



A Raspberry Pi-Powered IoT Smart Farming System for Efficient Water Irrigation and Crop Monitoring

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ABSTRACT

Water irrigation remain as a challenge to supply adequate amount of water to sustain the growth of plant and crops yield along the year in certain part of the world which are heavily affected by climate change. This scenario creates a huge risk toward the world food supply chain. Hence, the application of smart farming system is crucially important now to pave the way for a better the agriculture monitoring system to replace traditional manual monitoring labour by farmers. The smart farming system are usually equipped with environmental stimuli sensing system such as temperature, humidity, soil moisture, light intensity sensing sensors coupled with automation actuators to control the water irrigation rate for the crops in order to save water and at the same time provide adequate water supply for plant growth. The aim of using such smart farming system is to enable higher crops production and less human labour at the same time optimising resources available to minimize cost of farming. Hence, this paper aims to introduce a novel approach of a Raspberry Pi powered IoT smart farming system (ISFS) which can incorporate autonomous monitoring of plant irrigation, temperature, humidity, soil moisture and light intensity, to design a smartphone app that allows users to monitor plantation-related conditions in a user-friendly manner, and to enable automatic control of a drip irrigation system for plants based on data obtained on soil moisture, temperature and sunlight intensity. The proposed prototype with the functionality mentioned is aim to resolve the existing problem and to meet the demand of smart farming application in current era.

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1. INTRODUCTION

Due to the limitation availability of technology in the past, farmers had to deal with strenuous activities. The first agricultural revolution paved the way for the introduction of new technology such as tractors. Farmers would have seen a significant shift as a result of this, since they would be able to be much more efficient. We are currently in the midst of the third agricultural revolution, which is inextricably linked to the technological age. The new technologies that have emerged and will emerge are radically altering the way farmers grow crops

and to sustain crops yield against climate change which become more and more drastic by the years.

Variations in climate and water availability affect agriculture, which is the world's largest water user. Despite increased global food production, food security remains elusive, as global hunger has been on the rise since 2014, with one out of every nine people suffering from malnutrition in 2017 [1]. Furthermore, according to [2], agricultural production failures in the global breadbaskets will be 4.5 times more likely

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by 2030 and up to 25 times more likely by 2050. Understanding the effect of these events on agricultural yield is critical for achieving and maintaining global food security. On the other hand, the economy of many countries relies heavily on agriculture. In Malaysia, agriculture generates 7% to 12% of the country's gross domestic product (GDP) and employs around 16% of the workforce [3]. For optimal plant growth, a sufficient amount of water in the soil is required. Also, because water is such an important component of life, it is necessary to limit its use. As human population is growing at an alarming rate, this had been putting a strain on water resources. The per capita freshwater usage over the years from 1900 to year 2014 is depicted in the Figure 1. It is clearly shows that the trend of water usage had been increasing tremendously over the years to support agriculture, industry, and domestic usage. On the other hand, Figure 2 shows that the availability of freshwater resources per capita keep decrease over the years drastically which forms a dilemma now. Hence, from here it is observable that as time passes, the usage of fresh water grows but per capita freshwater resources decrease; forecasting that the availability of freshwater to support agricultural activities will be even more critical due to the scarce resources in the future. As approximately 70% of freshwater withdrawals are used for agriculture globally [4], this shows the importance of conserving water as much as possible in the agriculture industry. Figure 3 shows agriculture's share of freshwater withdrawals across the world in the year of 2017.

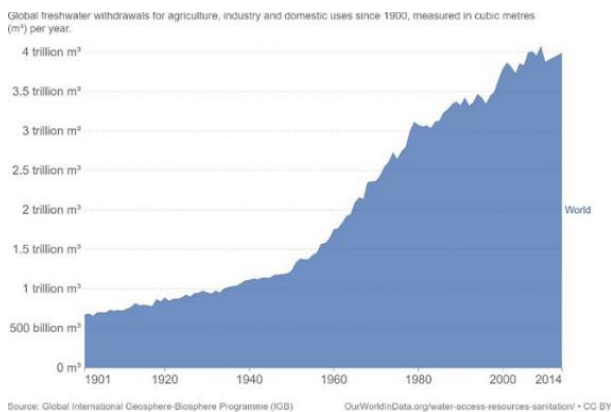


Fig 1. Global freshwater usage over the long run from year 1900 to year 2014 [5].

According to the Figure 3, geographically and by income level, there are significant differences where agriculture water use is 90 percent in low-income nations, 79 percent in middle-income nations, and just 41 percent in high-income ones [5]. As irrigation is one of the largest consumers of water, this necessitates the need to manage water irrigation systems where irrigated fields should not be over-irrigated or under-irrigated. Agricultural failure caused by irrigation is a major cause of crop loss annually, and this dilemma has grown exponentially in the period of water shortage. Growing adequate crops without increasing water usage is a major issue for the industry, especially in light of climate change. Farmers must boost crop efficiency through technological innovations in order to keep up with rising demand. In order to irrigate huge areas of land at the same time, farmers usually require a considerable amount of labour.

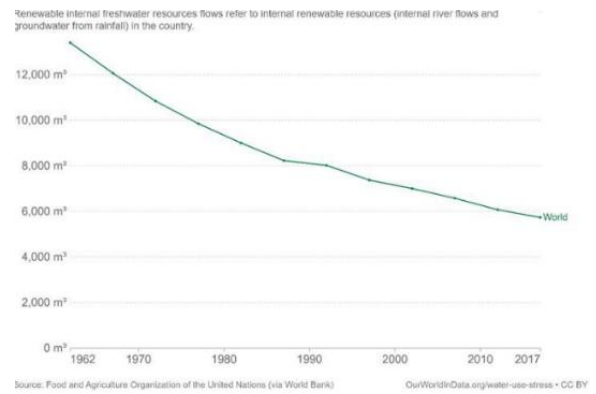


Fig 2. Renewable freshwater resources per capita over the years from 1962 to year 2017 [5].

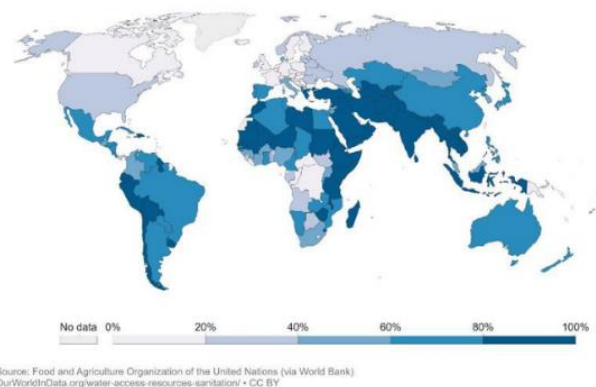


Fig 3. Agricultural water as a share of total water withdrawal at year 2017.

Farmers, especially those in economic hardship, are having a hard time meeting these requirements. Hence to overcome such limitation of increasing water usage with limited water resources and human labours use in agriculture, introduction of smart farming system is critically important to be applied to boost yield and maintain the quality and growth rate of crops in these drastic scenarios. Even though the phrase "smart agriculture" is often used, there is no broadly agreed meaning. The emergence of a coordinated agricultural operation model mixed with current technologies employing multiple information and communication technology (ICT) is known as smart agriculture [6]. Smart agriculture makes use of information, sensors, and the Internet to make crop yields more efficient. Agriculture may meet the aims of sustainable development, resource efficiency, and environmental preservation by combining these elements. Agriculture-dependent populations are aging in several nations throughout the world. Smart agriculture's research and use may be able to address the issue of traditional agricultural manpower's aging. Thus, utilizing Internet of Things (IoT) technology to facilitate smart farming is the new trend of technology application in enabling a better crop monitoring and increase yield from farming.

The network of physical items, or "things," integrated with sensors, software, and other technologies that allow them to communicate and exchange data with other devices and systems over the internet is known as the Internet of Things (IoT) [7]. These goods can be anything from commonplace things like wearable technology and home appliances to large-

scale industrial machines and infrastructure elements [8]. These items may gather and communicate data about their surroundings, activities, and status thanks to Internet of Things technology, which makes it possible to monitor, control, and automate a variety of processes in real time. IoT has the power to completely transform a wide range of industries, including manufacturing, transportation, healthcare, agriculture, and smart cities. This is because it allows devices to communicate with each other seamlessly. It claims to increase productivity, maximize resource use, enhance yield, sharpen judgment, and open up fresh avenues for innovation. IoT is therefore widely employed for smart control and optimization in a variety of industries [9-12].

IoT is utilized, for instance, in energy harvesting for powering ultra-low power sensors for environment monitoring in agriculture to track environment stimuli for smart farming application. By combining sensors and gadgets with green sustainable energy-harvesting technologies like microbial fuel cells [13-15], and plant microbial fuel cells [16-18], IoT sensors can monitor surroundings stimuli, such as sunlight, vibrations, or temperature variations without the use of conventional batteries or wired power sources in farm areas or remote agriculture land. This broadens the breadth of monitoring and control applications by enabling the deployment of IoT sensors in difficult-to-reach or remote areas where traditional power sources are problematic or unavailable [19]. Thus, sensors are powered by a combination of IoT and energy harvesting. Powering sensors is an important factor to take into account in IoT applications, especially in distributed or remote contexts [20]. In order to reduce energy consumption, IoT devices frequently use wireless communication protocols and low-power microcontrollers [21-22]. To extend battery life, energy-efficient design concepts like duty cycling and sleep modes are also used. Furthermore, developments in energy harvesting technologies help power IoT sensors without requiring regular battery changes or cable connections to the grid for electricity [23-26].

Thus, IoT coupled with energy harvesting combination is used in smart farming applications to monitor and regulate a number of variables, including light intensity, temperature, humidity, and soil moisture. A central management system receives data on environmental conditions from Internet of Things (IoT) sensors placed throughout the farm. Crop growth and resource efficiency can be optimized by farmers through real-time remote monitoring and adjustment of these variables. In order to improve productivity and sustainability in smart farming, IoT systems also analyse the data they have collected and offer insights and recommendations for crop management, pest control, and irrigation scheduling. The farmer can improve cultivation with this technology in a way that best meets the needs of the plants. The outcomes include higher agricultural yields, longer production times, better quality, and lower use of protective pesticides.

Thus this project aims to design a Raspberry Pi powered IoT Smart Farming System which is aim to provide continuous monitoring of soil moisture, humidity and sunlight intensity via IoT sensors and paired with a control system to automate the watering system to the crops based on the data collected from the sensors to enable optimum watering of the plants to ensure the yield of the crops, The system are linked to an mobile app to enable farmers to monitor the environment stimuli status, rate of watering and remote control of the system. The entire article

is organized as follows: Section 2 explains the literature review of the past related research, Section 3 will emphasize the materials and methods to fabricate the designed prototype, Section 4 discusses the result, testing and validation of the developed system, Section 5 concludes the article.

2. LITERATURE REVIEW

Numerous plant health monitoring system are designed paired with IoT sensors to enable smart farming applications paired with actuators to enable a sustainable control system to care the plants in order to promote growth, health and yield of the crops. Below summarise the past related researches to this work.

2.1 Plant Health Monitoring System

A plant health monitoring system is developed in [27], with its objectives is to keep track of the plant's moisture, light, and temperature. Microcontroller are interfaced with various sensors such as YL-38 + YL-69 which is a hygrometer acting as a moisture sensor to detect the moisture of the soil, a DHT 11 temperature and humidity sensor to monitor the temperature and humidity of the surrounding environment as well as a TEMT6000 light sensor to measure the illumination intensity received by the plants. All the sensors are link to the Arduino Uno microcontroller which is connected to the cloud to store the data for live monitoring using Ubidots IoT web interface. Thus, a set of live data gathering of temperature, humidity, soil moisture and light intensity is store in the cloud and plotted into graphs to show to the user via the user interface app. Figure 4 shows the block diagram of the proposed plant health monitoring system.



Fig 4. Block diagram of plant health monitoring system [27]

2.2 Automation for Humidity Monitoring and Irrigation System

The development of an automated irrigation system with humidity monitoring is discussed in [28]. The focus of the research is to integrate the YL-69 soil moisture sensor into an automatic sprinkler system. The sensor's reading will be presented on an LCD screen, and a graph will be created on the website in real time. The ESP8266 module is utilized as a Wi-Fi network server and for data processing. The sensor data is sent to the web server through a Wi-Fi network. The data reading is presented in a web browser on a computer that is linked to the internet. The final testing was carried out under a variety of humidity settings. The relay will switch on the water pump when the soil moisture level falls below 50 percent, according to the test results in this article. When the soil moisture level reaches 45 percent, it will switch off. The entire

procedure will take on an average of 1.29 seconds to complete. As a result, the automation system successfully controls the water consumption during the irrigation process based on the soil humidity level from the sensor. Figure 5 shows the block diagram of the specified system.

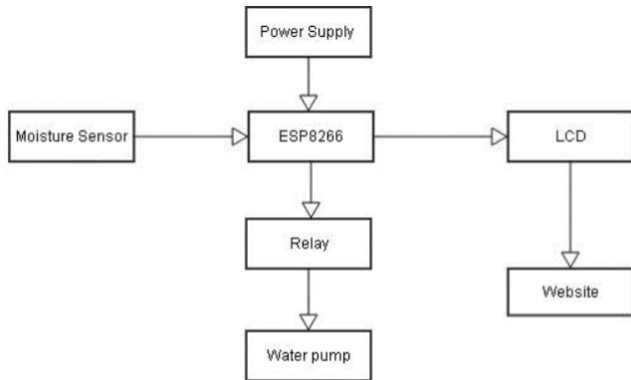


Fig 5. Block diagram of the automated irrigation system with humidity monitoring [28].

2.3 Agriculture Monitoring System

In another research done in [29], it showcase a system which uses an electrical gadget and an Android phone to demonstrate a smart agricultural monitoring system. This technology assists landlord plantations in monitoring and managing their plants in order to maximize productivity and improve the quality at various agricultural locations. There are several sensors here, such as moisture and temperature sensors, whose values are recorded in the cloud. The field is also managed using a mobile application. The data of the selected area will be shown on a mobile application, and the user will be able to monitor in real time condition of the plantation environmental stimuli of temperature and soil moisture to forecast crops health conditions. Figure 6 shows the system framework of the proposed design.

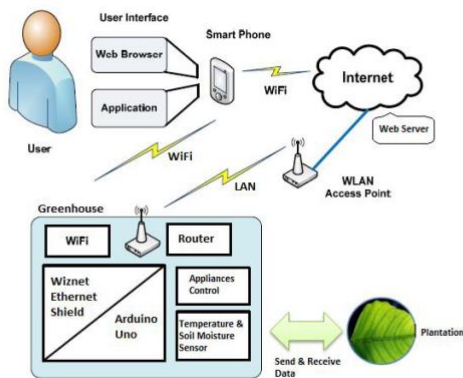


Fig 6. Agriculture monitoring system framework [29]

2.4 GSM Based Agriculture Monitoring and Controlling System

Another work in [30] shows the fundamental idea to use Wireless Sensor Network (WSN) technology to create an agricultural environment monitoring framework for measuring the environmental stimuli data to control the rate of activating a water pump connected to a rain gun irrigation system used to water the crops. The proposed rural environment observation server framework uses WSN-based ecological and soil sensors to collect natural and soil data from the outside. This concept employs moisture and temperature sensors to assist the field in controlling the water level as well as the temperature. They employed a wireless sensor network in place of a Global System for Mobile communication (GSM) network which will gather the environmental data and send the report to the mobile of the user. The following Figure 7 shows the block diagram of the proposed system.

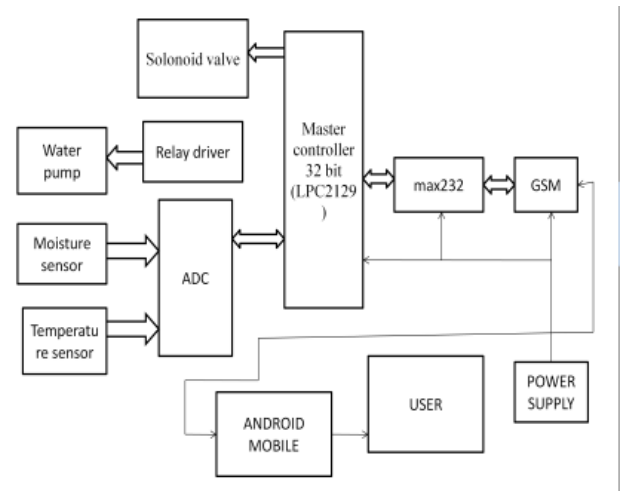


Fig 7. Block diagram for proposed System components [30]

2.5 Enhancing microbial fuel cell performance with carbon powder electrode modifications for low-power sensors modules

In the realm of microbial fuel cell (MFC) technology, the enhancement of performance is a critical area of research. Al-Badani et. A. [13-15] delves into this domain by exploring modifications to electrodes using carbon powder (CP) in various forms. The study investigates the impact of three different modifications involving CP on stainless-steel mesh (SSM), carbon cloth, and carbon felt electrodes. These modifications include CP alone, a combination of CP with ferrum, and a blend of CP with sodium citrate and ethanol. Such modifications aim to improve the efficiency and power output of MFCs, which is particularly crucial for applications like low-power sensor modules for temperature and humidity monitoring for smart farming applications. By experimenting with different electrode materials and modifications, researchers can potentially optimize the electron transfer processes within MFCs, leading to enhanced performance. The utilization of CP in electrode modifications offers a promising avenue for improving the overall efficiency of MFC systems. These modifications could potentially address challenges related to power generation and stability in MFCs, thereby contributing to the advancement of sustainable energy technologies. The study sheds light on the possibility of

powering temperature and humidity sensors for smart farming application by using MFC with electrode modifications using carbon powder for boosting the performance of MFC.

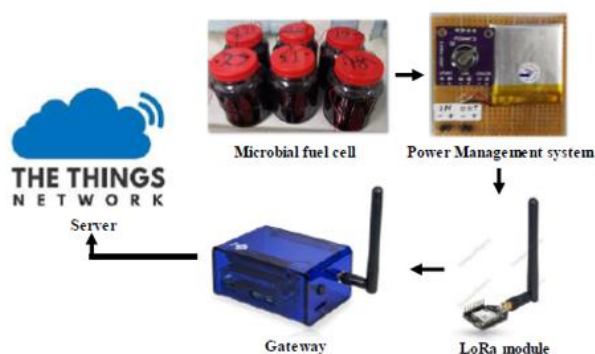


Fig 8. Temperature and humidity monitoring system powered by MFC for smart farming application [13-15].

2.6 Enhancing microbial fuel cell performance with carbon powder electrode modifications for low-power sensors modules

The study by Chong et al. [16-19] presents an innovative approach to utilizing Aloe Vera-derived plant-based cells for powering wireless temperature and humidity sensors aimed at remote sensor activation for environment monitoring purpose for smart farming application. The research focuses on designing a power management circuit capable of harnessing, storing, and effectively managing electrical energy harvested from Aloe Barbadensis Miller (Aloe Vera) leaves. This concept offers a sustainable and eco-friendly solution for energy harvesting, aligning with the growing interest in renewable energy sources and green technologies. By exploring the potential of plant leaves, particularly Aloe Vera, as a source of electrical energy, the study bridges the fields of electrical engineering, wireless technology, and ecology. The proposed system not only demonstrates the feasibility of utilizing natural resources for energy harvesting to power smart farming ultra-low power sensors but also highlights the importance of integrating plant-based solutions into the realm of energy technologies. This interdisciplinary approach opens up new avenues for research and development in the field of energy harvesting and sustainable power generation. The research on the application of Aloe Vera-derived plant-based cells for powering wireless devices represents a significant contribution to the field of energy harvesting and wireless sensor technology. The study showcases the potential of harnessing natural resources for energy production, emphasizing the importance of eco-friendly solutions in advancing wireless communication systems. This work paves the way for further exploration of plant-based energy sources and their integration into diverse technological applications.

3. RESEARCH METHODOLOGY

This section shall explain the materials and methods used in designing the Raspberry Pi Powered IoT Smart Farming System (ISFS) covering the hardware system design, software

application design and programming involved with the flow of works as shown in Figure 9.

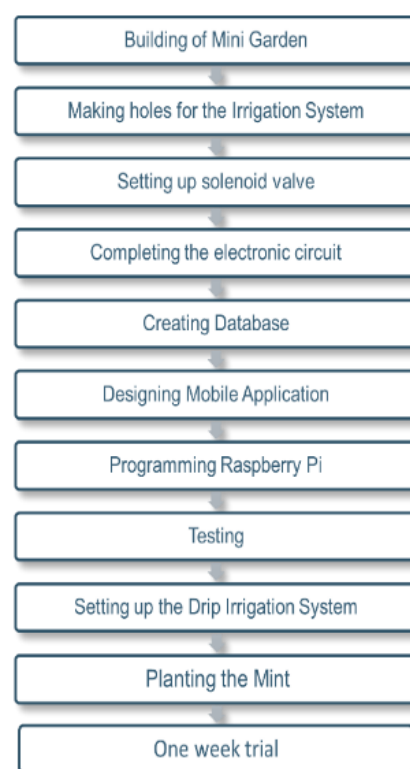


Fig 9. Flow of ISFS

Three separate sensors are required for this project: a soil moisture sensor, a temperature and humidity sensor, and a light sensor. These sensors are connected to a GrovePi which is mounted onto the Raspberry Pi, and the data collected by the sensors is sent to a Realtime Database. Based on the data collected by the sensors, the irrigation system will operate automatically. Finally, the user will be provided the database data to observe the condition and if necessary, the user can manually start or stop the irrigation system.

3.1 System Design

Figure 10 shows the design of the IoT Smart Farming System. A GrovePi is mounted onto the Raspberry Pi. Moisture sensor is connected to the port A1 of the GrovePi using grove cable. DHT11, humidity and temperature sensor, is connected to the port D4 of the GrovePi with a grove cable. Then the light sensor, TSL2561 is connected to general purpose input/output (GPIO) pins of the Raspberry Pi where:

- Vcc is connected to the 3.3V which is the first pin in the bottom row
- Gnd is connected to the ground which is the third pin in the top row
- SDA is connected to the second pin in the bottom row
- SCL is connected to the third pin in the bottom row

The relay module is connected to the port D3 in the GrovePi. The solenoid valve is then connected to relay and to the power supply.

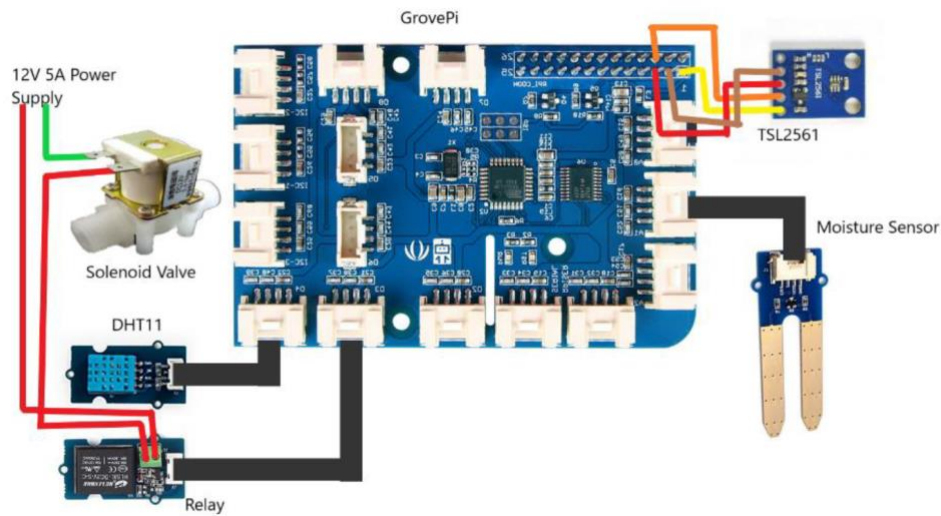


Fig 10. System Design of IoT Smart Farming System

3.2 Building Smart IoT Garden App

Figure 11 shows the app coding diagram of the IoT Smart Farming System. The smartphone application is the subsequent component of ISFS. MIT App Inventor is used to build a customized app for this project. First, navigate to the MIT App Inventor website and the button “Create Apps!” is clicked and it is prompted to log in using Google Account. A new project is started. The app is created by using the tools available in the website. All the required aspects are available under the left side Palette such as layouts, user interface and many more. These aspects can be directly click and drop onto the Viewer section at the position the aspect is wanted. The app’s layout is constructed with multiple horizontal layouts. All the added components will appear on the “Components” section on the right

Each component can be edited by selecting them and editing them on the “Properties” section the rightmost side. Media is uploaded in the “Media” section and can be used in the project. All this are done in the designer mode. The connection to database and the app is also made here by providing the Firebase Token and the URL that have been noted down when creating the database. The coding of the app is done by going to the “Blocks” tab. All the required functions are selected and coded together with the parameters in these section. Finally, click the “Build” tab to build the APK file of the app. The app is then installed in a smartphone.

Python Language is used to program the Raspberry Pi for this IoT Smart Farming System. The flowchart of the program can be found below in Figure 12.

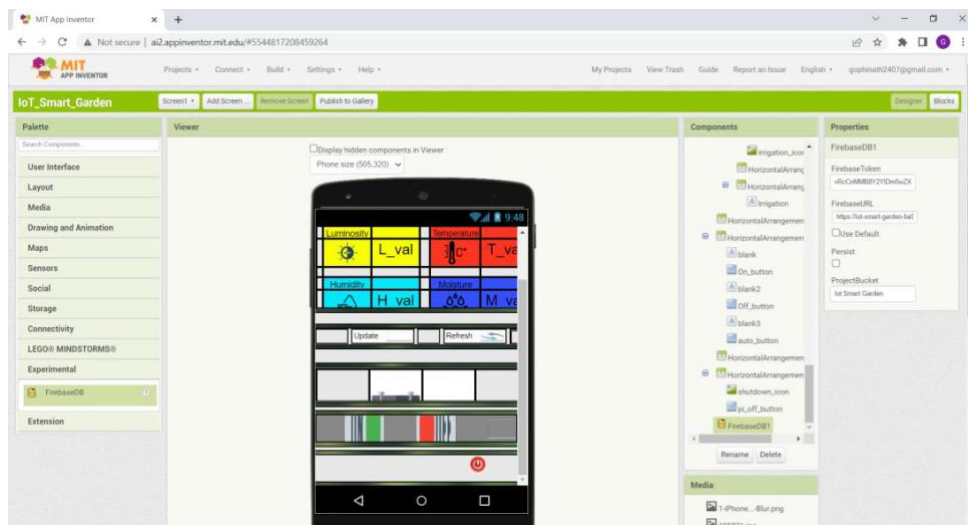


Fig 11. Smart IOT Garden App coding diagram

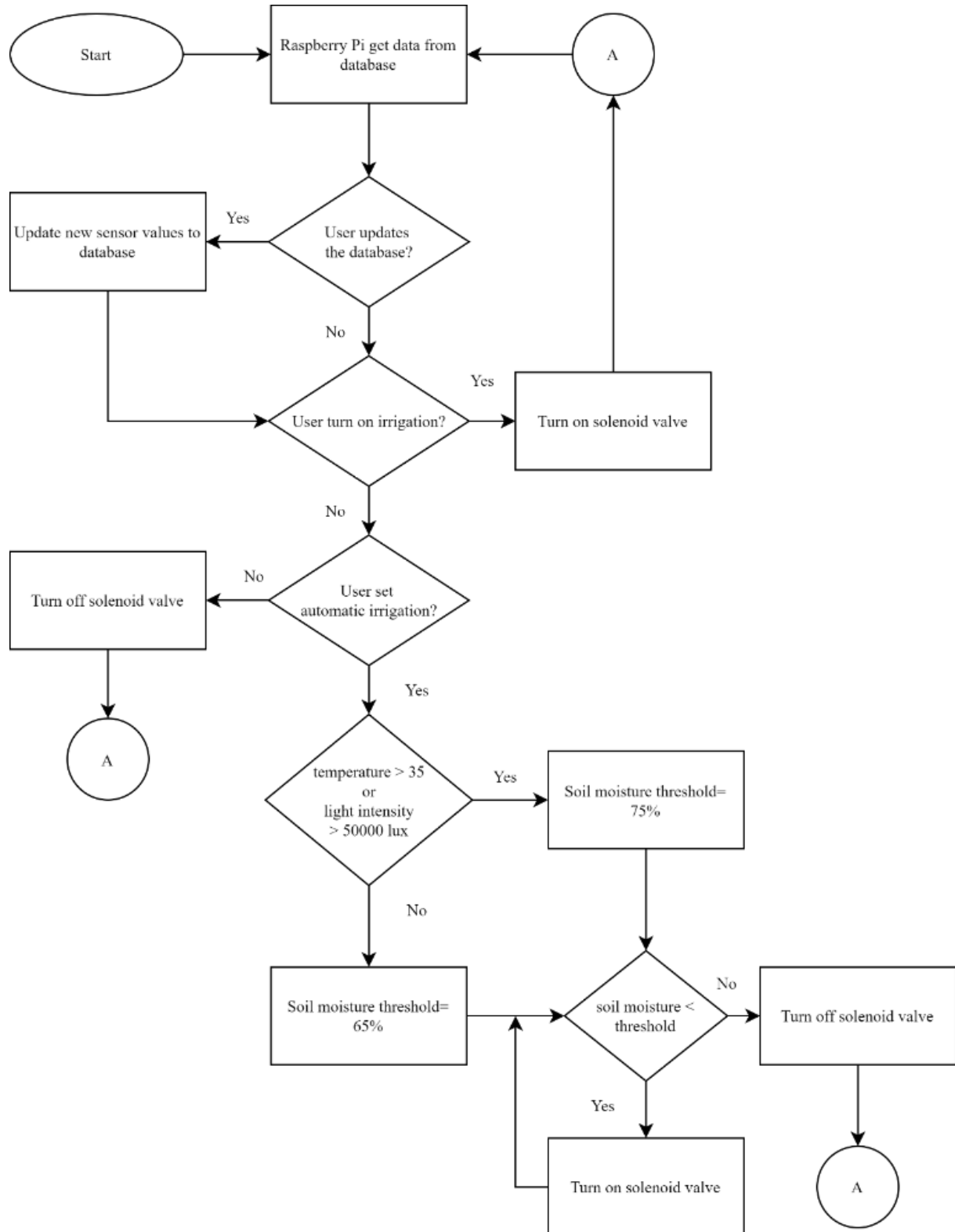


Fig 12. Flowchart of ISFS

The flowchart begins with the initialization phase where the Raspberry Pi boots up and establishes connectivity either to the internet or a local network. This step is crucial for enabling communication with remote servers or user interfaces. Once initialized, the system proceeds to acquire data from various sensors deployed across the farm. These sensors measure parameters such as temperature, humidity, soil moisture, and light intensity, providing essential insights into the farm's environmental conditions. Following sensor data acquisition, the system enters the decision-making phase. Here, algorithms analyse the collected data to make informed decisions regarding farm management tasks such as irrigation, fertilization, and pest control. These decisions are based on predefined thresholds or algorithms designed to optimize crop growth and minimize resource usage. For example, if the soil moisture level falls below a certain threshold, the system may trigger an irrigation event to ensure adequate hydration for the crops. After determining the necessary actions, the system proceeds to execute them. This involves controlling various actuators and devices deployed in the farm, such as irrigation systems, greenhouse ventilation fans, or pest control mechanisms. For instance, based on the decision to irrigate, the system activates the irrigation system for a specified duration to water the crops effectively. Simultaneously, the system provides a user interface for farmers to monitor the farm's status and make manual adjustments if needed. This interface displays real-time sensor data, system alerts, and allows users to configure parameters or preferences. Additionally, remote access is enabled to facilitate monitoring and control from anywhere, ensuring flexibility and convenience for farmers. To handle potential errors or exceptions during operation, the system incorporates error handling mechanisms. These mechanisms detect and address issues promptly to prevent system damage or data loss. Furthermore, the system logs all activities, including sensor readings, user interactions, and automated actions, to maintain a record of farm operations. This logging data can be used to generate reports summarizing farm conditions, actions taken, and any anomalies detected, aiding in decision-making and performance evaluation. Ultimately, the flowchart concludes with the termination of the process, marking the end of the outlined sequence of operations. Overall, this flowchart outlines the fundamental steps involved in an IoT Smart Farming System using Raspberry Pi, emphasizing data acquisition, analysis, decision-making, action execution, user interaction, error handling, and logging/reporting functionalities.

4. RESULTS AND DISCUSSION

4.1 Raspberry Pi

The Raspberry Pi was successfully configured for this project. The Raspberry Pi is equipped with a GrovePi. The GrovePi's port A1 is linked to the moisture sensor via grove cable. The GrovePi's port D4 is linked to the DHT11 humidity and temperature sensor using a grove cable. The TSL2561 light sensor is then linked to the Raspberry Pi's general-purpose input/output (GPIO) ports. The GrovePi's port D3 is where the relay module is attached. The relay and power supply are then connected to the solenoid valve. Raspberry Pi programming has made all these individual electronics to a single functional unit. All the sensors were tested and working successfully. The Python program is successfully built and running. The program

is able to communicate with the database and able to perform read and write operations in the database.

The first objective of this project was to build an IoT Smart Farming system powered by Raspberry Pi that incorporates autonomous monitoring of plant irrigation, temperature, humidity, soil moisture and light intensity. The Figure 9 shows that the IoT Smart Farming System powered by Raspberry Pi is able to monitor the mini garden's soil moisture, temperature, humidity and light intensity. This can conclude that the first objective is achieved.

4.2 IoT Smart Garden App

The Figure 13 shows the smartphone application that has been designed for this project. This application displays the plantation-related conditions which are luminosity, temperature, humidity, soil moisture and the irrigation status in the mini garden. The user can update the values by clicking the update button and refresh the app by clicking the refresh button. Furthermore, the user is able to turn on the irrigation, turn off the irrigation and set the irrigation to automatic through this application using IoT technology. This application shows the irrigation status by change in size of the ON, OFF or AUTO buttons. The app communicates with the database as well to read and write data into the database.



Fig 13. Smart IOT Garden App (Automatic Irrigation)

The second objective of this project was to design a smartphone app that allows users to monitor plantation-related conditions in a user-friendly manner. Hence, the second objective is completed. As shown in the Figure 10, the smartphone app displays luminosity, temperature, humidity and soil moisture. Furthermore, the user is able to turn on the irrigation, turn off the irrigation and set the irrigation to automatic through this application using IoT technology. Hence, the second objective is completed.

The third objective of this project was to enable automatic control of a drip irrigation system for plants based on data obtained on soil moisture, temperature and sunlight intensity. As shown in the Figure 10, the user is able to set the irrigation mode to automatic. This will trigger the raspberry pi to execute the automation script in the python. To further understand how the automation works refer to the flowchart in Figure 8 in Chapter 3. This can conclude that the third objective has been achieved.

4.3 IoT Smart Farming System

A mini garden was made using the wood planks and plywood that was prepared and covered with the tarpaulin sheet. A small compartment was built to keep the Raspberry Pi and power supply save from water and dirt from the mini garden. The mini garden is then completed after setting up all the electronics and the irrigation pipes with the solenoid valve. A one-week trial was conducted in IoT Smart farming System. Mint plants were planted in the mini garden and was observed for one week. The system was able to detect when it is necessary to water the plants and when it is not. The irrigation was able to be controlled using smartphone app as well.



Fig 14. Mini garden

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The aid of new technology has paved the agriculture field from manual monitoring and control to automation, resulting in higher production and less human participation. An automatic irrigation system is developed in this project to monitor and maintain the proper soil moisture content using an automatic irrigation system. The name of this system is ISFS. The Raspberry Pi microcontroller is used to create the control unit, which can be operated remotely via a mobile application. The soil moisture sensor is used in this project to determine the right moisture value of the soil. Over or under irrigation is avoided because the proper amount of water is used based on the data collected by the moisture sensor, temperature sensor, and light sensor. With the help of a solenoid valve, the user may increase or decrease the irrigation of the mini garden. The aim to design a smartphone app that allows users to monitor plantation-related conditions in a user-friendly manner and to enable

automatic and user control of a drip irrigation system for plants based on data obtained on soil moisture, humidity and sunlight intensity using Raspberry Pi has been achieved. A one-week trial is done and the plant growth is positive. As discussed in Chapter 4, all the objectives of this project which are to build an IoT Smart Farming system powered by Raspberry Pi that incorporates autonomous monitoring of plant irrigation, temperature, humidity, soil moisture and light intensity, to design a smartphone app that allows users to monitor plantation-related conditions in a user-friendly manner and to enable automatic control of a drip irrigation system for plants based on data obtained on soil moisture, temperature and sunlight intensity are met.

5.2 Recommendations

The most of useful elements were discovered while developing this project, and many of them were used. Some of these, nevertheless, cannot be included because of time restrictions and other factors. There are still more aspects to be explored in this IoT Smart Irrigation System. Due to small water container being the water source for the ISFS, the water pressure is low and causes small delay in the irrigation.

- A water pump can be installed to the irrigation system to improve the water pressure.
- This project can be improved by adding camera to the Raspberry Pi and integrate an Artificial Intelligence Model to capture the plants to identify plants growth rate and to detect plant leaf diseases.
- Different soil quality monitoring sensors allow for the usage of fertilizers in accordance with soil condition, which is particularly cost-effective for farmers can be added.

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