Вісник Тернопільського національного технічного університету
https://doi.org/10.33108/visnyk_tntu
Scientific Journal of the Ternopil National Technical University
2023, № 1 (109) https://doi.org/10.33108/visnyk_tntu2023.01
*ISSN 2522-4433. Web: **visnyk.tntu.edu.ua***

UDC 004.415

THE USE OF ABSTRACT MOORE AUTOMATON TO CONTROL THE SENSORS OF A SERVICE-ORIENTED ALARM AND EMERGENCY NOTIFICATION NETWORK

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Summary. *The paper aims to achieve the ability of an abstract Moore automaton to control the sensors of a service-oriented alarm system for notification of emergency situations in a metropolis. An important procedure is minimization of the internal settings of the automaton, on the basis of which there will be a graph of transitions to the machine for which a synchronous trigger is turned on – a switch between sensors, - which allows not only to receive information, but also to confirm that it is necessary to notify about the current emergency situation. The relevance of those proves the need for security of living in the urban environment. Constant monitoring of the parameters of the medium is of high necessity. This allows to balance the key factors influencing the system in order to make a sound management decision. The possible ways of using an abstract Moore automaton to control the sensors of a service-oriented alarm system about emergency situations in a metropolis is analysed.*

Key words: *Aufenkamp-Honu algorithm, equivalence, trigger, synchronous transition, graph, signal, combination, parameter.*

https://doi.org/10.33108/visnyk_tntu2023.01.111 *Received 11.01.2023*

The problem formulation. Urbanization not only excessively loads the environment but causes the problems bound with society functioning of in overpopulated cities. One of these issues is the safety of residence places. The problem lies in comprehensive study of parameters that influence the result and make it possible to balance the controlling influences on the system to obtain a considered management solution. This can be achieved through the development of a service-oriented network, which signals the possibility of an emergency situation, a threat to the environment and people, by means of installed sensors which constantly monitor the urban environment.

Analysis of available research results. British Standards Institution embraces all the mentioned by the term ‘Smart City’ [1]. In particular, this notion also denotes keeping the safety of human activity and environment by means of modern information communicative technologies [2]. At the same time, the energy efficiency of networks that transmit information about the state of the studied urban environment is of considerable importance [3]. That is why researchers [4–6] tend to use LoRaWaN technology to build service-oriented networks for notification of emergency situations and critical parameters within the framework of smart city technology [7]. The main problems to be solved in this case are creating of technologies for combining devices into a network and their management [8], as well as developing the models

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of a complex system of the research object [9], where network devices are points-sources of input information [5].

Objective of the research is to study the possible use of the Moore abstract automaton to control the sensors of the service-oriented network of alarm and emergency notification in the metropolis. A well-balanced network device management system allows receiving information without interference, failures and noise, which ultimately leads to efficient network operation. At the same time, the procedure for minimizing the internal states of automaton is important, based on which the transition graph of the automaton is built, after which a synchronous trigger – a switch between sensors – is turned on. This allows not only to obtain data but also to confirm or deny the occurrence of an emergency.

Statement of the problem. This paper considers the task of sensor management of a service-oriented network. The sensors of such a network are of the same type according to the types of tasks. For example, CO_2 carbon dioxide sensors in the residential area of the city. There can be several dozens to hundreds of such network devices in just one district of the metropolis. In addition to sensors, executive devices, controllers and other objects that require control automation with minimization of repetition of the same type of actions are connected to the network.

The use of abstract automaton for algorithmization of processes in service-oriented network requires the division of all states of the original abstract automaton into classes of equivalent states that do not overlap, and the replacement of each equivalence class by one state. According to this approach, it is possible to describe a mathematical model of a system where there are many input actions of the same type, transitions between states that allow to isolate similar input data, and to draw a conclusion for each group of input results, taking into account the limitations caused by transitions between states [10, 11]. That is, a minimum of states and a given output function are obtained. The idea of using an abstract automaton to control the sensors of a service-oriented network arose according to [11].

The given problem can be solved by the Aufenkamp-Hohn algorithm [12] while minimizing the number of internal states of the Milli automaton $S = \{X, Y, A, \lambda, \delta, a_0\}$:

1. Find successive partitions $\pi_1, \pi_2, ..., \pi_K, \pi_{K+1}$, of the set A into classes of one-, two-, ..., K, (K + 1)-equivalent states until at (K + 1) step it will turn out that $\pi_K = \pi_{K+1}$. In this case, the K-equivalent states are equivalent. The number of steps K, at which $\pi_K = \pi_{K+1}$, does not exceed N-1, where N is the number of internal states of the automaton.

2. In each equivalence class π, one representative of the class is selected, which form sets A' of the states of the minimal automaton S'.

3. The function of transitions δ' and outputs λ' of the automaton S' is determined on the set A'xX. For this, in the table of transitions and exits, the columns corresponding to the states included in the set A' are crossed out. The remaining columns of the transition table change their state to the equivalent one from the set A' to the corresponding elements.

4. One of the states equivalent to state a_0 is selected as a'_0.

In the minimization of the Moore automaton, the concept of 0-equivalence of states and the division of the set of states into 0-classes is introduced: any states of the Moore automaton, marked by the same output signals, are called 0-equivalent. For example, minimization of the Moore automaton can be given as follows (Table 1).

Table 1

Table of transitions and outputs of the Moore automaton

Y	y_1	y_1	y_3	y_3	y_3	y_2	y_3	y_1	y_2	y_2	y_2	y_2
A	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}	a_{11}	a_{12}
x_1	a_{10}	a_{12}	a_5	a_7	a_3	a_7	a_3	a_{10}	a_7	a_1	a_5	a_2
x_2	a_5	a_7	a_6	a_{11}	a_9	a_{11}	a_6	a_4	a_6	a_8	a_9	a_8

Then the partition of π_0 will be as follows:

$$\pi_0=\{B_1,B_2,B_3\};$$
$$B_1=\{a_1, a_2, a_8\}, B_2=\{a_6, a_9, a_{10}, a_{11}, a_{12}\}, B_3=\{a_3, a_4, a_5, a_7\}.$$

Accordingly, the partition by π_0 can be presented in the Table 2:

Table 2

Table of partition by π_0

У	B_1			B_2					B_3			
A	a_1	a_2	a_8	a_6	a_9	a_{10}	a_{11}	a_{12}	a_3	a_4	a_5	a_7
x_1	B_2	B_2	B_2	B_3	B_3	B_1	B_3	B_1	B_3	B_3	B_3	B_3
x_2	B_3	B_3	B_3	B_2	B_2	B_1	B_2	B_1	B_2	B_2	B_2	B_2

According to the given algorithm, π_1 is split:

$$\pi_1=\{C_1,C_2,C_3,C_4\};$$
$$C_1=\{a_1, a_2, a_8\}, C_2=\{a_6, a_9, a_{11},\}, C_3=\{ a_{10}, a_{12}\}, C_3=\{a_3, a_4, a_5, a_7\},$$

with the corresponding partition table (Table 3).

Table 3

Table of partition by π_1

У	C_1			C_2			C_3		C_4			
A	a_1	a_2	a_8	a_6	a_9	a_{11}	a_{10}	a_{12}	a_3	a_4	a_5	a_7
x_1	C_3	C_3	C_3	C_4	C_4	C_4	C_1	C_1	C_4	C_4	C_4	C_4
x_2	C_4	C_4	C_4	C_2	C_2	C_2	C_1	C_1	C_2	C_2	C_2	C_2

If perform the partition of π_2, the results will be obtained:

$$\pi_1=\{D_1, D_2,D_3,D_4\};$$
$$D_1=\{a_1, a_2, a_8\}, D_2=\{a_6, a_9, a_{11},\}, D_3=\{ a_{10}, a_{12}\}, D_3=\{a_3, a_4, a_5, a_7\},$$

indicating the completion of the splitting procedure, since the π_2 split repeats the π_1 split. After that, it is sufficient to choose arbitrarily one representative from each equivalence class D_1, D_2, D_3, D_4 – in this case, by the minimum number: $A=\{a_1, a_3, a_6, a_{10}\}$. Then, by removing 'redundant' states from the original table of transitions, the minimum Moore automaton can be determined (Table 4).

Table 4

The minimal Moore automaton obtained according to the Aufenkamp-Hohn algorithm

У	y_1	y_3	y_2	y_2
A	a_1	a_3	a_6	a_{10}
x_1	a_{10}	a_3	a_3	a_1
x_2	a_3	a_6	a_6	a_1

Considering [12], it should be noted that the equivalence of states can be proved using iterative methods, but there may be restrictions on the input values. But for this study, this limitation is not significant, since the states of sensors of the system are clearly defined [13].

Note that, taking into account [14], it would be illogical to stop only at the specified one (Table 4) to solve the given problem, since further decisions are transferred to the plane of human management. And this can cause problems of obtaining relevant data during optimization [15]. That is why it is worth setting a trigger that will direct the sensors to perform actions according to a certain protocol.

For a trigger-type task, a shortened transition table with two information inputs and a full transition table of an asynchronous trigger with two information inputs X and Y are built in practice.

When constructing transition tables of a synchronous trigger, it should be borne in mind that when C = 0, the internal state of the trigger does not change regardless of the states of inputs X and Y, i.e. Q (t + 1) = Q (t), and when C = 1, the synchronous trigger functions as a corresponding asynchronous [16]. Taking this into account, it is possible to obtain both abbreviated and full transition tables of a synchronous trigger.

It should be mentioned that the study of the synchronous trigger was considered in [17], where the prospects of using digital automata in modern systems and networks were pointed out, and it was also noted that a similar task requires multi-faceted analysis in different directions.

Analysis of numerical results. We minimize the abstract Moore automaton designed to control the sensors responsible for monitoring the state of one object in the service-oriented network of emergency and emergency notification in the metropolis and specified by the table of transitions and outputs (Table 5).

Table 5

Table of transitions and outputs

Y	y_1	y_2	y_3	y_4	y_1	y_2	y_4	y_2	y_1	y_1
A \ X	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}
x_1	a_1	a_3	a_6	a_4	a_7	a_5	a_4	a_9	a_7	a_{10}
x_2	a_5	a_1	a_3	a_6	a_{10}	a_9	a_8	a_{10}	a_9	a_5
x_3	a_7	a_4	a_5	a_2	a_8	a_8	a_1	a_3	a_{10}	a_7

We partition $\pi_0=\{B_1,B_2,B_3,B_4\}$. For the Moore automaton π_0 is partitioned by the input signal:

$$B_1=\{a_1, a_5, a_9, a_{10}\},\ B_2=\{a_2, a_6, a_8\},\ B_3=\{a_3\},\ B_4=\{a_4, a_7\}.$$

Construct the π_0 partition table (Table 6).

Table 6

π_0 partition table

	B_1				B_2			B_3	B_4	
A	a_1	a_5	a_9	a_{10}	a_2	a_6	a_8	a_3	a_4	a_7
x_1	B_1	B_4	B_4	B_1	B_3	B_1	B_1	B_2	B_4	B_4
x_2	B_1	B_1	B_1	B_1	B_1	B_1	B_1	B_3	B_2	B_2
x_3	B_4	B_2	B_1	B_4	B_4	B_2	B_3	B_1	B_2	B_1

According to π_0 partition table (Table 6), the partition of π_1 is performed. When performing this partition, the analysis is carried out only within each separate set of B_i:

$$\pi_1=\{C_1, C_2, C_3, C_4, C_5, C_6, C_7, C_8, C_9\}$$
$$C_1=\{a_1, a_{10}\}, C_2=\{a_5\}, C_3=\{a_9\}, C_4=\{a_2\}, C_5=\{a_6\}, C_6=\{a_8\}, C_7=\{a_3\}, C_8=\{a_4\}, C_9=\{a_7\}.$$

Due to the obtained results, the table of partition π_1 is constructed (Table 7)

Table 7

Table of partition of π1

	C_1		C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A	a_1	a_{10}	a_5	a_9	a_2	a_6	a_8	a_3	a_4	a_7
x_1	C_1	C_1	C_9	C_9	C_7	C_2	C_3	C_5	C_8	C_8
x_2	C_2	C_2	C_1	C_3	C_1	C_3	C_1	C_7	C_5	C_6
x_3	C_9	C_9	C_6	C_1	C_8	C_6	C_7	C_2	C_4	C_1

On the basis of the above mentioned table of partition π1, the partition of π2 is performed:

$$\pi_2=\{D_1, D_2, D_3, D_4, D_5, D_6, D_7, D_8, D_9\}.$$
$$D_1=\{a_1, a_{10}\}, D_2=\{a_5\}, D_3=\{a_9\}, D_4=\{a_2\}, D_5=\{a_6\}, D_6=\{a_8\}, D_7=\{a_3\}, D_8=\{a_4\}, D_9=\{a_7\},$$

which ultimately repeats the partition of π_1.

That is, the partitioning procedure can be completed, which makes it possible to create a combined table of transitions with the construction of a graph of transitions and to consider the combinations of the trigger, which will allow transferring the sensors to two stable states (action/stop) and make transitions between them (receiving information, transmitting information, checking own state, saving previous information for control in the cell). These transitions must be performed by all sensors in a certain sequence to ensure the relevance of the information received and transmitted by the service-oriented network.

Results of the research. From each equivalence class, we select one representative of this class. We choose a_1 from the set $D_1 = \{a_1, a_{10}\}$, therefore $a_1 \equiv a_{10}$. In the transitions table, we cross out the column that corresponds to the state of a_{10}, and in the rest of the table, we replace a_{10} with a_1. We obtain a combined table of transitions and outputs of the minimal automaton (Table 8).

Table 8

Combined table of transitions and outputs of the minimal automaton

Y	y_1	y_2	y_3	y_4	y_1	y_2	y_4	y_2	y_1
A \ X	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9
x_1	a_1	a_3	a_6	a_4	a_7	a_5	a_4	a_9	a_7
x_2	a_5	a_1	a_3	a_6	a_1	a_9	a_8	a_1	a_9
x_3	a_7	a_4	a_5	a_2	a_8	a_8	a_1	a_3	a_1

Based on Table 8, it is possible to construct the transition graph of the Moore automaton (Fig. 1).

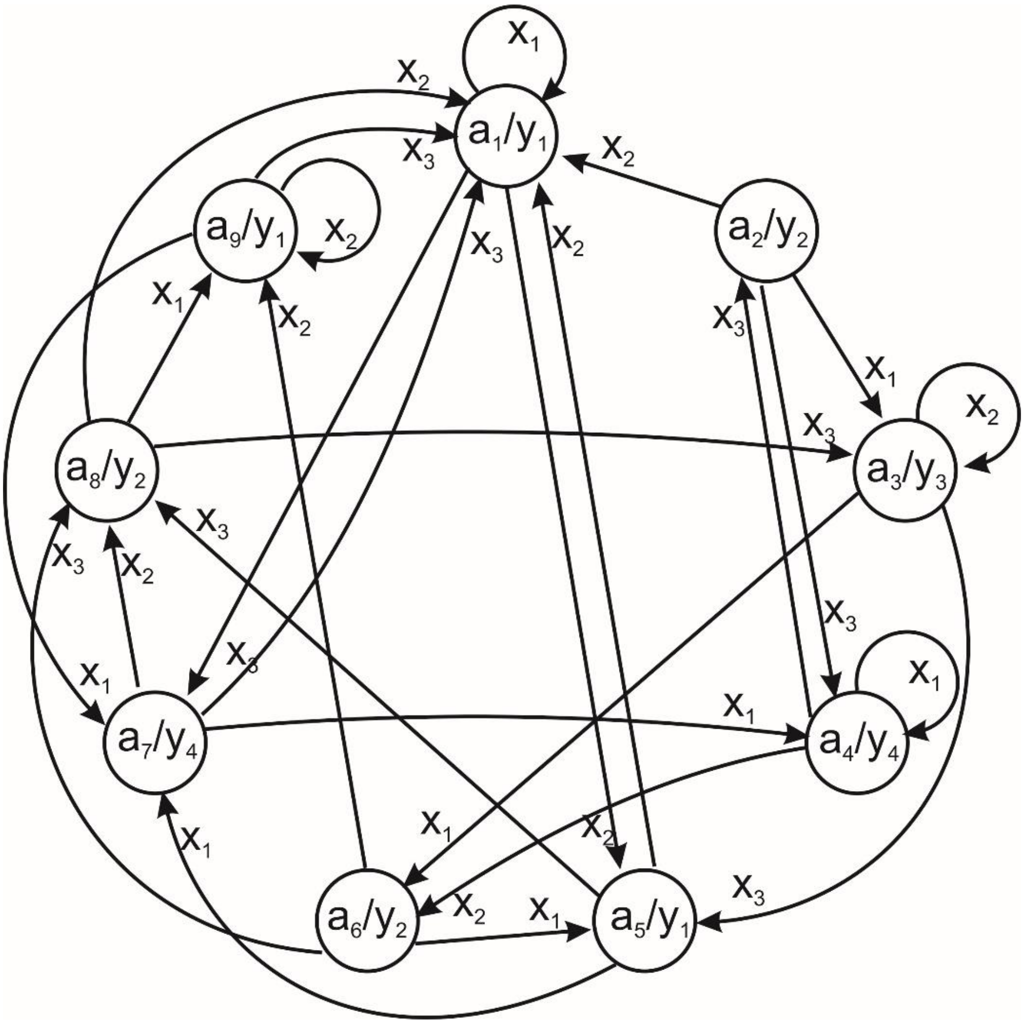

Figure 1. Transition graph of a Moore automaton

The automatic trigger has four possible options for transitions: «0-0», «0-1», «1-0», «1-1». Transitions table (Table 9) and signal combinations table (Table 10) were used to create the network test model.

Table 9

Experimental data of transitions

a) «0-0»

t		(t+1)
X	У	Q
0	0	0
0	1	Q(t)
1	0	$\overline{Q(t)}$
1	1	1

b) «0-1»

t			t+1
X	У	Q	Q
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	1
1	0	0	1
1	0	1	0
1	1	0	1
1	1	1	1

The end of the table

c) «1-0»

t			t+1
C	X	У	Q
0	0	0	Q(t)
0	0	1	Q(t)
0	1	0	Q(t)
0	1	1	Q(t)
1	0	0	0
1	0	1	Q(t)
1	1	0	$\overline{Q(t)}$
1	1	1	1

d) «1-1»

t				t+1
C	X	У	Q	Q
0	0	0	0	0
0	0	0	1	1
0	0	1	0	0
0	0	1	1	1
0	1	0	0	0
0	1	0	1	1
0	1	1	0	0
0	1	1	1	1
1	0	0	0	0
1	0	0	1	0
1	0	1	0	0
1	0	1	1	1
1	1	0	0	1
1	1	0	1	0
1	1	1	0	1
1	1	1	1	1

Table 10

Combination of signals

Q(t)	Q(t+1)	X	У
0	0	0	0
		0	1
0	1	1	0
		1	1
1	0	0	0
		1	0
1	1	0	1
		1	1

It can be noted that according to the transitions table (Table 9, b) there are correspondences to combinations of X and Y signals (Table 10).

Thus:

1. For the transition «0-0» X = 0, Y can be equal to 0 or 1.
2. For the transition «0-1» X = 1, Y can be equal to 0 or 1.
3. For the «1-0» transition, X can be equal to 0 or 1, and Y = 0.
4. For the «1-1» transition, X can be equal to 0 or 1, and Y = 1.

Then the transition matrix of the trigger can be written as follows:

0–0	0	b1
0–1	1	b2
1–0	b3	0
1–1	b4	1

where:

b1, b2, b3, b4 are random signals (0 or 1).

Determining of interdependence between the input variables of the trigger is a mandatory condition that provides the possibility of maximum simplification of circuits with memory, which ultimately also contributes to the energy efficiency of the network.

The obtained results can also be used in the implementation of 3D resumes, which allow personnel selection in real time with transitions between task events depending on the completed/uncompleted previous task. In this case, the trigger type can be RS, and to meet the conditions of the 3D resume, transitions will be made when a unit is submitted to the output upon successful completion of the task with a transition to another stage, or zero in the case of an incorrect response with a transition to questions at a lower level or exit from the testing service.

Conclusions. Within the research conducted by Academician Viktor Glushkov, it was noted about the widespread use of digital automata in various areas of business. Modern informatization and digitalization of society requires new or fundamentally improved approaches to the automation of operations and process management.

The paper analyses the possibility of using Moore's abstract automaton to control the sensors of the service-oriented network of emergency and emergency notification in the metropolis. It has been established that the minimization of the Moore automaton can be solved using the Aufenkamp-Hohn algorithm, which allows to isolate the equivalent state of the automaton: choose arbitrarily from each equivalence class one representative with the minimum number. After that, it is sufficient to remove from the original table of transitions other states that are superfluous for this case and determine the minimum Moore automaton. Then, the matrix of transitions of the trigger is formed, which, in this case, is not only just an action counter, but also triggers the action of the next sensor depending on what the input signal was.

The developed approach and the results obtained from the implementation of the test service-oriented network of notification of emergency and emergency situations in the metropolis allow the use of an abstract Moore automaton to automate the process of surveying sensors with verification of the received information from the source.

The obtained results can also be used in the implementation of 3D resumes, which allow personnel selection in real time with transitions between task events depending on the completed/uncompleted previous task.

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УДК 004.415

ВИКОРИСТАННЯ АБСТРАКТНОГО АВТОМАТА МУРА ДЛЯ УПРАВЛІННЯ ДАТЧИКАМИ СЕРВІС-ОРІЄНТОВАНОЇ МЕРЕЖІ ОПОВІЩЕННЯ ПРО НАДЗВИЧАЙНІ ТА АВАРІЙНІ СИТУАЦІЇ

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Резюме. *Метою роботи є дослідження можливості використання абстрактного автомата Мура для управління датчиками сервіс-орієнтованої мережі оповіщення про надзвичайні та аварійні ситуації в мегаполісі. Важливою є процедура мінімізації внутрішніх станів автомата, на основі чого будується граф переходів автомата, за яким вмикається синхронний тригер – перемикач між датчиками, – що дозволяє не просто отримати інформацію, а й підтвердити чи спростувати настання екстреної ситуації. Актуальність теми підтверджується необхідністю забезпечення безпеки проживання в урбаністичному середовищі. Необхідним є постійний моніторинг параметрів середовища, які дозволяють збалансувати керуючі впливи на систему для отримання зваженого управлінського рішення. Проаналізовано можливість використання абстрактного автомату Мура для управління датчиками сервіс-орієнтованої мережі оповіщення про надзвичайні та аварійні ситуації в мегаполісі. Встановлено, що проведення мінімізації автомата Мура можна вирішити за алгоритмом Ауфенкампа-Хону, що дозволяє вичленувати еквівалентний стан автомата: вибрати довільно з кожного класу еквівалентності по одному представнику за мінімальним номером. Після цього достатньо видалити з вихідної таблиці переходів інші, зайві для даного випадку, стани та визначити мінімальний автомат Мура. Після цього формується матриця переходів тригера, яка, у даному випадку, не лише є просто лічильником дій, а й запускає в дію чергового датчика залежно від того, який був вхідний сигнал. Розвинений підхід та отримані результати з реалізації у тестовій сервіс-орієнтованій мережі оповіщення про надзвичайні та аварійні ситуації в мегаполісі дозволяють використовувати абстрактний автомат Мура для автоматизації процесу опитування датчиків з перевіркою отриманої інформації від джерела. Отримані результати можуть бути також використані при реалізації 3D резюме, які дозволяють здійснювати відбір персоналу в режимі реального часу з переходами між подіями-завданнями залежно від виконаного/невиконаного попереднього завдання.*

Ключові слова: *алгоритм Ауфенкампа-Хону, еквівалентність, тригер, синхронний перехід, граф, сигнал, комбінація, параметр.*

https://doi.org/10.33108/visnyk_tntu2023.01.111 *Отримано 11.01.2023*