Journal of Telecommunication, Electronic and Computer Engineering
ISSN: 2180 – 1843 e-ISSN: 2289-8131 Vol. 17 No. 1 (2025) 11-17
jtec.utem.edu.my
DOI: https://doi.org/10.54554/jtec.2025.17.01.002

IoT-Integrated Smart Gardening System for Real-Time Monitoring and User-Controlled with Smart Film

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Article Info

Article history:
Received Apr 18th, 2024
Revised Jan 21st, 2025
Accepted Mar 11th, 2025
Published Mar 19sth, 2025

Index Terms:
Smart Garden
Smart film
Internet of things (IoT)
Node MCU

Abstract

Internet of things (IoT) refers to devices connected to the internet that enable human-to-human or human-to-computer communication. It facilitates the collection and exchange of data between these devices and users. This study presents an IoT-based Smart Garden integrated with smart film technology, designed to predict light intensity and monitor daily plant growth. Despite a strong interest in gardening, many individuals lack the time to properly care for their plants. Therefore, this study proposes a simple and efficient method for plant monitoring and control using a smartphone or other connected devices. The system incorporates three primary sensors: the DHT11 sensor (for temperature and humidity), a soil moisture sensor, and a light intensity module sensor. The water pump and smart film function as actuators, which can be controlled remotely or via a smartphone. This IoT-based Smart Garden with smart film collects real-time data and transmits it to users via a mobile application, ensuring convenient remote monitoring and control. This research demonstrates that smart gardening systems significantly reduce human intervention, making plant care more efficient. Moreover, the sensors continuously gather and update environmental data, allowing users to stay informed about plant conditions in real time without needing to be physical present.

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I. INTRODUCTION

Gardening is a hobby and recreational activity that can be enjoyed by people of all ages. According to Thompson [1], regular exposure to plants and greenery provides significant mental and physical health benefits. Nevertheless, in today's modern world, people are so busy with their daily routines that they lack the time to take care for their plants, which may lead to a loss of interest in gardening. Furthermore, it is difficult for gardeners to monitor their plants from afar when travelling. Besides, unstable weather conditions, such as monsoon and dry seasons, can significantly impact plant growth. For examples, during dry seasons and drought conditions, plants become stressed, nutrient transport slows, growth ceases and plants wilt due to water deficiency. Excessive exposure to light or intense sunlight and heat can cause chlorophyll breakdown in leaves, leading to scorched or bleached foliage, as emphasized by Poonam et al. [2].

Moreover, many gardeners still rely on manual watering and monitoring methods. As highlighted by Zaki et al. [3], due to time constraints and busy lifestyles, proper watering is often neglected. Irrigation systems are widely used in agriculture to supply water to the soil to maintain moisture levels during plant growth, but regular monitoring is still necessary to plants remain in good condition. Additionally, Abd Rahim et al. [4] noted that not all gardeners have sufficient knowledge and experience to properly manage their plants. Some plants require more attention grow properly, while others are cultivated purely for home gardening or decorative purposes. For photosynthesis to occur, plants must be provided with a suitable environment and watered regularly. To address these challenges, a monitoring system should be implemented. Such a system would not only tract plant health but also alerts users when growth conditions become unsuitable. The Internet of Things (IoT) can be leveraged to create this type of system. Currently, manual evaluation methods remain one of the oldest techniques used in gardening. However, as observed by Lakshmisudha et al. [5], farmers can monitor all parameters and analyze data more effectively using a smart gardening system integrated with IoT technology. With the advantages of a wireless sensor network system, this approach focuses on creating tools and devices to control, display and notify users, as highlighted by Gondchawar et al. [6]. Jagannathan et al. [7] also suggested that cloud computing devices can be integrated into such systems, incorporating sensors and tools to collect field data and precisely transmit information to the network.

Furthermore, weather conditions can shorten the lifespan of a garden, as some plants may perish due to insufficient rainfall, extreme heat, or high humidity, as highlighted by Biswal et al. [8]. To provide real-time monitoring, the proposed system incorporates various sensors and components. In this research, the sensors detect soil moisture and temperature, while an automated system controls water supply to the garden. Additionally, a microcontroller processers sensor data to regulate plant survival conditions. The water requirements of plants depend on soil type and plant species. Users receive regular updates on plant status, ensuring better maintenance. By incorporating electronic devises that continuously monitor soil and plant conditions, gardening can be optimized. As Dhanaraju et al. [9] stated, IoT technology enables remote monitoring and control, enhancing the overall efficiency and sustainability of gardening.

II. RESEARCH METHODOLOGY

In this project, three systems were implemented. The first system designed to automate plant irrigation. The second system is an innovative smart film integrated with an LDR sensor for light control. The third system temperature and humidity monotoring.

A. Smart Watering System

This system utilizes a NodeMCU 8266 as the brain of the system in this project. A soil moisture sensor is connected to the input pin of the microcontroller, while the output pins are interfaced with a water pump and a relay. The moisture sensor, embedded in the soil, utilizes two probes to measure the soil moisture content. The NodeMCU 8266 receives these moisture level readings and processes the analog signals from the sensor, converting them into digital values. When the moisture level drops below a predefined threshold, the NodeMCU sends a signal to the pump, activating it to deliver the required amount of water to the soil. The pump is equipped with a rotating platform that ensures proper water distribution through a connected pipe. If the soil remains dry, the sensor readings will indicate a decrease in moisture, triggering the relay to activate the pump. Once the moisture level reaches the desired threshold, the pump is turned off remotely. Figure 1 illustrates the smart watering circuit used in this system.

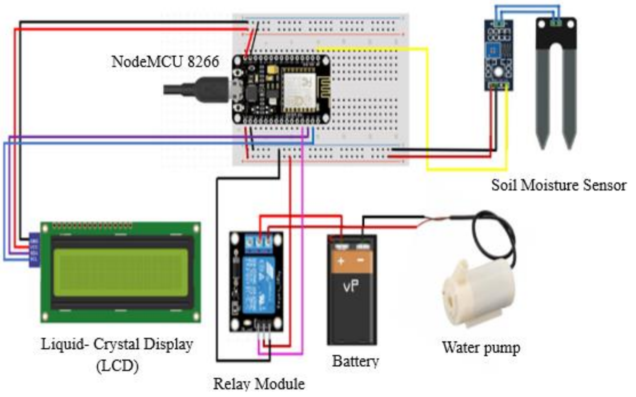

Figure 1. Smart Watering Circuit

B. Smart Film and LDR Sensor System

The goal of this system is to enable users to control smart film through their smartphones via an application with a simple touch. This modern technique integrates sensors, Android applications and microcontrollers, to allow automated film control, managing light intensity dynamically.

The experimental setup for controlling a smart film using an LDR sensor was implemented using a NodeMCU ESP8266 microcontroller, a relay module, a 9V battery, and a smart film. The LDR sensor was connected to the analog input pin (A0) of the NodeMCU, enabling it to detect variations in ambient light intensity. The relay module was interfaced with a digital GPIO pin (D1) on the NodeMCU to control the power supply to the smart film. The smart film was powered by a 9V battery through the relay, allowing it to switch between opaque and transparent states based on the detected light conditions. The NodeMCU was programmed using the Arduino IDE to continuously monitor the LDR sensor's output and trigger the relay when the detected light intensity exceeded a predefined threshold. This configuration enabled automated control of the smart film's transparency, providing an effective mechanism for dynamic light management and demonstrating the potential of smart films in responsive environmental applications.

The relay module (Delay Channel) serves as a control mechanism that allows the system to remotely activate or deactivate this film. It acts as a bridge between the microcontroller (NodeMCU 8266) and the smart film, enabling the system to introduce timed delays or process remote commands before turning the film ON or OFF. This feature ensures proper sequencing and allows user-controlled adjustments in the smart gardening system. Figure 2 shows the smart film and LDR sensor circuit.

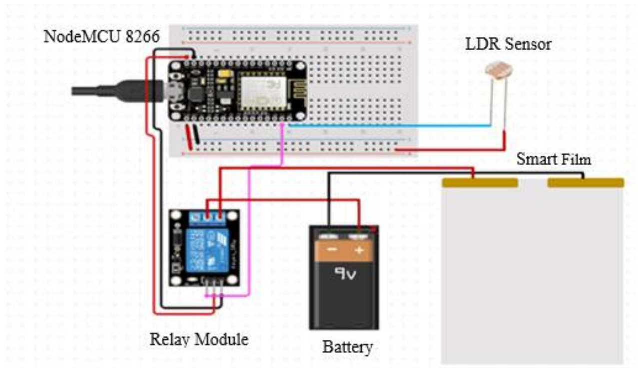

Figure 2. Smart Film and LDR Sensor Circuit

C. DHT11 Sensor System

The DHT11 sensor is a digital sensor that provides reliable readings of temperature and humidity. It operates using a single-wire communication protocol, making it suitable for integration with microcontrollers such as the NodeMCU ESP8266. NodeMCU is an open-source platform that combines microcontroller functionality with Wi-Fi capabilities, facilitating the development of IoT applications.

The experimental setup for measuring temperature and humidity included a DHT11 sensor, a NodeMCU ESP8266 microcontroller, and a 16x2 Liquid Crystal Display (LCD) for real-time data visualization. The circuit was assembled on a breadboard, with the DHT11 sensor connected to the NodeMCU via its digital output pin, powered by the 3.3V supply and grounded accordingly. The LCD was interfaced with the NodeMCU using I2C communication, with its SDA and SCL pins linked to GPIO D2 and D1, respectively, and powered by the NodeMCU. The Arduino IDE along with the

DHT11 and LiquidCrystal_I2C libraries, was used to program the NodeMCU, enabling efficient data acquisition and display.

The system was configured to read temperature and humidity data from the DHT11 sensor at 2-second intervals, process the readings, and display the results on the LCD. The temperature was displayed in degrees Celsius, while relative humidity was shown as a percentage. This setup provided an efficient method for real-time environmental monitoring and served as a foundation for further experimental analysis. Figure 3 illustrates the complete DHT 11 sensor circuit.

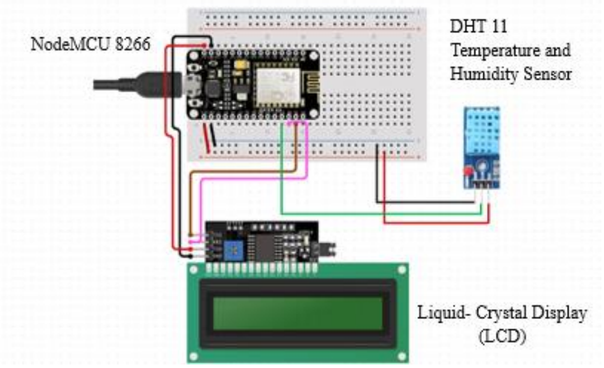

Figure 3. DHT 11 Sensor Circuit

The system employs a NodeMCU 8266 microcontroller integrated with a soil moisture sensor, LDR sensor, and DHT11 sensor to monitor critical environmental parameters. The microcontroller collects data from these sensors through its GPIO pins, where it is processed using pre-programmed logic written in the Arduino IDE. The processed data is then transmitted via the NodeMCU's built-in Wi-Fi module to the Blynk server, utilizing the Blynk library for seamless communication.

The Blynk application retrieves data in real-time from the server and displays it on a user-friendly interface, enabling users to monitor sensor readings and control actuators remotely. This capability allows users to perform actions such as activating the water pump or adjusting the smart film based on sensor data or manual input.

Additionally, delay module (Delay Channel) as a control mechanism that allows the system to remotely activate or deactivate the smart film. It acts as a bridge between the microcontroller (NodeMCU 8266) and the smart film, enabling the system to introduce a timed delay or process remote commands before turning the film ON or OFF. This feature ensures proper sequencing or user-controlled adjustments in the smart gardening system.

Figure 4 illustrates the system's flow chart, detailing the interaction between components and the flow of data within the system, from sensor inputs to microcontroller processing, Wi-Fi transmission, and user interface visualization.

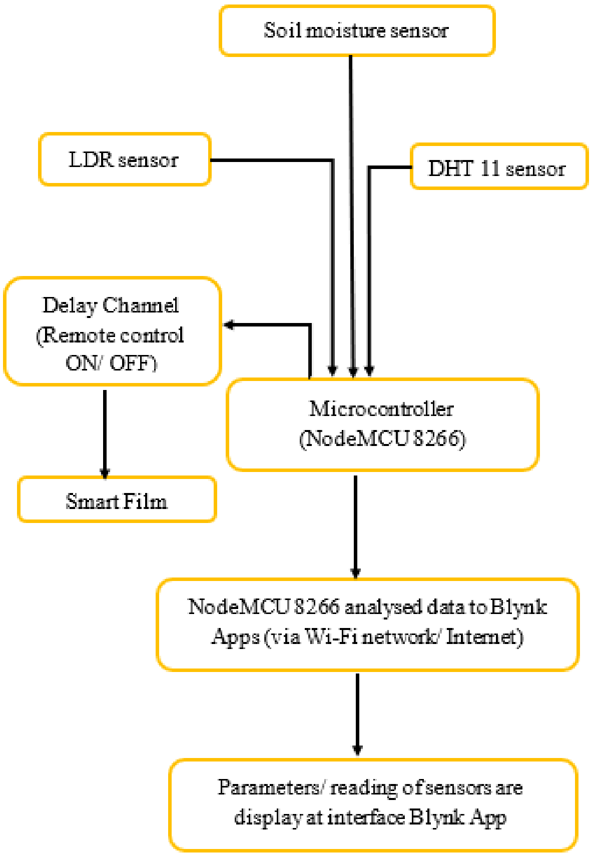

Figure 4 Flow chart of the entire system

III. RESULT AND ANALYSIS

The results and analysis of this project are presented in two main sections. The first focuses on hardware development, detailing the integration of various components, sensors, and the microcontroller in the prototype. The second section highlights the software implementation, encompassing the tools and applications used to display, monitor, and analyze the performance of the implemented system.

A. Smart Watering System

The implemented smart watering system demonstrates its functionality through the integration of a soil moisture sensor, relay channel, and water pump. The results, as displayed in Figure 5, confirm the system's ability to measure and display soil moisture levels on both an LCD and the Blynk app interface. The Blynk app also provides a user-friendly platform to remotely controlling the water pump via an ON/OFF button.

The soil moisture readings trigger appropriate actions, ensuring plants receive adequate water. The LCD serves as a local indicator, showing real-time moisture levels and the pump's operational status. The system, programmed using the Arduino IDE and powered by the NodeMCU 8266 microcontroller, ensures seamless data transmission between sensors, the pump, and the Blynk application. These results validate the system's effectiveness in automated irrigation management and remote monitoring, as shown in Figure 5.

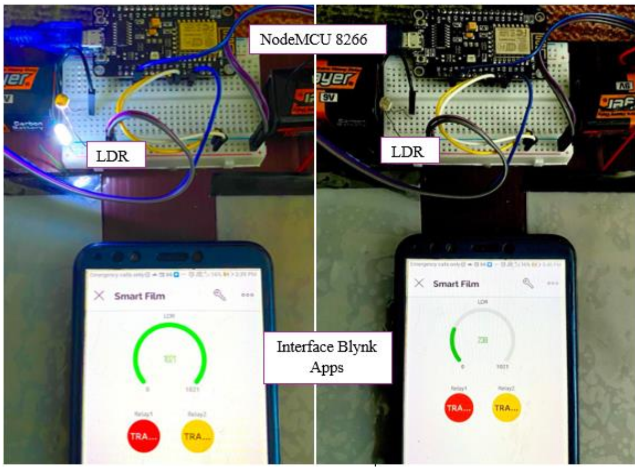

Figure 6. The intensity of LED light depend on the amount of light of surrounding

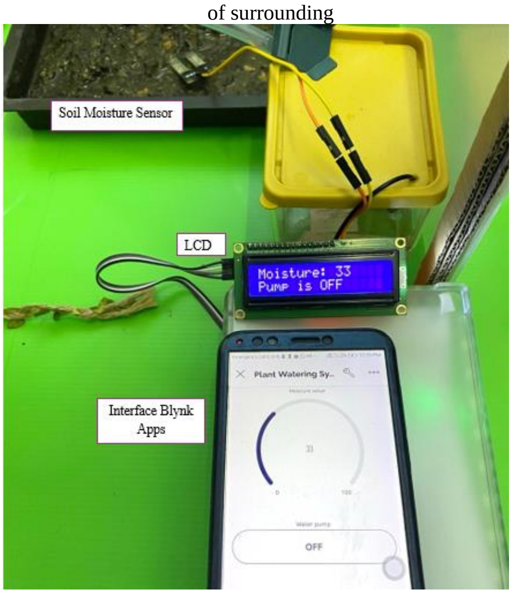

Figure 5. Value of soil moisture and button water pump appeared in LCD and Blynk interface

One of the primary advantages of smart watering systems is their capacity to monitor soil moisture levels in real-time. For instance, Afandi et al. [10] demonstrated that an automatic watering system can activate based on soil moisture readings, ensuring plants are watered only when necessary. This targeted approach not only conserves water but also prevents issues related to overwatering, such as root rot and nutrient leaching, which can adversely affect plant health and growth.

Moreover, integrating IoT technology into smart watering systems facilitates remote monitoring and control. Gade [11], emphasizes that smart water management systems leveraging ICT and IoT enhance water distribution and control, thereby optimizing water conservation. By utilizing data from various sensors, these systems can adapt to changing environmental conditions, such as rainfall and temperature fluctuations, further enhancing their efficiency. For example, systems can adjust watering schedules based on weather forecasts, reducing unnecessary irrigation during rainy periods.

Beyond water conservation, smart watering systems also contribute to sustainable water resource management. Wang [12] highlights that smart water systems enhance resource efficiency and sustainability, particularly in urban environments. By minimizing water wastage and ensuring efficient use of available resources, these systems play a vital role in addressing water scarcity issues, which are becoming increasingly critical due to climate change and population growth.

B. Smart Film and LDR Sensor System

The smart film and LDR sensor system demonstrate an effective integration of photoresistor-based light intensity detection and automated film opacity control. The LDR sensor operates on the principle of photoconductivity, where resistance decreases as light intensity increases. Figure 6 illustrates this relationship by showing LED intensity variations corresponding to changes in ambient light levels, with real-time readings displayed on the Blynk app interface.

The smart film can transition between transparent and opaque states when controlled via the Blynk app, as shown in Figure 7 and 8. This capability enables users to regulate the amount of light and heat passing through the film, enhancing environmental control. Figure 9 highlights the Blynk app's user-friendly interface, enabling users to switch between transparency and opacity modes with visual feedback on light intensity.

This system integrates seamlessly with the NodeMCU 8266 microcontroller to provide remote monitoring and control. The results validate the system's application in smart environments, where light management and heat control are essential. The demonstrated functionality confirms its potential for energy-saving and automation in sustainable systems.

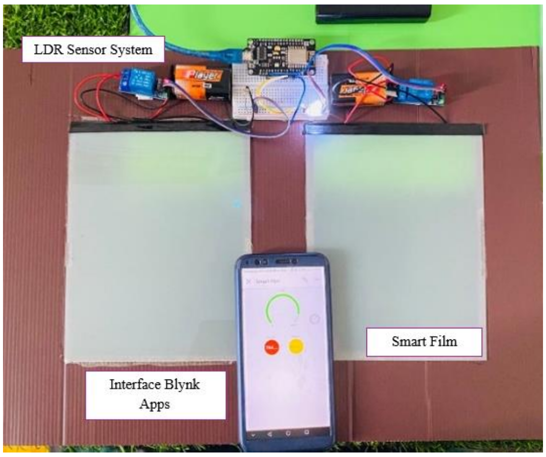

Figure 7. The film will change to opaque condition when press the button 'OPAQUE'

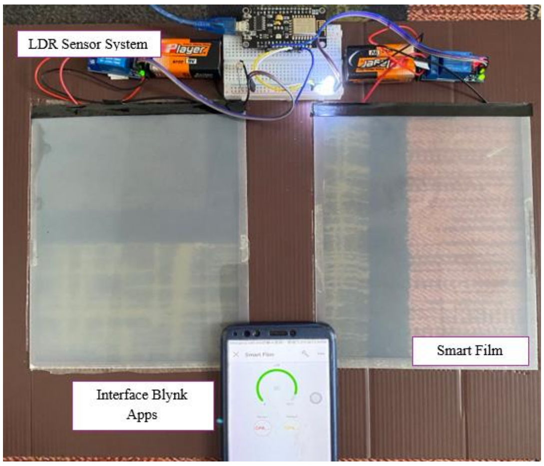

Figure 8. The film will change to transparent condition when press the button 'TRANSPARENT'

Figure 9. Smart film and light intensity user interface Blynk Apps

Controlling light intensity is a pivotal aspect of modern garden automation systems, directly influencing plant growth, nutritional quality, and resource efficiency. Automated systems that regulate light conditions enable precise environmental control, optimizing plant growth and enhancing agricultural productivity. Research demonstrates that varying light intensities significantly impact plant metabolic processes. For instance, Kitazaki et al. [13] observed metabolic reprogramming in lettuce under different light intensities while Song et al. [14], reported that higher light intensities enhance the accumulation of beneficial compounds like nitrates and soluble sugars, improving nutritional quality and market value.

The integration of automated light control systems, such as those utilizing LED illumination, supports sustainable agricultural practices by reducing resource consumption. Nagano et al. [15] highlighted the efficiency of LED systems in producing high-quality crops with minimal heat and energy input. Additionally, IoT-based smart greenhouses as explored by Jiang and Moallem [16], enable dynamic light adjustments ensuring that plants receive optimal light exposure while responding to environmental changes.

Automated systems also contribute to energy savings by combining artificial and natural light. As demonstrated by Lee et al. [17], these systems minimize energy consumption without compromising plant health. By reducing operational costs and environmental impact, they align with sustainability goals. Overall, automated light intensity control plays a crucial role in advancing sustainable agriculture, supporting increased yield, improved quality, and efficient resource utilization in horticultural practices.

C. DHT11 Sensor System

The hardware implementation of the DHT11 sensor demonstrates its effectiveness in monitoring temperature and humidity levels. As shown in Figure 10, sensor readings are displayed on both an LCD screen and the Blynk application interface, providing real-time data visualization. This dual-display functionality enhances usability by offering localized monitoring via the LCD and remote accessibility through the Blynk app.

The DHT11 sensor operates with high reliability, enabling precise measurement of environmental parameters crucial for garden automation. Its integration with the NodeMCU microcontroller ensures seamless data transmission to the Blynk app via Wi-Fi, enabling remote monitoring and control. This setup is particularly valuable for maintaining optimal environmental conditions, as temperature and humidity significantly impact plant growth and health.

The communication process begins when the NodeMCU sends a start signal to the DHT11 sensor by pulling the DATA pin low for at least 18 milliseconds. According to Nofriandi [18], this action prompts DHT11 sensor to prepare for data transmission. After receiving the start signal, DHT11 sends a low-voltage response signal lasting approximately 80 microseconds, indicating its readiness to transmit data. The NodeMCU then sets the DATA pin high for another 80 microseconds to prepare the DHT11 for data transmission as mentioned by Nofriandi [18].

Figure 10. The hardware implementation of the DHT11 sensor

The entire communication process takes approximately 4 milliseconds, during which the NodeMCU reads the transmitted data by monitoring the timing of the high signals to determine the binary values, as highlighted by Rosad et al. [19].

The integration with the Blynk application enables real-time visualization of data collected from the DHT11 sensor, allowing users to remotely monitor temperature and humidity, thereby enhancing the IoT system's functionality, as shown by Susetyo [20].

Figure 11 illustrates the complete setup of the proposed system, integrating the DHT11 sensor system, Smart Film and LDR sensor system, and Smart Watering system. These components work collectively to monitor and control environmental parameters including temperature, humidity, light intensity, and soil moisture. Real-time data is transmitted to the Blynk app, allowing for remote monitoring and control, demonstrating the system's practicality for smart gardening and automation applications.

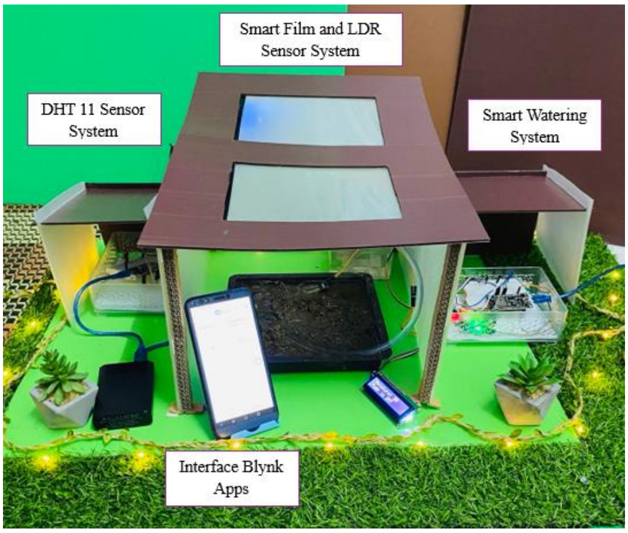

Figure 11. Complete Set-up of the entire system implementation

D. Data Analysis by Using ThingSpeak Server

The IoT data collection tool, ThingSpeak, is used to analyze data from various sensors, including pH, turbidity, voltage, temperature, moisture, and distance. The data collector gathers data from edge node devices (NodeMCU and ESP8266) and enables the modification of data for software-based historical data analysis. Users must first log in to their server accounts to access the data.

The main element of ThingSpeak activity is a channel that contains data fields and a status field. Once a ThingSpeak channel is created, the data is modified, processed, and interpreted using MATLAB code. The system can also respond to data with tweets and other alerts, as explored by Das [21]. The collected data reveals an increasing and decreasing pattern in the graph, indicating real-time fluctuations in sensor readings.

According to the graph shown in Figure 12, the soil moisture level fluctuated between 19% and 47% throughout the observation period, indicating transitions between dry and moist soil conditions. A significant peak in moisture level was recorded at 45% at 10:02:47 UTC, attributed to a watering event. Following this peak, the soil moisture gradually declined, ranging from 45% to 24% between 10:02:47 UTC and 16:31:00 UTC, reflecting the natural drying process of the soil over time.

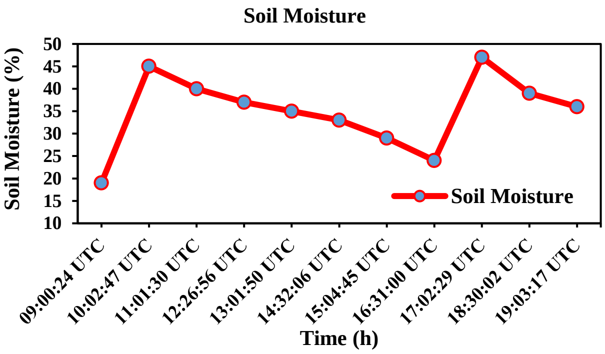

Figure 12. Soil Moisture vs Time in Real-time Data via ThingSpeak server

After 16:31:00 UTC, the soil moisture briefly increased to 47% at 17:02:29 UTC, indicating another watering event or external moisture input. This demonstrates the system's capability to accurately monitor and record real-time fluctuations in soil moisture levels. These observations are critical for optimizing plant watering schedules and promoting efficient water resource management. The system's ability to capture dynamic changes ensures its reliability and effectiveness in soil moisture monitoring applications.

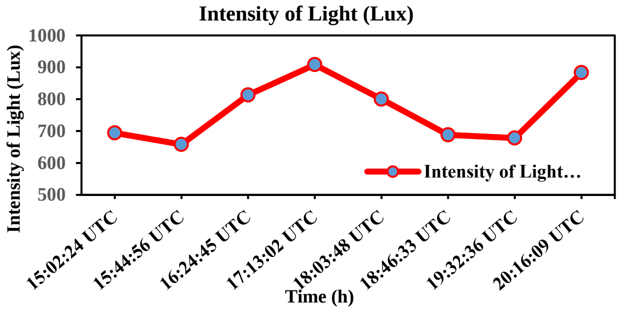

Figure 13. Light Intensity vs Time in Real-time Data via ThingSpeak Server

Moreover, the light intensity measured in lux using the LDR sensor was updated into the ThingSpeak Server, as shown in Figure 13. At 15:44:56 UTC, the light intensity was recorded at 658 lux, indicating that the greenhouse was slightly exposed to light while the film was in an opaque state. The highest light intensity value of 908 lux was recorded at 17:13:02 UTC, when the film was in a transparent state, allowing more light to enter the greenhouse. As a result, the LDR sensor detected a higher amount of light, increasing its sensitivity. When light strikes the surface of the LDR sensor, the resistance decreases, causing the recorded light intensity value to rise, depending on the brightness of the light source. The intensity of light was also monitored using the Arduino IDE's serial monitor.

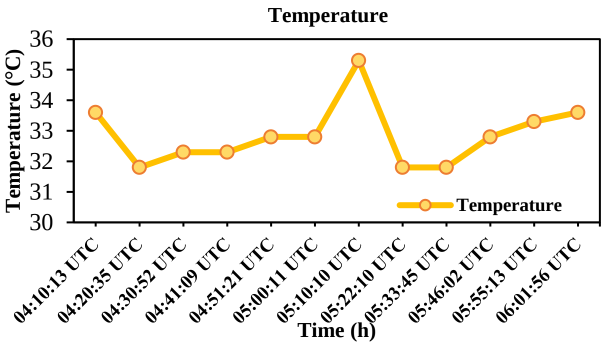

Figure 14. Temperature vs Time in real-time Data via ThingSpeak Server

Furthermore, Figure 14 illustrates temperature variations and highlights the corresponding real-time fluctuations in humidity. The temperature (in °C) reached a peak value of 35.3 °C at 05:10:10 UTC. At this same instance, as shown in Figure 15, the humidity level (in percentage) was recorded at 65%. The rise in temperature indicates exposure to more heat or brightness in the monitored environment.

As the temperature increased to its highest point, the humidity level exhibited a downward trend, demonstrating the inverse relationship between these parameters in a dry setting. This phenomenon reflects the natural evaporation process, where higher temperatures reduce moisture levels in the surrounding environment. These observations emphasize the system's reliability in detecting and recording environmental variations, providing critical insights for applications that requir precise temperature and humidity monitoring.

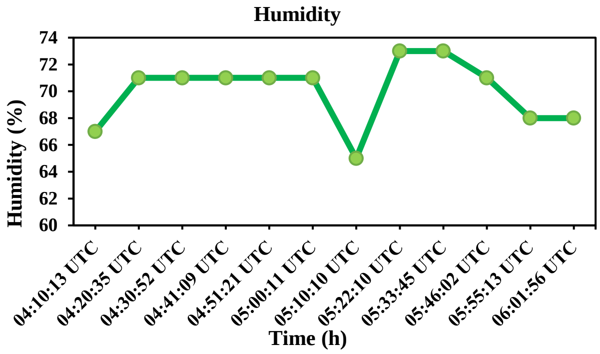

Figure 15. Humidity vs Time in real-time Data via ThingSpeak Server

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IV. CONCLUSION

In a nutshell, the project was successfully carried out and completed with most of the objectives achieved as projected. This project successfully developed a smart and user-friendly gardening system, integrating smart film technology to address real-life challenges. The project aimed to advance gardening and agriculture automation, allowing these sectors to flourish and reach their full potential. It focused on incorporating IoT technology into a system that enables users to monitor and control gardening conditions via a mobile application. This system benefits individuals with busy daily schedules by allowing them to nurture plant growth remotely.

Moreover, the system provides real-time statistics on key environmental factors in the garden, enabling local users and gardeners to manage their plants efficiently through the Blynk application. The monitored parameters include soil moisture, light intensity, temperature, and relative humidity. To sum up, despite various challenges, IoT technology has been successfully implemented in modern gardening, making it suitable for both indoor and outdoor applications. This project prototype will assist individuals and organizations in automatically monitoring essential parameters and ensuring proper garden maintenance. IoT technology provides solutions to various challenges by enabling devices within the network infrastructure to be monitored and controlled remotely.

ACKNOWLEDGEMENT

The authors would like to thank Universiti Sains Islam Malaysia (USIM) staff for guidance and assistance.

CONFLICT OF INTEREST

Authors declare that there is no conflict of interest regarding the publication of this paper.

AUTHOR CONTRIBUTION

The authors confirm contribution to the paper as follows: study conception and design: A.R.A. Rashid , M.K.A. Azmi; data collection: M.K.A. Azmi; analysis and interpretation of findings:Author A.R.A. Rashid, Author M.K.A. Azmi; draft manuscript preparation: Author W. M. Mukhtar, Author N.A.M. Taib, Author A.R.A. Rashid, Author M.K.A. Azmi. All authors had reviewed the findings and approved the final manuscript.

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