ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20250415140751

Preliminary communication
Received: 2025-04-15, Accepted: 2025-05-16

Smart Mini Greenhouse for Eco-Friendly Agriculture

Tomislav Šarić, Elizabeta Tedeško, Goran Šimunović, Sara Havrlišan*

Abstract: This paper presents a proposal for the design, development, and validation of a smart mini greenhouse intended for small-scale agricultural production. The main objective is to explore the feasibility of a cost-efficient smart mini greenhouse prototype. This paper briefly analyses the parameters that influence the process of plant cultivation. Parameters such as air temperature, air and soil humidity, solar radiation and amount of carbon dioxide are analysed. Based on the analysis of the successful process of plant cultivation, sensors are selected for the condition monitoring in the mini greenhouse. By selecting various sensors, actuators and the control unit (Arduino), a system for condition monitoring and dosing of the necessary elements in the process of plant growth (agricultural production) is formed. With the help of computer design tools, a proposal for the construction of a mini-greenhouse is made. The proposed components for growth support and condition monitoring are integrated into the defined construction of the mini-greenhouse. Testing is carried out by designing the control programme and implementing it. By building a mini greenhouse and integrating the selected components (sensors, actuators and other elements) with the control programme, the complete smart mini greenhouse was validated. The validation positively confirmed the proposed and built prototype model of a smart mini greenhouse for production.

Keywords: control monitoring; design; smart mini greenhouse

1 INTRODUCTION

Gardening, the cultivation of plants, is one of the most popular hobbies among individuals living in urban environments. Gardening has a calming and stress-relieving effect and is a healthy and effective way to spend free time. Some citizens want to have fresh produce (vegetables, flowers) all year round and grow it themselves, and there is usually not enough space for gardening in urban areas. The solution may lie in small greenhouses. Citizens in urban areas usually have a lot of work and other activities, so they do not have enough time to monitor and control the condition of the growing plants. The automation of small greenhouses that provide optimal conditions for growing plants can be seen as a solution. The cultivation of plants and flowers requires the setting of cultivation parameters for optimal growth. The integration of various sensors facilitates the monitoring of key parameters essential for plant cultivation. As we live in the era of Industry 4.0, functions such as the Internet of Things, Big Data, the application of artificial intelligence and the like are being used in this area. The Internet of Things, or IoT for short, is a technology that connects electronic devices, sensors and the internet to manage data and applications. The Internet of Things can be used in agriculture for crop management as a medium for monitoring and control, especially in greenhouses, and is referred to as precision farming [1]. One of the key elements of the Automated Urban Greenhouse (AUG) is the development of a network of smart sensors [2]. This network of smart sensors communicates with the AUG control interface and enables automatic control and monitoring of lighting, heating, irrigation and ventilation. The data processing of the sensors as well as the control and monitoring of the processes is done with different microprocessors, one of the most commonly used being the Arduino [3-6]. Various monitoring and control systems are available on the market, which are generally expensive. In the paper [7], the authors compare the systems based on various criteria: Price, light control, soil moisture control, humidity control, temperature control, availability of application and ventilation. One of the reasons for researching and planning a small greenhouse is the cost and an educational approach to developing solutions to problems. Cars, homes, factories are getting smarter, so the aim of this work is to realise a Smart Mini Greenhouse for agricultural production. In order to achieve the set goal, various knowledge in the field of computer-aided design (CAD), monitoring and automatic control, sensors and of course a good knowledge of the process of plant cultivation must be applied. This paper is a presentation of the final thesis in the undergraduate course of mechanical engineering, which was successfully realised in the phase of analysis, design and implementation of the Smart Mini Greenhouse [8].

2 DESIGN OF THE GREENHOUSE AND PARAMETERS OF THE PLANT CULTIVATION PROCESS

A greenhouse is an object that enables the protected and controlled cultivation of plants. The construction consists of walls and a roof, which is usually made of transparent material. The inside of the greenhouse, which is exposed to sunlight, is warmer than the outside temperature. Plants grown in a greenhouse require regulated climatic conditions. A small greenhouse is customised to the type and size of the plants. A small greenhouse is also known as a cold frame. The shape of the greenhouse is shown in Fig. 1, and the flat roof is the most commonly used form of greenhouse [1].

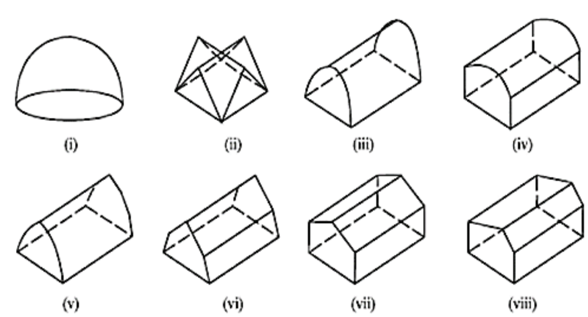

Figure 1 Classification of greenhouses based on the shape of the roof [1]

Various parameters are usually measured in the greenhouse, including heat (air temperature), humidity, soil moisture, solar radiation and the concentration of carbon dioxide (CO_2). Different plants require different conditions for optimum growth. Below you will find a brief description of selected parameters that are important for efficient greenhouse operation.

Heat is expressed by measuring the temperature (°C). The required temperature varies from plant to plant and is one of the key parameters for plant growth. Seed germination takes place at precisely defined temperatures. It is therefore important to maintain the temperature required for each plant species. Temperature can be measured using various thermometers (an example of a thermometer in a greenhouse is shown in Fig. 2) or sensors. Plants consume carbon dioxide (CO_2) and release oxygen (O_2), generating heat. The release of heat can be beneficial for plants that respond to higher temperatures, but for plants that do not require heat, it can lead to stunted growth and disease.

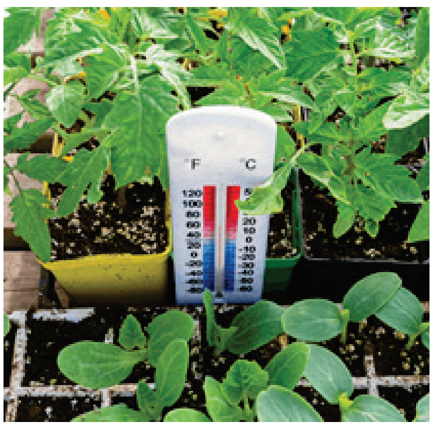

Figure 2 Thermometer [9]

Humidity is important to keep the climate in the greenhouse healthy. Humidity is the amount of water vapour contained in the air and can be measured with a hygrometer, as shown in Fig. 3. When carbon dioxide (CO_2) is processed, the oxygen that is emitted is warm and moist.

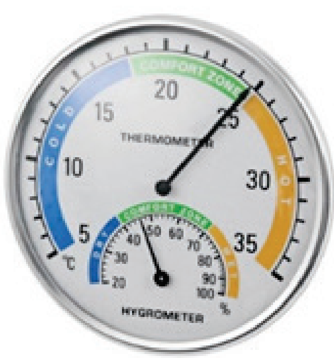

Figure 3 Hygrometer [10]

High moisture levels can lead to the growth of mould and various diseases that are harmful to plants. It is important to monitor the humidity in the greenhouse and regulate it regularly.

Soil moisture is also an important parameter for plant cultivation. Water supplies the plants with nutrients. It is important to supply the plants with a sufficient amount of water.

The amount of sunlight is a necessary parameter for plant growth, as plants need it for the photosynthesis process. Some plants require sunlight, others prefer to grow in the shade. In the greenhouse, the amount of light can be controlled with various curtains, blinds and UV protection covers. If the natural light is not sufficient, special lighting (UV light sources) can be installed in the greenhouse.

The measurement of carbon dioxide (CO_2) concentration is often neglected, although carbon dioxide is a critical parameter for plant photosynthesis. A carbon dioxide level that is too low hinders plant growth, but a carbon dioxide level that is too high is also not favourable for the plants.

2.1 Selection of Components for Smart Greenhouse Control

A smart greenhouse significantly simplifies plant care by automating environmental control. For a greenhouse to be smart, it must be able to replace humans in almost all aspects of plant cultivation. A smart greenhouse must be able to control the optimum temperature. It should also be able to recognise whether the plants need to be supplied with water. If the amount of water is insufficient, a message is sent for corrective action.

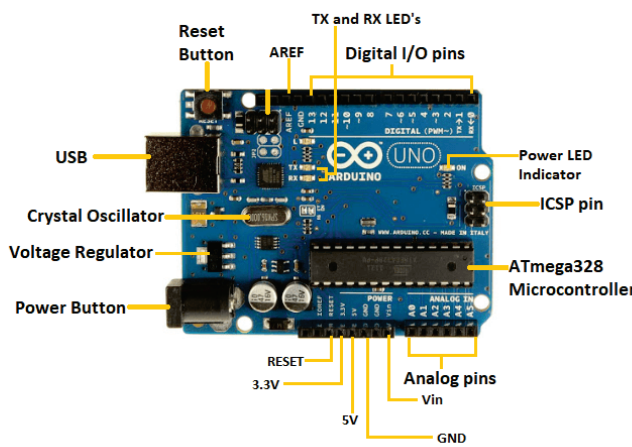

Figure 4 Arduino UNO [11]

Above you will find a brief overview of the devices selected and installed when planning the smart greenhouse. Mainly low-cost components were selected to monitor and control the processes of the smart greenhouse. Arduino UNO is a standard Arduino control board. Arduino UNO is one of the most popular control boards. It is easy to use compared to other control boards such as the Arduino Mega control board and is strongly supported by the Arduino user community. The Arduino UNO [11] control board (Fig. 4) is a practical and cost-effective solution for users entering the world of mechatronics. The Arduino UNO control board is based on the Atmel ATmega328P microcontroller.

The Arduino UNO control board has 6 analogue inputs, 14 digital input/output pins (6 of which can be used as PWM outputs), a voltage regulator, a USB port, a power port, a power LED indicator, a 16 MHz crystal, a reset button and an ICSP (In-Circuit Serial Programming) port. The In-Circuit Serial Programming pin or ICSP pin allows the user to programme using the Arduino board's firmware. Digital input/output pins can have the value High or Low. They are labelled with numbers from D0 to D13. The analogue pins are labelled A0 to A5. Their function is to read the analogue sensor signal. They can also be used as GPIO pins (General Purpose Input Output). The AREF or analogue reference pin is used to supply the control board with a reference voltage from an external power supply.

The power LED indicator shows when the power is switched on (the LED lights up) and when the power is switched off, the LEDs do not light up. The TX and RX LEDs indicate successful data flow between the computer and the control boards. The reset button is used to reset the connection or the control panel itself. The USB port allows the Arduino UNO control board to be connected to the computer and is required for its programming, it can also serve as a power source. The crystal oscillator has a frequency of 16 MHz which makes the Arduino UNO Control Board powerful. The voltage regulator converts the input voltage into a voltage of 5 V. The GND pins are ground pins and serve as 0 volt pins. Vin is the input voltage. Two Arduino UNO control boards are used in conjunction with the upgrade to control all the actuators to be installed in the greenhouse.

2.2 Selecting the Humidity and Air Temperature Sensor

The DHT11 [12] is a digital temperature and humidity sensor (Fig. 5). It is a reliable and stable sensor characterised by good quality, fast response, protection against interference and economy. Calibration has been carried out beforehand under controlled laboratory conditions so that the sensor is ready for use immediately after purchase.

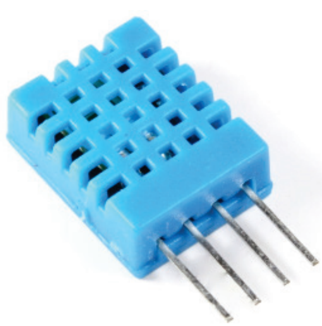

Figure 5 DHT11 sensor [12]

The temperature is measured with a surface-mounted NTC temperature sensor - a thermistor. The thermistor is a variable resistor made of semiconductor material. Changing the temperature changes its resistance. The PTC thermistor (Positive Temperature Coefficient) has a positive temperature coefficient with a measuring range of –50 to +220 °C.

The soil moisture sensor [13] measures the moisture content of the surrounding soil. The sensor is manufactured using the immersion gold process, which protects the nickel surface during the oxidation process. The soil moisture sensor (Fig. 6) is a fork-shaped probe with two exposed conductive plates. The resistance of the probe is inversely proportional to the soil moisture. If there is a lot of water in the soil, the current flows more easily, the conductivity is better and the resistance is lower. Dry soil conducts the current less well and therefore offers a higher resistance. The output voltage of this sensor is calculated by measuring the resistance and the value of the moisture content in the soil is obtained. There is a module on the sensor for connection to the Arduino control board. Such sensors have at least three pins: Vcc, GND and AO. Vcc is the pin that supplies the sensor with power. It is recommended to select a value between 3.3 V and 5 V. GND is the ground pin. AO (Analogue Output), an analogue output pin, generates an output voltage that is proportional to the moisture content. Two analogue soil moisture sensors were used in this work.

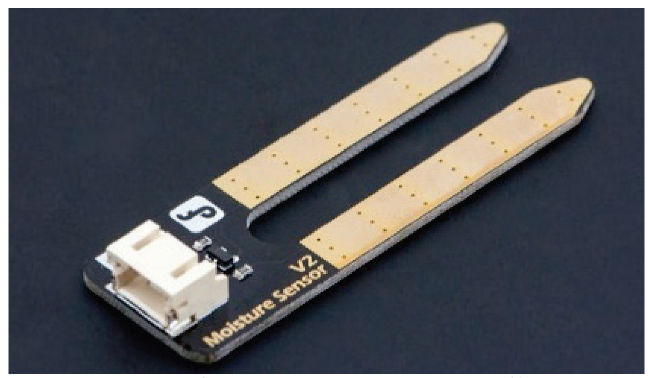

Figure 6 Gravity: Analogue soil moisture sensor [13]

2.3 Selection of Actuators and Motor Drivers

The actuators required to control the greenhouse are a stepper motor and a servomotor. The stepper motor from Moons, type MS17HD2P417A-01, was used in this work. This drive is used to open and close the greenhouse cover. A spindle is connected to its shaft, which converts the rotation of the stepper motor into a linear movement of the lever, which is connected to the greenhouse cover. The servo motor used in this project is the TowerPro MicroServo SG90. Since it is sometimes not necessary for the roof of the greenhouse to be open because the temperature in the greenhouse is not critically high, it is sufficient to open the window/flap to allow airflow. This flap is located at the front of the greenhouse, opposite the fan. This servo motor is used to open and close the flap.

The Arduino UNO [14] controller board cannot fulfil the parameters for operating the selected actuators. It is necessary to upgrade the Arduino L293D Motor Driver Shield (Fig. 7). The L293D shield is one of the most popular motor driver shields capable of controlling motors without additional modules. It can control up to four bidirectional DC motors, two stepper motors and two servo motors.

To communicate with the user, the system is upgraded with an Arduino GSM/GPRS SIM800F shield that enables the use of the GSM mobile phone network. General Packet Radio Service (GPRS) is a protocol that enables wireless data transmission. In order for the GSM/GPRS SIM800F Shield to work with the formatted programme, a special library must be loaded that enables sending and receiving text messages, making and receiving calls and connecting to the Internet.

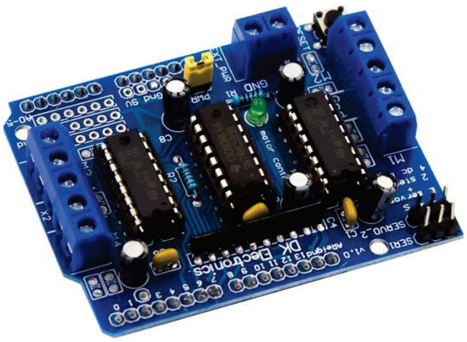

Figure 7 Arduino L293D motor driver shield [14]

3 DESIGN OF THE GREENHOUSE WITH IMPLEMENTATION OF THE COMPONENTS

The moulded greenhouse is designed for small-scale production. The chosen final dimensions of the greenhouse are 280 × 380 × 220 mm. The construction of the greenhouse is shown in Fig. 8 with a view of the opening of the greenhouse cover. A fan is installed at the rear. The fan is used in combination with a damper as a source of airflow in the greenhouse. The fan and the stepper motor are connected to the Arduino Motor Driver shield L293D. On an Arduino UNO control board there are not enough pins for all the motors, sensors and other components. Sensors, buttons and LEDs are connected to the main board of the Arduino UNO. If the DHT11 temperature and humidity sensor detects a temperature that is too high, it sends a signal to the Arduino UNO main control board. A decision is made as to whether the temperature is too high or whether it has reached a critical value. These intervals are determined empirically and entered into the Arduino code depending on the plants planted in the greenhouse.

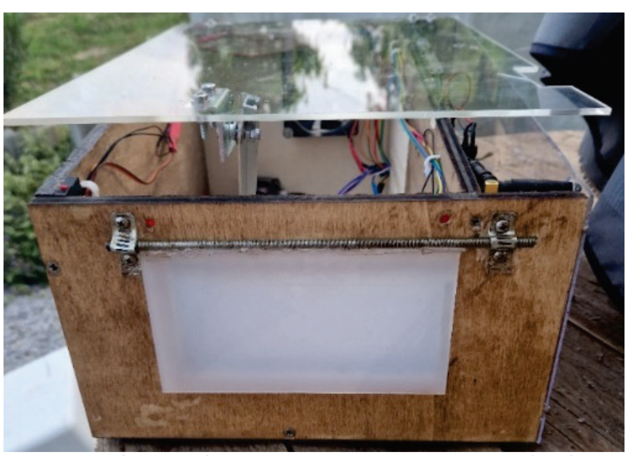

Figure 8 Structure of a greenhouse with a movable cover and flap [8]

A flap (window) is attached to the front of the greenhouse, which is used to ventilate the greenhouse when the lid is closed and the temperature is not critically high. A gear wheel is mounted on the shaft of the servomotor, one tooth of which is extended to a lever that opens the flap by pressing it. When the servomotor turns in the other direction, the lever moves away and the flap closes under its own weight.

Figure 9 Stepper motor with a spindle for lifting the greenhouse cover [8]

A stepper motor is installed inside the greenhouse, to which the shaft is connected (Fig. 9). Activating the stepper motor raises the greenhouse cover until a limit switch is activated, which sends a signal to stop the spindle rotation. The cover is closed by activating the stepper motor in the opposite direction until the limit switch on the greenhouse housing is activated and the cover is closed.

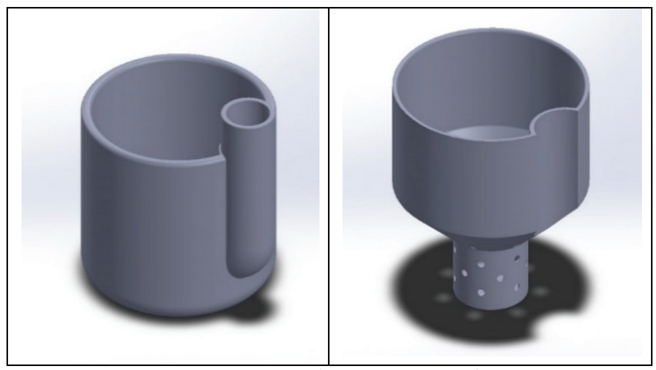

Figure 10 Model of a moulded vessel [8]

The problem of dosing water for plants was solved by designing containers in the SolidWorks programme. The containers were modelled with the aim of extending the time between watering the plants. The containers consist of two parts (Fig. 10). The outer shell is a cylinder that has an additional pipe at one point through which water is poured. The inner container, in which the plant is planted, consists of a larger and a smaller cylinder connected by a cone. The cone and the smaller cylinder are provided with holes. The soil comes into contact with water through the holes and the plant draws exactly as much water through the roots as it needs, significantly extending the time between waterings.

The control system is powered by four AA batteries. The housings are located on the outside of the greenhouse near the Arduino boards, which can be seen in Fig. 11. Attention must be paid to how the batteries are discharged and they must be replaced in good time. Instead of batteries, it is possible to realise a permanent power supply via a rectifier. The GSM/GPRS SIM800F uses additional energy from the charger.

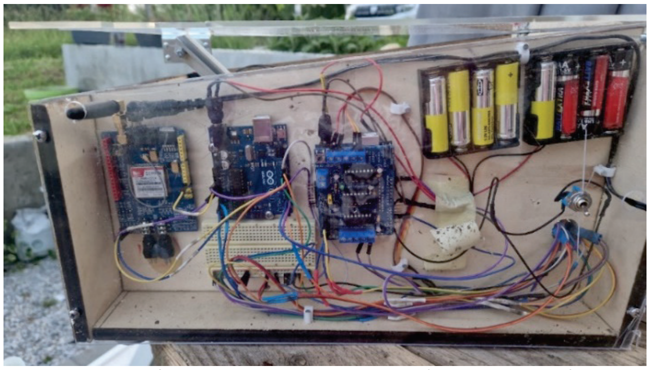

Figure 11 Control boards and power supply of the greenhouse [8]

3.1 Implementation of the Programme Support for the Smart Greenhouse

The system operates by transmitting all sensor-recorded parameters to the Arduino UNO control board, which contains a driver programme (Arduino code) that checks the status of the sensors. So that the driver programme can process the received values, the so-called Arduino libraries must be loaded.

Two management programmes, "Master" and "Slave", were developed to operate the greenhouse. The master programme is used to read sensors, start servomotors and send SMS messages. The slave programme receives the commands from the master programme to control the fan and the stepper motor.

The master Arduino programme uses "if - then - else" loops. The conditions that are constantly checked are the humidity in the greenhouse, the air temperature in the greenhouse and the soil moisture of the plants in the greenhouse.

If the air temperature in the greenhouse is above the set value of +25 °C, the greenhouse is ventilated by opening the flap and switching on the fan. If the temperature continues to rise and exceeds the value of +35 °C, the greenhouse cover is also opened. The subordinate Arduino programme uses a do-while loop.

The DHT11 sensor detects whether the temperature in the greenhouse has risen above +25 °C and sends the information to the main Arduino board with the master programme. The programme then sends a signal to the servomotor and opens the valve. It also sends a signal to the additional Arduino board with the slave programme, which switches on the fan. If the temperature is higher than +35 °C, the master sends an additional signal to the slave programme that further action is required. The slave programme then starts the stepper motor and opens the greenhouse lid. The lid and flap are closed and the fan is stopped according to the same principle, whereby a drop-in temperature is recognised.

Another condition that is constantly monitored is the level of soil moisture in the pots with plants. If the exposed circuit boards of the gravity sensor for soil moisture detect a drop-in moisture below the permissible limit, a signal is sent to the Arduino UNO main control board. A red LED is activated as a visual warning of a change in status. When the soil moisture status changes, the SIM800F shield establishes a connection to the GSM. Once connected, the SIM800F Shield sends an SMS message to the mobile phone with information on which container needs to be refilled. After the plant has been watered, the Gravity soil moisture sensor recognises a change in soil moisture and the red LED assigned to the pot goes out. The realised, tested and implemented programme code can be found in [8].

After selecting and installing all components and implementing the software control system, functional testing of the complete smart greenhouse was conducted. Various scenarios were simulated, and the tests confirmed that the system meets the predefined project requirements.

4 CONCLUSION

This study presents the design and implementation of a smart greenhouse system tailored for small-scale agricultural production. The main parameters for the process are listed, and the parameters for the design of the task in question are particularly emphasised and explained. Based on the analysed parameters, the components required to monitor and smart management of the process in the greenhouse were selected. The Arduino interface and control boards were chosen for their cost efficiency and relative ease of use. They were implemented in a small greenhouse and the hardware and software solutions were tested. After the tests were completed, the realised project of a small smart greenhouse for agricultural production was confirmed. The installed management system can be relatively easily customised in appearance and size to the new greenhouse, depending on the available space and the size of the plants. Depending on the requirements, the number of sensors or motors can be increased or decreased. If desired, additional sensors can be added, e.g. a light sensor. If the greenhouse is located near a water connection, it is also possible to implement an automatic irrigation system which minimises the need for human intervention in the greenhouse. In order to reduce the overall project cost, cost-effective components and materials were selected for the construction of the greenhouse.

Acknowledgements

This research was funded by the University of Slavonski Brod, Republic of Croatia (project SmartPRO).

5 REFERENCES

[1] Kumar, A., Tiwari, G. N., Kumar, S., & Pandey, M. (2006). Role of Greenhouse Technology in Agricultural Engineering. *International Journal of Agricultural Research*, *1*(4), 364-372. https://doi.org/10.3923/ijar.2006.364.372

[2] Meah. K., Forsyth, J., & Moscola, J. (2019). A Smart Sensor Network for an Automated Urban Greenhouse. *The IEEE International Conference on Robotics, Electrical and Signal Processing Techniques (ICREST2019)*, 21 February 2019, Dhaka, Bangladesh. https://doi.org/10.1109/ICREST.2019.8644079

[3] Shimpi, M., Thorat, V., Gavade, S., Pawar, S., & Rajule, N. (2022). Smart Greenhouse Automation and Monitoring System. *The 6th International Conference on Computing, Communication, Control and Automation (ICCUBEA), Pimpri*

Chinchwad College of Engineering (PCCOE), Aug 26-27 2022, Pune, India.
https://doi.org/10.1109/ICCUBEA54992.2022.10010745

[4] Ardiansah, I., Bafdal, N., Suryadi, E., & Bono, A. (2020). Greenhouse Monitoring and Automation Using Arduino: A Review on Precision Farming and Internet of Things (IoT). *International Journal on Advanced Science Engineering Information Technology*, *10*(2), 703-709. https://doi.org/10.18517/ijaseit.10.2.10249

[5] Mahfuz, N., Jahan, R., Islam, Md. M. I., Nigar, M., & Karmokar, S. (2020). Microcontroller Based Intelligent Greenhouse Environment Monitoring and Controlling System. *IEEE International Women in Engineering (WIE) Conference on Electrical and Computer Engineering (WIECON-ECE)*, 26-27 December 2020, Bhubaneswar, India. https://doi.org/10.1109/WIECON-ECE52138.2020.9397991

[6] Kirci, Y. C. P., Erdinc, E., & Celik, Y. (2021). Smart greenhouse and smart agriculture. *Conference of Open Innovations Association*, FRUCT Oy, 455-459.

[7] Sahaidak, T. & Huzynets, N. (2021). Investigation of Greenhouse Monitoring and Control system. *Journal Advances in Cyber-Physical Systems*, *6*(1), 54-62. https://doi.org/10.23939/acps2021.01.054

[8] Tedeško. E. (2023). Smart Mini Greenhouse for Agricultural Production. *Undergraduate Thesis*, University of Slavonski Brod, Slavonski Brod. (in Croatian)

[9] See https://www.greenhousemag.com/article/2020-structures-guide-5-tips-for-temperature-control-in-your-growing-environment/

[10] See https://www.msschippers.com/thermometer-with-hygrometer-analogue-4305813.html

[11] See https://www.javatpoint.com/arduino-uno

[12] See https://ardubotics.eu/hr/senzori/1104-senzor-temperature-i-vlage-dht11.html

[13] See https://www.dfrobot.com/product-599.html

[14] See https://www.engineersgarage.com/arduino-l293d-motor-driver-shield-tutorial/

Authors' contacts:

Tomislav Šarić, full professor
University of Slavonski Brod,
Mechanical Engineering Faculty in Slavonski Brod,
Trg I. B. Mazuranic 2, 35000 Slavonski Brod, Croatia
tsaric@unisb.hr

Elizabeta Tedeško, bachelor student
University of Slavonski Brod,
Mechanical Engineering Faculty in Slavonski Brod,
Trg I. B. Mazuranic 2, 35000 Slavonski Brod, Croatia
etedesko@unisb.hr

Goran Šimunović, full professor
University of Slavonski Brod,
Mechanical Engineering Faculty in Slavonski Brod,
Trg I. B. Mazuranic 2, 35000 Slavonski Brod, Croatia
gsimunovic@unisb.hr

Sara Havrlišan, assistant professor
(Corresponding author)
University of Slavonski Brod,
Mechanical Engineering Faculty in Slavonski Brod,
Trg I. B. Mazuranic 2, 35000 Slavonski Brod, Croatia
shavrlisan@unisb.hr