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Implementation of a Smart Farming Automation System

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Abstract
This study presents the design and implementation of a smart farming system that automates irrigation on farmland using an Arduino microcontroller, a Wi-Fi module, and various sensors. The system detects the soil moisture level and determines the optimal time to irrigate crops. It also monitors water levels to prevent overwatering, which can damage root systems. The main objectives of this project are: to develop a robust embedded system for real-time data collection from sensors deployed in agricultural fields, to design a user-friendly interface for farmers to remotely monitor and control farming processes, and to implement intelligent systems that automate irrigation based on sensor data. Traditional agricultural practices rely heavily on manual labor and often lack real-time monitoring capabilities, resulting in inefficiencies, resource wastage, and suboptimal yields. Furthermore, unpredictable weather and the demand for precise resource management pose significant challenges. Addressing these issues requires a technologically advanced and integrated approach. The methodology adopted follows Rapid Prototyping and Iterative Model and this involves quickly developing an initial prototype, testing its functionality, gathering feedback, and then iteratively improving the design until the final implementation is achieved. The system was developed and tested to ensure functionality aligned with design specifications. The prototype successfully demonstrated autonomous control of irrigation based on soil moisture readings. In conclusion, smart farming—also known as precision agriculture—leverages technologies such as embedded systems, artificial intelligence (AI), and big data analytics. Through the integration of sensors, GPS, and automated machinery, it enables efficient crop and livestock management while promoting sustainability by reducing waste and conserving water.

***Keywords**: Arduino; Moisture Sensor; Real-time Data Collection; Irrigation; Wi-Fi module.*

1. Introduction

Agriculture remains the backbone of many economies, providing food, raw materials, and employment to a significant proportion of the global population [1]. However, conventional farming methods face growing challenges including inefficient resource use, erratic weather patterns, and the need to increase productivity to meet rising food demand [2]. In response, embedded system technologies are increasingly integrated into agriculture to enhance field monitoring and automate essential tasks [3]. A major challenge in modern agriculture is providing timely information and assistance to farmers. Accessing reliable knowledge for sustainable farming remains difficult. [4] suggest that intelligent web applications can help disseminate useful information about sustainable practices.

Historically, agriculture has progressed through technological phases—from manual tools to mechanized systems [5]. The digital revolution, propelled by advances in computing and communication technologies, has introduced precision agriculture, emphasizing data-driven decision-making [6]. Embedded systems represent the next frontier, enabling extensive field data collection and transformation into actionable insights.

The adoption of embedded systems in agriculture is driven by goals of efficiency,

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sustainability, and yield improvement [7]. Conventional practices often lack the precision necessary to manage water, fertilizers, and pesticides effectively (Green et al., 2017). Embedded solutions enable real-time monitoring and resource control tailored to specific crop needs, contributing to environmental sustainability [9].

With the global population projected to reach 9.7 billion by 2050 [10], food production must increase significantly. Climate change adds further complexity by affecting crop cycles and yields. Previous studies have explored various embedded system applications in precision agriculture, smart irrigation, and crop monitoring [11], [12], [13]. However, few have offered comprehensive designs tailored for small to medium-scale farmers. This study aims to address this gap by developing an effective and scalable field monitoring and automation system.

2. Related Works

The Smart Farming Automation System demonstrated effective automation of irrigation based on real-time soil moisture readings. These results align with the goals of precision agriculture, which seeks to optimize resource usage and improve crop yields through technology integration.

Ayaz *et al*, [4] emphasized that IoT-based smart agriculture solutions improve monitoring accuracy and reduce human error in decision-making, which directly supports the automatic irrigation approach employed in this system. The sensor-based irrigation model implemented here is consistent with the findings of Kim *et al*, [14], who reported significant water savings when automated systems respond to soil moisture levels in real time.

Furthermore, Gupta &Singh [15] highlighted that embedded systems in agriculture allow for timely and data-driven irrigation decisions, resulting in enhanced productivity. The system's ability to reduce water wastage aligns with Rehman *et al* [3], who stressed the importance of smart irrigation in achieving sustainable water use under climate variability. Finally, Rehman *et al*. [3] noted that automation using microcontroller-based designs offers low-cost, scalable solutions for smallholder farmers. This supports the practical and affordable design of the Arduino-based system developed in this study. Overall, the results confirm that integrating sensor feedback with automated control systems significantly contributes to efficient, sustainable, and intelligent farming practices.

3. Materials and Methods

3.1 Design Methodology

The smart farming system was developed using the Rapid Prototyping and Iterative Model**,** which is the process that involves quickly developing an initial prototype, testing its functionality, gathering feedback, and then iteratively improving the design until the final implementation is achieved.

3.2 System Components

The design and construction involved two main parts namely the hardware and software part

- **i.** *Hardware*: Assembled on a Vero board and housed in a plastic casing.
- **ii.** *Software*: Written in C using the Arduino IDE compiler for the Arduino microcontroller.

3.3 Design Phases

- i. *Circuit Design*: this deals with the drawing of the circuit diagram and placing each of the components in its rightful place where it will be useful and allow for easy functioning of the proposed system.
- ii. *Simulation Design:* this deals with designing the system on a simulation software to make the code write-up easy for the designer and how the hardware part will be connected.
- iii. *Programming Design*: this deal with the design of the programming input that will be used to run the proposed system.
- iv. *Physical:* this is the translation of the circuit diagram, programming design into physical functional device.

3.2 *Major Components*

- i. *Soil Moisture Sensor* – Detects water content in soil.
- ii. *Arduino Uno* – Controls sensor inputs and actuator outputs.

iii. *Relay Module* – Switches the water pump using control signals.
iv. *DHT11 Sensor* – Measures temperature and humidity.
v. *Pump* – Delivers water from a reservoir to the field.
vi. *Jumper Wires* – Make electrical connections between modules.
vii. *OLED Display* – Visually presents real-time sensor readings.

3.5 Circuit and System Diagrams

Figures 1 to 3 illustrate the block diagram, circuit simulation, and system flowchart showing sensor connections, pump activation logic, and data display operations. This block diagaram of the smartbase farming automation system in Figure 1 shows how the components used in the system are incoporated with the arduino mcu.

Figure 2 illustrates how each component—including the DHT11 sensor, soil moisture sensor, water pump, and OLED screen—is interfaced with the microcontroller (Arduino Uno). The *DHT11 sensor* has three pins: the yellow (data) pin is connected to digital pin 2 on the Arduino, the red (VCC) pin is connected to the 5V power output, and the black (GND) pin is connected to the Arduino's ground (GND). The *soil moisture sensor* is connected as follows: the analog output pin (A0) of the sensor is connected to the A0 analog input on the Arduino. The sensor's GND pin is connected to the Arduino's GND, and the VCC pin is connected to the 5V power supply on the Arduino.

The *water pump* is interfaced through digital pin 4 on the Arduino. The negative (GND) wire of the pump is connected to the Arduino's ground, while the positive wire is connected to digital pin 4, which controls the pump based on soil moisture readings.

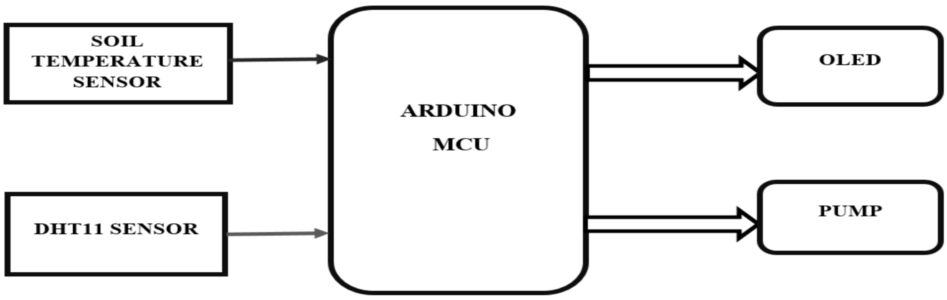

Figure 1 Smart based Agriculture Farming System Block Diagram

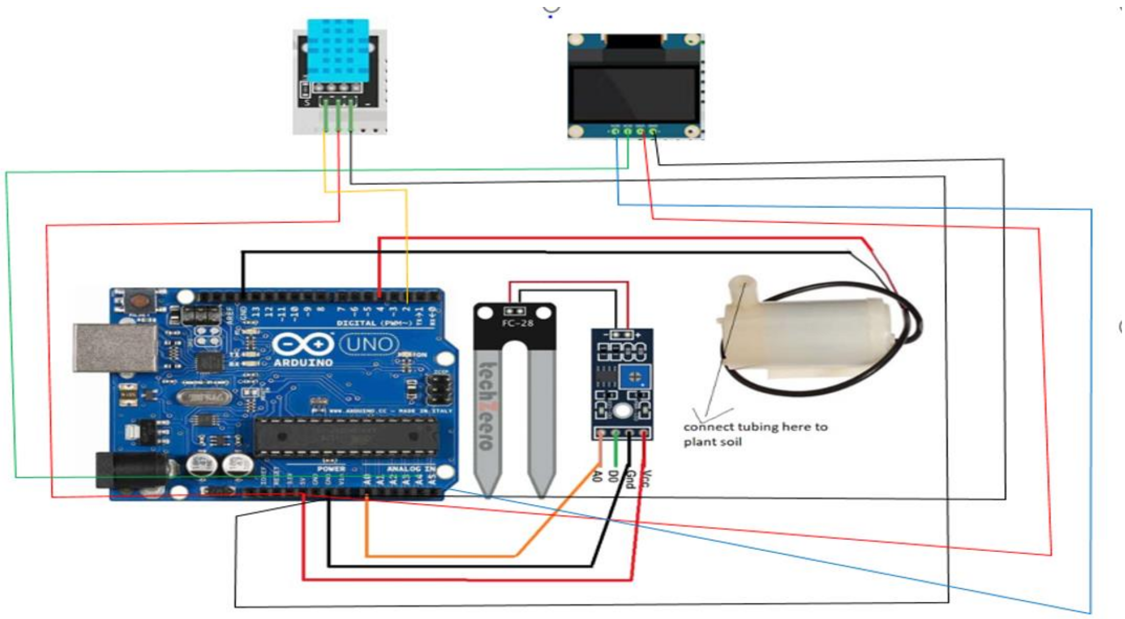

Figure 2: Smart Farming Control System Circuit Simulation Diagram

The *OLED display module* used in this project is based on the I²C communication protocol. It has four pins: VCC, GND, SDA, and SCL. The VCC pin is connected to the 5V power supply on the Arduino, and the GND pin is connected to the Arduino's ground. The SDA (Serial Data) pin is connected to the Arduino's A4 pin, while the SCL (Serial Clock) pin is connected to A5. These connections allow the Arduino to send display data to the OLED module using I²C communication.

Figure 3 shows how the flow chart diagram explained how the components of the smart irrigation system work from one to another; from the start process to the end stage.

4. Results and Discussion

4.1 System Description

The developed system integrates soil moisture and temperature/humidity sensors connected to an Arduino Uno microcontroller, which processes inputs and automates irrigation accordingly.

4.2 System Operation

Upon powering the system, the soil sensor detects moisture levels and sends the data to the microcontroller. If the moisture level is below the preset threshold, the microcontroller activates the water pump. Readings from the DHT11 and moisture sensors are continuously displayed on an OLED screen.

4.3 Code Functionality

The Arduino sketch includes libraries for the OLED display and DHT11 sensor. It initializes both modules and continually reads and displays real-time temperature, humidity, and soil moisture data. The pump is controlled based on the soil moisture value.

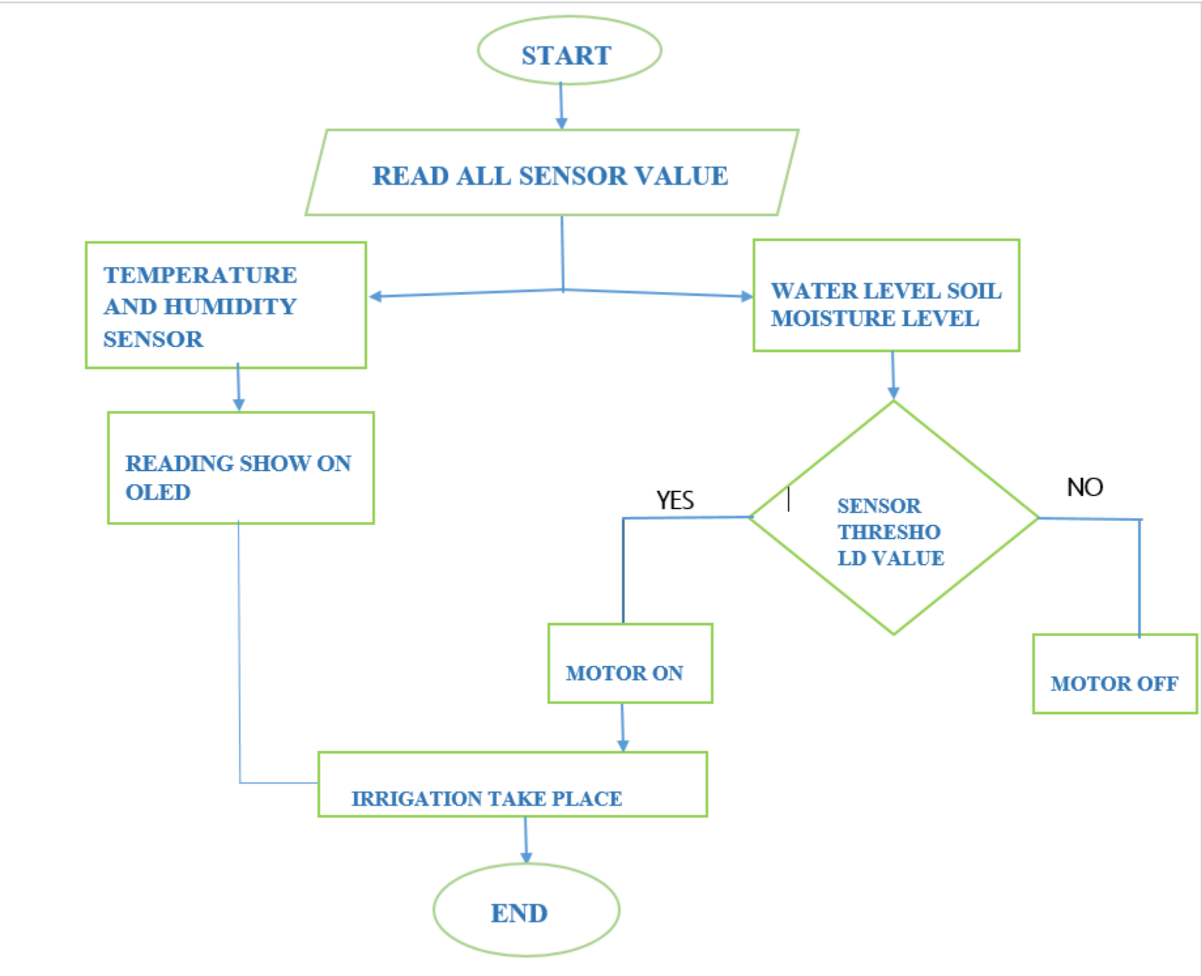

Figure 3: System Flowchart

Figures 5 to 8 demonstrate input/output cases, from idle state to active irrigation and data display.

Figure 4 shows the input stage of the irrigation system with the components (e.g. Soil sensor, Aduino mcu, Water pump and DHT11) and materials (e.g. Water, Sand, Plastic bowl 2x). The OLED screen displayed the soil sensor value, temperature value and humidity value.

Figure 5 shows the soil moisture sensor dipped into the soil to detect water content in the soil and also the water pump is fully submerged in water in a separate bowl.

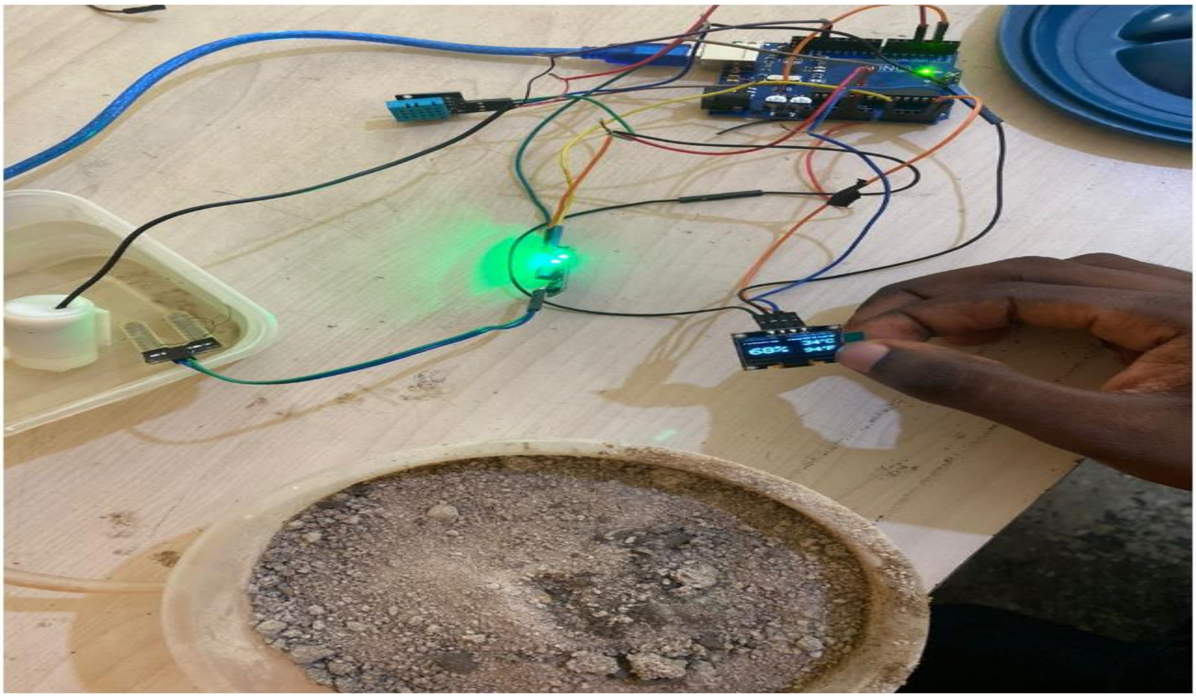

Figure 4 - case1: smart base farming in idle mode

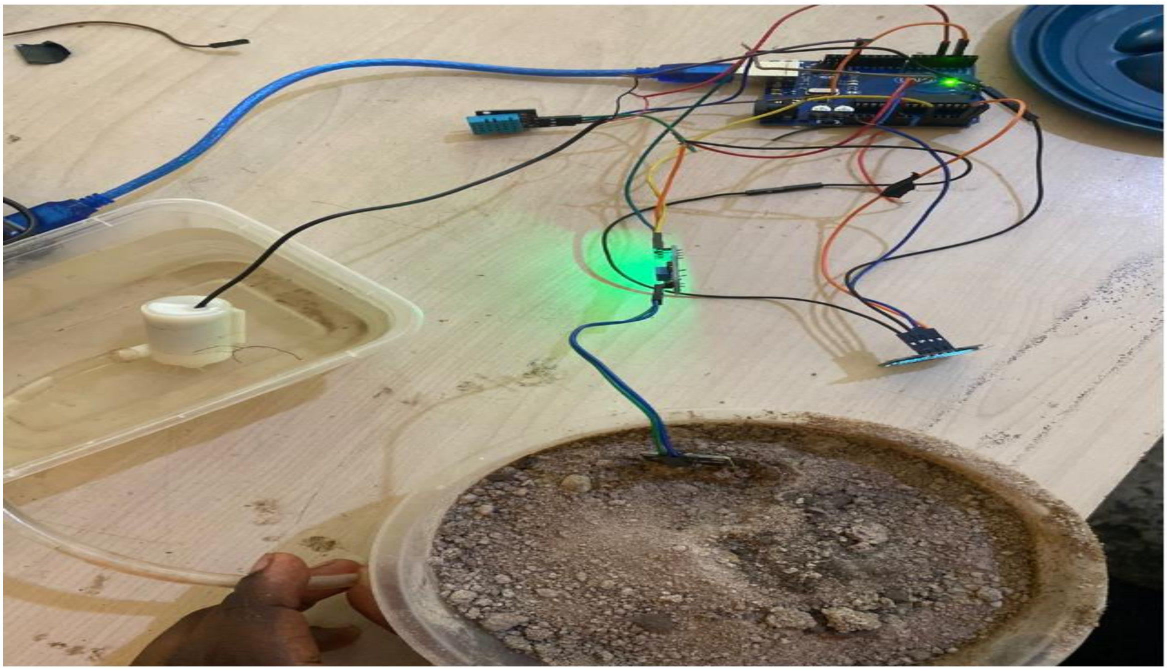
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Figure 5 case 2: Soil Moisture Sensor is Dipped in the Soil

Figure 6 shows how Pump turn ON automatically with an outlet pipe to supply water into the soil after been detected by the soil sensor, that is; there is low level of water in the soil.

Figure 7 shows how pump turn OFF automatically, while it has reach certain level of water needed in the soil; detected by the soil sensor.

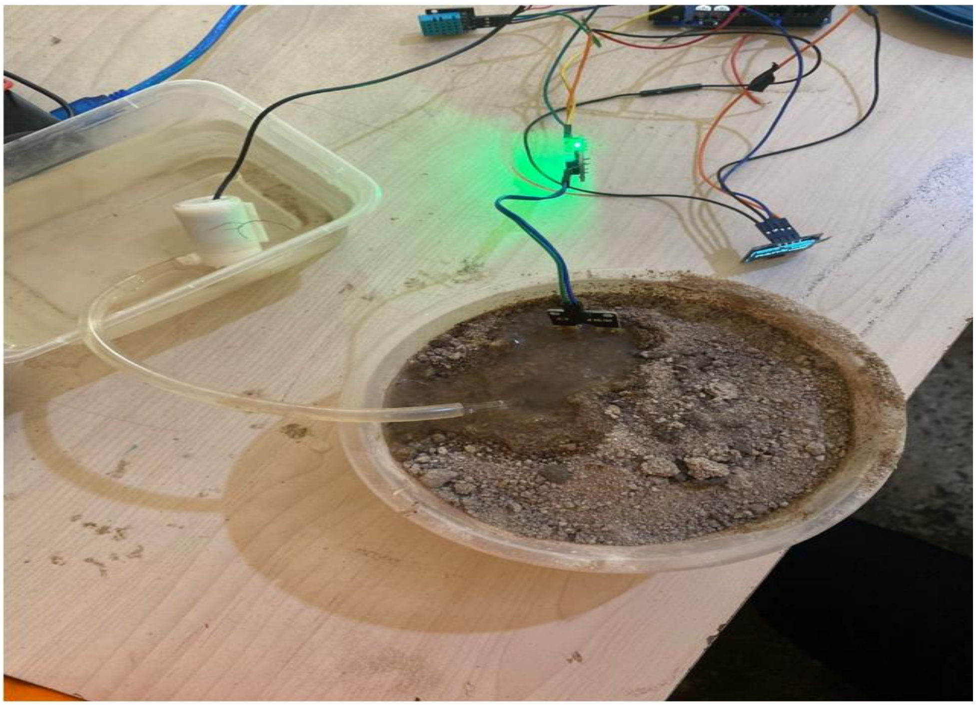

Figure 6 case3: Pump Turn ON Automatically

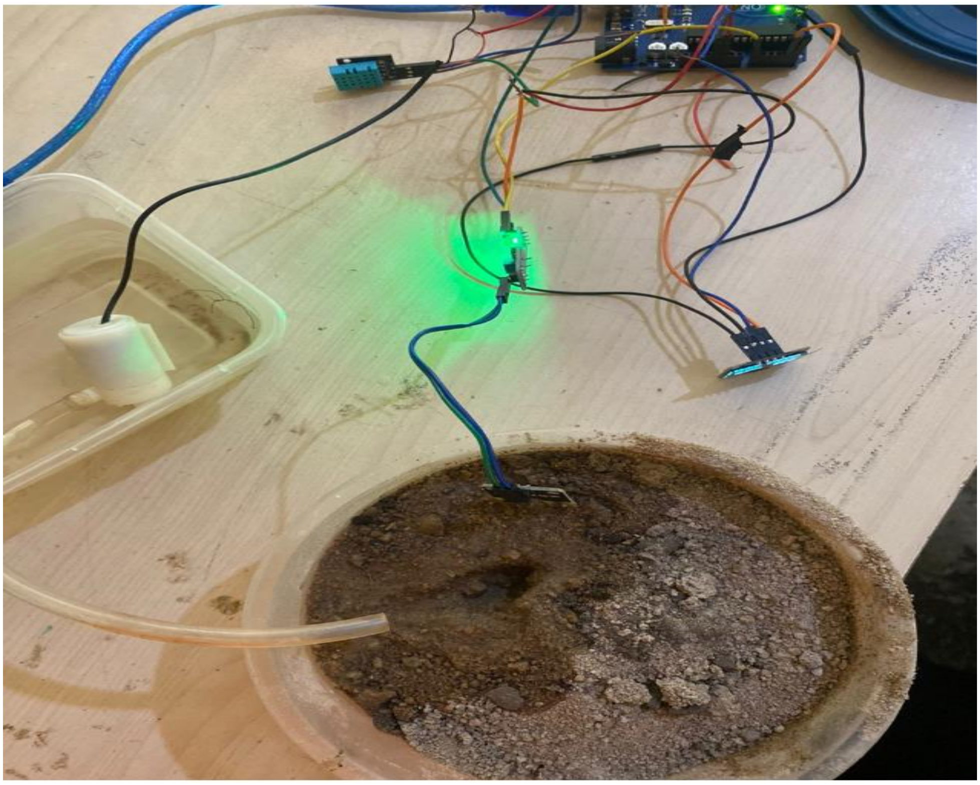

Figure 7 case4: Pump Turn OFF Automatically

Figure 8 shows where the entire component is enclosed in a case powered ON and shows the reading value of soil moisture, humidity and temperature.

5. System Evaluation

The Smart Farming Automation System was tested to verify its performance in monitoring environmental conditions and automating irrigation based on soil moisture levels.

5.1 Programming Test

The system code was compiled and tested using simulated data. Sensor values were accurately captured, and the OLED display correctly showed real-time temperature, humidity, and soil moisture readings.

5.2 System Test

The complete system was set up using a soil-filled container and a water reservoir. When powered, the system initialized and entered idle mode. The soil moisture sensor detected the water content and sent data to the microcontroller. When moisture was below the threshold, the pump activated automatically to irrigate the soil. Once the required level was reached, the pump turned off, confirming the automation logic worked as intended. All sensor readings were displayed on the OLED screen, validating the system's functional accuracy.

6. Conclusion

The Smart Farming Automation System developed in this study demonstrates the practical application of embedded systems in addressing critical challenges in agriculture. By integrating soil moisture and temperature/humidity sensors with an Arduino-based control unit, the system successfully automated irrigation in response to real-time field conditions. The evaluation confirmed that the system reduced water wastage, improved monitoring accuracy, and operated reliably under varying test conditions.

These outcomes are consistent with previous findings that emphasize the role of embedded systems and automation in achieving sustainable agriculture through efficient resource utilization. Importantly, the low-cost and scalable design of this system highlights its suitability for smallholder farmers, who often face resource and financial constraints.

As global food demand rises alongside climate variability, such affordable, technology-driven solutions will be vital in ensuring sustainable productivity. This work not only validates the effectiveness of sensor-based irrigation systems but also contributes to ongoing efforts to make precision agriculture accessible to farmers at all scales.

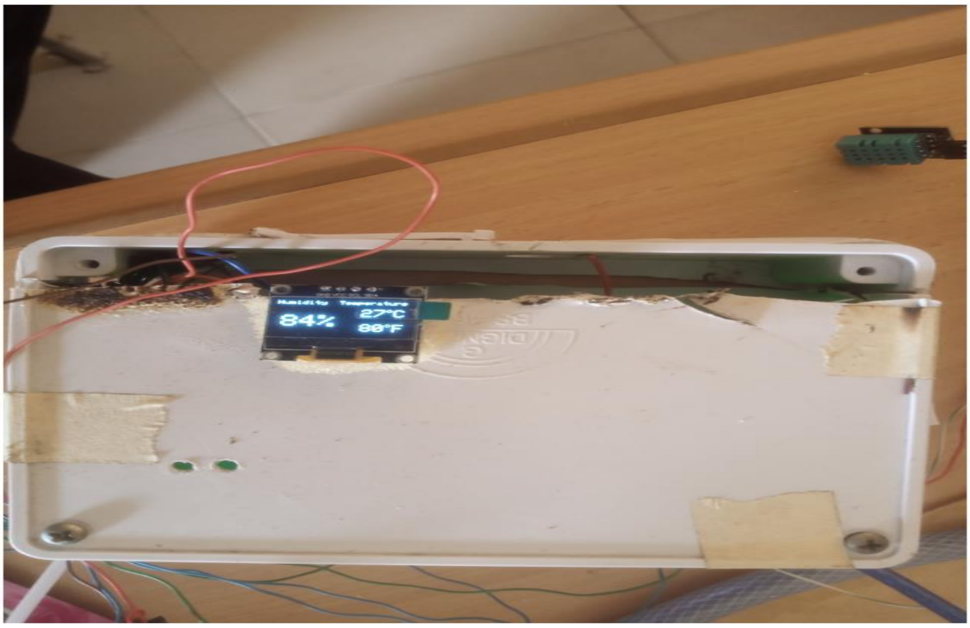

Figure 8: System Enclose in a Case

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