AN INFRASTRUCTURE APPROACH TO BUILDING AN IOT ECOSYSTEM FOR AGRICULTURE

Evgeni Valchev, Todorka Glushkova

Abstract. *The article aims to present an infrastructural approach to building IoT-based platforms necessary to optimize, rationalize and implement new technological solutions in the field of agriculture. The modeling and construction of such systems are necessary from the point of view of environmental friendliness, based on European and world standards, as well as reducing costs and providing an optimal habitat for plants and animals in the studied territory.*

Key words: IoT Infrastructure, Intelligent Agriculture.

Introduction

Agriculture is a major sector that plays a key role in sustainable development and feeding the population. With the development of the digital era, the use of smart technologies such as the Internet of Things (IoT) and the development of cyber-physical systems (CPS) [1] are transforming traditional agricultural practices and offering new opportunities for optimization, automation and a higher level of sustainability and efficiency. The implementation of IoT systems in smart crop and livestock farming [2] provides undeniable advantages and opportunities for monitoring critical factors such as soil moisture, temperature, climatic conditions and plant and animal health in real time. This enables farmers to make more informed decisions, reduce costs and minimize harmful impacts on the environment.

The article examines the infrastructure approach to building an IoT ecosystem, focusing on its role in increasing productivity, environmental sustainability and standardization according to European and global regulations. The goal is to create an effective IoT platform that will improve resource management and assist farmers in more efficient and optimal management of this important sector for the development of the modern economy.

Motivation and related works

The development of IoT technologies in the fields of agriculture and animal husbandry has made significant progress in recent years. Research is focused on various systems and approaches based on the integration of sensors, cloud platforms, artificial intelligence and big data analysis.

IoT devices such as smart sensors and sensor groups for measuring various soil parameters, combined with dynamically incoming data from weather stations and drones, are used to collect data in real time. In agriculture, the main monitored parameters are humidity, temperature, nutrient levels and crop condition. This data helps farmers optimize irrigation, improve yields and reduce costs for fertilizers and pesticides, thereby preserving the ecological conditions of cultivated areas. For example, SmartFarmNet [3] and FieldView [4] are IoT platforms that provide information for monitoring and managing agricultural processes. IoT-based irrigation systems integrate 10-centimeter soil moisture sensors with weather data from weather sites or portable weather stations to start the irrigation system only when needed, which helps to significantly reduce water loss and increase yields [5]. Drones equipped with IoT-technologies provide aerial images to diagnose problems such as crop diseases, over-irrigation or incorrect fertilization [6]. The incoming dynamic data makes it possible to automate a large part of the activities. The use of robotic devices, in turn, optimize tasks such as planting and harvesting and reduce labor costs by increasing the accuracy of execution.

Cyber-physical systems are complex integrated systems that provide services to users through interactions of physical and virtual components. They find application in a wide range of areas such as industry, transportation, healthcare, energy, urban management and others. The Cyber-Agricultural System (CAS) is a model of cyber-physical system in agriculture that has become established in practice, which uses dynamic sensing, artificial intelligence, intelligent actuators and scalable cyber-infrastructure in agriculture. The goal of these systems is automation and increasing the efficiency, productivity and sustainability of ecologically clean food production in the conditions of a changing climate [7].

Virtual-Physical Space (ViPS), as a reference IoT-based architecture, is being developed by a team at the University of Plovdiv. The goal of this architectural framework is to provide universality and adaptability to different CPS platforms in different application areas [8]. Due to the fact that in ViPS the individual software components and agents interact according to the dynamically changing environmental conditions (physical and virtual) and their knowledge and beliefs, ViPS-adapted platforms can be considered as cyber-physical spaces. In the field of agriculture, two prototypes of CPS platforms based on the ViPS architecture have been implemented – in the field of agriculture (ZEMELA [9]) and smart animal husbandry.

In the next section, we will consider an approach to building an IoT-based architecture, tailored to the need to provide services in a cyber-physical environment in the conditions of smart agriculture.

Our approach

The development of such platforms, providing services through appropriate interaction with the IoT, is quite complex and requires solving tasks at different levels and degrees of complexity. In order to develop a prototype IoT platform for smart agriculture, it is necessary to analyze various aspects in advance, such as:

- **Problem area analysis** – in the applied analysis, the team must analyze the entire subject area, as well as existing systems, advantages and disadvantages, optimizations and other processes.
- **Analysis of technological solutions** – Compared to the previous analysis, it is necessary to perform a technological analysis of possible technological applicable solutions that can be applied in the specific subject area. The stage is extremely important for the implementation of a sustainable solution.
- **Technology selection** – the phase aims at a detailed analysis of possible technological solutions, distributed by layers and selecting the most suitable ones for the implementation of the project. The selection is made based on the following criteria: team expertise, technological compatibility, possible technological implementation and realization.
- **Prototyping** – this stage includes the development of working prototypes at all layers, through which the workability of the overall concept is proven. At this stage, problem areas in the overall project are also revealed, for which a thorough analysis must be

performed.

- **Prototype testing and improvement** – testing is performed in a real environment. The process aims to verify the work of the prototypes and identify potential problem areas.
- **In-depth data analysis** – It is necessary to conduct a thorough analysis when data is received and cover the critical minimum of the data volume. The analysis is performed using a number of statistical and mathematical methods. When conducting the analysis, the most stable models for information analysis are selected and ongoing research is based on them.
- **Data Verification** – Verification is a process involving specialists from the applied subject area, with each transaction being checked and verified based on live observations. This stage is important for verifying the authenticity of the data and making additional corrections.
- **Data Synchronization** – Implementation of algorithms for automatic synchronization of incoming information based on verification of data from the transition stage. In this phase, the sensitivity and operation of the system are adjusted to read the information and provide verified conclusions.
- **Environmental Compatibility** – the final phase regarding environmental standards aims to add additional parameters and information so that the system can strive to reduce the ecological footprint in nature in relation to the use of the system.

Such a class of systems consists of multiple layers covering every aspect of the implementation. Regarding the modeled system for intelligent livestock farming [10], we will consider the following components:

- **Crine devices** for animals and pastures equipped with sensor groups providing information for the needs of the studied area
- **Sensor networks** necessary for collecting data from all available devices/sensors
- **Transmission medium** for connection between sensor networks and server modules
- **Sensor network** for collecting and primary processing of information, as well as controlling the connected devices

- **Databases** and systems for primary processing of information
- **Server systems** for processing and analyzing information. Data collection, analysis and normalization.
- **Client applications** and information visualization
- **Analysis of information** in terms of ecological compatibility and optimization of processes.

All layers and components of the system are inextricably linked and visualized in the following diagram (Fig. 1). The system's design and implementation principle is consistent with the selected technological solutions, as well as their customization and inclusion in the specific subject area. Conventional technologies for communication, sensor and sensor network implementation, and software support are used. However, for the specific implementation, conventional technologies are modified to correspond to the needs of the subject area. This is also the basic foundation on which the above-mentioned phases are implemented.

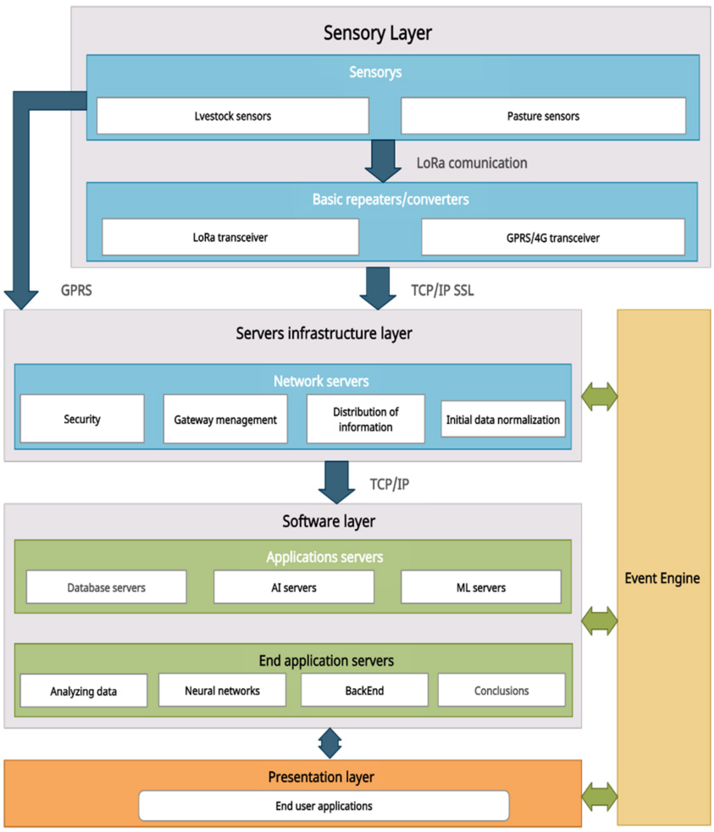

Figure 1. Architectural framework of the modeled IoT platform

The entire system is designed and based on processes and models that provide a high level of scalability, which provides the ability to process unlimited data sets. The approach aims to analyze information regardless of the number of transactions over time.

Results and discussions

Based on the presented approach, a complete prototype of all described application layers and functionalities has been implemented [11]. The prototype covers every activity described above, and the extracted information has been analyzed based on statistical methods and algorithms.

Sensor devices have been installed on the animals and pastures, for the implementation of which several experimental prototypes have been created. The sensor devices are shaped like a collar that does not irritate the animals and does not interfere with their normal life and behavior (Fig. 2.)

Figure 2. Developed IoT sensor devices

Sensor devices provide the opportunity to collect important information about the condition and behavior of cows. The collected data is used to process information about: behavior and behavioral analysis; location of each animal, as well as its location in relation to the herd; distance traveled; detailed analysis of the animal's life cycle etc.

Additional environmental information is also used to verify animal data. When developing a specific system for grazing cows, information about the quality of the grass and weather conditions is of key importance.

The data from the totality of the overall information collected for each individual animal, as well as for the static data from the pastures, is systematized and processed in parallel, as well as superimposed on each other. This provides conclusions and solutions on the basis of which the system has the ability to visualize conclusions. The software implementation provides a number of options for adjusting incoming data (Fig. 3)

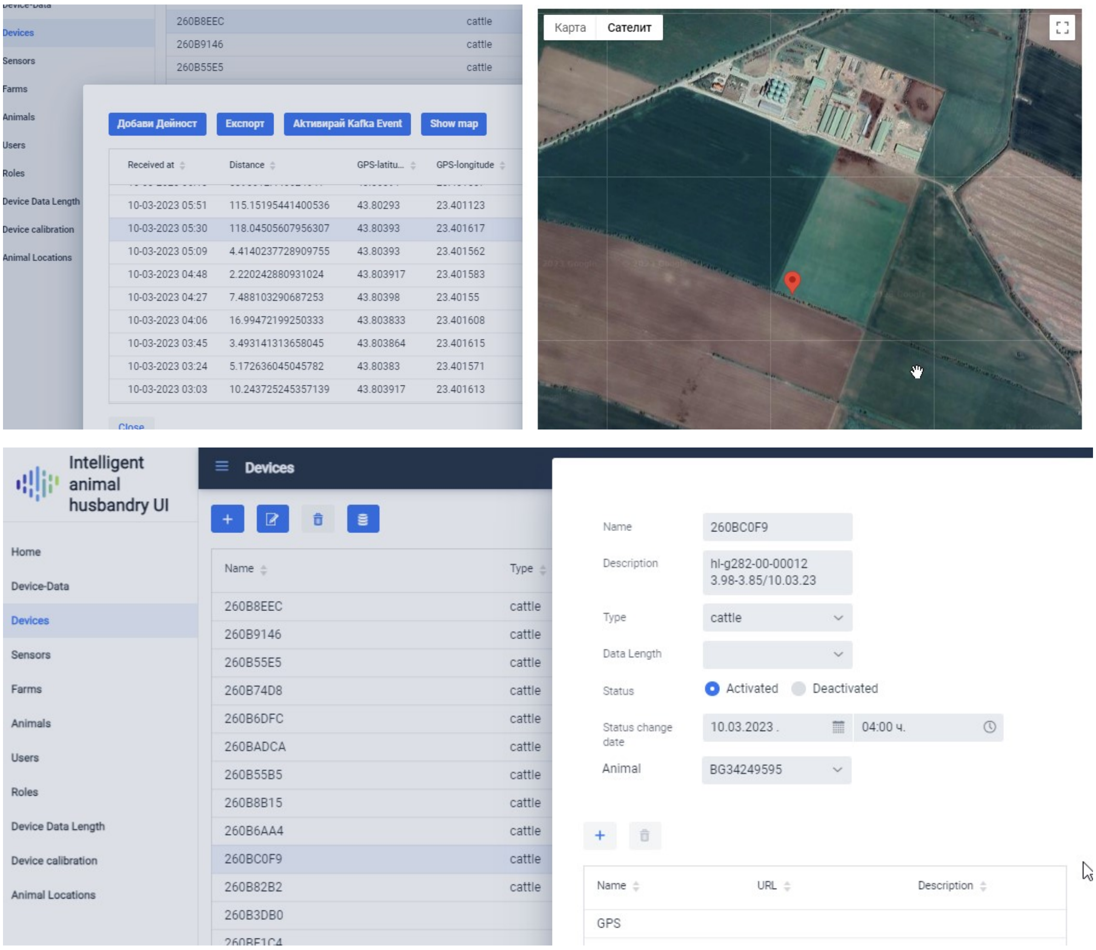

Figure 3. Software implementation

The benefits of implementing the system are related to increasing animal welfare (thanks to monitoring and prevention of undesirable situations); increasing the caloric intake and resilience of each individual animal; reducing the costs of raising animals; increasing environmental compatibility based on new environmental standards, etc.

In the process of implementing the prototype, we encountered many challenges, such as: the need to create durable edge sensors with a battery life of 12 months without charging, device robustness, removing some of the intelligence of data processing in the devices themselves, wide-spectrum sending of the radio signal; sustainable reception of information over long distances from multiple devices; processing and collection of information, etc. The solution to the problems is based on the development and implementation of over 10 prototypes of IoT devices, sensor network and application software. In the development phase, all of the above-mentioned problems were eliminated in parallel. The prototyping of the platform, as well as each of its layers, is in line with environmental and geolocation compatibility and allows for future development.

Conclusions

The implementation of IoT ecosystems in livestock and agriculture represents a significant step towards optimized and efficient resource management, cost reduction, and environmental footprint minimization. The proposed infrastructure approach allows for standardized construction of CPS-based platforms in this critical sector. In the course of work on a prototype in the field of smart livestock farming, in addition to the undeniable benefits, some problems and challenges were identified. The team's plans are focused on the use of AI algorithms and Deep Neural Networks in an aspect of Deep Reinforcement Learning (DRL [12]) to determine the status of animals and predict their behavior based on dynamically incoming data from IoT sensor networks.

Acknowledgments

This study is supported by the project FP23-FMI-002 "Intelligent software tools and applications in research in mathematics, informatics, and teaching pedagogy" at the "Paisii Hilendarski" University of Plovdiv.

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Evgeni Valchev[1],Todorka Glushkova[2],
[1,2] Paisii Hilendarski University of Plovdiv,
Faculty of Mathematics and Informatics,
236 Bulgaria Blvd., 4027 Plovdiv, Bulgaria
Corresponding author: glushkova@uni-plovdiv.bg