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AN INTERNET OF THINGS (IOT) AND CLOUD-BASED SMART IRRIGATION SYSTEM IMPLEMENTED USING THE NODEMCU ESP8266 MODULE

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ABSTRACT

The agriculture sector today is facing more challenges from the need for efficient water resource management and improved agricultural productivity, issues that are further intensified by global climate change. The recent popularity and widespread adoption of the Internet of Things (IoT) have created new opportunities for technological advancements that enhance agricultural efficiency and support farmers globally. This paper presents the development of an IoT-enabled smart irrigation system to optimize water usage through real-time monitoring and automate the irrigation control. This approach leverages embedded systems, IoT infrastructure, and HTTP protocols. The proposed system integrated with a NodeMCU ESP8266 module, DHT11 temperature–humidity and FC-28 soil moisture sensors, with data visualization and storage handled through the cloud based ThingSpeak dashboard. The NodeMCU ESP8266 module collects and processes data from the sensors to autonomously control the operation of the water pump. Using built-in Wi-Fi capability, the module sends real-time sensor data to the ThingSpeak IoT platform. Also, users can operate the water pumps remotely through a smartphone application. The system periodically checks soil moisture and activates the relay module to water the plants only if the soil is dry and the temperature is suitable. This study highlights the potential of IoT-based smart irrigation systems to improve agricultural productivity, optimize the efficient water utilization, and enhance sustainability in modern farming.

Keywords: Internet of Things (IoT), Irrigation system, ESP8266, ThingSpeak.

1. Introduction

Indian agriculture is the nation's foundation, sustaining the lives of billions of people and supplying essential food for both India and the global community. Indian agriculture employs about 68% of the total population and contributes 33% of the country's capital. Crop irrigation is the major use of freshwater, consuming nearly 70% of the supply. Traditional water irrigation methods used by many farmers often result in under-irrigation or over-irrigation, which ultimately reducing crop yields and decreasing resource sustainability [1], [2].

The world's population forecasted by the United Nations will reach up to 9.4 to 10.1 billion by 2050 and 9.4 to 12.7 billion by 2100, creating huge demand for food. Research published in Nature

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Food highlights the urgency of this challenge, estimating that global food output must increase by 70% between now and 2050. Consequently, ensuring food security and fostering sustainable economic progress relies on the immediate adoption of innovative and highly efficient agricultural technologies [3]. Therefore, implementing Agriculture 4.0 technologies like artificial intelligence, Internet of Things (IoTs), and edge computing in crop irrigation leads to a transformative improvement in agricultural water management [4].

In the context of Agriculture 4.0, the IoT involves a network of devices capable of sensing and actuating, all connected to share information through a central platform. These automated devices, often called "things," can send large amounts of data across a network with no need for human involvement either person-to-person or person-to-computer. They are extensively used in fields like smart homes, retail, smart cities, industry, energy systems, agriculture, and healthcare [5]. Effective monitoring systems are crucial for plant development and growth, making them essential for designing irrigation control systems that maximize food production while minimizing water waste. IoT-based irrigation systems manage water resources sustainably and effectively by enabling remote monitoring, automatic control, and precise water application. The IoT system monitors soil moisture, climate, and plant needs in real-time by integrating various technological components, including sensors, controllers, networks, and cloud platforms [4]. To promote water conservation, Zhang et al. have developed a system for monitoring factors such as moisture, temperature, and nutrients using the IoTs to assist for the fertilization and irrigation decisions in citrus cultivation [6].

Ramachandran et al. discussed the use of IoT technology in agriculture, specifically factors effecting on the irrigation, different architectures of IoT, sensors, and controllers. Their discussion also included available cloud platforms, software tools for irrigation scheduling, and machine learning algorithms for predicting real-time water demand [7]. Rao et al. developed an IoT system for automatic irrigation, utilizing a Raspberry Pi to enhance crop yield while minimizing water usage. The system autonomously calculates and dispenses the optimal water volume for irrigation based on input from soil humidity and temperature sensors [8]. Mezouari et al. developed an Arduino UNO–based smart irrigation system incorporating a resistive soil moisture sensor, a water flow meter, and a temperature–humidity sensor. The system automatically triggers irrigation via a relay module and pumping motor when the soil is dry or the temperature surpasses 30°C [9]. Saban et al. was presented a smart farming system, which utilizes a wide-range wireless sensor network. The system achieves this broad coverage by integrating long-range wireless area network (LoRaWAN) a key IoT technology with established industrial Programmable Logic Controllers (PLCs) as a control devices [10].

Conventional farming suffers from several drawbacks, namely the financial burden and the lack of automated control and monitoring systems. This work introduced a smart irrigation system that combines cost effective the ESP8266 module, environmental sensors and open source cloud-based ThingSpeak analytics platform for real-time operation. By integrating various sensors like DHT11 and soil moisture, the embedded system optimally controls irrigation according to environmental data, leading to greater agricultural output and a reduction in water consumption.

2. System Overview/Development of IoT enable smart irrigation system

The IoT enable smart irrigation system consists of hardware and software components integrated into a unified architecture. This section provides the block diagram and flowchart of proposed system.

2.1 Block diagram

The block diagram of proposed IoT-based smart irrigation system is shown in Figure 1.1. In this work, an NodeMCU ESP8266 module is connected to both a soil moisture sensor and a temperature-humidity sensor. These sensors continuously measure the soil's moisture level and ambient environmental conditions, transmitting the collected data to the microcontroller. The system is automated based on a pre-set moisture threshold value programmed into the ESP8266 module. If the sensed data exceeds or falls below this threshold, the microcontroller automatically activates or deactivates the solenoid-controlled pump, thereby regulating the water supply to meet the plant's needs. All current sensor readings are simultaneously displayed on a local Liquid Crystal Display (LCD). The data will be transmitted to the ThinkSpeak IoT cloud platform using the NodeMCU ESP8266 module, where it will also be stored. ThingSpeak dashboards allow users to easily access and visualize the data, helping them automatically understand soil health and environmental conditions.

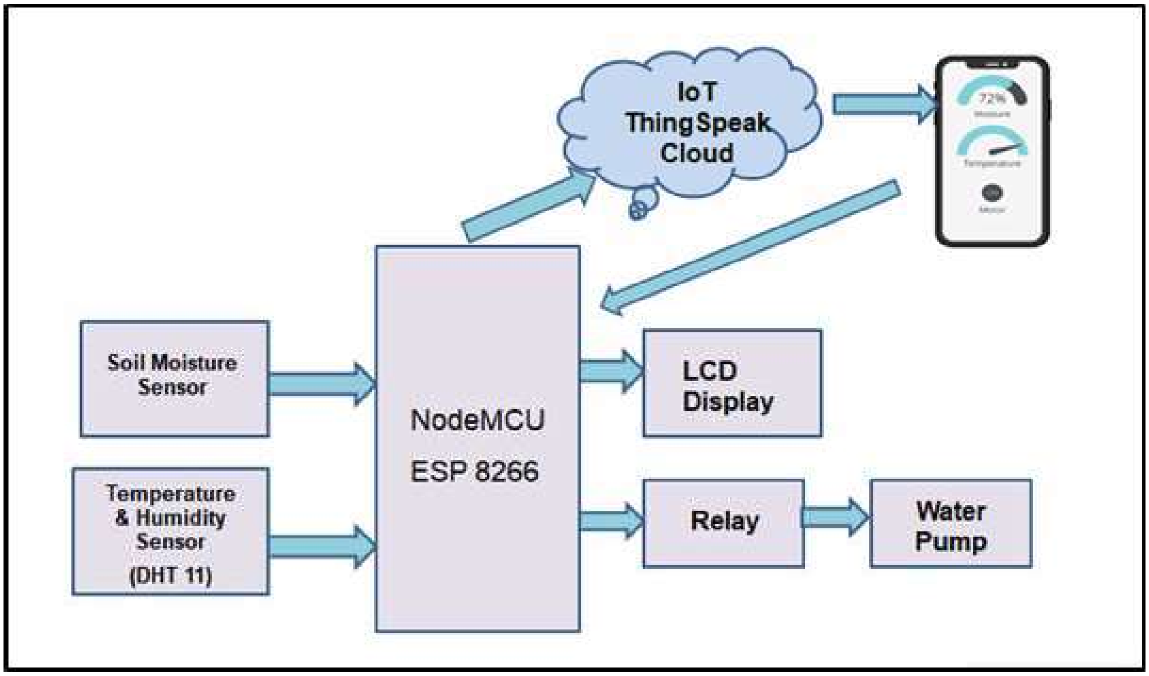

Figure 1.1: Block diagram of IoT-based smart irrigation system

2.2 System flowchart

The process flow for monitoring the sensor and controlling the pump value for IoT-based smart irrigation system is shown in Figure 1.2.

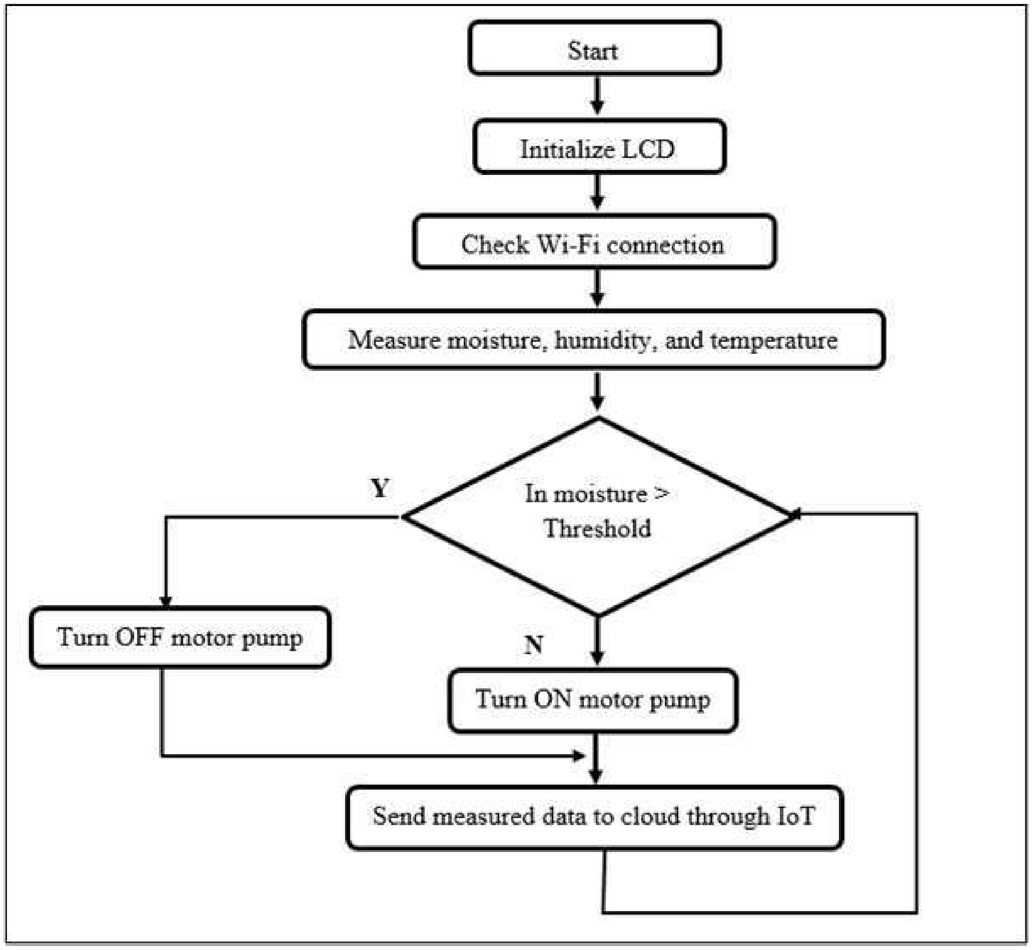

Figure 1.2. Flowchart of the smart irrigation system.

3. IoT Architecture for Smart Water Irrigation System

IoT architecture is the multi-layered framework that connected different devices, wire and wireless networks, different communication protocol, data analytical model, and applications interact to collect, process, and utilize data. The IoT architecture is the dynamic in nature. In the past few years, researchers have proposed different architectures such as 3- layer, 4 - layer, 5 - layer and 7-layer architectures [11]. Most IoT-based irrigation systems follow a layered architecture comprising sensing/perception, communication, processing, and application layers.

The generic high-level Internet of Things (IoT) architecture typically composed of three primary layers: (1) the perception/physical layer, (2) the network layer, and (3) the application layer.

3.1 The **perception layer / physical layer** act as the data collector, sensing and gathering information from the surrounding environment. This raw data is essential for the operations of the higher layers. In this system, perception layer includes soil moisture sensor, temperature-humidity, and submersible pump deployed in agricultural fields.

3.2 The **communication layer / network layer** is referred to as the transmission layer. It provides a vital intermediary connecting between the perception layer and the application layer. For data transmission, a variety of technologies and protocols are employed. Network layer facilitates data transmission using wired or wireless communication technologies such as Bluetooth, Zigbee, Wi-Fi, LoRaWAN, cellular networks and ethernet. The network layer protocols handle device addressing, packet routing, and data forwarding across networks. These include IPv6 over Low-Power Personal Area Networks (6LoWPAN), the Routing Protocol for Low-Power and Lossy Networks (RPL), Stream Control Transmission Protocol (SCTP), and Transport Layer Security

(TLS). In addition, standard transport layer protocols such as Transmission Control Protocol (TCP) and User Datagram Protocol (UDP) are used over both IPv6 and IPv4 networks [12].

3.3 The final layer, **the application layer**, sits at the top of the stack and delivers services and functions directly to the end-users. This is the layer where users interact with the IoT system to carry out requests and transactions. Key activities performed at this level include data querying, visualization, report generation, analysis, authentication, and platform interaction.

4. System Components

The system's main hardware components are NodeMCU ESP8266 module, soil moisture sensor, temperature-humidity sensor, relay, submersible pump and a power supply.

4.1 NodeMCU ESP8266

The NodeMCU ESP8266 module is a low cast, open-source development board featuring Wi-Fi (802.11 b/g/n) connectivity, making it ideal for Internet of Things (IoTs) applications. The pin diagram of NodeMCU ESP8266 is shown in Figure 1.3. Its internal structure is built around the ESP-12E module, featuring the ESP8266 chip with a Tensilica Xtensa 32-bit LX106 RISC microprocessor, which operate at a maximum clock speed of 160 MHz. The board is equipped with 128 KB of RAM and 4 MB of flash memory for storing applications and data. This module has 30 pins available for connecting to external devices. Furthermore, it offers 17 General Purpose Input/output (GPIO) pins for interfacing with external electronic components such as buttons, sensors, and LEDs. It also offers one Analog to Digital input pin with 1024 step resolution [13].

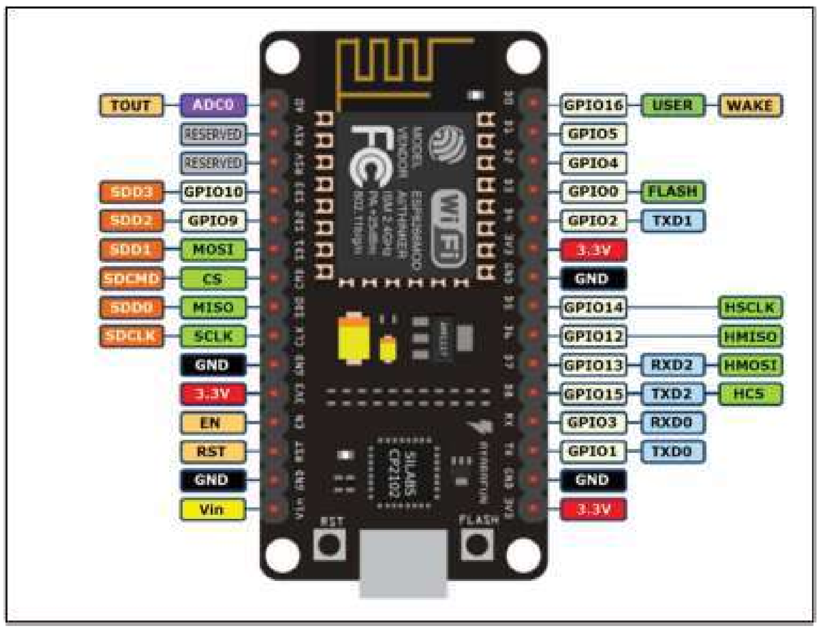

Figure 1.3 : Pin diagram of NodeMCU ESP8266 module

4.2 Temperature Humidity Sensor—DHT11

We use the DHT11 inexpensive digital sensor module measures both humidity and temperature, as shown in Figure 1.4 (a). It is providing a pre-calibrated, reliable digital output signal. This sensor is powered by an advanced, high-performance 8-bit microcontroller. Its design ensures high reliability and sustained stability over time. It measures temperature (0-50°C with ±2°C accuracy) and humidity (20-90% RH with ±5% RH accuracy), using a single-wire interface and operating between 3.3V and 5V [14].

4.3 Soil Sensor FC-28

The FC-28 is a simple soil moisture sensor designed for use in automated plant watering systems, as shown in Figure 1.4 (b). It measures soil moisture content based on electrical resistance principle and provide an analog voltage output. The module includes an LM393 driver and can operate from a wide, single voltage supply, specifically 3.3–5 V. A potentiometer is available on the module for adjusting the sensor's sensitivity [15].

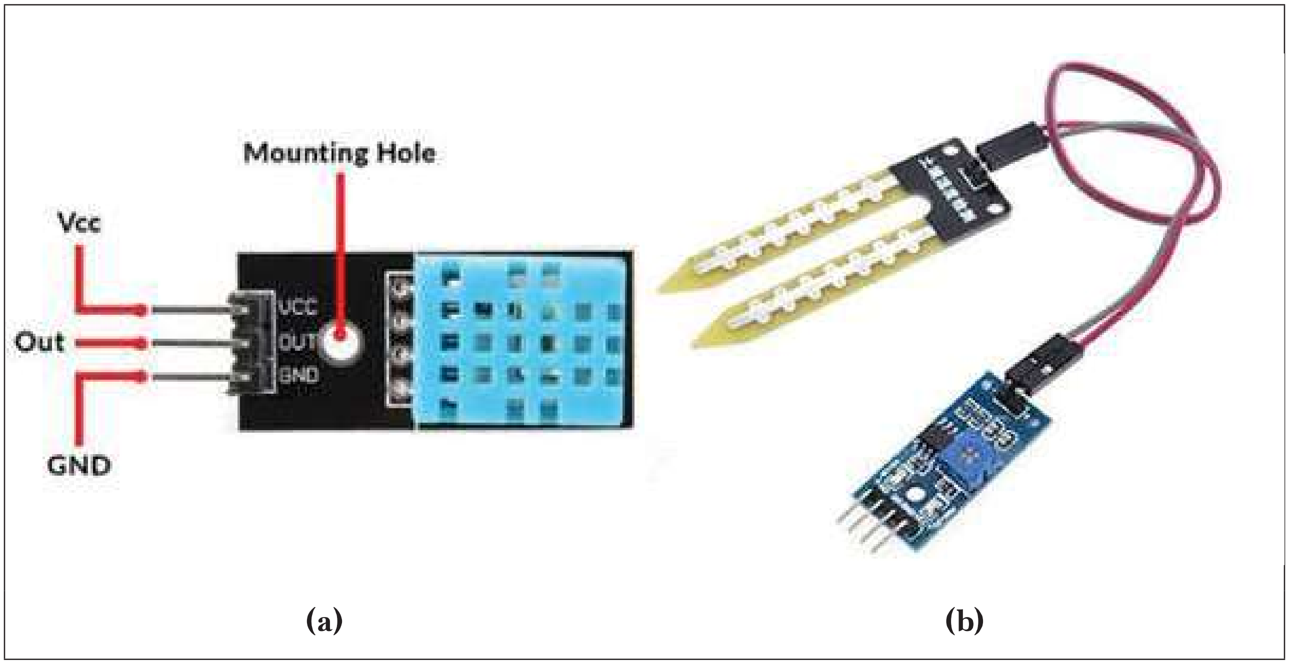

Figure 1.4: (a) Pin diagram of temperature-humidity (DHT 11) and (b) soil moisture (FC-28) sensor

4.4 Relay module

A relay module functions as an electromechanical switch designed to control high-voltage or high-current loads using a relatively low-voltage signal provided by a microcontroller. A benefit of using a relay is electrical circuit protection between the input and output section. It achieves this by providing complete isolation between the low-voltage control circuit such as microcontroller and the high-power circuit. Each channel in the module has three connections named normally close (NC), normally Open (NO), and common (COM). In this work, the relay's specific purpose is to act as the primary switching mechanism for the water pump. It will turn the pump ON or OFF based on the control signal it receives from the ESP8266 board [9].

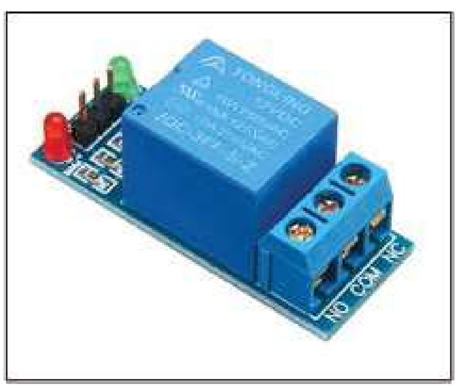

Figure 1.5: Relay module

Software implementation

The system utilizes the open-source Arduino platform, which offers an accessible GUI for developing everything from elementary sensors to advanced IoT applications. The software used in this project is Arduino IDE 2.3.3, in which NodeMCU programming performed with C/C++ language.

5. System / Hardware and Software Implementation

The calibrated soil moisture sensor, temperature-humidity sensor, relay module and water pump are submain hardware of the drip irrigation system. The ESP8266 low-cost, System-on-Chip (SoC) microchip with integrated Wi-Fi capability is main hardware component of this system. The Microcontroller Unit (MCU) serves as the central hub, constantly monitoring soil moisture and environmental parameters while executing necessary data processing. These measurements are simultaneously uploaded to the ThingSpeak cloud platform using the HTTP protocol for remote collecting, storing, monitoring and analysis application. The sensor data is also locally available to LCD display for immediate visualization.

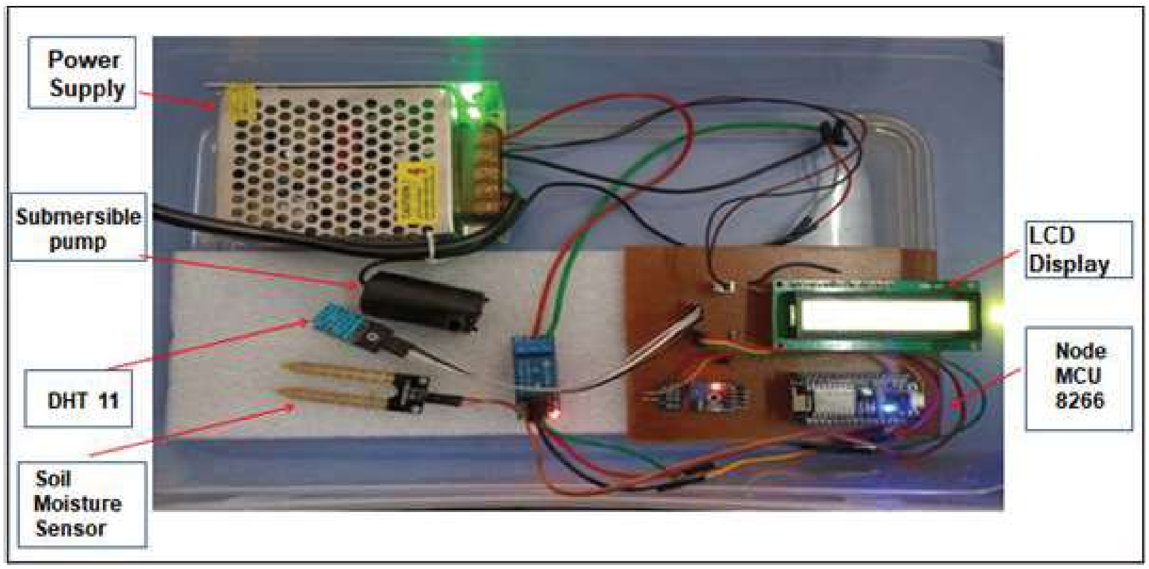

Figure 1.6: Development of smart irrigation system.

6. Results and Discussion

The ESP8266 module utilizes the Wi-Fi facility to transmit the gathered data to our dedicated ThingSpeak cloud channel every 15 second. The ThingSpeak IoT cloud dashboard contains eight private channel fields, but only three are currently displayed for this system application. Figure 1.7 shows the detailed description of ThingSpeak platform dashboard, which contained the soil moisture level, temperature, and humidity of environment. From Figure 1.7 (a), the graph shows the water content within the soil varies. Temperature data visualized via the ThingSpeak platform is presented in Figure 1.7 (a), allowing the farm owner to monitor environmental conditions remotely through graphical displays. Recorded temperatures data fluctuated between a peak of 32°C and a minimum of 30°C. Similarly, Figure 1.7 (c) displays the real-time humidity levels, which are the more stable at 60% during the observation period.

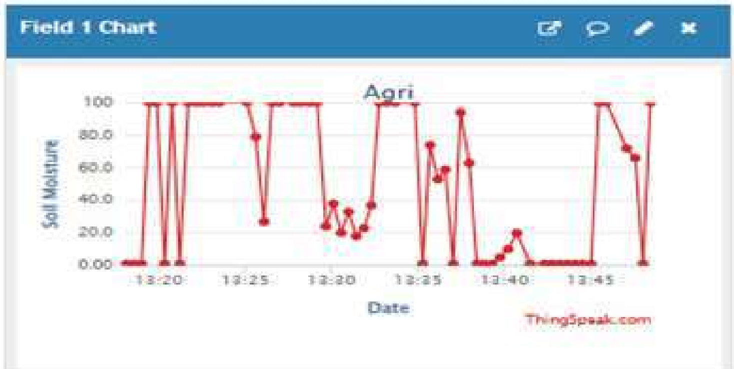

Figure 1.7 (a): Soil moisture data on ThingSpeak platform

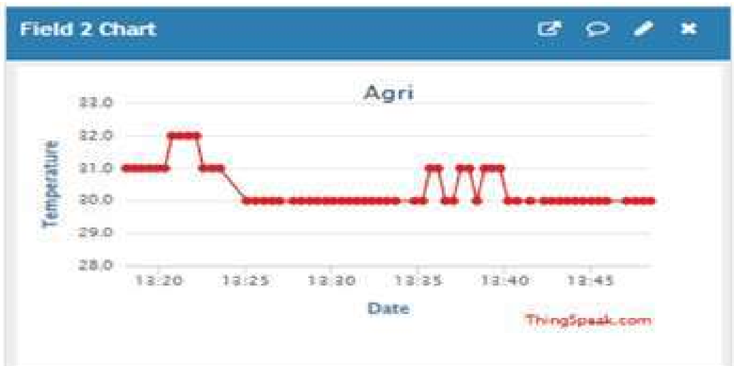

Figure 1.7 (b): Temperature data on ThingSpeak platform

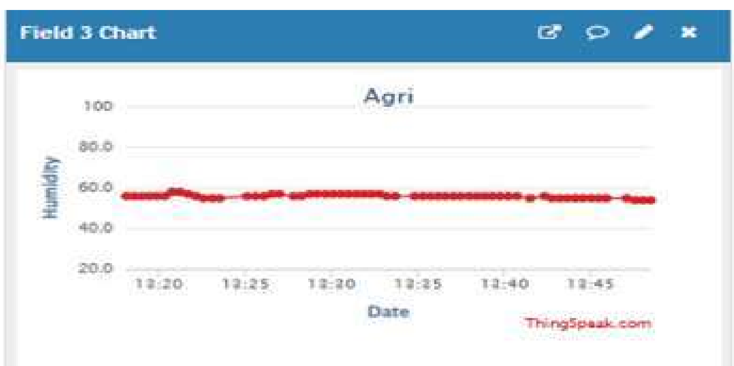

Figure 1.7(c): Humidity data on ThingSpeak platform

7. Conclusion

This IoT-based smart agriculture system integrates embedded systems, IoT, and cloud computing as a novel approach to enhance crop yield, improving food security and fostering sustainable agriculture. By leveraging modern technologies, the proposed systems enhance irrigation efficiency and reduce water consumption, providing farmers and agronomists a powerful tool for enhancing crop yield and environmental responsibility. The system developed using the ThingSpeak cloud platform to facilitate wireless communication between the device and the farm owner, to improving user interaction. Employing an ESP8266 microcontroller in combination with the DHT11, soil moisture, and water level sensors, the proposed system supports continuous and accurate data collection necessary for real-time irrigation management.