A model of a cyber-physical installation for smart greenhouse agriculture

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Abstract. The article reviews the main aspects, parameters and effects integrated by smart agriculture. An analysis of the main definitions of the "smart agriculture" concept is drawn, and, a cyber-physical installation for smart greenhouse agriculture is modeled on that basis. The specific benefits from the cyber-physical systems in the agricultural production process are also defined by taking into account the actual prerequisites, factors and indicators related to smart-based agriculture. The main restrictive conditions are generated, as well as the managing parameters and the criterion for optimality of the model of a cyber-physical installation for smart greenhouse agriculture. At the same time, the architecture of a cyber-physical installation for smart greenhouse agriculture is described, while there are the specific mathematical variables integrated in it from the optimization task set in the model. Highlighted are the specific activities performed by each structural element of a cyber-physical installation for smart greenhouse agriculture, where their practical-and-applied benefits and efficiency are also defined, which ultimately leads to achieving the set optimization criterion – maximum return of the invested financial resources.

1 Introduction

The relevance of the Concept for smart agriculture nowadays is related primarily to a basis of cumulatively available fundamental global needs – supplying the growing world population with foodstuff, efficient use and preservation of the global natural assets, climatic and nature-sustainable development of agriculture, meeting the requirements of Industry 4.0 for digitalization and smart-based development of agriculture as a sector of economy. A number of authors have researched the meaning of the "smart agriculture" concept as a starting point for reforming and restructuring the agricultural industry.

According to some authors [1], innovative technologies, such as artificial intelligence, the Internet of things and mobile internet provide realistic solutions for a number of challenges in the agricultural sector. Many authors [2, 3, 4, 5, 6, 7, 8, 9] assume that smart agriculture is based on the integration of information and communication technologies into machines, equipment and sensors related to agricultural production. On this basis, the combined application of information-and-communication technological solutions, such as

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accurate equipment, the Internet of things, blockchain, cloud technologies, sensors and driving mechanisms, geopositioning systems, large bulks of data, unmanned aircrafts and robotics are a prerequisite for achieving more efficient, more productive and more-sustainable agriculture. This accurate-based and resource efficient approach is influenced by the parameters of Industry 4.0 and enables the implementation of the cyber-physical systems in agriculture as a prerequisite for smart-based planning, management, resource return and yield efficiency.

In some publications [3], smart-based agriculture is determined as the latest agricultural revolution, which, through the Internet of things, connects smart machiness and sensors in farms, and makes the sustainable agricultural practices data-based. A number of publications [10] assume that a smart farm should be based on a blockchain security framework, which efficiently checks the status of the device and the sensor disorders, and mitigates threats. The researched authors also point out that a key point in smart agriculture is "optimization", which is aimed at optimizing each variable and input during the production stage [3]. The sustainability of agriculture using information technologies is reduced to increasing the quantity and quality of the manufactured production, and, at the same time – keeping the environmental balance, preserving the natural resources and avoiding their irreversible depletion.

According to some other authors [11], the digitalization of agriculture facilitates monitoring, marketing, technologies and accelerates the production process through smart and critical application of digital models and technologies.

Smart agriculture is a management concept focused on providing to the agricultural industry an infrastructure for using advanced technologies – including big data, cloud computing and the Internet of things – for following up, monitoring, automation and analyzing operations. [4]

The technologies, which are most often mentioned in literature [3, 4], and are applicable in smart agriculture, are the following:

- sensors for scanning the soil and managing irrigation, light, humidity and temperature;
- telecommunication technologies, such as GPS and GIS;
- hardware and software for specialized applications;
- digital tools for taking online decisions;
- smart forecasting;
- smart planning;
- smart management;
- robotics;
- automation.

It can be summarized on the basis of the carried out theoretical research of "smart agriculture" that it resolves the main problems related to sustainable development and environment preservation through optimal, but also environment-friendly and nature-sparing use of the soil, water and energy [12, 13]. In that sense, the main task in implementing cyber-physical systems in greenhouse production is observing the parameters of the core resources involved in manufacturing agricultural production:

- management of maintaining a healthy soil;
- irrigation management;
- pesticide use management;
- energy source management;
- management of the provided light;
- management of biodiversity in the soil and air;
- production process management.

The researches by a number of theoretical sources show that the sustainability of smart agriculture is a complex, multilayer concept, which sets as a goal achieving in parallel profitability and preservation of the global natural assets and ecological balance for the future generations.

2 Formulation of the main parameters of the Model of a cyber-physical installation for smart greenhouse agriculture

2.1 Parameters ensuring the optimality of the model

The integration of the cyber-physical system within the Concept for smart greenhouse agriculture requires the formulation of the main target parameters. Undoubtedly, the introduction of the philosophy of the cyber-physical systems in greenhouse production is aimed at achieving higher added value based on a more efficient decision making (in respect to expedience, resource consumption and profitability) and more efficient production operations (in respect to resource consumption and effectiveness), related to the exploitation of resources, data gathering and analysis in the course of the production process, the cultivation of the farm lands and harvesting the crop. That means to largely reduce the conventional manufacturing and labour processes on account of the automated, smart-based and smart-managed production-and-technological operations.

The restrictive conditions in the model of a cyber-physical installation for smart greenhouse agriculture result from the need to reduce resource consumption in the agricultural production process. The main production resources in agriculture are time (as duration of the entire production process), water (for irrigation), chemicals ensuring healthy and high quality production (fertilizers, spraying chemicals, etc.), energy (used for heating and air-conditioning), labour (in terms of costs for human resource remunerations), depreciation of the used technical equipment (in cash equivalent), penalty fines related to breaching the ecological and biological equilibrium (if that is the case). The aforementioned resources have their value expression, and, in general, determine the cost price for manufacturing 1 kg of agricultural greenhouse production.

The managing parameters in the model of a cyber-physical installation for smart greenhouse agriculture should be related to preliminary set borderline values in respect to the qualitative and quantitative characteristics of the soil, humidity, heat, illumination, biodiversity, as well as in respect to the borderline qualitative parameters for the content of pesticides in the agricultural production.

On the background of the defined restrictive conditions and managing parameters in the model of a cyber-physical installation for smart greenhouse agriculture, there could also be determined the optimality criterion – maximum return of the invested financial resources.

2.2 Structural parameters of the model

The determined target parameters of the model of a cyber-physical installation for smart greenhouse agriculture have their substantial contribution also for structuring the cyber-physical installation itself. It has a six-degree hierarchical structure, where each structural element is interrelated and determinating in respect to all the others. On this basis, the cyber-physical installation for smart greenhouse agriculture has the following structure (Figure 1):

- a greenhouse agricultural system, comprised of its two main subsystems – production and management one, where the physical manufacturing process takes place in a particular temporal and spatial aspect;

- a sensor-smart system designed for gathering data from the real-life physical farm land through sensors, controlling apparatuses, technologies, management systems, which through the Internet of things maintain connection both with the real-life physical environment, and with the virtual one;
- an information system, where the signals gathered by the sensor-smart system are transformed into semantically rationalized information;
- a cyber system functioning as a central information centre, comprised of a network of cyber devices, which store a large bulk of information for different time periods, and with different situational variables, which analyze algorithms, models and instruments via specific methodologies that have been programmed in them, and generate, on this basis, alternative options for a choice of management decisions;
- a smart system generating in-depth knowledge about the physical greenhouse agricultural system based on expert systems, whereby a certain decision is analyzed and informationally supported;
- a management and feedback system, which implements the decision chosen by the system and configures the feedback from the cyber space to the physical greenhouse agricultural system.

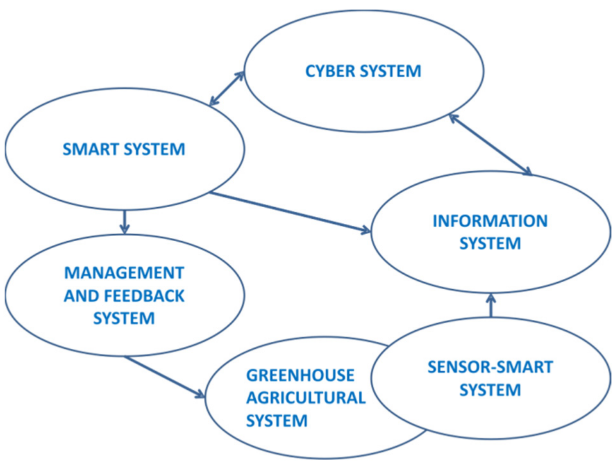

Fig. 1. Architectural structure of a cyber-physical installation for smart greenhouse agriculture.

At the same time, the described smart greenhouse agriculture is based on information and communication technologies. Thus, the model of a cyber-physical installation for smart greenhouse agriculture should include in its structure three interrelated and interdependent technological areas:

- management information systems;
- smart-based agriculture;
- process automation;
- robotized performance of certain activities.

The management information systems are associated with data gathering, processing, storing, analyzing and using by its designation on the basis of sensors, transducers and other technological solutions. It is these systems that allow adequate smart-based forecasting, planning, coordinating, controlling and managing the agricultural production processes. The management information systems draw their physical data from the soil, the air, from plants' root and foliar systems. This data is gathered by the sensor-smart system of the cyber-physical installation and is processed and transformed into digital information (by the information system of the cyber-physical installation), which is compared to the determined borderline values in the restrictive conditions defined in the model (by the cyber system of the cyber-physical installation). If necessary (when the measured physical data exceeds the indicated limits), in a smart-based way (through the management and feedback system of the cyber-physical installation) specific production-and-technological processes are activated, such as irrigation, heating or cooling, or ventilating, opening and closing the roof of the greenhouse, nourishing the soil with certain substances, treating the foliage against pests, etc.

Smart agriculture concerns managing the spatial and temporal variability to ensure the return of the invested financial resources with coordinated observation of no impact, or at least, reducing the impact on the environment. Critically important are the systems facilitating the decision making in view of ensuring optimality in respect to the return of the invested resources.

The automation of the agricultural production processes issues from the commands given by the smart system to the main robotized and automated elements of the cyber-physical installation.

Robotics (unmanned aircrafts for treatment, drones, etc.) ensures maintaining the parameters, which are set via the restrictive conditions of the model, and, on this basis, achieving the optimality criterion set as a goal.

3 A model of a cyber-physical installation for smart greenhouse agriculture

The model of a cyber-physical installation for smart greenhouse agriculture is related to a particular process organization, which is based on the parameters ensuring the optimality of the model and of its structural parameters. (Figure 2).

Fig. 2. A model of a cyber-physical installation for smart greenhouse agriculture. Author's own elaboration.

The sensor-smart system of a cyber-physical installation for smart greenhouse agriculture gathers via sensors and transducers data from the real-life physical greenhouse agricultural system about:

- the soil humidity;
- the minerals in the soil;
- the temperature of the air;
- the air humidity;
- the air circulation;

- plants' illumination;
- the condition of plants' foliage in view of the presence of a certain type of pests;
- the condition of plants' root system foliage in view of the presence of a certain type of pests.

The data gathered via the sensors and transducers is transmitted into the information system, where it is turned into semantically meaningful and relevant information. The synthesized information is transmitted from the information system into the cyber one, where a comparison is made with a big database, as well as an analysis of the condition of the physical greenhouse agricultural system. On the basis of the integrated restrictive conditions of the model in respect to the resources, the cyber system provides recommendations for the necessity of carrying out certain operational activities, such as fertilizing, irrigating, spraying against pests, heating or cooling the air, ventilating and other agricultural activities related to the normal development of the cultivated crops.

The smart system of the cyber-physical installation for smart greenhouse agriculture is based on the alternative options for a decision generated by the cyber system, where the latter provides approval for carrying out certain operational activities. At the same time, on the basis of the integrated therein managing parameters of the model of a cyber-physical installation for smart greenhouse agriculture, it defines accurately and precisely:

- the quantities of water necessary for irrigation and the duration of the irrigation process;
- the quantities of fertilizers or chemicals, whereby soil is enriched (if such a need is defined by the cyber system);
- the quantity of energy necessary for reaching particular temperature of the air (heating or cooling);
- the quantity of water, which has to be sprayed into the air in the greenhouse, or the time necessary for the greenhouse roof to remain opened (on the basis of information from a sensor in the indoor greenhouse environment about humidity outside of the greenhouse) until reaching the required air humidity;
- the extent of the opening of the roof or of other parts of the greenhouse in view of ensuring the necessary circulation of the air and illumination, providing for the respective period of the crops growth;
- the type and quantity of the substance necessary for treating plants' foliage or root system in the greenhouse.

Upon diagnosing the needs of the real-life physical agricultural environment, the smart system sends data about those needs also to the information system, which generates a new move to the cyber system, in order to check the result, which would have been generated when carrying out the activities determined by the smart system of the cyber-physical installation for smart greenhouse agriculture. Thus, the cycle of the cyber-physical installation is turned again, but solely and only in respect to the relation "information system – cyber system – smart system".

The management and feedback system, after completing the verification of the efficiency of the activities envisaged to be performed (the verification is on the basis of going through the cycle "information system – cyber system – smart system", ordered by the smart system), commands the automated and robotized systems and technologies to perform certain operational activities, such as:

- programming and starting the drip irrigation systems;
- programming and starting the robotized fertilizing equipment;
- programming and starting the air-conditioning units;
- programming and starting the installations for air humidification or opening to a certain extent the roof and/or other parts of the greenhouse in view of ensuring the

necessary humidity of the air on the basis of information from the external environment of the greenhouse;

- programming and starting the air circulation installations or opening to a certain extent the roof and/or other parts of the greenhouse in view of ensuring the necessary air flow on the basis of information from the external environment of the greenhouse;
- programming of the opening to a certain extent of the roof and/or other parts of the greenhouse and starting this process in view of ensuring the necessary and illumination of the crops;
- programming and starting drones for spraying the plants and/or their root system in view of protecting them from certain pests.

The management and feedback system of a cyber-physical installation for smart greenhouse agriculture follows the main parameters of the physical greenhouse agricultural system through the sensor-information system of the installation. If necessary, it will send commands to the latter to carry out specific activities. Thus, the entire process cycle of the cyber-physical installation for smart greenhouse agriculture is activated again.

4 Conclusion

Modelling a cyber-physical installation for smart greenhouse agriculture in an abstract and synthesized way summarizes the main parameters of a real-life example for a smart-based agricultural system. The precise definition of the restrictive conditions, the managing parameters and the criterion for optimality of the agricultural production, as well as the integration of those mathematical variables into the real-life architecture of a cyber-physical system adapted for the needs of the smart-based greenhouse agriculture, leads to achieving several major effects:

- reduced duration of the communication, management, planning and forecasting processes related to the functioning of the greenhouse;
- reduced time for carrying out particular agricultural activities;
- reduced loss of resources when performing certain agricultural activities, such as fertilizing, spraying, irrigating, heating, cooling, etc.;
- efficient growing of agricultural crops is ensured on the basis of accurate, precise and correct adherence to the technological processes and norms in agriculture.

The model of a cyber-physical installation for smart greenhouse agriculture leads to the following synergic effects, which provide grounds for the model to be upgraded and further improved:

- a rational production organization enabling the optimal capacity loading of both facilities and staff;
- optimal production costs ensuring the cost price per kilogram or generated yield;
- efficient production, technological and social added value ensuring the ecological and biological equilibrium, the preservation of the natural resources and the sustainability of production in a long-term period of time.

The aforementioned effects irrevocably determine also the achievement of the criterion for optimality set in the model of a cyber-physical installation for smart greenhouse agriculture – maximum return of the incurred financial expenses.

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