IJEEC

International Journal of Electrical Engineering and Computing
Vol. 8, No. 2 (2024)

Short report
UDC 334.027/.028:005.336
DOI 10.7251/IJEEC2402074P

A System for Remotely Monitoring and Controlling Temperature within an Egg Artificial Incubator

Nataša Popović[1], Božidar Popović[2]

[1] Department of Automation and Robotics, [2] Department of Electronics and Electronic Systems, Faculty of Electrical Engineering, University of East Sarajevo, East Sarajevo, Bosnia and Herzegovina

E-mail address: natasa.popovic@etf.ues.rs.ba, bozidar.popovic@etf.ues.rs.ba

Abstract— **According to a report by the Food and Agriculture Organization of the United Nations, poultry meat is the leading contributor to global growth in total meat production. This growth is facilitated by the short production cycle of poultry, advancements in genetics, animal healthcare, feeding methods, breeding techniques, and improved environmental conditions, enabling producers to adapt quickly to market demands. Proper hatching practices are critical to maximizing the number of healthy chicks and minimizing their mortality rate. There are two primary methods of hatching: natural incubation, where hens incubate eggs by sitting on them, and artificial incubation, which uses incubators. In artificial incubation, monitoring and controlling key environmental factors, particularly temperature and humidity, are essential. Maintaining the incubator's temperature within an optimal range is crucial, with literature recommending a range of 37°C to 38°C and an ideal temperature of 37.8°C. This paper introduces a system for remotely monitoring and controlling temperature within an artificial incubator. The system integrates hardware and software based on the Internet of Things (IoT) framework. For this purpose, a proportional-integral-derivative (PID) controller is designed to maintain the desired temperature, with temperature data stored in a database and accessible online. The proposed system offers a cost-effective yet highly efficient solution, primarily designed for small-scale hatcheries. With modifications, it can be adapted for broader agricultural applications, including greenhouses, silos, and stables. By contributing to digital agriculture, the system supports sustainable farming practices, which are essential for the future of agriculture.**

Keywords-Artificial egg incubation, Internet of Things, Temperature control, Digital agriculture

I. INTRODUCTION

The United Nations, in the report cited in [1], predicts that poultry meat consumption will rise to 145 million tons by 2029, accounting for 50% of the total meat consumed globally. This indicates that poultry meat will remain the primary driver of overall meat production growth, representing half of the total meat produced in the next decade. The short production cycle of poultry meat, along with rapid advancements in genetics, modern health care methods for all poultry species, feeding practices, breeding conditions, and rearing environments, enables producers to respond quickly to market demands.

To achieve these predictions, optimal conditions must be ensured at all stages of poultry breeding and poultry meat production. In the chick-hatching phase, an important step is the egg incubation process. Egg incubation is a process in which fertilized eggs hatch into chicks under optimal temperature and humidity levels. Hatching can be natural or artificial. In natural hatching, a hen provides all the necessary conditions by sitting on the eggs (typically up to 15), regularly turning them, and incubating them until the chicks hatch. Artificial hatching involves the use of artificial incubators that mimic the natural hatching process by automatically maintaining the necessary incubation conditions for a large number of eggs and performing other essential tasks to ensure successful hatching. During incubation, fertilized eggs must be exposed to heat to warm them and enable the proper development of embryos into chicks. In addition to incubation, the placement, positioning, and turning of eggs must be carried out correctly to maximize the number of healthy chicks hatched and minimize the mortality rate.

In artificial incubation, successful hatching depends on properly maintaining the appropriate environmental conditions within the incubator (temperature, humidity, air quality), particularly during the incubation phase. Among these factors, temperature is the most critical and has the greatest impact on successful chick hatching [2]. The optimal ambient temperature varies depending on the poultry species and the specific incubation stage, but generally, it should range between 37°C and 38°C [3].

Modern commercial automated artificial incubators are equipped with heating and cooling units, air humidifiers, ventilation systems, and mechanisms for egg turning [3]. Large-scale industrial incubators can accommodate several hundred to several thousand eggs, while smaller-scale farmers who produce chicks for their own needs typically use artificial incubators with a capacity of a few dozen eggs. Small-scale farmers may also use non-commercial artificial incubators, custom-made to meet their specific requirements and breeding needs. These incubators provide all the functionalities of commercial ones, which are often expensive and not cost-effective for incubating smaller quantities of eggs. Such incubators can be effectively implemented using Internet of Things (IoT) hardware and software, while various techniques and methods from the field of automatic control systems can be used to regulate environmental conditions (e.g., PID or fuzzy controller design). Many development boards in the IoT domain are suitable for such solutions. For example, Raspberry Pi boards were used in [4] and [5], while Arduino was implemented in [6]-[8]. PID control was applied in [6] and [9], whereas fuzzy control was implemented in [10] and [11]. In [12], a smart automatic balanced system with an Android application and Bluetooth module for wireless communication was proposed, while the authors of [13] developed a temperature and relative humidity controller with a GSM module and SMS notifications. A thermoelectric incubator was proposed in [14], and an egg incubation system with a closed-loop temperature control was described in [15].

This paper introduces a system for remotely monitoring and controlling temperature within an artificial incubator used for hatching chicken eggs. A PID controller was designed to maintain the temperature at 37.8°C. Temperature readings are accessible via a web browser through an Internet connection. The proposed system offers a simple, cost-effective, yet highly efficient and scalable solution intended for small-scale hatcheries, ensuring the necessary temperature conditions for proper embryo development.

The paper is organized as follows. The second chapter presents the basic characteristics of artificial incubators and the temperature conditions that must be met in artificial incubation. The third chapter describes the development of a system for regulating and remotely monitoring the temperature in an artificial incubator used for chicken egg incubation. Finally, the conclusions and future research directions are provided.

II. Artificial Incubation

A. Artificial Incubators

Artificial hatching among birds in nature has been observed for a very long time. It is known that the bird *Eulipoa Wallacei*, native to the Indonesian islands, buries its eggs on sun-exposed ocean shores in the sand or in the volcanic soil at a depth of 60cm to 100cm [16], [17]. The eggs are exposed to solar energy and ocean waves, which provide the necessary heat and moisture, allowing the embryos to develop correctly and hatch into healthy chicks. Here, the sand acts as an artificial incubator, while the solar energy and waves provide the essential environmental conditions for embryo development - temperature and humidity. Fig. 1 depicts *Eulipoa Wallacei* on the shore after burying the eggs at night.

Figure 1. *Eulipoa Wallacei* buries its eggs deep in the sand at night.

The first artificial incubators constructed and used by humans for hatching chicks originated in ancient Egypt and China, dating back two to three thousand years [18, 19]. These incubators were made of mud and clay, heated with coal, and equipped with ventilation openings as shown in Fig. 2. Temperature was regulated by adjusting the fire intensity used for heating and by opening or closing the ventilation openings. Humidity was maintained by covering the eggs with moistened jute. It was not until the late 19th century, with the invention of the thermometer and the widespread adoption of electricity, that it became possible to design artificial incubators capable of more effectively maintaining the environmental conditions needed for egg incubation.

The expansion of poultry meat production in the 1960s, combined with the development of digital computers, other electronic components, and industrial automation, enabled the creation of semi-automated and automated artificial incubators. These incubators featured automatic air humidifiers, temperature regulation with a precision of ±0.1°C, automatic egg turning 24 times a day, alarm systems for any potential issues, digital displays showing all monitored parameters, and centralized computer control of the entire incubation process. The new millennium introduced sophisticated technologies that improved monitoring and regulation of environmental parameters within incubators. Today’s commercial incubators, in addition to standard components, include automated systems

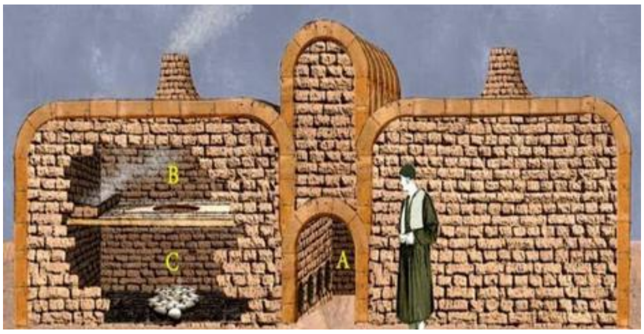


Figure 2. Egyptian incubator: A-the entrance to the incubator used for monitoring and maintaining the system; B-the area where eggs are placed for incubation, potentially elevated to optimize heat distribution; C-the lower chamber, which appears to house heat sources such as burning coals or materials to regulate temperature and humidity. The structure features chimneys or vents for ventilation and temperature control.

for measuring carbon dioxide levels, assessing embryo weight, and measuring egg temperatures in situ (shell and internal temperature). All these data, along with other relevant parameters, are used to optimize heating, cooling, humidifying, and ventilation processes within the incubator. In general, commercial artificial incubators can be classified in various ways [19], [20] as given in Table 1. Fig. 3 shows single-layer and multi-layer incubators.

TABLE I. TYPES OF ARTIFICIAL INCUBATORS

Criterion	Type
arrangement of eggs	• single-layer (horizontal or flat) • multi-layer (stacked or deep)
heating method	• hot water • hot air
capacity	• small (50–600 eggs) • medium (600–5,000 eggs) • large (tens or hundreds of thousands of eggs)
airflow or ventilation systems	• still-air incubators • forced-air incubators
operating mode	• manual incubators • semi-automatic incubators • automatic incubators

The rapid advancement of the Internet of Things (IoT) paradigm over the past decade has led to the development of smart incubators. These incubators are highly effective for small-scale hatcheries, offering simple and efficient control and monitoring of environmental parameters during incubation. Unlike conventional artificial incubators, smart incubators can connect to the Internet through wired or wireless communication networks, enabling poultry farmers to monitor all essential incubation parameters anytime and anywhere. The core components of a smart incubator include a microcontroller and various types of sensors. Additionally, numerous IoT development platforms provide excellent tools for creating systems to measure, control, and monitor environmental conditions in such incubators.

The use of artificial incubators offers several advantages, including reduced labor requirements for farmers, high egg incubation capacity, enhanced hygiene conditions, and the flexibility to hatch chicks and raise poultry year-round.

B. Temperature Conditions for Egg Incubation

Maintaining an optimal incubation temperature is crucial for hatching a high number of healthy chicks with strong performance [22]. The temperature during incubation must be carefully adjusted to meet the specific needs of the embryo and fetus at different stages of development. The incubation period varies across poultry species. For example, chicken eggs require 21 days to hatch, divided into two stages: the first stage spans days 1 to 18, while the second stage covers days 19 to 21. The incubator temperature must be appropriately adjusted for each stage to ensure successful hatching.

The optimal incubator temperature for hatching eggs of all poultry species should be between 37°C and 38°C [3]. To maintain the eggshell temperature at an appropriate level, the incubator temperature must be set between 37.5°C and 38°C [22]. While eggshell temperature fluctuates during incubation, deviations of up to 0.1°C from the incubator temperature do not negatively affect hatching outcomes. According to [23], the best hatching results in warm-air incubators are achieved by maintaining a temperature between 37.8°C and 38°C, with fluctuations not exceeding 0.5°C. Similarly, [24] suggests that the incubator temperature should range between 37.5°C and 38°C during the first 18 days of incubation. In the hatching phase, starting on day 19, the temperature should be reduced to between 36.1°C and 37.2°C [25].

Figure 3. Single-layer and multi-layer incubators.

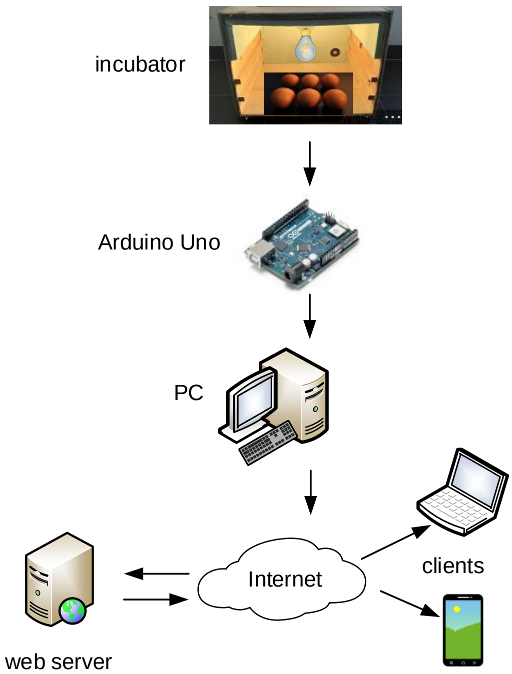


Figure 4. Functional diagram of a system.

III. Development Of A Proposed System

Fig. 4 illustrates the functional diagram of the developed system for temperature regulation and remote monitoring in an artificial incubator designed for chicken egg incubation. The system monitors and controls the incubator's internal temperature, stores the recorded data in a database, and enables users to access the measurements via a web browser. The implementation combines Internet of Things (IoT) hardware with a software-based PID controller for precise temperature regulation.

The hardware component of the system, shown in Fig. 5, consists of a microcontroller, a heater, a temperature sensor module, a relay, a potentiometer, and a communication module.

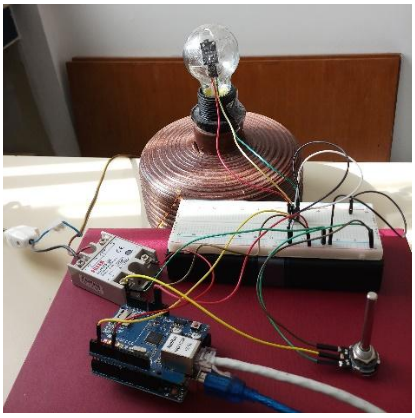


Figure 5. Experimental setup of a system.

The system is based on the Arduino Uno development board [26], which powers the sensor module, reads temperature values from its output, and generates a digital signal to turn the relay and heater on or off. A 40 W incandescent bulb is used as the heating element. The SSR-25DA relay is employed to instantly switch the heater on or off depending on the measured temperature. A potentiometer is used to manually set the reference temperature, which is configured to 37.8°C.

A sensor module, featuring an integrated DS18B20 temperature sensor and a 4.7 kΩ resistor, was utilized to measure the temperature inside the incubator. The DS18B20 is a digital temperature sensor that provides direct readings in Celsius degrees. It communicates with the microcontroller via a single data transmission bus, which also serves as a power supply line, supporting voltages between 3 V and 5.5 V.

The Arduino Uno board connects to the Internet using a communication module, specifically an Ethernet module, which is part of a series of extension modules that expand the functionality of Arduino boards.

The software component of the system, which implements the control logic for temperature reading and regulation, was developed using the Arduino IDE. To support the operation of all hardware components, several predefined libraries were included at the beginning of the code. The OneWire.h library was used for communication with the digital temperature sensor. The SPI.h library facilitated communication between the microcontroller and peripheral devices through the serial port. For the Ethernet module to function and connect the Arduino board to the Internet, the Ethernet.h library was utilized, while the PID_v1.h library supported the operation of the PID controller. Communication between the client and server was established by specifying appropriate MAC and IP addresses. A series of commands were implemented for initializing the Ethernet connection, sending HTTP requests, transmitting data to the server, and executing the PID loop, enabling temperature control and interaction with the database. Relevant parameter values can be monitored in the IDE environment using the serial monitor (as shown in Fig. 6) or visually through the serial plotter (Fig. 7).

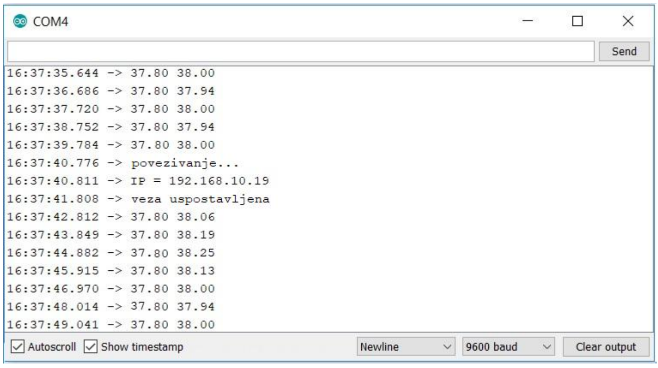


Figure 6. Serial monitor display.

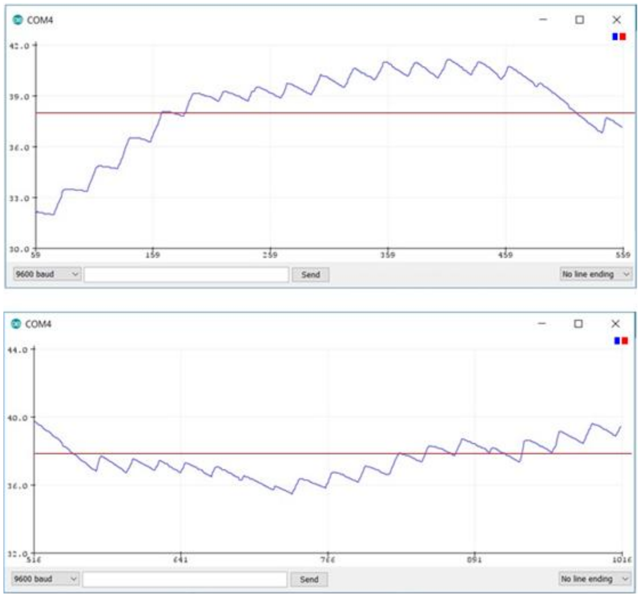
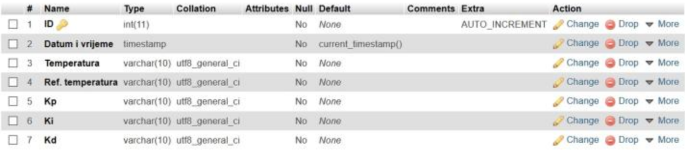


Figure 7. Serial plotter display.

To store the measured temperature values, a MySQL database was created, containing a table with the relevant parameters, Fig. 8. The system reads the temperature every second and records the average of thirty consecutive measurements into the database every thirty seconds. Three .php files were developed: one to establish a connection with the database, another to enable communication between the

Arduino board and the database, and the third to display parameter values from the database in a web browser. The Apache HTTP server was used to host the web application.



#	Name	Type	Collation	Attributes	Null	Default	Comments	Extra	Action
1	ID	int(11)			No	*None*		AUTO_INCREMENT	Change Drop More
2	Datum i vrijeme	timestamp			No	current_timestamp()			Change Drop More
3	Temperatura	varchar(10)	utf8_general_ci		No	*None*			Change Drop More
4	Ref. temperatura	varchar(10)	utf8_general_ci		No	*None*			Change Drop More
5	Kp	varchar(10)	utf8_general_ci		No	*None*			Change Drop More
6	Ki	varchar(10)	utf8_general_ci		No	*None*			Change Drop More
7	Kd	varchar(10)	utf8_general_ci		No	*None*			Change Drop More

Figure 8. Elements of a table within the database.

The most important objective was determining whether the system maintained the reference temperature correctly. Through running the experiment, it was observed that the designed PID controller maintained the temperature on the reference value if its parameters were set to K_p=10, K_i=3, and K_d=1. Furthermore, in the case of disturbances in the system, which violated the temperature inside the incubator, the controller could regulate the temperature value and achieve the reference quickly and very efficiently. Fig. 8 shows the step response of the developed system. It verifies that the system behaves as expected and is capable of maintaining the temperature at the desired set point.

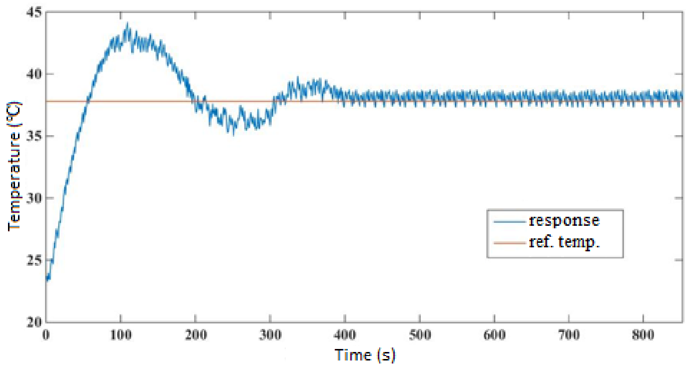
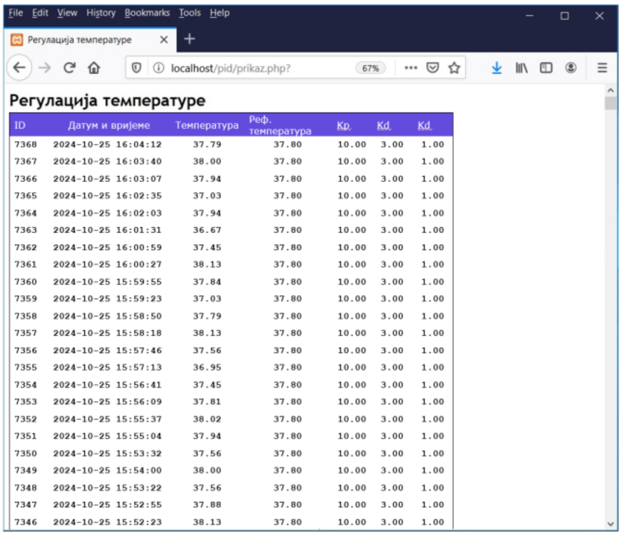


Figure 9. Display of measured and reference temperature values in a web browser.

Laboratory testing of the system confirmed its capability of effectively controlling the temperature and maintaining it within the recommended limits specified in the available literature. Fig. 9 shows a portion of the display of the measured and reference temperature values in the web browser, generated from the database, which supports the test results.



Регулација температуре

ID	Датум и вријеме	Температура	Реф. температура	Kp	Kd	Kd
7368	2024-10-25 16:04:12	37.79	37.80	10.00	3.00	1.00
7367	2024-10-25 16:03:40	38.00	37.80	10.00	3.00	1.00
7366	2024-10-25 16:03:07	37.94	37.80	10.00	3.00	1.00
7365	2024-10-25 16:02:35	37.03	37.80	10.00	3.00	1.00
7364	2024-10-25 16:02:03	37.94	37.80	10.00	3.00	1.00
7363	2024-10-25 16:01:31	36.67	37.80	10.00	3.00	1.00
7362	2024-10-25 16:00:59	37.45	37.80	10.00	3.00	1.00
7361	2024-10-25 16:00:27	38.13	37.80	10.00	3.00	1.00
7360	2024-10-25 15:59:55	37.84	37.80	10.00	3.00	1.00
7359	2024-10-25 15:59:23	37.03	37.80	10.00	3.00	1.00
7358	2024-10-25 15:58:50	37.79	37.80	10.00	3.00	1.00
7357	2024-10-25 15:58:18	38.13	37.80	10.00	3.00	1.00
7356	2024-10-25 15:57:46	37.56	37.80	10.00	3.00	1.00
7355	2024-10-25 15:57:13	36.95	37.80	10.00	3.00	1.00
7354	2024-10-25 15:56:41	37.45	37.80	10.00	3.00	1.00
7353	2024-10-25 15:56:09	37.81	37.80	10.00	3.00	1.00
7352	2024-10-25 15:55:37	38.02	37.80	10.00	3.00	1.00
7351	2024-10-25 15:55:04	37.94	37.80	10.00	3.00	1.00
7350	2024-10-25 15:53:32	37.56	37.80	10.00	3.00	1.00
7349	2024-10-25 15:54:00	38.00	37.80	10.00	3.00	1.00
7348	2024-10-25 15:53:22	37.56	37.80	10.00	3.00	1.00
7347	2024-10-25 15:52:55	37.88	37.80	10.00	3.00	1.00
7346	2024-10-25 15:52:23	38.13	37.80	10.00	3.00	1.00

Figure 10. Display of measured and reference temperature values in a web browser.

IV. Conclusion

Among all the environmental conditions that must be maintained in an artificial incubator, keeping the temperature at the optimal level is of utmost importance to ensure the maximum hatch rate of chicks and minimize mortality. The described system for regulating and remotely monitoring the temperature in the incubator for hatching chicken eggs provides a simple, cost-effective, and efficient solution intended for small poultry farms, where a small number of chicks are hatched for personal use or for sale to third parties. The system is based on hardware components and software from the Internet of Things (IoT) domain and utilizes an internet connection to display the temperature values measured inside the incubator. Users can access the temperature readings via a web browser. Temperature control in the developed system is enabled by a PID controller. Laboratory tests have shown that the system maintains the temperature within the prescribed limits that ensure proper embryo development and healthy chick hatching. The proposed system, in its current form, can be used not only for incubating chicken eggs but also for incubating eggs of other poultry species, with only the reference temperature needing to be adjusted. This work represents the authors' initial research into the application of the Internet of Things concept in agriculture and has significant potential for further development. The functionality of the proposed system can be expanded by adding humidity and air quality sensors, Wi-Fi modules, smartphone notifications, and more, which will be the subject of future research. Additionally, with minor modifications to the developed system, it is possible to create systems that could be effectively used in various applications related to environmental parameter monitoring and control, particularly in agriculture (greenhouses, storage facilities, grain silos, stables, etc.). This is highly significant in the context of the ongoing digital transformation, which is also reflected in the concept of digital agriculture. Digital agriculture aims to lead to sustainable farming, which includes small producers – a topic of much discussion today, and without which the future would be unimaginable.

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Nataša Popović received a B.Sc., M.Sc., and PhD from the Faculty of Electrical Engineering, University of East Sarajevo. She holds the position of assistant professor with the same faculty in the Department of Automation and Robotics. Her research interests are modern control systems, information and communication technologies, control systems application in agriculture, biomedical engineering, and the Internet of Things. She authored and co-authored more than 50 journal and conference scientific papers and participated in many national and international educational and research projects. She is a member of the IEEE, ETRAN Society, and Alumni Association of Electrical Engineers.

Božidar Popović (PhD) is an associate professor at the Faculty of Electrical Engineering, University of East Sarajevo in the Department of Electronics and Electronic Systems. His field of expertise includes electronics, sensors, embedded computer systems, industrial automation, communication systems, Internet of Things, environmental monitoring, and digital agriculture. He was involved in several national and international projects related to higher education, curriculum modernization and cooperation with industry. He is a member of the IEEE, ETRAN Society, and Alumni Association of Electrical Engineers