

# *Adaptive Computing System for Distributed Process Control*

Victor Ababii, Viorica Sudacevschi, Rodica Braniste, Ana Turcan,

Constantin Ababii, Silvia Munteanu

Computer Sciences and Systems Engineering Department

Technical University of Moldova, Chisinau, Republic of Moldova



**Abstract** – This paper is dedicated to solve some issues related to climate change that negatively affect the productivity and quality of agricultural products. Agricultural production processes are spatially distributed processes and require a special approach in the development of control systems. The paper proposes the development of an adaptive computing system based on Intelligent Agents. Two types of Agents are defined with functions of perceiving the controlled process and with functions of action on the process. The set of Agents forms a mesh network that ensures the communication between them in order to exchange the decisions taken by each Agent. The decisions generated by the multitude of Agents are based on the application of the knowledge and mathematical models on which the Fuzzy Logic and the Neural Networks are based. The functionality of the Agents and the system as a whole is demonstrated on the basis of the functional schemes and the sequence diagram specifying the mode of communication and the sequence of operations performed by the set of Agents. The adaptation of the system to the agricultural production process takes place by updating the knowledge at each decision-making cycle.

**Keywords** – Climate change, Intelligent Agents, Intelligent Agriculture, Distributed Process, Fuzzy Logic, Neural Networks.

## I. INTRODUCTION

The rapid climate changes that are taking place on the Earth planet, and their evolution forecasts, show a negative influence on agriculture that will be negatively reflected on food security and quality water supply in the coming period [1, 2]. At the same time, can be mentioned the negative influence of the COVID-19 pandemic situation on agriculture, expressed by reducing the access of human personnel on agricultural lands and their involvement in the production process. All this requires the application of new control methods in agriculture based on adaptive models and architectures, in particular the application of systems based on Artificial Intelligence [4] and systems based on Intelligent Agents [5].

Numerous scientific papers address this issue in which various monitoring and control systems specific to the field of agriculture are developed. The paper [6] proposes the design of an intelligent information management system in

agriculture based on the Internet of Things (IoT). At the basis of this paper is the concept of Agricultural Information Technology (AIT) which provides for the application of modern methods and techniques of acquisition, communication, storage and processing the information by applying intelligent algorithms. As a result of the application of the AIT concept is the integration of all services in a Digital Agriculture (DA) system that provides monitoring and control services.

Another paper dedicated to this field of research is [7], which proposes an analysis of how to apply a wireless sensor network (WSN), based on LORA technology, in the development of intelligent monitoring services in agriculture. A functional extension for application in Intelligent Agriculture is also described in the paper [8] that provides control services, based on IoT technology, and the detection and classification of diseases using image processing of plant leaves.

A study of an intelligent IoT-based system for agriculture is also described in the paper [9]. This system offers a method of cultivating plants, through minimal human involvement, in which are automatically controlled such soil parameters as: humidity, temperature, pH, etc. The application of an automatic learning algorithm allows to prevent the possibility of plant disease.

This paper proposes the design of an adaptive calculation system to control the distributed plant growth processes (agricultural production) for an Intelligent Agriculture. The control system is based on a multitude of Agents, which monitor the qualitative and quantitative parameters of the

plant growth process, while ensuring the optimization of resource consumption (energy, water and mineral fertilizers, etc.) in order to obtain maximum profit.

**Statement of the design problem**

The design of the adaptive computing system to control the distributed processes with application in agriculture presents a continuation of the research carried out in the field of Multi-Agent systems [10, 12, 15], sensor networks [13, 14], collective computing systems [11, 14] and collective decision-making systems [11, 12, 15].

Let the agricultural production process  $PA$  is defined:

$$PA = \{X, A, Y, U, K, F, Q(U) \rightarrow \min, Q(F) \rightarrow \max\}, \tag{1}$$

where:  $X = \{x_i, \forall i = \overline{1, N}\}$  - the set of values that determine the state of the production process;  $A = A^X \cup A^U$  - the set of Agents involved in controlling the production process,  $A^X = \{A_i^X, \forall i = \overline{1, N}\}$  - is the sub-set of Agents with functions to identify (Perceive) the state of the production process and  $A^U = \{A_j^U, \forall j = \overline{1, M}\}$  - is the sub-set of Agents with functions to action (Actuators) on the production process;  $Y = \{Y_i, \forall i = \overline{1, N}\}$  - the multitude of decisions generated by the Agents  $A^X$ ;  $U = \{U_j, \forall j = \overline{1, M}\}$  - the multitude of decisions generated by the Agents  $A^U$ ;  $K = K^X \cup K^U$  - the set of knowledge that each Agent possesses:  $K^X$  for  $A^X$  and respectively  $K^U$  for  $A^U$ ;  $F = \{F_l, \forall l = \overline{1, L}\}$  - the final products obtained as a result of the application of the production process;  $Q(U) \rightarrow \min$  - mathematical model for minimizing resource consumption;  $Q(F) \rightarrow \max$  - the mathematical model for obtaining a maximum profit.

The purpose of implementing the model (1) is to gradually move from the Traditional Agriculture (TA) to Smart Agriculture (SAG) or Digital Agriculture (DAg).

**II. DESIGNING THE AGENTS**

An Agent presents a logical structure with functions of perceiving the state of the process, storing and processing data, communicating with other Agents, making decisions based on the intelligent algorithms and acting on the controlled process.

The set of Agents consists of two sub-sets  $A = A^X \cup A^U$ , where:  $A^X \cap A^U \neq \emptyset$  which means that the functions of a process action agent  $A^U$  can be merged with the functions of a process status identifier Agent  $A^X$ .

The functional diagram of the Agents for identifying the state of the process is presented in Figure 1.

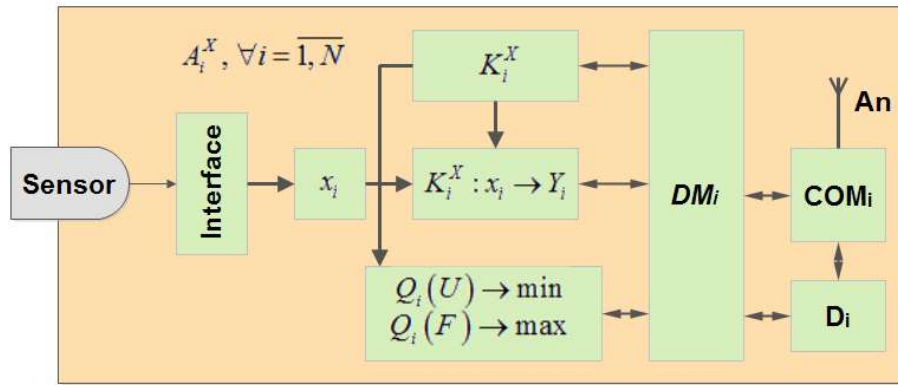


Figure 1. Agents' functional diagram for identifying the status of the process.

Each Agent  $A^X = \{A_i^X, \forall i = \overline{1, N}\}$  with process status identification functions includes: **Sensor** for perceiving the process status parameter; **Interface** for signal adjustment, Analog-Digital Conversion and data normalization;  $x_i$  - process status, parameter value  $i$ ;  $K_i^X$  - the knowledge base accumulated by the Agent in the process of operating the system;  $K_i^X : x_i \rightarrow Y_i$  - data processing based on

mathematical model (2) and knowledge  $K_i^X$ ;  $Q(U) \rightarrow \min$  and  $Q(F) \rightarrow \max$  - mathematical models for optimizing the control process;  $DM_i$  - the decision-making block;  $D_i$  - data storage;  $COM_i$  - wireless communication block;  $An$  - antenna.

Functional logic of the Agent  $A^X$  to identify the state of the process is based on the mathematical model (2):

$$Y_i = \begin{cases} DM_1(x_i) | x_i \in S_{i,1}(x_i); \\ DM_2(x_i) | x_i \in S_{i,2}(x_i); \\ \dots, i = \overline{1, N} \\ DM_h(x_i) | x_i \in S_{i,h}(x_i); \\ NOP | other. \end{cases} \quad (2)$$

where:  $Y = \{Y_i, \forall i = \overline{1, N}\}$  - the set of decisions generated by the Agents  $A^X$  in relation to the state of the process  $X = \{x_i, \forall i = \overline{1, N}\}$ ;  $DM_h(x_i) | x_i \in S_{i,h}(x_i), i = \overline{1, N}$  - decision  $DM_h$ , in relation to the value of the process status parameter  $x_i$ , is validated if the condition is met  $x_i \in S_{i,h}(x_i)$ , where  $S_{i,h}(x_i)$  is a sub-range of variation of the state parameter  $x_i$ ;  $NOP | other$  - lack of decision.

The functional diagram of Agents  $A^U$  for action on the process is shown in Figure 2.

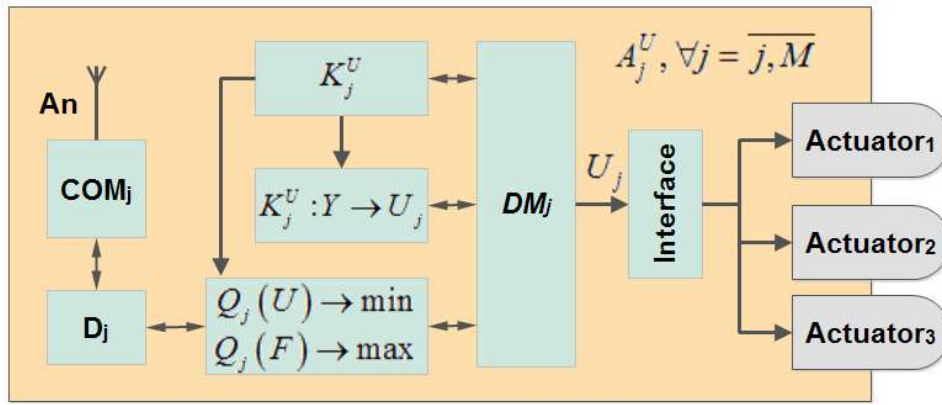


Figure 2. Agents' functional diagram for action on the process.

An Agent  $A_j^U, \forall j = \overline{1, M}$  with process action functions includes the following components:  $COM_j$  - communication block in the wireless network with antenna  $An$ ;  $D_j$  - data storage;  $K_j^U$  - the knowledge base accumulated by the Agent in the process of operating the system;  $K_j^U : Y \rightarrow U_j$  - data processing based on mathematical model (3) and knowledge  $K_j^U$ ;  $Q(U) \rightarrow \min$  and  $Q(F) \rightarrow \max$  - mathematical models for optimizing

the control process;  $DM_j$  - the decision-making block  $U_j$  which generates commands to act on the process; **Interface** - for adapting the action signals on the process; three elements of action (**Actuator**<sub>1,2,3</sub>) for various intervention operations in the controlled process.

Functionality of the Agents  $A_j^U, \forall j = \overline{1, M}$  with functions of action on the process is determined by the mathematical model (3):

$$U_j = \begin{cases} DM_1(Y) | g(Y) \in S_{j,1}(Y_{j,1}); \\ DM_2(Y) | g(Y) \in S_{j,2}(Y_{j,2}); \\ DM_3(Y) | g(Y) \in S_{j,3}(Y_{j,3}); \\ NOP | other; \end{cases}, j = \overline{1, M} \quad (3)$$

where:  $U = \{U_j, \forall j = \overline{1, M}\}$  - the set of decisions generated by the Agents  $A^U$  in relation to the decisions  $Y = \{Y_i, \forall i = \overline{1, N}\}$  generated by the Agents  $A^X$ ;  $DM_o(Y) | g(Y) \in S_{j,o}(Y_{j,o}), i = \overline{1, N}, o = 1, 2, 3$  - decision  $DM_o$  in relation to the decisions'  $Y$ , generated by the Agents  $A^X$ , is validated if the condition is met  $g(Y) \in S_{j,o}(Y_{j,o})$ , where  $g(Y)$  it is the function of validating the decision and  $S_{j,o}(Y_{j,o})$  it is the set of admissible solutions for that decision validation;  $NOP | other$  - lack of decision.

### III. WAY OF OPERATION OF THE ADAPTIVE COMPUTING SYSTEM FOR THE DISTRIBUTED PROCESSES CONTROL

To solve the control problem with the process defined by the mathematical models (1), (2) and (3) the set of Agents  $A^X$  and  $A^U$  forms a mesh network that ensures the transfer of data from one Agent to all others. In this way each Agent will have complete information regarding the decisions  $Y$  generated by the Agents  $A^X$ , and respectively the decisions

$U$  generated by the Agents  $A^U$  .. This information is used by Agents in calculation models (2) and (3) to optimize the control process.

The interaction between the Agents and the sequence of operations performed by them is shown in the diagram in Figure 3.

The sequence diagram shown in Figure 3 determines the sequence of operations performed by the set of Agents and the interaction between them:

1: NWC - the configuration of the mesh network in which take place the identification and formation of the Agents' list that currently are present in the system structure. This list is still used by Agents to coordinate data exchange;

2: PP - perception of the process in which take place the acquisition of the state value of the process, Analog - Digital Conversion and their normalization;

3:  $DM^X$  – calculations based on the mathematical model (2) and decision making  $Y = \{Y_i, \forall i = \overline{1, N}\}$  by the Agents  $A^X$

4:  $COM(Y)$  – communication in the mesh network in which the transmission takes place by the Agents  $A^X$  of decision values  $Y$ . The decision  $Y$  are received by the Agents  $A^X$  and  $A^U$ . The values of decisions  $Y$  are still used to optimize the control process, to update the knowledge base and to make decisions  $U = \{U_j, \forall j = \overline{1, M}\}$  by the Agents  $A^U$ ;

5:  $DM^U$  – calculations based on the mathematical model (3) and decision making  $U = \{U_j, \forall j = \overline{1, M}\}$  by the Agents  $A^U$ ;

6:  $ACT(U)$  – action on the process controlled with the values of decisions  $U$ ;

7:  $COM(U)$  – communication in the mesh network in which the transmission takes place by the Agents  $A^U$  of the decision values  $U$ . Decisions  $U$  are received by the Agents  $A^X$  and  $A^U$ . The decisions' values  $U$  are still used to optimize the control process and to update the knowledge base;

8:  $Q(U), Q(F)$  – optimizing the control process in order to minimize resource consumption and maximize the quality and quantity of the final product;

9:  $K^X, K^U$  – updating the knowledge. Based on current knowledge and decisions  $Y$  and  $U$ , generated by the Agents  $A^X$  and  $A^U$ , is updated the sub-interval  $S_{i,h}(x_i)$  of variation of the state parameter  $x_i$  (see the mathematical model (2)), and decision validation function  $g(Y)$  and the set  $S_{j,o}(Y_{j,o})$  of admissible solutions for validating that decision (see the mathematical model (3)).

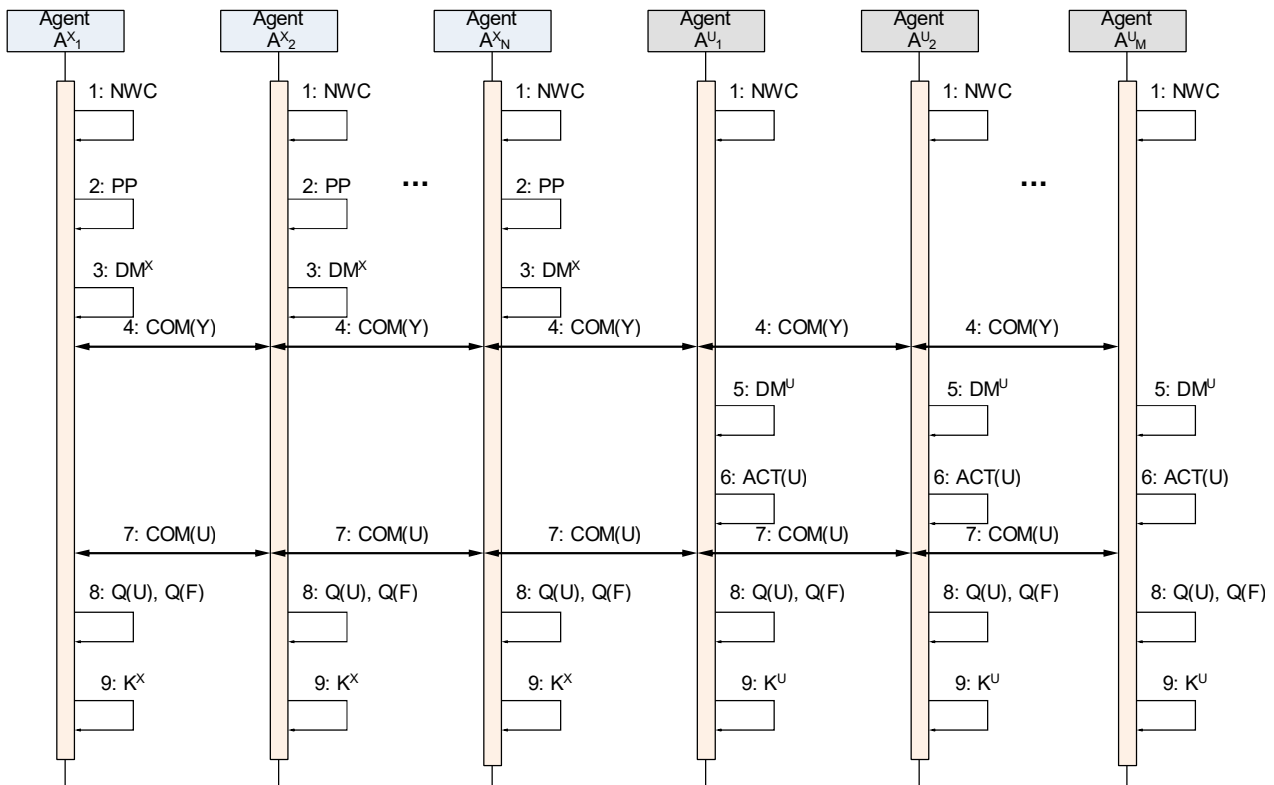


Figure 3. The interaction between Agents and the sequence of operations.

#### IV. THE IMPLEMENTATION OF AGENTS AND FUNCTIONAL TESTING OF THE SYSTEM

The implementation of the Agents and the functional testing of the adaptive computing system for the control of distributed processes was performed based on the Genuino-101 Kit which has sufficient hardware resources, development environments and libraries to implement and test of program products [16].

For the functional testing, a system was modeled for the control of a plant growth process in open space with the following parameters:

- $N=3$ , where: Agent  $A_1^X$  perceives air humidity with four sub-intervals  $S_{1,h}(x_1)$  variation of the state parameter  $x_1$ ; Agent  $A_2^X$  perceives soil moisture with three sub-intervals  $S_{2,h}(x_2)$  variation of the state parameter  $x_2$ ; Agent  $A_3^X$  perceives the air temperature with four sub-intervals  $S_{3,h}(x_3)$  variation of the state parameter  $x_3$ ;
- $M=3$ , where: Agent  $A_1^U$  control with the water supply system of the irrigation system; Agent  $A_2^U$  control with water access to the irrigation area; Agent  $A_3^U$  control with water spray in the air to maintain air humidity within the set range; The mathematical model (2) for decision-making by the Agents  $A^X$  is based on Fuzzy Logic [4]. The classification of sensitivity intervals are defined by the description of the respective Agent;
- The mathematical model (3) for decision-making by the Agents  $A^U$  is based on Neural Networks [4] in which the values of the decisions are applied at the input  $Y$ , at the exit of the Neural Network the decisions are obtained  $U$ . Synaptic weights  $W$  of the Neural Network are optimized in the learning process and are part of the knowledge  $K^U$  of the Agent and are adapted to each control iteration of the system.

#### V. CONCLUSION

This paper presents the results of the design of an adaptive computing system for controlling the distributed processes. The designed system is oriented for application in the field of agriculture where technological processes are spatially distributed and require full control over the entire area.

The functionality of the system is based on two sub-sets of Intelligent Agents with cognitive properties that adapt to the controlled process by updating knowledge. All Agents

form a mesh network that ensures the data transfer between them. The first subset of Agents is aimed to perform operations to identify (perceive) the status of the controlled process and foreseen the acquisition, storage, processing and communication between Agents. The second subset of Agents is process-oriented (Actuators) and foreseen the communication, storage, processing, and controlled process action.

Each process status identification Agent operates based on a mathematical model that provides the application of Fuzzy logic for decision making. Action agents are applied to the process models which are based on the Neural Networks.

For functional testing, an adaptive computing system for distributed process control was modeled which consist of three Agents for process status identification and three Agents for process action. The set of Agents has been implemented based on the Genuino-101 Kit which ensures communication between devices based on BLE wireless technology. The test program products were developed in the IDE Arduino 1.8.12.

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