

# *Cognitive Distributed Computing System for Intelligent Agriculture*

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**Abstract** – This paper contains the obtained results in the research and design of cognitive systems with distributed computing and its applying in Intelligent Agriculture. Only some aspects of Intelligent Agriculture related to the organization of the irrigation process and the efficient use of water resources are approached. The functionality of the system is based on the development of a network of data processing nodes and local control of the water distribution process. The architecture of the distributed computing system presents a network of nodes with Mesh topology, in which the computing power is evenly distributed. Fuzzy logic models and Neural Networks are used as data processing and knowledge interpretation models. The paper presents: how to define the irrigation space for Smart Agriculture, mathematical models, the result of designing data processing and water distribution nodes, sequence diagram, and a case study that explains how the distributed computing system with cognitive properties works.

**Keywords** – Distributed Computing, Data Processing Node, Cognitive Systems, Fuzzy Logic, Neural Networks, Intelligent Agriculture, Automatic Irrigation, Efficient Use Of Water.

## I. INTRODUCTION

The Republic of Moldova, being mainly a country with an agrarian economy, is increasingly subject to climatic phenomena, which define the state of dry or droughty. These phenomena are triggered by several factors of nature, namely: low atmospheric precipitation, limited water supply in the soil accessible to plants, low humidity and high air temperature, high wind speed, etc. As an example, due to the drought, in 2020, many regions of the Republic of Moldova suffered very high economic losses, which reached up to 100% of the planned (forecasted) harvest, with a territorial coverage of over 50% of the republic's area.

The drought phenomenon affects almost all countries whose economies are oriented towards agricultural production. For these reasons, in the last 10 years, scientific research has been intensified towards the development of intelligent irrigation systems to ensure the efficient distribution, transportation and use of water resources. These systems are based on the most advanced technologies in the field of computer science and communications

An IoT - based irrigation process monitoring system is also described in paper [3], the functionality of which is based on the analysis of several saturation parameters of the irrigation process as well as the water and electricity consumption.

Recently, there has been a trend in the development of smart farms [4], the aim of which is to rapidly increase the quality and quantity of agricultural crops, taking into account limited water resources, optimizing the use of pesticides and labor. The ideas developed in the paper are oriented towards the application of the most modern technologies in the field to obtain a reliable agriculture based on IoT, by integrating the technologies offered by: Wireless Sensor Networks (WSN), Cloud Computing, Data Mining and others.

From the above we can mention the fact that the functioning of an intelligent irrigation system is based on techniques and technologies offered by Wireless Sensor Networks (WSN) [5, 6], which ensure a distributed / concurrent processing of data [7] and the organization of data exchange between system components, and respectively, mathematical models based on Artificial Intelligence [8] (Neural Networks, Fuzzy Logic, Genetic Algorithms, Knowledge-Based Models, etc.), which ensure the functional and decisional logic of the system.

This paper proposes the design of a distributed computing system with cognitive properties for application in the control of irrigation processes in Intelligent Agriculture. The concept of the system is based on the functionality of sensor networks [9] which performs a collective / distributed computing algorithm [10, 12] with adaptive properties [11] to the current state of the irrigation process and the functionality of its components.

II. THE STATEMENT OF THE DESIGN PROBLEM

Let be defined the space  $OXY$  of the Intelligent Agriculture (Figure 1), which includes: the set of data processing and water distribution nodes (Data Processing and Water Distribution Nodes)  $DPN = \{DPN_{j,i}, \forall (j = \overline{1, J}, i = \overline{1, I})\}$ , where  $j \in [OY]$  which shows the discrete coordinate of the position  $DPN$  one the axis  $OY$ , and  $i \in [OX]$  which shows the discrete coordinate of the position  $DPN$  on the axis  $OX$ ; the set of communication and water transport systems (Communication and Water Transport Systems)  $CWT = \{CWT_{j,i}, \forall (j = \overline{1, J}, i = \overline{1, I} \& j \neq i)\}$ ; Central Control Unit  $CCU$ ; water storage tank (Water Storage)  $WS$ .

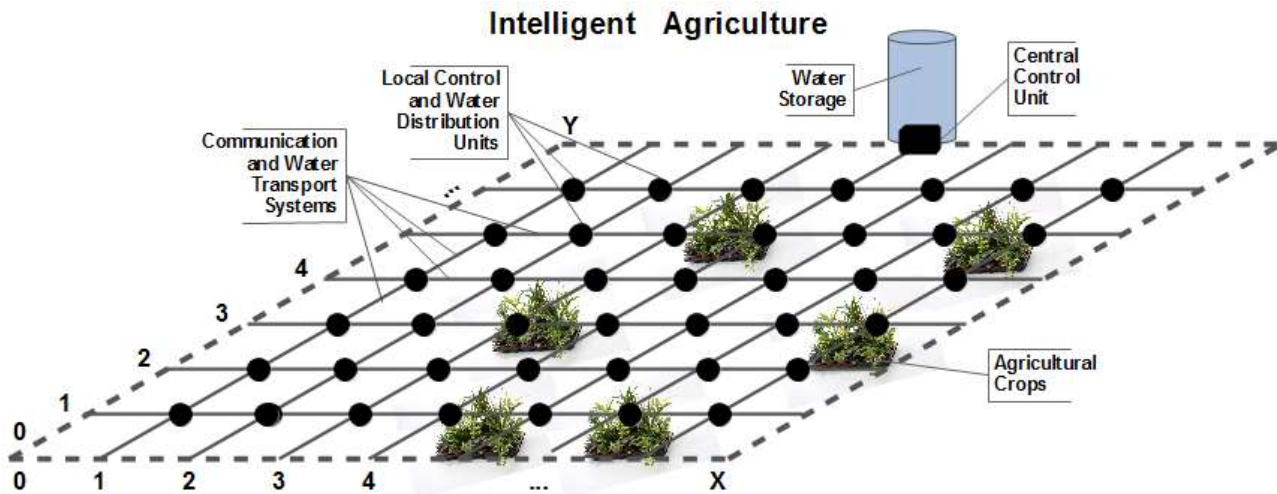


Figure 1. The defined space for Intelligent Agriculture.

The set of data processing and water distribution nodes  $DPN$  through the multitude of communication and water transport systems  $CWT$  forms a distributed computing network (with Mesh topology) and a network of pipelines for water transport.

The functioning of the distributed computing cognitive system for Intelligent Agriculture consists of the following operations:

- the set of nodes for data processing and water distribution  $DPN = \{DPN_{j,i}, \forall (j = \overline{1, J}, i = \overline{1, I})\}$  acquires the status information of the controlled area, which includes: air and soil humidity, and air and soil temperature;

- each node  $DPN_{j,i}, \forall (j = \overline{1, J}, i = \overline{1, I})$  analyzes the acquired information and in relation to the knowledge accumulated in the operation process generates information for the central control unit  $CCU$  and all data processing and water distribution nodes  $DPN$  located in the vicinity;
- central control unit  $CCU$  accumulates status information from all data processing and water distribution nodes  $DPN$ , analyzes the information and in relation to their condition, if necessary, initiates an irrigation process;
- based on the information accumulated and the knowledge available for each data processing and water distribution node  $DPN$  updates its knowledge, which will be the basis for the next decision-making operations.

### III. MATHEMATICAL MODEL

At the basis of the functioning of the cognitive system with distributed computing for Intelligent Agriculture is the mathematical model (1):

$$IA = \{S, D, K(F), U, K(W), Q(D, V, E) \rightarrow \min, Q(D, C) \rightarrow \max\}, \quad (1)$$

where:  $S = \{S_{j,i}, \forall (j = \overline{1, J}, i = \overline{1, I})\}$  it is the state of space  $OXY$  consisting of states  $S_{j,i}$  generated by each data processing and water distribution node  $DPN = \{DPN_{j,i}, \forall (j = \overline{1, J}, i = \overline{1, I})\}$ ;

$D = \{D_{j,i}, \forall (j = \overline{1, J}, i = \overline{1, I})\}$  is the state vector generated by each data processing and water distribution node  $DPN = \{DPN_{j,i}, \forall (j = \overline{1, J}, i = \overline{1, I})\}$ , which is transmitted to the central control unit  $CCU$ ;

$K(F) = \{K(F)_{j,i}, \forall (j = \overline{1, J}, i = \overline{1, I})\}$  is the knowledge applied by each data processing and water distribution node  $DPN = \{DPN_{j,i}, \forall (j = \overline{1, J}, i = \overline{1, I})\}$  for performing operations based on Fuzzy Logic. This knowledge ensures the operation  $S_{j,i} \xrightarrow{K(F)_{j,i}} D_{j,i}, \forall (j = \overline{1, J}, i = \overline{1, I})$ ;

$U = \{U_{j,i}, \forall (j = \overline{1, J}, i = \overline{1, I})\}$  is the control vector generated by each device  $LCW = \{LCW_{j,i}, \forall (j = \overline{1, J}, i = \overline{1, I})\}$  to control the water distribution process;

$K(W) = \{K(W)_{j,i}, \forall (j = \overline{1, J}, i = \overline{1, I})\}$  are the knowledge applied by each data processing node  $DPN = \{DPN_{j,i}, \forall (j = \overline{1, J}, i = \overline{1, I})\}$  for performing operations based on Neural Network models. This knowledge ensures the operation  $D \xrightarrow{K(W)_{j,i}} U_{j,i}, \forall (j = \overline{1, J}, i = \overline{1, I})$ ;

$Q(D, V, E) \rightarrow \min$  - it is the quality function that ensures the minimization of water and energy consumption;

$Q(D, C) \rightarrow \max$  - it is the quality function that ensures the quantity and quality of agricultural products.

### IV. SYNTHESIS OF THE DATA PROCESSING AND WATER DISTRIBUTION NODE

The structure of the data processing and water distribution node  $DPN$  is shown in Figure 2. This diagram shows an intersection of the pipes and the water sprayer, and the connection diagram of the valves to control the water distribution direction. Data processing node  $DPN$  generates discrete signals (**ON/OFF**), which open or close the respective valves to control the direction of water distribution.

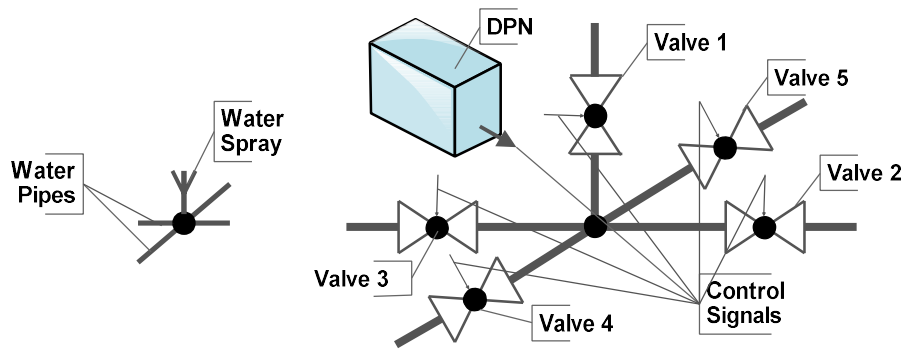


Figure 2. The structure of the data processing and water distribution node.

**Synthesis of the Data Processing Node.**

The functional diagram of the data processing node is shown in Figure 3, where it is indicated: the set of sensors  $S1...S4$  with functions for identifying the temperature and humidity of the soil, and the temperature and humidity of the soil; input interface  $II$  with analog-to-digital conversion and data adaptation functions; data processing block  $S_{j,i}$  based on knowledge  $K(F)_{j,i}$  which presents models of Fuzzy logic; stack memory  $M\{D_{j,i}[\Delta T]\}$  for storing the set of Fuzzy values  $D_{j,i}$  on the period of time  $\Delta T$ ; stack memory  $M\{D[\Delta T]\}$  for storing the set of Fuzzy values  $D$  on the period of time  $\Delta T$ ; data processing block  $D$  based on knowledge  $K(W)_{j,i}$  which presents models of Neural Networks; output interface  $OI$  with functions to amplify the control signals, which act on the control valves ( $Valve1...Valve5$ ) of the water distribution direction, through  $A1...A5$ ; knowledge update block  $K(F)_{j,i} \xrightarrow{G(S_{j,i}, K(F)_{j,i}, D_{j,i}[\Delta T])} K(F)_{j,i}$  for data processing  $S_{j,i}$  based on Fuzzy Logic models; knowledge update block  $K(W)_{j,i} \xrightarrow{G(U_{j,i}, K(W)_{j,i}, D[\Delta T])} K(W)_{j,i}$  for data processing  $D$  based on Neural Network models (it is an operation of updating the coefficients  $W$ ); communication block  $WiFi COM$  for the exchange of data between the set of data processing nodes  $DPN$  and the central control unit  $CCU$ .

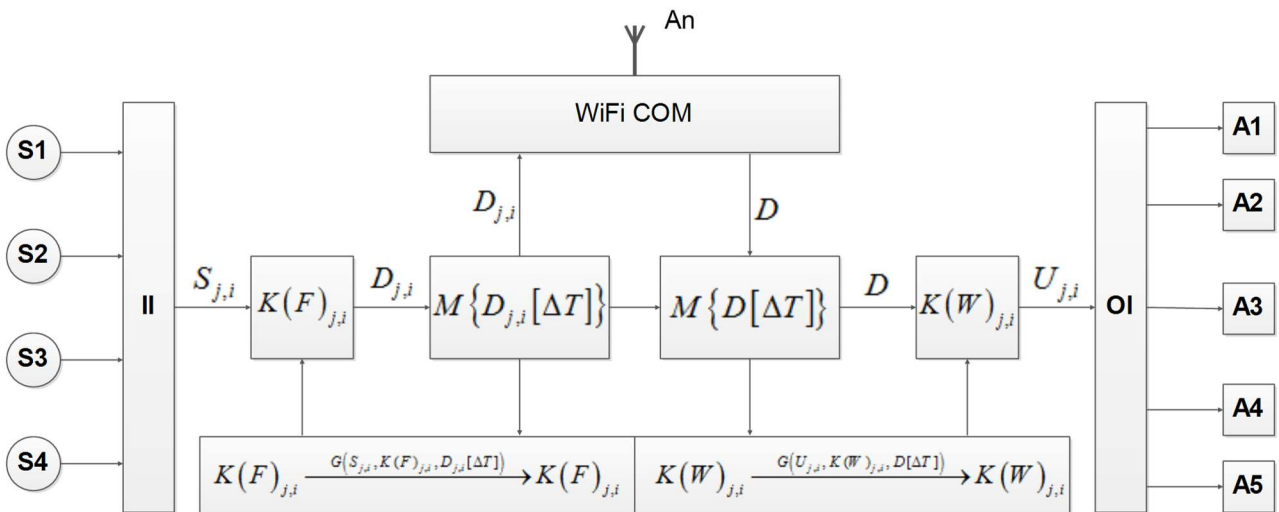


Figure 3. Functional diagram of the data processing node.

Mathematical model for data processing  $S_{j,i}$  based on Fuzzy logic it is presented in formula (2):

$$K(F)_{j,i} : D_{j,i} = \begin{cases} d_{j,i}^1 | S_{j,i} \in S_{j,i}^1; \\ d_{j,i}^2 | S_{j,i} \in S_{j,i}^2; \\ d_{j,i}^3 | S_{j,i} \in S_{j,i}^3; \\ d_{j,i}^4 | S_{j,i} \in S_{j,i}^4; \\ d_{j,i}^5 | S_{j,i} \in S_{j,i}^5. \end{cases} \quad (2)$$

The mathematical model (2) provides 5 types of classification of the state values identified by the sensor set  $S_1...S_4$ . Application of a knowledge update algorithm  $K(F)_{j,i}$  allows you to select the optimal values for  $S_{j,i}^1...S_{j,i}^5$  o ensures the quality conditions set out in expression (1). Neural Network Model for data processing  $D$  is shown in Figure 4.

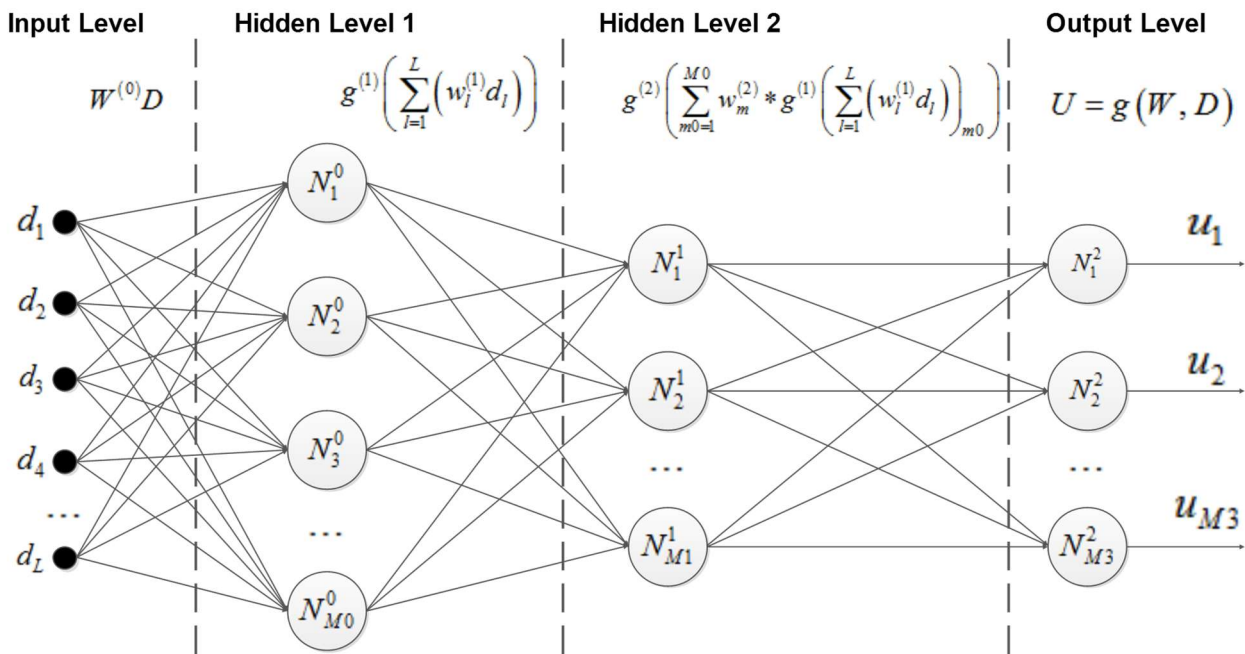


Figure 4. Neural Network Model.

The Neural Network model includes 4 levels:

**Input Level** – forms the input vector  $D$  of the data processing and water distribution node  $DPN_{j,i}$ ;

**Hidden Level 1** – selects and groups the importance of the input vector values  $D$  for decisions made by the device  $DPN_{j,i}$  in configuration and the respective state conditions;

**Hidden Level 2** – calculates the route of interconnection of water pipes to ensure its transport to the device  $DPN_{j,i}^*$  selected by the central control unit  $CCU$  for irrigation;

**Output Level** – in relation to the calculated route, control decisions are made with the valves to direct the water in the required direction.

Node  $DPN_{j,i}$  valve control signals  $U$  are calculated based on the mathematical model (3):

$$K(W)_{j,i} : u_{m3} = g^{(3)} \left( \sum_{m1=1}^{M1} \left( w_{m1}^{(3)} * g^{(2)} \left( \sum_{m0=1}^{M0} w_{m0}^{(2)} * g^{(1)} \left( \sum_{l=1}^L (w_l^{(1)} d_l) \right) \right) \right) \right), \forall m3 = \overline{1,5} \quad (3)$$

V. THE FUNCTIONING OF THE COGNITIVE SYSTEM WITH DISTRIBUTED COMPUTING FOR INTELLIGENT AGRICULTURE

Interaction between Data Processing and Water Distribution Nodes *DPN* , and the central control unit *CCU* is presented based on the sequence diagram (Figure 5). The sequence diagram shows that most operations are performed in parallel by all *DPN* and *CCU* .

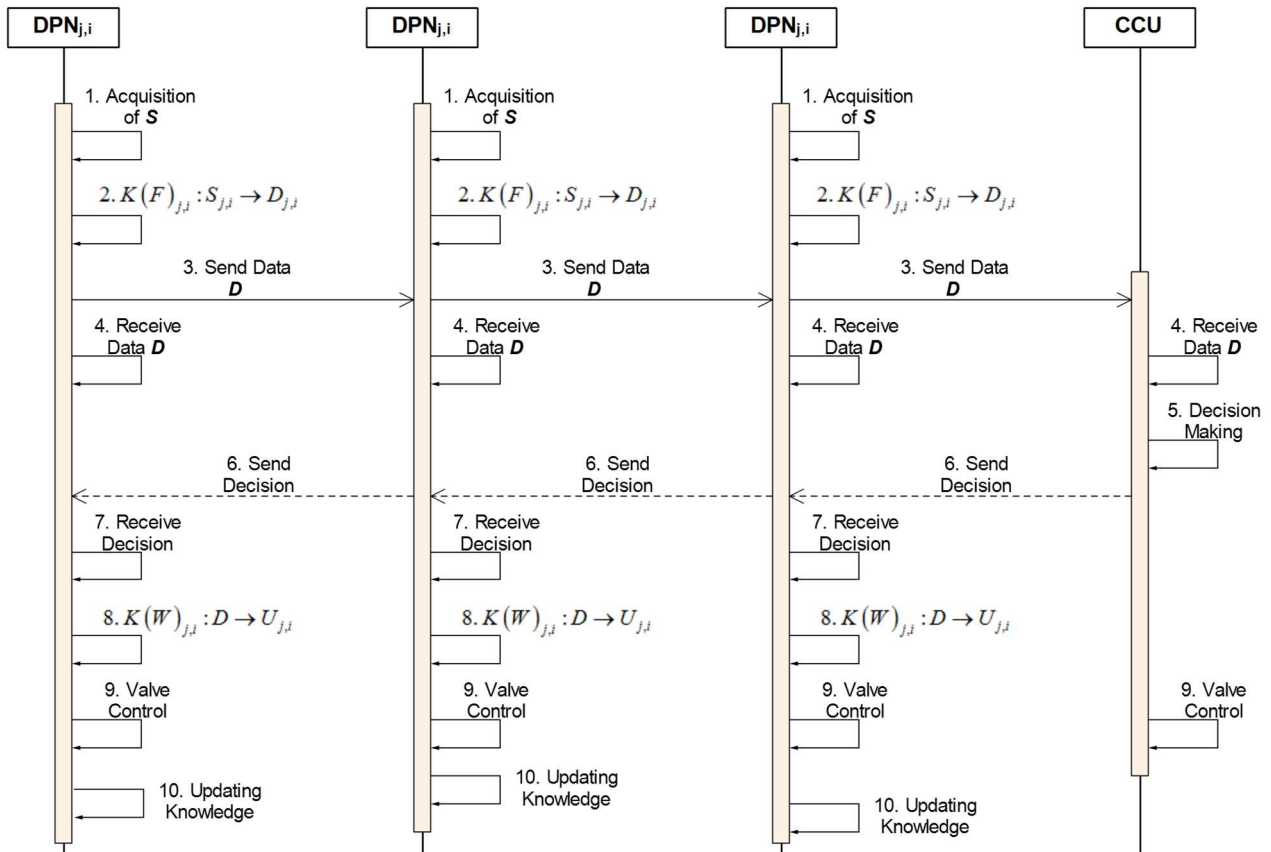


Figure 5. Sequence diagram.

Specifying the operations performed by the data processing nodes *DPN* and the central computing device *CCU* :

1. Acquisition of status signals *S* of the irrigation process;
2. Input signal *S* processed based on the mathematical model (2);
3. Transmission of vector *D* component data;
4. Reception of the vector *D* ;
5. Calculating and making decisions based on mathematical models:  $Q(D, V, E) \rightarrow \min$  and  $Q(D, C) \rightarrow \max$  ;
6. Transmission by the central control unit *CCU* of the calculated decision;
7. Decision reception by the data processing and water distribution nodes *DPN* ;
8. Vector *D* data processing based on the mathematical model (3) achieved on the basis of the Neural Network shown in Figure 4;
9. Generating the control signals *U* with valves to ensure the transport of water to the destination point;

10. Updating knowledge  $K(F)_{j,i}$  and  $K(W)_{j,i}$ .

VI. CASE STUDY

Is given the space  $OXY$  of Intelligent agriculture (Figure 1), which contains  $6 * 7$  data processing and water distribution nodes  $DPN$ . As a result of the performed measurements, were obtained the state values generated by the set of sensors  $S$  (air temperature and humidity, soil temperature and humidity) (Table 1).

Table 1. The obtained results from the set of sensors  $S$ .

$S_{j,i}$	1	2	3	4	5	6	7
1	27;42;32;65	27;42;33;60	27;42;33;60	27;42;33;63	27;42;32;63	27;42;32;63	27;42;32;60
2	27;42;32;65	27;42;33;60	27;42;33;60	27;42;33;63	27;42;32;63	27;42;32;63	27;42;32;63
3	27;42;32;65	27;42;30;75	27;42;30;75	27;42;30;75	27;42;30;75	27;42;32;63	27;42;32;63
4	27;42;32;64	27;42;32;60	27;42;32;60	27;42;32;60	27;42;32;63	27;42;32;53	27;42;32;63
5	27;42;32;67	27;42;33;60	27;42;32;65	27;42;32;65	27;42;32;65	27;42;32;55	27;42;32;65
6	27;42;33;60	27;42;33;60	30;22;36;15	27;42;33;69	27;42;32;65	27;42;33;58	27;42;32;64

From Table 1 it is observed that the data processing and water distribution node  $DPN_{6,3}$  identified the most critical state values of the plant growth process. As a result of data processing by the central control unit  $CCU$  was made the decision to irrigate the area defined by the coordinates  $6, 3$  ( $DPN_{6,3}$ ). After applying the mathematical model (3), based on Neural Networks, were generated the following control signals  $U$  with valves (according to Figure 2 in the respective order: Valve 1, Valve 2, Valve 3, Valve 4, Valve 5), to ensure the transport of water in the area with the coordinates  $6, 3$  (Table 2).

Table 2. Valve control signals.

$DPN_{j,i}$	1	2	3	4	5	6	7
1	0;0;0;0;0	0;0;0;0;0	0;0;0;0;0	0;0;0;1;1	0;0;0;0;0	0;0;0;0;0	0;0;0;0;0
2	0;0;0;0;0	0;0;0;0;0	0;0;0;0;0	0;0;0;1;1	0;0;0;0;0	0;0;0;0;0	0;0;0;0;0
3	0;0;0;0;0	0;0;0;0;0	0;0;0;0;0	0;0;0;1;1	0;0;0;0;0	0;0;0;0;0	0;0;0;0;0
4	0;0;0;0;0	0;0;0;0;0	0;0;0;0;0	0;0;0;1;1	0;0;0;0;0	0;0;0;0;0	0;0;0;0;0
5	0;0;0;0;0	0;0;0;0;0	0;0;0;0;0	0;0;0;1;1	0;0;0;0;0	0;0;0;0;0	0;0;0;0;0
6	0;0;0;0;0	0;0;0;0;0	1;1;0;0;0	0;0;1;0;1	0;0;0;0;0	0;0;0;0;0	0;0;0;0;0

As a result of the activation of the valves according to Table 2, was obtained the water transport route which is shown in Figure 6



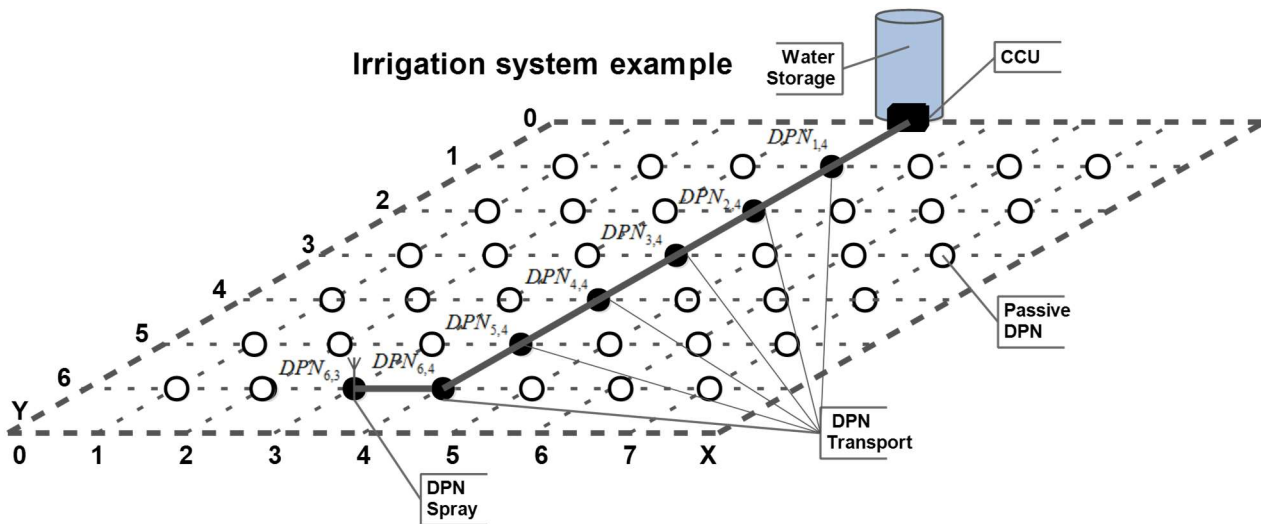


Figure 6. Obtaining the water transport route.

The information presented in Tables 1 and 2 is also used in the learning process of the cognitive system with distributed computing for Intelligent Agriculture.

The content of Table 1 is used to optimize the values  $S_{j,i}^1 \dots S_{j,i}^5$  from the mathematical model (2), which ensures the quality conditions defined in model (1).

The content of Table 2 is used in the learning process of Neural Networks of the data processing and water distribution node *DPN*.

### VII. CONCLUSION

The accomplished research in this paper has the object to solve some specific problems for most countries whose economy is oriented towards agricultural production. The basic idea developed in the paper is to automate the plants' irrigation process and to ensure the efficiency of water consumption by applying a cognitive system with distributed computing that is a part of the complex structures of Intelligent Agriculture.

The functionality of the distributed computing cognitive system is determined by a multitude of data processing nodes, which form a Mesh network topology, and a central data processing device. Data processing nodes perform operations to identify the state of the monitored agricultural area, apply Fuzzy logic models to process this data and transform it into Fuzzy values that are communicating between the system nodes and the central data processing device. The central data processing device analyzes the data obtained on the basis of which the decision is made to initiate the irrigation process for the data processing node with critical state conditions. As a result of the decision, an interconnection is formed between the data processing and water distribution nodes that ensure the transport of water to the area with critical state conditions.

The functional logic of the distributed cognitive data processing system for Intelligent Agriculture is based on Fuzzy and Neural Network logic models, the coefficients of which are updated at each data processing step.

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