Development of an automaton based on rigid logic to control the irrigation system

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Abstract. Managing the distribution of water resources for the southern regions of Russia is of great importance in connection with limiting the consumption of fresh water. The use of saline water can lead to soil salinization and negatively affect crop production. The article deals with the problem of constructing a sequential automaton for controlling the system of switching networks when watering plants on the example of the sanatorium "Rus" in the city of Anapa, Krasnodar Territory. The Mediterranean zone, where the city of Anapa is located, is characterized by a low level of precipitation, which leads to the need for artificial irrigation of plants. The existing irrigation system using a water tank truck based on the GAZ-53 is physically outdated, which required the development of a modern automated system. The flower alleys, located on the territory of the sanatorium, were structured in a tree-like form. The construction of a control device based on rigid logic is based on the Mealy automaton. A method for constructing a control system for a tree-like water supply network has been developed, which makes it possible to control the main, distribution and supply branches. A block diagram of an irrigation machine has been developed, which has a tree-like branching, which shows control signals and states of transitions. Synthesized logical equations for the control of the water supply system, using a blocking control system with feedback. It is proposed to use the Omron programmable logic controller and CX-One software as software and hardware. The distribution of the address space of the controller is shown. Simulation modeling of the system operation was carried out, which showed the correct logic of control over the work of water pressure supply in water pipelines. Implementation of the developed system will improve the quality of irrigation of plants and minimize the cost of irrigation.

1. Introduction
The city of Anapa is located at the junction of the Greater Caucasus and the Taman Peninsula. The climate is characterized by the temperate climatic zone of the Mediterranean zone. Precipitation ranges from 417 to 440 mm per year. The lack of moisture strongly affects the life of plants, which requires the creation of artificial irrigation systems [1,2]. The creation of an irrigation control system is based on the
synthesis of control mechanisms by the example of the "Rus" sanatorium located in the central part of Anapa, Krasnodar Territory. Since the middle of the last century, much attention has been paid to the methods of automatic watering of plants [3–5], but the development of methods for the synthesis of digital control devices for tree-like irrigation systems is also relevant. Previously, the synthesis of a sequential automaton was shown using the example of recognition of tissue and cell pathologies [6,7].

2. Equipment and devices used in studies
Theoretical studies were carried out on the basis of the analysis and synthesis of the construction of digital devices using rigid logic. A practical solution is based on the construction of ladder circuits for programming an industrial controller using the open standard IEC 61131.3.

3. The results of the study and their discussion

3.1. Study of the existing irrigation system
On the flower beds of the "Rus" sanatorium, various flowers are grown that grow in the southern and central regions of Russia, including the Volga region (mainly Marigolds, Coleus and Iris), which need artificial irrigation. Lack of moisture leads to drying out of the soil and oppression of plants (figures 1-3).

![Figure 1. Optimal watering of plants.](image1)  ![Figure 2. Permissible watering of plants.](image2)  ![Figure 3. Lack of moisture led to drying out of the soil.](image3)

The sanatorium "Rus" has one main alley with the intersection of the central and lateral alley. Currently, a GAZ-53 vehicle with a tank is used for the irrigation system (figure 4). There is a need to develop an automated irrigation system.

![Figure 4. Water tanker based on GAZ-53.](image4)

3.2. Synthesis of automatic control system for irrigation
To construct the control automaton, the alley scheme was presented in the form of a structural model (figures 5-6). Figure 5 shows an alley layout containing a central main alley - A, a central perpendicular alley - B, and a side alley - C. Figure 6 shows a tree structure model.
The developed logic diagram of the automatic watering machine, taking into account the model of the tree-like structure of the alleys (figure 6), is shown in figure 7.

Each branch of the tree uses a logic diagram of the state of the switches. When a pulse arrives to activate the output signal, the control is also energized via the blocking branch. Turning off water
pipelines is carried out using signals - pA, pB and pC to the first (main) branches of the water supply system.

Let us describe the control signals of the sequential automaton controlling the main water supply system (level 1) using table 1.

**Table 1.** Coding of switches of main water pipelines.

| On p₂ p₁ | Off     | Main line       | Logical equation                  |
|----------|---------|-----------------|-----------------------------------|
| 0 0      | 0 (pA)  | Main basic      | \( A = (\overline{p}_2 \cdot \overline{p}_1 \lor A) \cdot pA \)          |
| 0 1      | 0 (pB)  | Secondary       | \( B = (\overline{p}_2 \cdot p_1 \lor B) \cdot pB \)                      |
| 1 0      | 0 (pC)  | Side            | \( C = (p_2 \cdot \overline{p}_1 \lor C) \cdot \overline{pC} \)          |

An example of the coding of the switches for the distribution and supply lines of the main water supply system A is shown in tables 2 and 3.

**Table 2.** An example of the coding of the distribution pipe switches main water supply A.

| r₂ r₁  | Distribution pipelines | Logical equation |
|--------|------------------------|------------------|
| 0 0    | Center top             | \( A_1 = (\overline{r}_2 \cdot \overline{r}_1 \lor A_1) \cdot A \) |
| 0 1    | Central                | \( A_2 = (\overline{r}_2 \cdot r_1 \lor A_2) \cdot A \)         |
| 1 0    | Center bottom          | \( A_3 = (r_2 \cdot \overline{r}_1 \lor A_3) \cdot A \)          |

**Table 3.** An example of the coding of the switches of the supply branches of the distribution water pipe A1.

| n₂ n₁  | Supply pipelines       | Logical equation |
|--------|------------------------|------------------|
| 0 0    | Top (left)             | \( A_{11} = (\overline{n}_2 \cdot \overline{n}_1 \lor A_{11}) \cdot A \) |
| 0 1    | Central                | \( A_{12} = (\overline{n}_2 \cdot n_1 \lor A_{12}) \cdot A \)       |
| 1 0    | Bottom (right)         | \( A_{13} = (n_2 \cdot \overline{n}_1 \lor A_{13}) \cdot A \)       |

The coding of the switches of the distributing and supplying branches of the water pipes B and C is similar.

To develop the program, we will enter the addresses of the elements of the ladder-contact circuit when programming the OMRON CP1L controller (table 4).

**Table 4.** Addresses of the elements of the control signals of the relay-contact circuit.

| Switch | Appointment                  | Address |
|--------|------------------------------|---------|
| p₁     | Management of pipelines Main line | 0.04    |
| p₂     |                              | 0.03    |
| pA     |                              | 0.06    |
| pB     | Turning off the water pressure | 0.07    |
| pC     |                              | 0.08    |
| r₁     | Distribution water supply control | 5.01    |
| r₂     |                              | 5.02    |
| n₁     | Water supply control         | 6.01    |
| n₂     |                              | 6.02    |

A fragment of the ladder circuit built according to the IEC61131.3 standards is shown in figure 8. The ladder circuit was developed using the CX-Programmer software.
3.3. Irrigation system simulation
In order to check the correctness of the algorithms, a simulation of the operation of the irrigation scheme was carried out (table 5), which shows the inclusion of the branches of the main water pipeline A. When the water pressure is applied, the feedback with the active coil is activated. Watering is turned off by giving a control signal on the main water supply.

Table 5. Simulation of the automatic irrigation.

| Circuit simulation | Explanation of how the circuit works |
|--------------------|--------------------------------------|
| Water pressure supply in the main water supply A | Water pressure switch is activated in the main pipelines A |
| Water supply in distribution pipe A1 | The water pressure switch is activated in the main pipelines A |
| Water supply in supply lines A11 and A12. The A11 branch is managed through a lock. | |

For further automation of the process of irrigation of plants, it is possible to install sensors of soil moisture, optical observation of plants, which will fully automate the irrigation process [8].
4. Conclusions
The article has developed a technique for constructing an automaton based on rigid logic for a tree-like structure of an object. On the example of the development of an irrigation system, logical schemes of transitions and states have been developed. The PLC program is written in Ladder Diagram language using IEC 61131 Part 3. The simulation of the circuit showed the correct logic of the system. The implementation of this project will allow the introduction of a modern control system for irrigation of plants in the sanatorium "Rus" in Anapa.

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