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IoT Revolution in Agriculture: Crafting an Advanced Soil Monitoring System for Modern Farming

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ABSTRACT

Agriculture serves as the backbone of human civilization, providing sustenance, raw materials, and livelihoods to billions of people worldwide. However, soil, is a complex and dynamic ecosystem that can be affected by various factors, such as climate, land use practices, and natural processes. To ensure sustainable and efficient agriculture, it is crucial to monitor the condition of the soil continuously. A soil monitoring system offers invaluable insights into soil properties, nutrient levels, moisture content, and other critical factors influencing crop growth and agricultural productivity. By leveraging connected devices, sensors, and data analysis, IoT in agriculture holds the potential to revolutionize crop management, livestock monitoring, resource optimization, and supply chain efficiency. The Internet of Things (IoT) has emerged as a powerful tool in the agricultural sector, transforming traditional farming practices into smart agriculture or precision agriculture. With IoT, farmers can make informed decisions, maximize productivity, reduce costs, and contribute to sustainable practices. This project aims to implement the concept of IoT on a soil monitoring system to monitor the condition of trees based on data acquired using a pH level sensor, a temperature and humidity sensor, and a soil moisture sensor. The project successfully monitored parameters, with data stored in a cloud database, fulfilling the project's objective of implementing the concept of IoT on a soil monitoring system to monitor the condition of trees based on data acquired using various types of sensors. Future work or recommendations are imperative so that soil monitoring systems will become increasingly sophisticated, enabling farmers to achieve higher productivity, conserve resources, and contribute to a more sustainable and efficient agricultural sector.

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1. Introduction

Agriculture plays a significant role in Malaysia's economy and society, serving as a crucial sector for the country's development and continues to contribute in various ways [1]. Based on statistics from the Ministry of Economy, the agricultural sector emerged as the second most important sector of Malaysian trade in 2020, with a contribution of 6.8 percent, surpassing the trade of mining products [2]. Based on several authors [3-9,23,28], the Internet of Things (IoT) has emerged as a transformative technology in the agricultural sector, revolutionizing traditional farming practices and driving the concept of smart agriculture or precision agriculture. By leveraging connected devices, sensors, networks, and data analytics, IoT in agriculture enables farmers to make data-driven decisions, optimize resource management, enhance crop yields, and promote sustainable practices [10,11,29]. One of the key applications of IoT in agriculture is soil monitoring and management. IoT-based soil monitoring systems utilize sensors embedded in the soil to collect data on parameters such as moisture content, temperature, pH levels, nutrient levels, and salinity [12,13]. These sensors continuously measure these parameters and transmit the data wirelessly to a central platform for analysis. Through web or mobile applications, farmers can access real-time information about soil conditions, enabling them to optimize irrigation, fertilization, and crop management practices [14]. By monitoring soil moisture levels, farmers can prevent over-irrigation, reduce water waste, and ensure that crops receive optimal moisture for growth. A well-implemented soil monitoring system provides valuable information to farmers and agricultural practitioners, facilitating informed decisions and optimising agricultural practices [15].

Based on previous research, most soil monitoring systems offer a number of benefits, but they also possess inherent flaws that must be considered. The previous method for soil moisture detection relied mostly on manual collection and wired sensing technologies. Manual acquisition, besides being time and cost-intensive, often has a poor track record of being timely. Given the limited number of nodes and wide dispersion associated with conventional wired networks, it is logical to move away from them. Soil monitoring systems based on this technique are mostly expensive and time-consuming to operate. This project aims to implement the IoT concept on a soil monitoring system to monitor the condition of trees based on data acquired using a pH level sensor, a temperature and humidity sensor, and a soil moisture sensor. By combining different parameters, farmers can acquire a holistic understanding of soil conditions, make targeted management decisions, and optimize resource utilization. Blynk IoT will serve as a cloud database for this project to manage data from IoT devices, allowing users to collect, store, analyse, and interact with the information generated by the connected devices in a convenient and efficient manner. This new approach can offer a valuable solution by providing real-time monitoring of essential parameters, enabling proactive measures to be taken in response to deviations from optimal conditions. By leveraging IoT and sensor technology, the system can contribute to improved crop yield, cost efficiency, and overall crop quality compared to previous studies.

1.1 Related Works

Agriculture relies heavily on the quality of the soil and its nutrients [25,26]. Numerous projects are underway across the globe to enhance soil nutrient levels. A significant consideration is determining the soil's properties. According to previous research [23,28], the IoT may be employed in agriculture, many businesses are now focusing on IoT topics because they see this as an area with great potential for growth in the future. As a consequence, new platforms and proprietary outcomes are created. GSM, Bluetooth, LTE, and Wi-Fi are just a few of the numerous IoT-specific technologies and networks that have been included into the Internet of Things [24,27]. So, there's LoRaWAN (low power Wi-Fi), IEEE P802.11ah (low power Wi-Fi), SigFox, nWave and RPMA. Environmental data, such as wind direction, temperature, light intensity, wind speed CO2, EC and humidity are collected by sensors and soil sensors put outdoors in an agricultural environment monitoring system. In order to give relevant information to consumers, the agricultural environment monitoring services convert the data into a database.

According to R. Dagar *et al.,* [16]. The IoT has the potential to improve several aspects of agriculture, including resource management, crop management, yield and quality monitoring, and more. Internet of Things sensors such as pH, temperature, volumetric water flow, and moisture are used in the proposed model. To gain insights into cutting-edge agricultural technologies, researchers examined current farming methods and the issues they confront, as well as polyhouses. An IoT sensor network that gathers data and transfers it to a server over a Wi-Fi network, allowing the server to act on it, is provided as a model. A "Smart Farming System Utilising IoT for Effective Crop Development" by M. S. D. Abhiram *et al.,* [17] described a comprehensive IoT-based system for monitoring soil and environmental factors for efficient crop development. At the Node MCU, sensors keep tabs on the humidity, moisture, and temperature in the soil. The Wi-Fi will also send a text message to the farmer's phone, notifying them of any changes in the surroundings of the field. There is another study by S. Nuchhi *et al.,* [18] that uses an IoT ecosystem with sensors to monitor soil moisture, humidity, temperature, and NPK levels in agricultural areas. This system utilizes sensors such as moisture sensors and Thing Speak platforms for IOT applications in real-time and provides recommendations to farmers regarding suitable crops and fertilisers via mobile applications. Farmers benefit from the job since it helps them make the right choices and get a higher yield, along with the lucrative situation that goes along with it.

2. Methodology

2.1 Systems Design

Systems design is an interdisciplinary engineering process that aims to create efficient and functional systems. A system is composed of interconnected components that work together to perform a specific task or function. The systems design process involves considering various elements such as data, components, modules, interfaces, and software and hardware architecture. Integrating these elements allows a system to meet specific operational requirements. In the case of the implementation of the concept of IoT on a soil monitoring system to monitor the condition of trees, the overall system design is depicted in Figure 1. This design encompasses the various components and connections necessary to create an effective system for monitoring and managing the soil conditions of a tree.

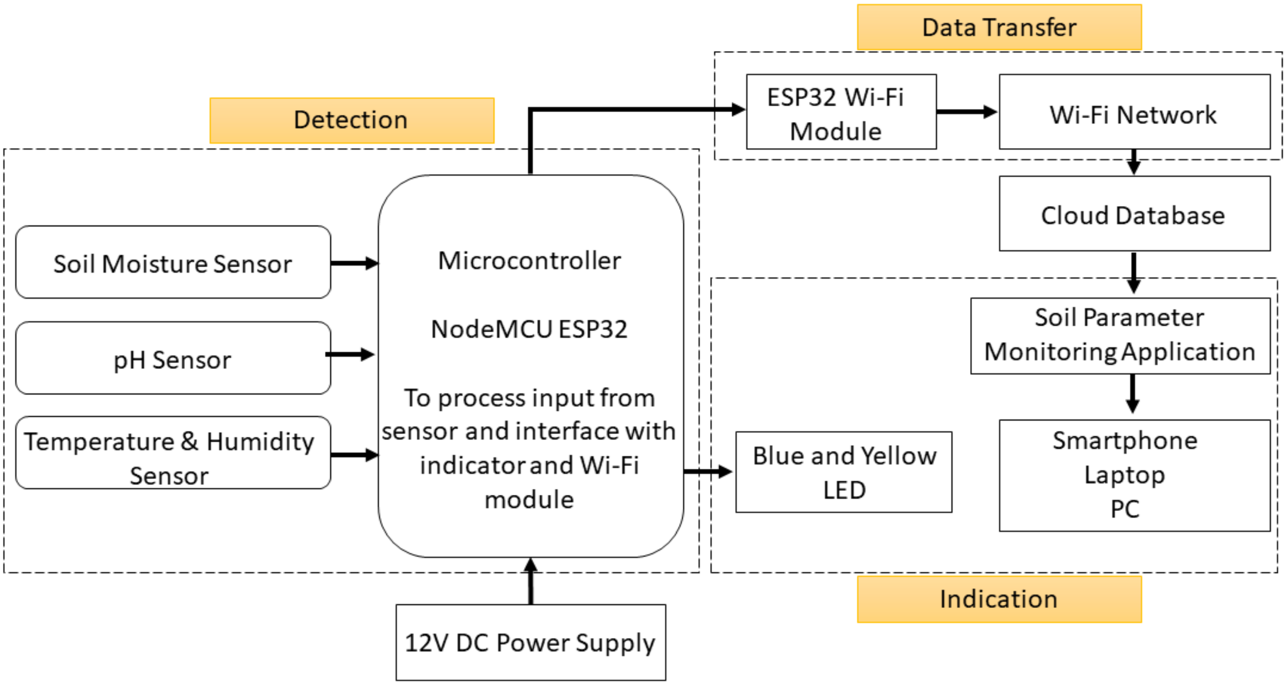

Fig. 1. System Design

This block diagram is divided into 4 parts, namely detection, data transmission & storage, data analysis and user interface. For the detection part, the sensor selections consist of temperature & humidity sensors, capacitive soil moisture and soil pH sensors. The pH sensor finds alkaline soil. The range is 0–14. If pH is below 7, it is acidic; above 7, it is alkaline. A temperature and humidity sensor measures the ambient air using a capacitive humidity sensor and a thermistor, which outputs a digital signal. Soil moisture is measured by a sensor using gravimetric methods to yield voltage values that can be matched to soil moisture content (using the volume and weight of dry and wet soil). NodeMCU ESP32 microcontroller will process the input from all sensors.

As for data transmission, collected data from all sensors will be sent from the microcontroller to a cloud database on the Blynk IoT platform using its built-in Wi-Fi module. Blynk Cloud provides data storage capabilities, allowing one to store and access historical data within the Blynk app. It is also supporting integration with various IoT platforms and services. It provides APIs (Application Programming Interfaces) that allow users to connect and exchange data with external systems, databases, or cloud services.

A mobile application is used as the user interface in this project. Data from the cloud that has been analysed before is integrated and used in the mobile application for this project, including the real-time data visualization and prediction modules. Development of the mobile app takes place on the Blynk application platform. When data is updated on one device, it instantaneously and automatically spreads to all other connected devices. Soil adjustments may be made so that an economically viable crop can thrive. Farmers can act on which parameters have problems since these parameters are crucial for producing the highest grade of crops.

2.2 Product Development

The real-time monitoring of soil conditions requires several steps to ensure safety and proper functioning. The process begins by setting up the I/O ports on the NodeMCU ESP32 and connecting to the internet. Once the connections are established, the sensors are activated to commence gathering data from the site area. Each sensor performs specific tasks, such as measuring temperature and humidity, detecting soil pH, and assessing soil moisture content. The collected data is then sent to a database via the Internet for processing. The processed data is displayed on a dashboard app created using the Blynk IoT platform. The system also includes a warning system that sends notifications to the farmer’s phone in case any parameters deviate from the desired range. This enables the farmer to make informed decisions and take corrective action to produce higher-quality crops. The system continuously retrieves and updates data every 10 minutes until it is turned off. Several hardware devices used in the project to utilise the system are the NodeMCU ESP32, analog pH sensor, soil moisture sensor, and temperature and humidity sensor (DHT22).

2.2.1 NodeMCU ESP32

The ESP32 evaluation board was developed by expressive systems, and the ESP family of microcontrollers are very powerful controllers with fast clock rates, wireless connection, and even camera interfaces. The ESP32 includes an integrated low-noise amplifier (LNA) and an impedance matching circuit, simplifying the design applications for makers and developers. NodeMCU ESP32 was chosen for this project due to its energy efficiency, wire-less integration, and capability to operate in severe conditions at temperatures ranging from -40 °C to 125 °C, as shown in Figure 2 [19].

Fig. 2. NodeMCU ESP32 [19]

2.2.2 Analog pH sensor

The acidity or alkalinity of a solution may be determined using an analogue pH sensor, as shown in Figure 3 below [20]. Power in the range of 3.3 to 5.5 volts DC can be supplied via the on-board voltage regulator chip, making it compatible with any control board, such as an NodeMCU ESP32. To measure the pH of a sample, the probe is dipped into it, which causes hydrogen ions in it to interact with other positively charged ions on the glass membrane, resulting in an electrochemical potential given to the electronic amplifier module, which then converts it to pH units.

Fig. 3. Analog pH Sensor [20]

2.2.3 Soil moisture sensor

Figure 4 below shows the capacitive soil moisture sensor module that will be used in this project to measure the moisture in the soil [21]. In this project, a capacitive-type electromagnetic soil moisture sensor is calibrated using gravimetric methods. The dielectric differential between water and soil is used by capacitive soil moisture sensors, with dry soils having a relative permittivity of 2–6. Accurate measurement of soil water content is critical for applications in agronomy and botany, where under- and over-watering soil can lead to inefficiency or wasted resources. Calibration is required in each setting to accurately measure water content because water can account for up to 60% of the volume of some soils, depending on porosity.

Fig. 4. Soil Moisture sensor [21]

2.2.4 Temperature and humidity sensor

In Figure 5 below, the DHT22 (AM2302) Temperature and Humidity Sensor is a low-cost digital temperature and humidity sensor with rudimentary functionality [22]. It measures the ambient air using a capacitive humidity sensor and a thermistor and delivers a digital signal on the data pin. The sensor is factory-calibrated, facilitating easy integration with other microcontrollers. The sensor is capable of measuring temperatures ranging from -40°C to 80°C and humidity levels ranging from 0% to 100% with an accuracy of 1°C and 1%, respectively. As a consequence, the DHT22 is chosen for its improved resolution, longer measurement range, and increased accuracy over the competition. It is capable of measuring temperature and relative humidity, has low power consumption, and has excellent long-term stability.

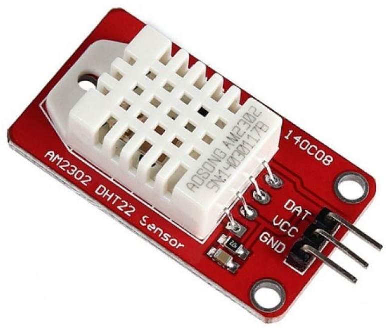

Fig. 5. DHT22 Temperature and Humidity Sensor [22]

2.3 Complete Product Development

This section will look forward about the development on the hardware system for the project. Figure 6 below depicts the groundwork as it shown the connection between the hardware components that will make up the system. It showcases the sensors used and an NodeMCU ESP32 wired together.

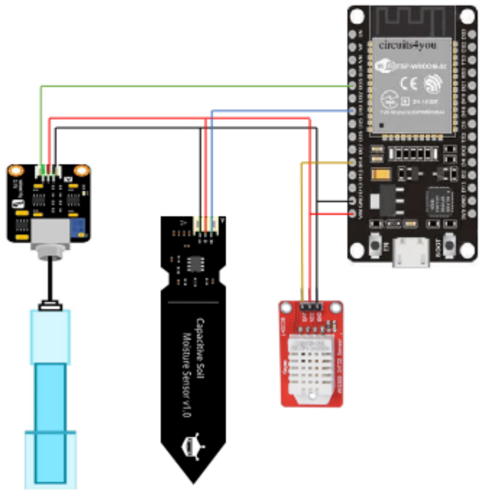

Fig. 6. Schematic diagram

The system for monitoring soil conditions in real-time requires several steps to ensure safety and proper functioning. Figure 7 below depicts the electrical hardware architecture of the IoT-based system for monitoring soil parameters. The electronic system was being built and maintained inside the PVC enclosure junction box. The junction box contains all of the sensors utilised in this project, including the temperature sensor, the humidity sensor, the soil moisture sensor, and the pH sensor. This degree of protection is required to avoid fires and ensure that strong, dependable connections remain tight over an extended period. The sensors' casings were made using a 3D printer. The material used to print is PLA-F filament, which has the lowest price, neat winding, higher heat resistance, smooth printing, and absence of bubbles during the printing process. All the sensors' boards and NodeMCU ESP32 were screwed into the box using nuts and washers.

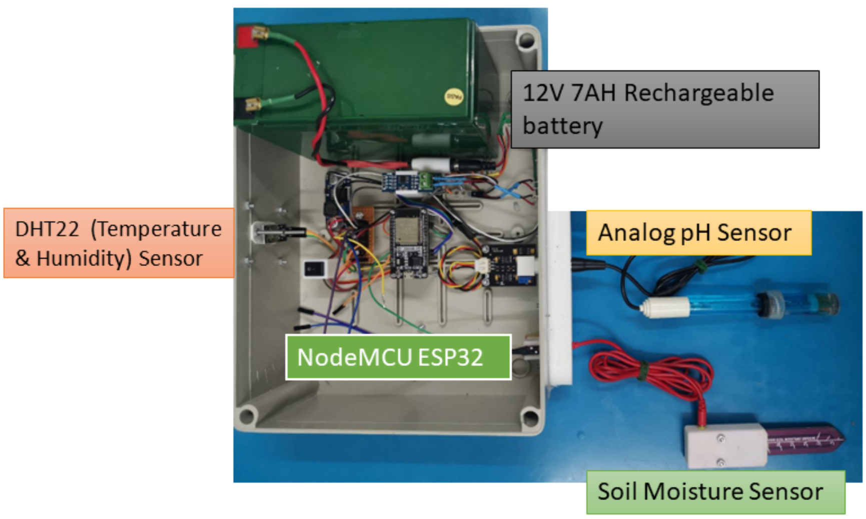

Fig. 7. Complete arrangement of electronic components

3. Results and Discussions

The data gathered by the sensors at the Faculty of Electrical Engineering Technology, UniMAP, is transmitted to the database provided by the Blynk IoT platform. This data is automatically updated every 10 minutes on the cloud platform and stored in the database. Based on Table 1, these are all the collected data downloaded from the Blynk IoT platform in CSV format so that the data can be analysed more easily using Microsoft Office Excel in offline mode.

Table 1
Sample of data collection

Time	Data Stream	Value
06/23/22 05:00:00 PM	Humidity	64.26 %
06/23/22 04:00:00 PM	Humidity	62.43 %
06/23/22 03:00:00 PM	Humidity	53.26 %
06/22/22 08:00:00 PM	Moisture	61.41 %
06/22/22 07:00:00 PM	Moisture	62.52 %
06/22/22 06:00:00 PM	Moisture	61.81 %
06/23/22 05:00:00 PM	pH Value	6.23
06/23/22 04:00:00 PM	pH Value	6.14
06/23/22 03:00:00 PM	pH Value	5.82
06/23/22 05:00:00 PM	Temperature	30.02 °C
06/23/22 04:00:00 PM	Temperature	31.12 °C
06/23/22 03:00:00 PM	Temperature	33.03 °C

To facilitate monitoring and understanding of the current site conditions, the mobile application developed using the Blynk App syncs the data from the database and presents it on the dashboard that had been designed before. This dashboard, accessible through both the mobile and web interfaces, displays the collected data in a digital format. Users can conveniently monitor the data and gain insights into the site's situation even when they are not physically present at the site. Additionally, the collected data can be downloaded in CSV format, enabling users to analyse and manipulate the data further using tools like Microsoft Office Excel. Figure 8 shows all the sensors' current values in the Blynk Apps through a web dashboard using a laptop, while Figure 9 shows the mobile dashboard on a smartphone.

Fig. 8. Blynk's web dashboard

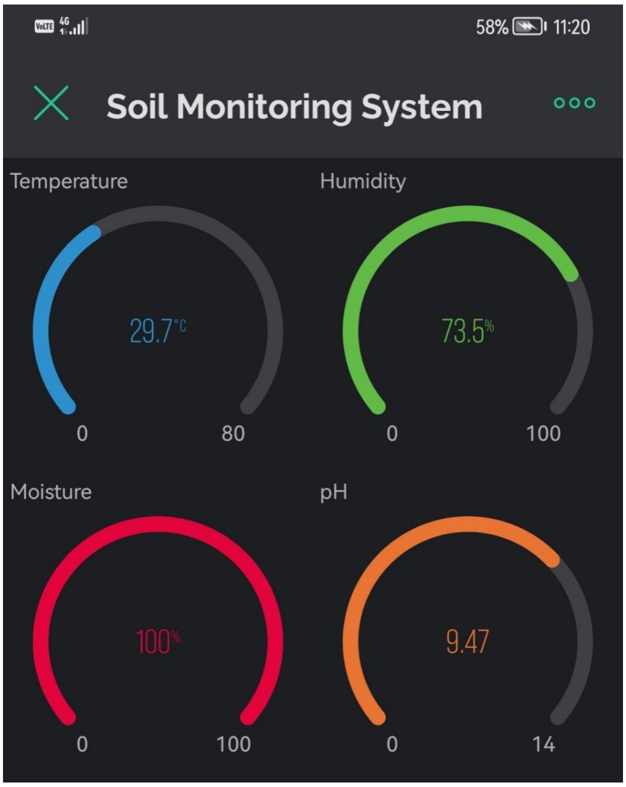

Fig. 9. Blynk's mobile dashboard

According to the results and research, farmers can monitor the tree's growth using the IoT platform, making this project preferable to the current project methodology. This project also utilised user- and administrator-friendly Blynk Apps, allowing easy monitoring, data collection, and real-time display. Farmers may access it using the Blynk App on their smartphone or laptop. In this project, there was also a warning system set up using an internet connection and push notifications through the Blynk App to help farmers identify any issues affecting the production and quality of the tree or if there is a disease that needs to be taken care of early. Based on Figure 10, after the device was tested for an entire week, the results showed that the surrounding temperature around the mango farm is about 37 °C to 40 °C. This temperature range is considered normal for the weather in Perlis, as Perlis is known for its high surface temperature and the fact that cumulus and cumulonimbus clouds gather early in the afternoon almost every day.

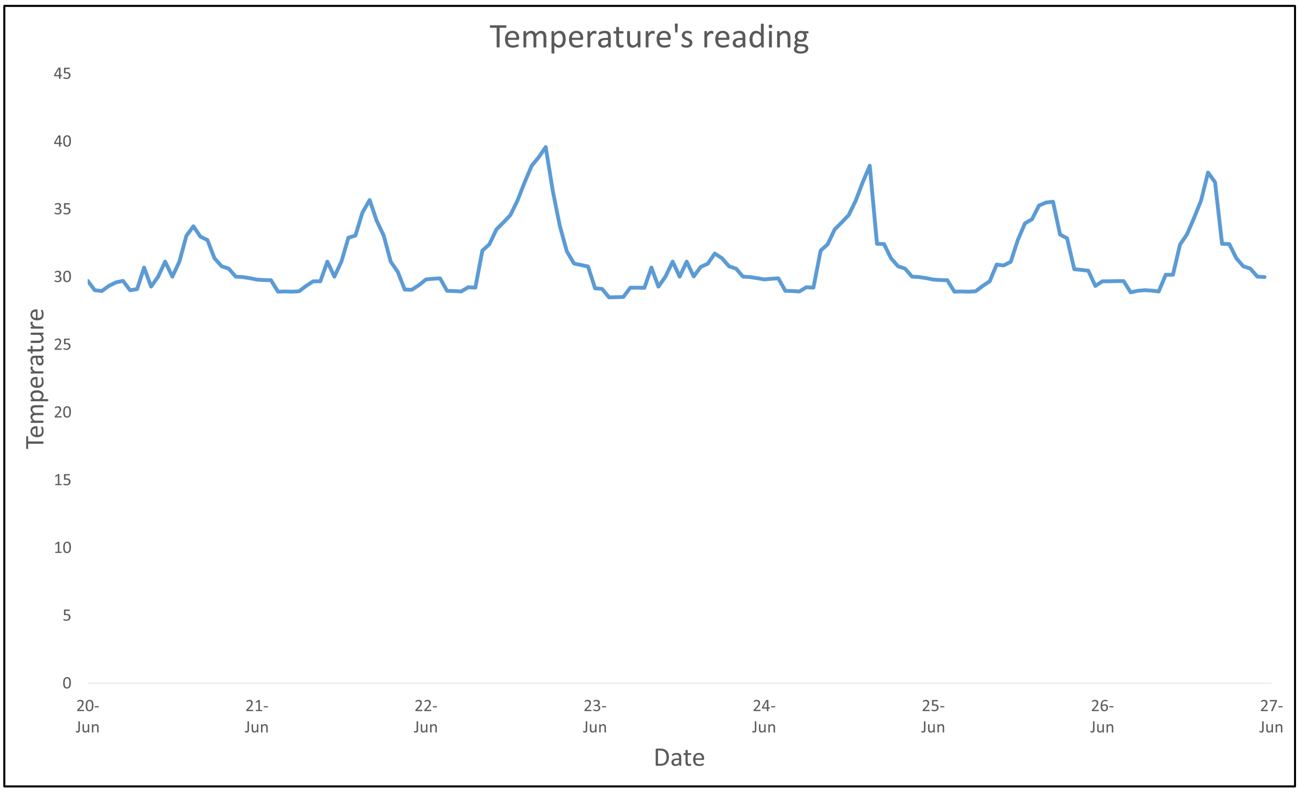

Fig. 10. Temperature reading

As for the relative humidity, the humidity level is within the allowable range of around 40% to 85%, as shown in Figure 11. The humidity is lower in the afternoon than it is during the night. Mostly, if there are any significant differences in terms of humidity or temperature value, it is due to climate factors such as heavy rain or strong wind, as these factors are uncontrollable natural phenomena. In addition, the analysis shows that the reading of relative humidity will be the opposite of the temperature reading. As the surrounding temperature increases, the relative humidity will decrease and vice versa.

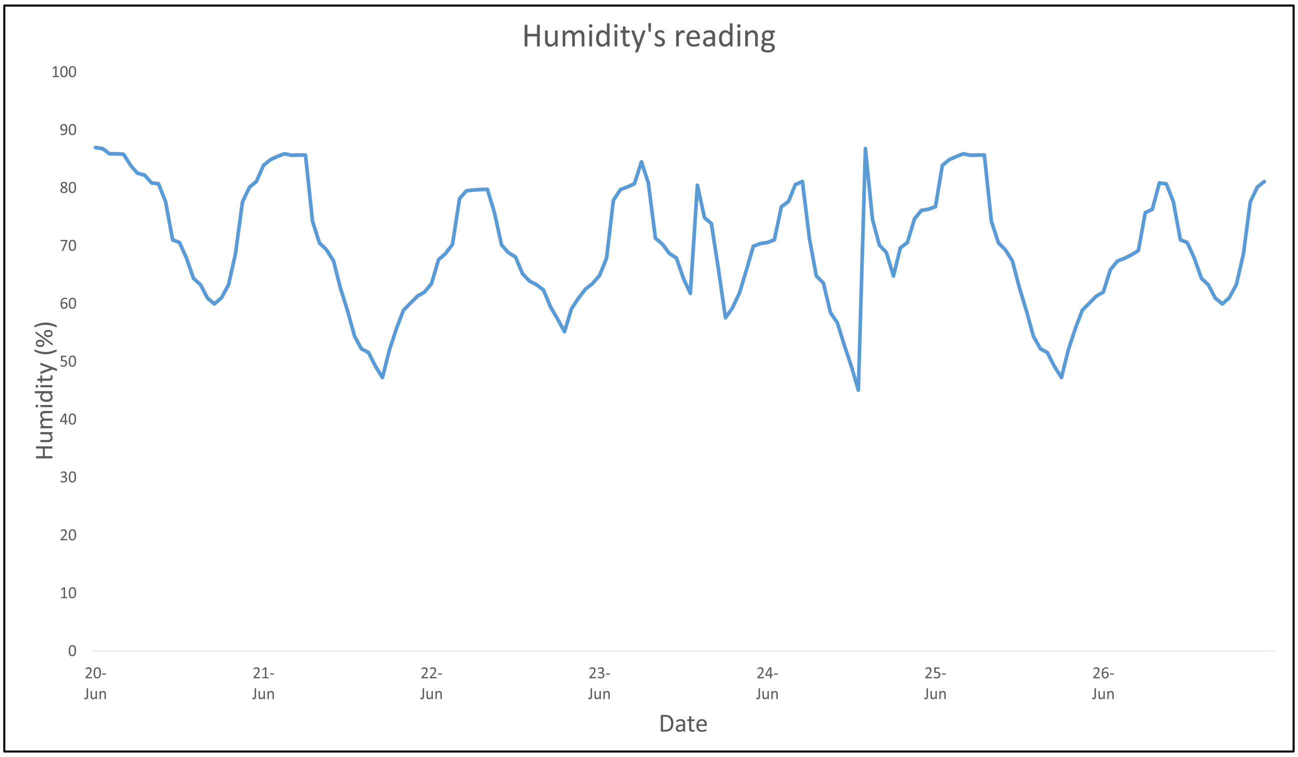

Fig. 11. Humidity's reading

The amount of nutrients and chemicals that are soluble in soil water is affected by the soil's pH. This means that the amount of nutrients available to plants is also affected by the soil's pH. Soil acidity may cause plant poisoning as a result of adverse reactions in plants. If the soil pH is too low, manganese, a plant nutrient, may be toxic in large amounts. Figure 12 shows that the pH level for the soil of the mango farm from June 20 until June 26 is consistently oscillating from 5.2 to 6.8, which is acceptable to trees, and this pH range is typically fairly consistent with tree root development. The inconsistent value of pH in the soil may be affected by climate change. Rainfall is a key factor in affecting soil reactivity. Temperature and rainfall control the severity of leaching and the weathering of soil minerals. Soil pH decreases over time in warm and humid69 settings, a process known as acidification. This occurs due to the interaction with CO2 in the atmosphere, which forms carbonic acid, rainwater has a somewhat acidic pH (typically about 5.7). When this water travels through the soil, it causes basic cations from the soil to leach as bicarbonate, increasing the amount of Al3+ and H+ compared to other cations. Soil weathering and leaching are less severe in dry regions. As a result, pH might be neutral or alkaline. Soils developed in high rainfall areas are often acidic (low pH value), while soils developed in low rainfall areas are alkaline (high pH value). This shows that the Faculty of Electrical Engineering Technology's mango trees is of high quality since the pH level is in the range that makes it easiest for nutrients to be used.

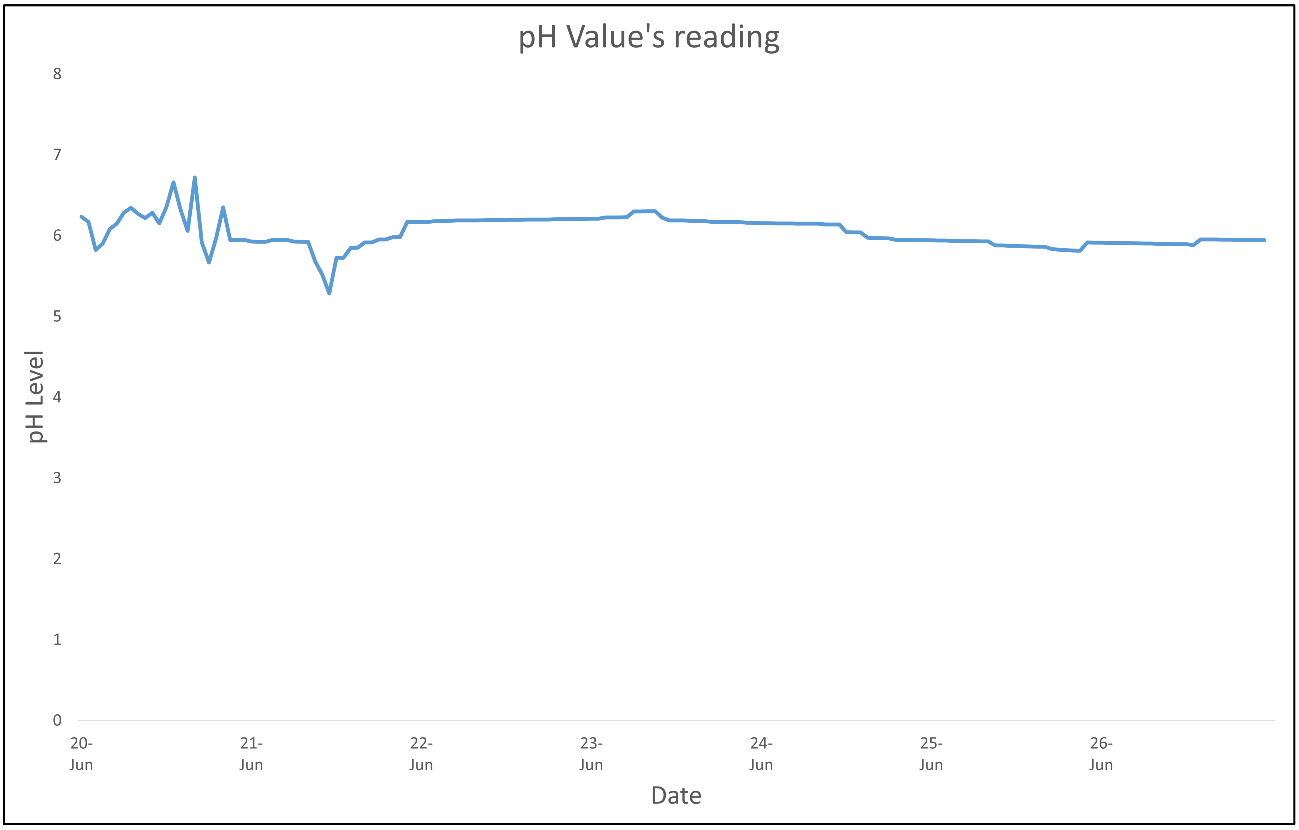

Fig. 12. PH Level's reading

Soil moisture has a crucial role in regulating water and heat energy passage between the land surface and the atmosphere through evaporation and plant transpiration. Moisture in the soil is essential for the creation of weather patterns and the production of precipitation. Dry weather promotes many blooms before blossoming, but chilly weather is essential from flowering through late fruit development. Figure 13 showed the soil moisture of the mango tree is between 55% and 90%, which means it is in good condition. If the value of the soil moisture suddenly increases or decreases abruptly, it may be caused by the sudden heavy rain that caused the soil to become a bit wet but still in the allowable range for the trees' growth. During the rainy season, when the fruit begins to develop, the device is being tested. So, soil moisture should be greater than 40% during the wet season.

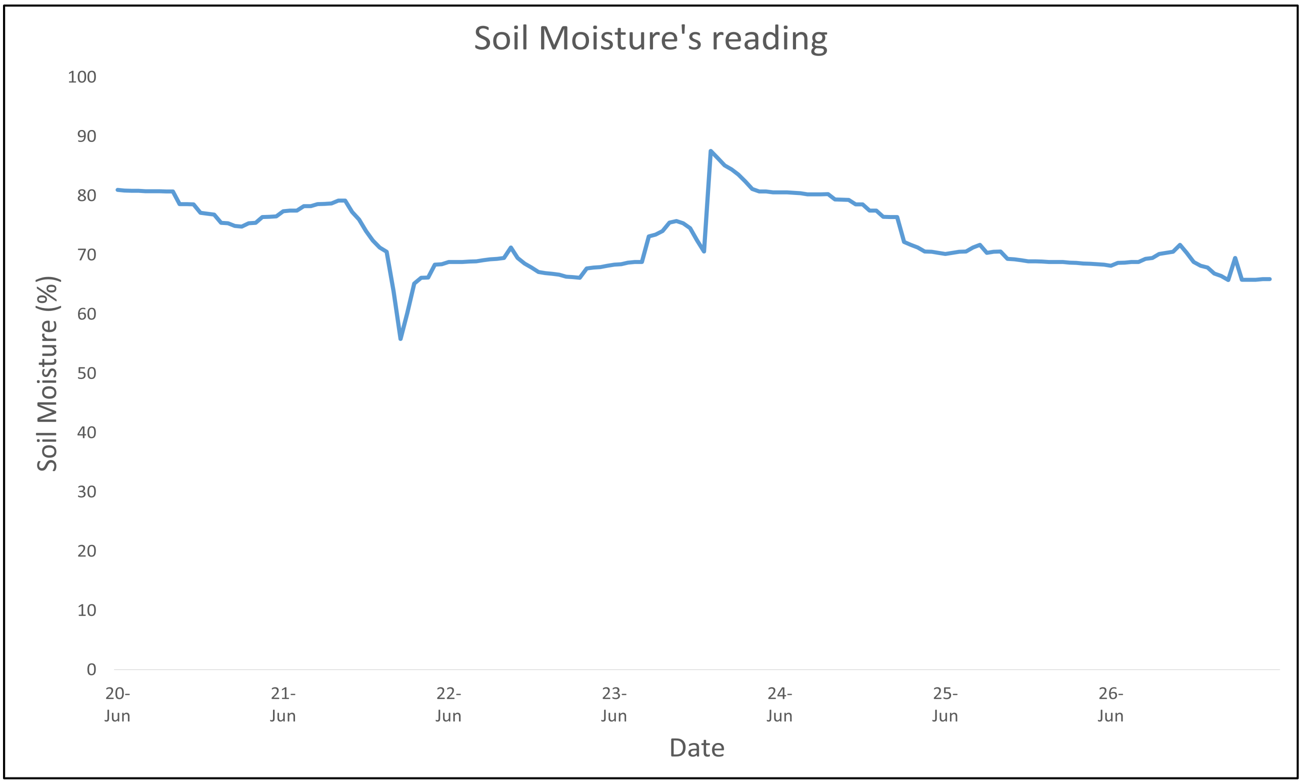

Fig. 13. Soil Moisture's reading

4. Conclusions

The successful implementation of the concept of IoT on a soil monitoring system to monitor the condition of trees was demonstrated in this experiment. This technology enabled real-time tracking of important metrics and analysis of soil quality, providing crucial data for informed decision-making and corrective actions. Sensors were used to measure temperature, humidity, soil moisture, and pH level, providing detailed information about the soil's physical and chemical characteristics necessary for optimizing the growth conditions of the tree. By leveraging IoT and sensor technology, the system can contribute to improved crop yield, cost efficiency, and overall crop quality. To further improve the current project, additional system development may include:

i. The developed system can be customized to fit a variety of soil types and can be enhanced by adding a GPS module to determine the amount of moisture in a specific area and exploring the use of drones or cameras to periodically record sky and ground conditions to monitor crops and their health.
ii. Evaluating the system in different soil types and environmental conditions and integrating the system with other smart farming technologies to provide a more comprehensive solution for precision agriculture.

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