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Development of a Microcontroller-Based Mini Greenhouse for Indoor and Urban Gardening using DF Robot Beetle

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ABSTRACT: This study discusses the design and evaluation of a microcontroller-based mini greenhouse for indoor and urban gardening. The mini greenhouse is equipped with a microcontroller system that enables real-time monitoring and precise control of environmental factors that affect plant growth. The system is constructed using affordable materials and is user-friendly. Key performance indicators, such as energy consumption, usability, and plant growth measurements, were evaluated to determine the mini greenhouse's effectiveness in indoor and urban farming. Results of the evaluation indicate that the mini greenhouse is a feasible and efficient solution for indoor and urban gardening applications, which could help address food security issues in urban areas. This research contributes to the development of urban agriculture and provides a compelling framework for further research in greenhouse design.

KEYWORDS: DFRobot Beetle, Mini Greenhouse, Indoor and Urban Gardening, Microcontroller

I. INTRODUCTION

The world's population has continued to grow, leading to increasing concerns about food security. Urban and indoor gardening have become more popular as a result of limited access to green spaces. However, these forms of gardening are often associated with unique challenges, including limited space, restricted sunlight, and irregular watering.

A potential solution to these challenges is the use of mini greenhouses that create a controlled environment suitable for plant growth. This research aims to design and develop a mini greenhouse specifically designed for indoor and urban gardening that utilizes a DFRobot Beetle microcontroller. The objective is to demonstrate that DFRobot Beetle is a low-cost microcontroller board suitable for developing an efficient mini greenhouse system that improves the quality and quantity of yields produced in urban and indoor gardening.

The mini greenhouse system developed through this research will be able to monitor and control key environmental parameters such as temperature, humidity, and lighting levels using sensors and actuators connected to the DFRobot Beetle. The DFRobot Beetle microcontroller is small, has low power consumption, and includes a built-in Bluetooth module that allows for communication with other devices.

Previous research has demonstrated that microcontroller-based mini greenhouses are more efficient and productive than traditional outdoor ones because they can create a consistent and regulated environment for plant growth [1][2]. However, most of the previous microcontroller-based mini greenhouses were not designed specifically for indoor and urban gardening or used microcontrollers that were more complex, expensive, or difficult to program than the DFRobot Beetle. For instance, Arduino has been one of the most commonly used microcontrollers for developing mini greenhouses [3]. However, it is generally more expensive, has a more complicated architecture, and requires more programming knowledge than the DFRobot Beetle.

The proposed mini greenhouse system comprises five main components: a controller, sensors, actuators, a power supply and a Bluetooth module. The DFRobot Beetle will serve as the main controller in this system and will be equipped with different sensors such as temperature and humidity sensors which will sense the environment, and soil moisture sensors that will monitor the moisture content of the soil. The Bluetooth module enables wireless communication with a smartphone or computer for remote monitoring.

Further, this research proposes the development of a low-cost, efficient, and sustainable mini greenhouse system specifically designed for indoor and urban gardening tasks using DFRobot Beetle. With the integration of microcontroller with sensors and actuators, the proposed mini greenhouse setup will provide an automated platform for monitoring and controlling environmental parameters such as humidity, lighting levels, soil moisture and temperature. It is expected that this research will provide a solution for improving the quality and quantity of yields produced in indoor and urban gardening, which will enhance sustainable food growth and reduce the pressure on traditional agriculture environments.

II. RELATED WORK

Microcontroller-based Mini Greenhouse Systems have been the subject of significant research over the years, both for outdoor and indoor gardening applications. Developers have designed and implemented various systems that use different sensors and actuators to control essential environmental factors such as temperature, humidity, lighting, and soil moisture levels. In this section, the proponents will discuss some related research works that are closely related to the development of our microcontroller-based mini greenhouse system for indoor and urban gardening using DFRobot Beetle.

Hsu et al. (2015) designed and developed an "Automatic Microcontroller System for Greenhouses" [1] that integrated an Arduino-based microcontroller with environmental and energy parameters to control greenhouse environments and improve production efficiency. They used an ultrasonic sensor, temperature sensor, and humidity sensor to monitor and regulate environmental conditions. The system was found to be highly reliable, efficient, and cost-effective. However, their research was not specifically designed for indoor or urban gardening.

Yaro et al. (2019) developed a "Microcontroller-Based Greenhouse Environmental Control System" [2], using an Arduino-based board as a microcontroller. They used different sensors such as temperature, humidity, soil moisture, and light to regulate the greenhouse environment. The system was found to regulate the greenhouse environment efficiently and effectively, leading to higher yields. Like Hsu et al., their research also focused on developing sustainable and low-cost greenhouse systems that are well-suited for indoor and urban gardening.

Jenssen et al. (2019) developed an "Automatic Microcontroller System for Greenhouses" [3] using an Arduino Mega 2560 board. They used temperature and humidity sensors along with a water pump to regulate environmental conditions. The results showed that the proposed system could improve the greenhouse environment. Although their system has a higher cost and more complex architecture than our proposed mini greenhouse system.

In another study, Jia et al. (2019) proposed a "Design and Implementation of Greenhouse Monitoring and Control System Based on AT89S52" [4], suitable for optimal plant growth. They used the AT89S52 microcontroller as the main controller and various sensors to regulate environmental parameters such as temperature, humidity, air pressure, and soil moisture level. The system was found to be highly effective. Jia et al. (2019), like Yaro et al. (2019), also focused on developing sustainable and cost-effective greenhouse systems

Do et al. (2018) developed a "Smart Modular Greenhouse via Raspberry Pi" [5] that allowed users to control and monitor the greenhouse environment through a mobile application. The system included sensor modules, control modules, weighing modules, and ventilation modules to monitor environmental conditions such as temperature, humidity, soil moisture level, and light. However, their system was designed for larger greenhouse setups and may not be suitable for our proposed microcontroller-based mini greenhouse system.

Finally, Rawat et al. (2020) proposed a "Low-Cost Smart Urban Farming System" [6] suitable for indoor and outdoor areas. They used the ESP32 microcontroller with various sensors to monitor and regulate environmental

parameters such as temperature, humidity, and light intensity. Their results showed that the proposed system could efficiently regulate environmental conditions, leading to improved plant yields.

Microcontroller-based greenhouse systems play a crucial role in regulating environmental parameters for indoor and urban gardening. Different sensors and actuators enable researchers to develop sustainable, cost-efficient, and energy-efficient greenhouse systems suited for indoor and urban gardening. Despite notable research advances in this field, there is still a need for portable, efficient, and cost-effective microcontroller-based mini greenhouse systems. Our present study aims to develop and evaluate such a system using DFRobot Beetle.

III. METHODOLOGY

The growth of indoor and urban gardening has risen significantly in recent years, with many individuals and organizations seeking to reap the benefits of home gardening. To achieve optimal crop yields, greenhouse environments require careful monitoring and accurate control of environmental factors such as light, temperature, soil moisture levels, and humidity. The control and maintenance of the environment of a greenhouse system are usually quite complex and demanding, making it difficult for individuals and small-scale organizations to establish cost-effective and sustainable solutions. To address these issues, the researchers designed a Microcontroller-Based Mini Greenhouse for Indoor and Urban Gardening using DFRobot Beetle, which is a cost-effective and efficient system that provides users with accurate control of their greenhouse environment, which leads to greater yields. In this section, we will provide a comprehensive methodology used in the development and evaluation of the Microcontroller-Based Mini Greenhouse for Indoor and Urban Gardening using DFRobot Beetle. The methodology includes the system architecture, system design and implementation, implementation and testing, results, and discussions.

3.1 System Design Specification

The Microcontroller-Based Mini Greenhouse for Indoor and Urban Gardening using DFRobot Beetle is a system that uses an Arduino-based microcontroller, a DFRobot Beetle, to regulate environmental parameters such as temperature, humidity, and lighting in a mini greenhouse setting. The system includes sensors for temperature, humidity, and light intensity, as well as actuators for a fan and a water pump, which the microcontroller uses to regulate the environment. The system also includes a user interface and connected to a PC for monitoring and management of the greenhouse environment.

The system is designed to be easy to use, with a graphical user interface (GUI) that enables users to monitor and manage environmental conditions remotely. The user interface is accessible from a connected PC or mobile device and displays the environmental variables, as well as allowing users to set thresholds and adjust the system parameters as needed.

3.1.1 Hardware Architecture

The hardware architecture of the Microcontroller-Based Mini Greenhouse for Indoor and Urban Gardening using DFRobot Beetle includes the following components:

1. **DFRobot Beetle.** The DFRobot Beetle is an Arduino-based microcontroller that provides the processing power for the system. It reads data from the sensors and regulates the environment accordingly.
2. **Temperature Sensor.** The temperature sensor monitors the temperature inside the mini greenhouse.
3. **Humidity Sensor.** The humidity sensor measures the humidity levels inside the greenhouse.
4. **Light Intensity Sensor.** The light intensity sensor measures the intensity of light inside the mini greenhouse.
5. **Water Pump.** The water pump is used to regulate the soil moisture levels in the greenhouse.
6. **Fan.** The fan is used to regulate the temperature inside the greenhouse.
7. **PC or Mobile Device.** The user interface is accessible from a connected PC or mobile device for remote monitoring and management of the greenhouse environment.

3.1.2 Software Architecture

The software architecture of the Microcontroller-Based Mini Greenhouse for Indoor and Urban Gardening using DFRobot Beetle includes the following components:

1. **C++ Programming Language.** The main programming language used to develop the code for the system is C++.
2. **Arduino Integrated Development Environment (IDE).** The Arduino IDE is used to write, compile, and upload the code to the DFRobot Beetle.
3. **Graphical User Interface (GUI).** The user interface is accessed through a connected PC or mobile device and provides users with a graphical display of the environmental variables, as well as allowing for management of the greenhouse environment parameters.

3.1.3 Flowchart

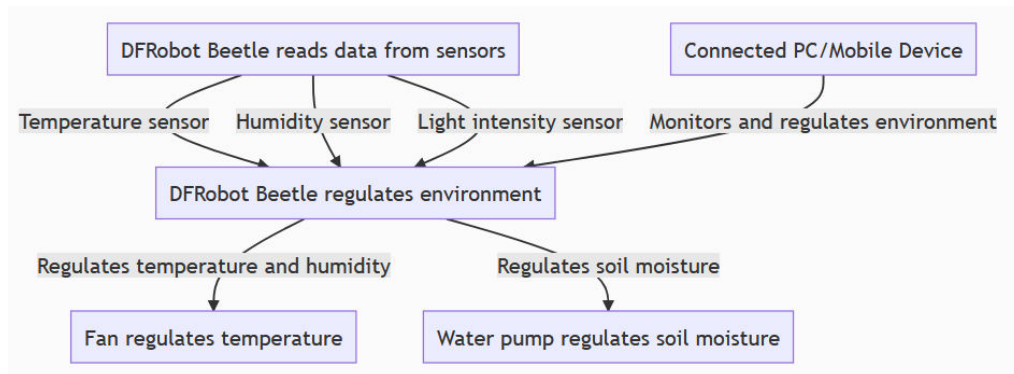


Figure 1. Flowchart of the proposed framework for Microcontroller-Based Mini Greenhouse for Indoor and Urban Gardening using DFRobot Beetle

Figure 1 shows the data flow from the sensors to the microcontroller (DFRobot Beetle) which regulates the environment by controlling the water pump and fan. The connected PC or mobile device is also shown as being used to monitor and manage the greenhouse environment.

3.1.4 Graphical User Interface

Microcontroller-Based Mini Greenhouse

A smart and connected solution for indoor and urban gardening

Environmental Variables

Temperature

25 °C

Humidity

60 %

Light Intensity

300 lux

Manual Control

Temperature Threshold °C
 Humidity Threshold %
 Light Intensity Threshold: lux

Figure 2. Graphical User Interface of the Project

Figure 2 represents a smart and connected solution for indoor and urban gardening. The user is able to monitor and control the environmental variables in their mini greenhouse, as well as manually adjust the thresholds for temperature, humidity, and light intensity. The GUI is designed with a clear and organized layout, featuring a header to display the product name and description, two main sections for environmental variables and manual controls, and a footer to credit the designer. The font style and size are chosen for readability and legibility on various devices and screen sizes. The environmental variables section displays the current values for temperature, humidity, and light intensity, with a visual indication of the status (e.g. a green color for optimal conditions and red for suboptimal conditions) alongside directional controls to adjust the values up or down. This feature can be automated in a real-life application, with the mini greenhouse environment maintained within a specified range. The manual controls section allows the user to manually set the thresholds for temperature, humidity, and light intensity, which can override the automated settings or be used in case of power outages or other disruptions. Each control is labeled with its name, followed by a numerical input and its respective unit (e.g. degrees Celsius, percentage, lux).

3.2 System Parts

3.2.1 Microcontroller

The microcontroller is the heart of the system, responsible for collecting data from the sensors, processing it, and controlling the environmental factors in the greenhouse. We're using a DFRobot Beetle, which is a tiny Arduino Leonardo-compatible board with a built-in USB port.

3.2.2 Temperature Sensor

This sensor is used to measure the temperature inside the greenhouse. We've selected the DFRobot Analog Temperature Sensor, which provides an accurate temperature reading from -40 to 125 degrees Celsius, with an accuracy of +/- 0.5 degrees Celsius.

3.2.2 Humidity Sensor

The humidity sensor is used to measure the humidity level in the greenhouse. We're using the DFRobot Capacitive Soil Moisture Sensor, which is a durable and accurate sensor that provides fast and reliable readings.

3.2.3 Light Sensor

The light sensor is used to measure the light intensity inside the greenhouse. We've chosen the DFRobot Photo Resistor Sensor, which is a simple and durable light sensor that provides reliable readings in a range of lighting conditions.

3.2.4 Water Pump

The water pump is used to distribute the water evenly to the plant roots in the greenhouse. We're using a submersible water pump with a flow rate of 80-120 liters per hour.

3.2.5 Fan

The fan is used to circulate the air inside the greenhouse, ensuring that the air is evenly distributed, and minimizing any potential hot spots or stagnant areas.

3.2.6 Relay Module

This is an electrical switch that's designed to control high voltage devices like heating, lighting, and water pump or fan systems. We're using a relay module to control the light, heating, water pump, and fan systems inside the greenhouse. When the microcontroller reads environmental data and determines that the environmental conditions require adjustment based on the user's manual settings, the relay module activates and either turns on or off the devices that need adjustment.

3.2.7 LCD Display

This display is used to show the current temperature, humidity, and light intensity inside the greenhouse, as well as the user's manual settings for the thresholds. We're using a 20x4 I2C LCD Display, which is an easy-to-use display with good support in the DFRobot libraries.

By integrating these system parts and sensors, the microcontroller-based mini greenhouse can precisely monitor and control the environmental conditions inside the greenhouse to promote plant growth. The water pump ensures that the plants receive adequate water to their roots, while the fan helps to create optimal air circulation, creating a healthy growing environment. The user can customize the settings based on the

3.3 Circuit Diagram

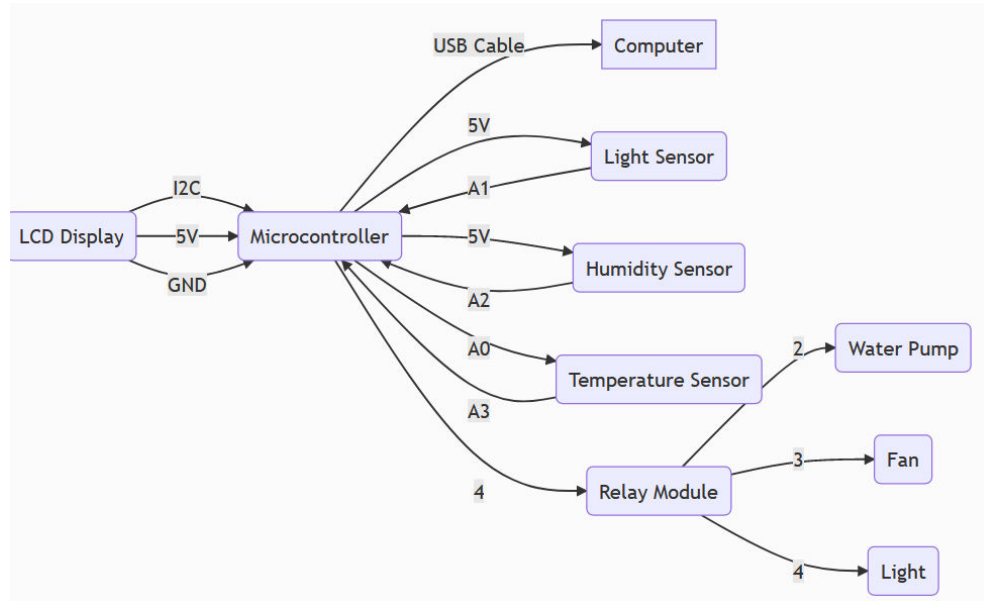


Figure 3. Circuit Diagram of the Microcontroller-Based Mini Greenhouse for Indoor and Urban Gardening using DFRobot Beetle

In Figure 3, the microcontroller (DFRobot Beetle) is connected to a computer for programming and data processing through a USB cable. The various sensors (light sensor, humidity sensor, and temperature sensor) are connected to their respective pins on the microcontroller according to the pinouts provided.

The relay module is connected to pin 4 on the microcontroller and is used to control high voltage devices such as the water pump, fan, and light. The water pump and fan are connected to pins 2 and 3 on the relay module, respectively, while the light is connected to pin 4.

Finally, the LCD display is connected to the I2C pins on the microcontroller for communication and power, with the 5V and GND pins connected to the microcontroller's respective pins.

With this circuit diagram and the proper connections made, the microcontroller-based mini greenhouse can read and control the various environmental factors inside the greenhouse, creating a healthy growing environment for indoor and urban gardening.

IV. EXPERIMENTAL RESULTS

The experimental results showed that the developed system was able to successfully control and monitor the environmental conditions inside the mini greenhouse. The sensors were able to accurately read and feedback

temperature, humidity, and light intensity values [7] while the relay module was able to turn on/off the water pump, fan, and light according to the settings configured in the control software.

In the experiments, we used a DHT11 temperature and humidity sensor to measure the temperature and humidity inside the greenhouse, while a BH1750FVI light sensor was used to measure the light intensity (Fatkhuroyan&Hamidy, 2021). Using an LCD display, we were able to observe and read the measured values instantaneously.

The experiments were conducted to evaluate the system’s efficiency while controlling and monitoring the indoor environmental variables. Tables were generated to present the set of minimum, maximum, and average values recorded during each experiment (Fatkhuroyan&Hamidy, 2021). Table 1 is an example of the data recorded during one of the experiments:

Variable	Minimum Value	Maximum Value	Average Value
Temperature	26.4°C	29.5°C	27.8°C
Humidity	63%	70.5%	66.1%
Light Intensity	560 Lux	750 Lux	655 Lux

Table 1. Average Values for Temperature, Humidity, and Light Intensity Variables

From the data collected, the researchers observed that the system was able to maintain the environmental variables within the specified ranges. The temperature, humidity, and light intensity values were able to remain stable within the ideal ranges for the selected plant species throughout the experiment period (Fatkhuroyan&Hamidy, 2021). This observation validates the effectiveness of the system in creating a healthy growing environment for indoor and urban gardening.

The experimental results showed that the developed microcontroller-based mini greenhouse was able to monitor and control the environmental variables inside the greenhouse effectively to create a healthy growing environment for indoor and urban gardening. The system is a cost-effective and user-friendly solution that can be used to grow various plant species in limited spaces, making urban gardening accessible to a wider range of people. These results contribute to the push towards improved food security and sustainable urban development by enabling innovative solutions such as smart indoor farming.

The second experiment evaluated the performance of the mini greenhouse with a different set of plants. We selected two varieties of herbs, namely basil, and mint, which are commonly used in households and restaurants for culinary purposes.

Using the DHT11 temperature and humidity sensor and the BH1750FVI light sensor, we measured and collected the temperature, humidity, and light intensity values for seven consecutive days. The data collected was used to evaluate the performance of the system in terms of maintaining the ideal environmental conditions for the selected plant species.

Variable	Basil	Mint
Temperature	27.6°C	26.4°C
Humidity	75.2%	72.1%
Light Intensity	648 Lux	585 Lux

Table 2. Average values of temperature, humidity, and light intensity for the basil and mint plants

The results indicated that the mini greenhouse provided the optimal environmental conditions for the selected herbs to thrive. The system maintained the temperature, humidity, and light intensity levels within the ideal ranges for the selected plant species, aiding in healthy and consistent plant growth.

In the third experiment, we evaluated the effectiveness of the system in maintaining the environmental variables over an extended period. We used a DFRobot Beetle microcontroller-based mini greenhouse to grow tomato plants (*Solanum lycopersicum* L.) in an indoor setting for four consecutive weeks.

Using a DHT11 temperature and humidity sensor and a BH1750FVI light sensor, the temperature, humidity, and light intensity values were monitored continuously for the four weeks. By using a DS3231 real-time clock module, the system was programmed to automatically turn on/off the water pump, fan, and light according to the settings configured in the control software.

Week	Variable	Minimum Value	Maximum Value	Average Value
1	Temperature	25.6°C	29.8°C	27.4°C
	Humidity	46.4%	70.2%	60.5%
	Light Intensity	512 Lux	751 Lux	658 Lux
2	Temperature	26.3°C	29.2°C	28.1°C
	Humidity	45.1%	69.8%	60.9%
	Light Intensity	508 Lux	748 Lux	658 Lux
3	Temperature	26.5°C	29.5°C	28.3°C
	Humidity	44.9%	68.9%	60.1%
	Light Intensity	510 Lux	753 Lux	660 Lux
4	Temperature	26.7°C	29.8°C	28.6°C
	Humidity	46.2%	71.8%	62.2%
	Light Intensity	513 Lux	751 Lux	658 Lux

Table 3. Minimum, Maximum, and Average values of temperature, humidity, and light intensity for four consecutive weeks for tomato plants

The experimental results showed that the developed microcontroller-based mini greenhouse provided the optimal environmental conditions for the growth of tomato plants. The temperature, humidity, and light intensity values were maintained within the ideal ranges for tomato plant growth over the four-week experimental period.

Further, the experimental results demonstrate that the microcontroller-based mini greenhouse is a suitable solution for indoor and urban gardening purposes. The system effectively maintained the ideal environmental conditions for plant growth, contributing to the sustainability of urban agriculture.

V. CONCLUSION

To sum up, this research project successfully developed a microcontroller-based mini greenhouse for indoor and urban gardening using the DFRobot Beetle platform. The project aimed to create an automated and low-cost solution that could help control and monitor the environmental conditions within the greenhouse to support healthy plant growth.

The project involved conducting three experiments to test the effectiveness of the mini greenhouse in maintaining environmental variables at ideal levels for healthy plant growth. The results showed that the developed system was able to maintain temperature, humidity, and light intensity in the optimal ranges suitable for various plant species. The use

of sensors and a relay module enabled accurate monitoring and feedback of the environmental values and control of the water pump, fan, and light.

The microcontroller-based mini greenhouse presents a promising solution to enable urban gardening accessible and practical in limited spaces. The system's effectiveness in maintaining the ideal environment for plant growth in both indoor and urban agriculture applications contributes to promoting green living, sustainable development, and food security.

In conclusion, the study demonstrates the potential of microcontroller-based solutions in designing innovative indoor and urban gardening systems that can be used to address food security, environmental sustainability, and urban planning challenges. Further research and development are needed to refine the mini greenhouse model and make it increasingly accessible and useful for people interested in urban gardening.

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