 \lor a_3 \lor a_4 x_3 \lor a_5 \lor a_7 \lor a_8 x_4 \lor a_13$ | (1) |
| $y_2 = a_2 \lor a_6 \lor a_8 x_4 \lor a_10 x_2 \lor a_11 \lor a_13$ | (2) |
| $y_3 = a_1 \lor a_2 \lor a_4 x_3 \lor a_6 x_4 \lor a_11 \lor a_13$ | (3) |
| $y_4 = a_4 x_3 \lor a_4 x_3 \lor a_6 x_4 \lor a_8 x_4 \lor a_10 x_2 = a_4 \lor a_8 \lor a_10 x_2$ | (4) |
| $y_5 = a_0 \lor a_2 \lor a_3 \lor a_4 x_3 \lor a_5 \lor a_8 x_4 \lor a_11$ | (5) |
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\begin{align*}
y_6 &= a_0 \lor a_1 \lor a_6 \lor a_7 \lor a_{10}x_2 \\
y_7 &= a_5 \lor a_6 \lor a_{11} \\
D_1 &= a_0 \lor a_2 \lor a_4x_1 \lor a_6 \lor a_8x_4 \lor a_{10}x_2 \lor a_{11} \lor a_{12}x_5 \lor a_{13} \\
D_2 &= a_1 \lor a_2 \lor a_5 \lor a_6 \lor a_7 \lor a_8x_4 \lor a_9x_1 \lor a_{10}x_2 \lor a_{13} = \\
&= a_1 \lor a_2 \lor a_5 \lor a_6 \lor a_7 \lor a_8x_4 \lor a_9x_1 \lor a_{10}x_2 \lor a_{13} \\
D_3 &= a_3 \lor a_4x_1 \lor a_5 \lor a_6 \lor a_9x_1 \lor a_{10}x_2 \lor a_{12}x_5 = \\
&= a_3 \lor a_4x_1 \lor a_5 \lor a_6 \lor a_9x_1 \lor a_{10}x_2 \lor a_{12}x_5 \\
D_4 &= a_4x_3 \lor a_8x_4 \lor a_9x_1 \lor a_{10}x_2 \lor a_{10}x_2 \lor a_{12}x_5 = \\
&= a_4x_3 \lor a_8x_4 \lor a_9x_1 \lor a_{10}x_2 \lor a_{12}x_5 \\
\end{align*}

Formulas (4), (9), (10), and (11) have been simplified using the gluing law. Using the laws of double negation and de Morgan formulas, the initial expressions from the basis of AND, OR, NOT are converted to the basis of AND, NOT.

\begin{align*}
y_1 &= a_0 \land a_1 \land a_5 \land a_4x_3 \land a_5 \land a_7 \land a_8x_4 \land a_{13} \\
y_2 &= a_2 \land a_6 \land a_9x_4 \land a_{10}x_2 \land a_{11} \land a_{13} \\
\end{align*}

Convert all other formulas by analogy. With the help of the Logic Converter from the MultiSIM simulator program we will minimize the logic functions, which determine each of the control signals of the KS 1 triggers according to Table 4. The results of the minimization of the logic functions are shown in the figures (Figs. 3–15) [9].

\begin{align*}
J1 &= \overline{O_1}O_2O_1; \\
K1 &= \overline{O_1}O_2O_4 + \overline{O_3}O_4; \\
J2 &= \overline{O_1}O_3 + \overline{O_4}O_4; \\
K2 &= \overline{O_1}O_4 + \overline{O_3}O_4; \\
J3 &= \overline{O_1} + \overline{O_2}; \\
K3 &= \overline{O_1} + \overline{O_2}; \\
J4 &= \overline{O_2}O_3O_4; \\
K4 &= \overline{O_2}O_3; \\
\end{align*}

Fig. 3. Minimization of the logic function to control trigger signals $K1$

Fig. 4. Minimization of the logic function to control the trigger signals $J1$
Now let's minimize the logical functions of KS 2, using also Logic Converter from the MultiSIM simulator. The result of minimization of logical functions (Figs. 11–15).

\[
Y_1 = \overline{Q_1}Q_2\overline{Q_3}Q_4 + \overline{Q_1}Q_2Q_3\overline{Q_4}; \\
Y_2 = \overline{Q_1}Q_2Q_3\overline{Q_4} + \overline{Q_1}Q_2Q_4 + Q_1\overline{Q_3}Q_4; \\
Y_3 = \overline{Q_1}Q_2\overline{Q_4} + \overline{Q_1}Q_3Q_4; \\
Y_4 = \overline{Q_1}Q_2Q_3\overline{Q_4} + \overline{Q_1}Q_2Q_4 + Q_1\overline{Q_3}Q_4 + Q_2Q_3Q_4; \\
Y_5 = \overline{Q_1}Q_3Q_4 + Q_2Q_3Q_4 + Q_1\overline{Q_2}Q_3Q_4 + Q_1Q_2\overline{Q_3}Q_4.
\]
Conclusion

Minimized logic functions for KS 1 and KS 2 will be used in the construction of the model of digital automata of automated integrated fire protection system.

To simplify the CA scheme the minimized logic functions for KS 1 and KS 2 are analyzed and the same logic functions are defined. On the basis of the functional diagram of CA its circuit diagram on the selected series of digital integrated circuits is built.

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ПРОВЕДЕНИЕ СИНТЕЗА ЦИФРОВОГО АВТОМАТА
ДЛЯ АВТОМАТИЗИРОВАННОЙ СИСТЕМЫ ПОЖАРОТУШЕНИЯ

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Повышение уровня систем противопожарной защиты НПЗ остается одной из важнейших составных частей обеспечения защиты населения от угроз техногенного характера. Скорость развития инноваций позволяет применить искусственный интеллект при создании автоматизированных систем пожарной безопасности. Цель исследования. Данное исследование на-
правлено на построение модели автоматизированной интегрированной системы управления противопожарной защитой (АИСУПЗ). Материалы и методы. Для решения задач исследования использованы методы построения графов, задание графов алгоритмом работы автоматизированной интегрированной системы противопожарной защиты. Данная система является новым подходом к решению вопроса безопасности промышленных объектов нефтеперерабатывающей отрасли.

**Результаты.** Предложенная новая модель программной реализации цифрового автомата в автоматизированной интегрированной системе обнаружения и мониторинга пожара нефтеперерабатывающего предприятия дала возможность создать банк расчетных и аналитических данных по всем потенциально возможным видам разрушения конструкции узлов. Разработанная технология дает возможность обработки поступающего сигнала, содержащегося на циклограммах, в промежуточную форму для синтеза цифровых автоматов при помощи инновационных инструментальных средств.

Ключевые слова: автомат Милн, цифровой автомат, граф, вершина графа, минимизация логической функции.

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