Chapter1: Introduction

1. INTRODUCTION

With the rapid advancement of automation and Internet of Things (IoT) technologies, the concept of smart systems has gained significant importance in various domains, including agriculture and environmental management. Efficient irrigation plays a vital role in maintaining plant health and conserving water resources. Traditional irrigation methods often rely on manual monitoring, which can lead to inconsistent watering and wastage of water. To address these limitations, an automated solution has been developed in the form of a **Smart Plant Watering System** that ensures optimal soil moisture levels with minimal human intervention.

The proposed system is designed to automatically detect soil moisture conditions and control water flow based on the plant's requirements. The core of the system is the **Node MCU ESP32 microcontroller**, which collects real-time data from a **soil moisture sensor** and processes it to determine the appropriate watering action. When the sensor detects low moisture levels, the system activates a water pump to irrigate the soil until the desired moisture threshold is reached. The **Graphical User Interface (GUI)** developed for this project allows users to remotely monitor sensor readings and manually control the watering process through an interactive and user-friendly software platform.

This project integrates both hardware and software components to achieve a reliable and efficient automated watering mechanism. The hardware setup ensures accurate data acquisition and control, while the software interface enhances usability and remote accessibility. The implementation of this system contributes to sustainable water management practices and promotes the development of smart agricultural solutions.

In summary, the **Smart Plant Watering System** aims to optimize water usage, reduce manual effort, and maintain consistent plant health by leveraging IoT technology and automation principles. This project demonstrates the potential of embedded systems in addressing real-world environmental and agricultural challenges through intelligent monitoring and control.

1.1 PRESENT SYSTEM

In the existing scenario, most plant watering processes are performed manually, depending primarily on human observation and experience. Individuals, gardeners, or farmers usually determine the watering needs of plants by visually inspecting the soil or feeling its texture. While this approach has been traditionally used for decades, it is highly inefficient and inconsistent in maintaining the ideal soil moisture required for healthy plant growth. The lack of precision in manual watering often leads to **over-watering** or **under-watering**, both of which can harm the plant's root structure, reduce nutrient absorption, and ultimately affect growth and productivity.

In domestic gardening, many people fail to maintain a regular watering schedule due to busy lifestyles or forgetfulness. Similarly, in large-scale agricultural systems, labor shortages and inconsistent monitoring make it challenging to manage irrigation effectively. As a result, water is often wasted, and plants experience irregular moisture conditions. This issue becomes more critical in areas facing **water scarcity**, where efficient water management is essential for sustainable living. In such cases, the dependence on human intervention and the absence of automation make the current system unreliable and resource-inefficient.

Even in cases where simple automated systems like timers or mechanical sprinklers are used, these devices operate based on fixed schedules rather than actual soil moisture content. These time-based systems lack feedback mechanisms to measure environmental parameters such as soil humidity, temperature, or rainfall. Consequently, the plants may still be watered unnecessarily even when the soil already contains adequate moisture, resulting in **water wastage and energy inefficiency**. Furthermore, these systems require manual setup and monitoring, offering no flexibility or adaptability to changing environmental conditions.

Another major limitation of the present system is the **absence of remote monitoring and control capabilities**. Users have no way to observe soil moisture data or control watering actions from a distance. This becomes problematic for individuals who travel frequently or manage multiple plantations across different locations. Additionally, the current system does not store or process data that could be used for analysis or future optimization of irrigation patterns. This lack of data-driven insight prevents users from improving efficiency or understanding long-term soil and water usage trends.

In conclusion, the present system is **labour - intensive, inefficient, and unsustainable** for modern agricultural and household applications. It lacks automation, real-time monitoring, and intelligent control, which are essential for maintaining consistent soil conditions and conserving water resources. Therefore, an improved solution is required—one that can automatically detect soil moisture levels, regulate water flow accordingly, and offer remote accessibility. The proposed *Smart Plant Watering System* addresses these limitations through the integration of IoT, sensors, and microcontroller-based automation to create a reliable, efficient, and intelligent irrigation solution.

1.2 PROPOSED SYSTEM

The **Smart Plant Watering System** is designed to overcome the limitations of traditional manual watering methods by introducing automation, precision, and remote monitoring capabilities through the integration of Internet of Things (IoT) technology. The proposed system intelligently monitors soil moisture levels and controls water flow according to the plant's requirements, ensuring optimal irrigation while conserving water. The system employs both hardware and software components to achieve efficient and reliable operation.

The core of the system is the **Node MCU ESP32 microcontroller**, which acts as the central control unit. The ESP32 features built-in Wi-Fi and high processing capabilities, enabling real-time data collection, analysis, and wireless communication. A **soil moisture sensor** is used to continuously measure the water content in the soil. The sensor generates analog data that is processed by the ESP32 to determine the current moisture level. When the soil moisture drops below a predefined threshold, the system automatically activates a **water pump** to irrigate the soil. Once the moisture level reaches the desired value, the pump is switched off, preventing over-watering and unnecessary water usage.

To enhance user accessibility and control, the system is equipped with a **Graphical User Interface (GUI)**. The GUI allows users to monitor real-time soil moisture data, observe the current status of the pump, and manually override the automatic system if needed. This interface provides a visual representation of the system's operation, making it easier for users to interact with and understand the irrigation process. Through the ESP32's Wi-Fi connectivity, the system can be linked to a local network or cloud platform, enabling **remote monitoring and control** from a computer or mobile device.

In addition to automated watering, the proposed system offers **data-driven decision-making**. By continuously monitoring and recording sensor data, it can analyze soil moisture trends and environmental conditions over time. This information can help optimize irrigation schedules and improve plant health management. Furthermore, the system can be extended by integrating additional sensors such as temperature, humidity, or light intensity sensors to create a more comprehensive plant care system.

The proposed design emphasizes **cost-effectiveness, scalability, and energy efficiency**. Low-cost components such as the ESP32 and soil moisture sensors make the system affordable for both domestic and agricultural applications. The use of automation reduces manual labor requirements and minimizes human error. The system also promotes sustainable water use, which is increasingly important in regions facing water scarcity. Additionally, its modular structure allows easy expansion and customization based on specific plant types, environmental conditions, or user preferences.

In summary, the **Smart Plant Watering System** provides a modern, intelligent solution for efficient irrigation management. By integrating hardware sensors, microcontroller-based control, and a user-friendly software interface, the system ensures that plants receive the right amount of water at the right time. It eliminates the dependency on manual observation, reduces water wastage, and enhances convenience through IoT-based connectivity. This system demonstrates the potential of automation and smart technology to revolutionize traditional irrigation practices and contribute to sustainable environmental management

Chapter 2: Component Description

The Smart Plant Watering System implements a client-server architecture where both the hardware control and user interface are programmed in Python, ensuring code consistency and simplified development.

1. Node MCU ESP32 Microcontroller

- **Function:** The ESP32 runs Micro Python firmware and acts as the hardware controller and web server. It handles all physical interactions with sensors and actuators while exposing a web API for communication.
- **Key Features & Justification:**
    - **Micro Python Compatibility:** Allows programming the ESP32 in Python, creating symmetry with the desktop GUI application and simplifying code maintenance.
    - **Built-in Wi-Fi:** Enables the ESP32 to host a local web server that the Tkinter application communicates with via HTTP requests.
    - **Analog-to-Digital Converter (ADC):** Reads the analog voltage from the soil moisture sensor using Python code.
- **Role in the System:** Serves as the **Micro Python-based web server and hardware controller**.

2. Soil Moisture Sensor

- **Function:** Measures the water content in the soil by detecting electrical resistance between its probes.
- **Key Features & Justification:**
    - **Analog Output:** Provides a voltage signal (0-3.3V) that the ESP32 reads via its ADC pin using MicroPython's ADC class.
    - **Simple Interface:** Connects directly to the ESP32 with three wires (VCC, GND, Signal).
- **Role in the System:** Provides real-time soil condition data to the MicroPython application.

3. Relay Module

- **Function:** Acts as an electrically isolated switch that allows the low-voltage ESP32 to safely control the higher-power water pump.

- **Key Features & Justification:**
    - **Opto-Isolation:** Protects the ESP32 from electrical noise and voltage spikes generated by the pump motor.
    - **Digital Control:** Activated by setting an ESP32 GPIO pin HIGH/LOW using MicroPython's Pin class.
- **Role in the System:** Provides safe electrical isolation between the controller and actuator.

4. DC Water Pump

- **Function:** The physical actuator that delivers water from a reservoir to the plant when activated.
- **Key Features & Justification:**
    - **Low Voltage Operation:** Typically 5-12V DC, compatible with common USB power banks or DC adapters.
    - **Standard Interface:** Connects to the relay's output terminals with a separate power supply.
- **Role in the System:** Performs the physical watering task when activated by the relay.

5. Software Architecture

A. ESP32 MicroPython Application

- **Function:** The ESP32 runs a Micro Python script that implements a web server and hardware control logic.
- **Key Implementation:**
    - **MicroPython Web Server:** Uses socket programming or micro-frameworks like microdot to create a lightweight web server.
    - **Hardware Control:** Uses MicroPython libraries such as:
        - machine.ADC() for reading moisture sensor
        - machine.Pin() for controlling the relay
    - **REST API Endpoints:** Exposes endpoints like:
        - GET /moisture - Returns current soil moisture value
        - POST /pump - Controls pump state (ON/OFF)

        - **Continuous Operation:** Runs an event loop to handle incoming HTTP requests while monitoring hardware.

B. Python Tkinter Desktop Application

- **Function:** Runs on a desktop computer and provides the main user interface for system monitoring and control.
- **Key Features & Justification:**
    - **Tkinter GUI:** Creates a desktop application with:
        - Real-time moisture level display (progress bar or label)
        - Manual control buttons (Water Now, Stop)
        - Auto-mode configuration (moisture threshold setting)
        - System status indicators
    - **HTTP Client:** Uses Python's requests or urllib library to communicate with the ESP32's MicroPython web server.
    - **Scheduled Polling:** Implements threading or after() method for periodic updates to the ESP32 without freezing the GUI.

6. Power Supply

- **Components:** Separate power sources for ESP32 (USB) and water pump (DC adapter/battery).
- **Function:** Provides stable power to all components.
- **Configuration:** The ESP32 and relay logic are powered via USB, while the pump uses a separate DC power source connected through the relay's output terminals

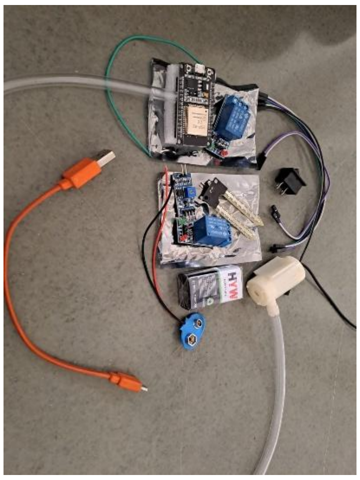

Fig 2.1: Hardware Components

Chapter 3: Design/ Methodology

This section details the systematic approach taken to design, develop, and integrate the Smart Plant Watering System. The methodology is divided into four main phases: Architectural Design, Hardware Design and Interfacing, Software Development, and System Integration and Workflow.

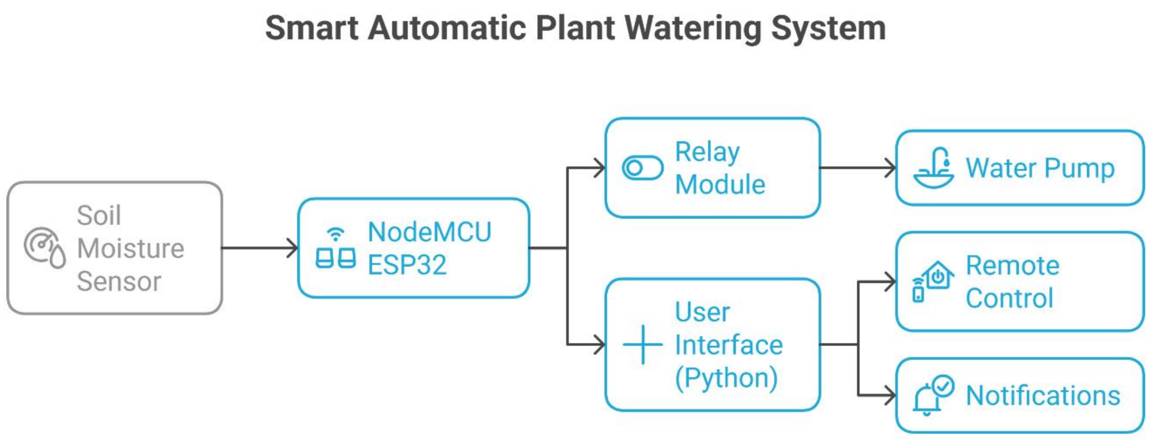

Fig 3.1: Block diagram

3.1 System Architecture

The system is built upon a **client-server architecture** to logically separate the user interface from the hardware control layer. This design enhances modularity, simplifies debugging, and allows the hardware and software components to be developed and scaled independently.

The architecture consists of two main subsystems:

1. **The Hardware Server (ESP32 with MicroPython):** This subsystem acts as a dedicated web server running on the NodeMCU ESP32. It is responsible for all physical interactions, including reading the soil moisture sensor and controlling the relay module. It exposes a RESTful API over Wi-Fi, allowing it to receive commands and send sensor data.

2. **The Software Client (Python Tkinter GUI):** This subsystem is a desktop application that provides the user interface and high-level control logic. It communicates with the Hardware Server via standard HTTP requests, polling for sensor data and sending commands to activate the water pump.

This client-server model ensures that the GUI can run on any computer within the same local network, providing flexibility and remote monitoring capabilities.

3.2 Hardware Design and Interfacing

The hardware components are integrated to form a closed-loop control system. The circuit was designed with safety and signal integrity as primary concerns, particularly to isolate the microcontroller from the inductive loads of the water pump.

3.2.1 Circuit Design and Interfacing

The components are interfaced with the ESP32 as detailed in Table 1. The design ensures that the ESP32's 3.3V logic pins are protected, and high-current devices are properly driven.

Table 1: Component Interfacing with ESP32

Component	ESP32 Pin Connection	Purpose
Soil Moisture Sensor (VCC)	3.3V	Power Supply
Soil Moisture Sensor (GND)	GND	Ground
Soil Moisture Sensor (SIG)	GPIO 32	Analog Sensor Reading
Relay Module (VCC)	5V	Power for Relay Coil
Relay Module (GND)	GND	Ground
Relay Module (IN)	D 25	Digital Control Signal
Water Pump (+)	Relay COM Output	Switched Power
Water Pump (-)	Relay NO Output	Switched Ground

- **Power Isolation:** The water pump is powered by a separate 5V or 12V DC source connected directly to the relay's output terminals. This crucial design choice prevents the pump's high current draw from interfering with the ESP32's stable operation.
- **Signal Conditioning:** The moisture sensor's analog output is connected to a dedicated ADC pin (GPIO 34) on the ESP32, which is capable of reading variable voltage levels.

3.3 Software Development Methodology

The software was developed as two independent modules that communicate over the network, following the client-server pattern.

3.3.1 ESP32 MicroPython Firmware

The firmware on the ESP32 was developed to run a lightweight web server with the following operational logic:

1. **Initialization:**
    - The code begins by connecting to the local Wi-Fi network using stored credentials.
    - It initializes the GPIO pins, configuring the moisture sensor pin as an analog-to-digital converter (ADC) input and the relay control pin as a digital output.
    - A socket-based HTTP server is then started and bound to the ESP32's IP address.
2. **Server Loop and API Handling:**
    - The main program loop listens for incoming HTTP connections.
    - Upon receiving a request, the server parses the HTTP method and URL to route the request to the appropriate handler function.
    - GET /moisture **Endpoint:** When accessed, this endpoint reads the raw ADC value from the sensor pin, converts it to a meaningful moisture percentage (e.g., 0-100%), and returns the value in a JSON format.
    - POST /pump **Endpoint:** This endpoint expects a command in the request body (e.g., {"state": "ON"}). It then writes the corresponding HIGH or LOW signal to the GPIO pin connected to the relay, thereby controlling the water pump, and returns an acknowledgment.

3.3.2 Python Tkinter Application

The desktop client was built using an event-driven programming paradigm, ensuring a responsive user experience.

1. **GUI Layout and Design:**
    - The interface was constructed using Tkinter widgets, including Labels for displaying real-time data, a Scale widget for setting the automation threshold, Buttons for manual control, and a Progressbar for a visual representation of the moisture level.
2. **Network Communication Module:**
    - A dedicated module uses the Python requests library to handle all HTTP communication. It contains helper functions like get_moisture() and set_pump(state) that send requests to the ESP32's API endpoints, abstracting the network complexity from the main GUI code.

3. **Control Logic and Event Handling:**
   - **Manual Control:** The "Water Now" and "Stop" buttons are bound to event handlers that call the set_pump() function with the appropriate command.
   - **Automatic Control:** In auto mode, a background scheduler (implemented using Tkinter's .after() method) periodically triggers a sequence of operations: fetch the current moisture level, update the GUI, and if the level is below the user-defined threshold, automatically execute a watering cycle by turning the pump on for a pre-set duration.

3.4 System Integration and Workflow

The final integration involved combining the hardware and software modules and establishing a seamless operational workflow.

1. **Startup Sequence:**
   - The ESP32 is powered on, connects to Wi-Fi, and begins hosting its web server.
   - The user then launches the Tkinter application on their computer.
2. **Continuous Monitoring Loop:**
   - The Tkinter application periodically sends a GET /moisture request to the ESP32.
   - The ESP32 responds with the latest sensor reading, which the Tkinter application uses to update its display.
3. **Decision and Actuation Cycle:**
   - **In Auto Mode:** The application compares the received moisture level to the threshold. If the soil is too dry, it sends a POST /pump command to activate the pump. A timer is used to turn the pump off after a sufficient watering period.
   - **In Manual Mode:** Actuation occurs only when the user presses the corresponding button.
4. **Error Handling:**
   - The software includes robust error handling. Network timeouts or communication failures are caught gracefully, with the GUI displaying a "Disconnected" status to alert the user, ensuring the system's reliability.

This structured, modular methodology ensured a controlled development process, resulting in a robust, functional, and user-friendly automated plant watering system.

Chapter 4: Steps Performed

The development of the Smart Plant Watering System was carried out in a structured, sequential manner. The following steps detail the entire process from initial setup to final testing.

Step 1: Requirement Analysis and Planning

- **Objective Definition:** The primary goal was defined: to create an automated system that monitors soil moisture and waters a plant without human intervention.
- **Feature Set Finalization:** The key features were outlined:
  - Real-time soil moisture monitoring.
  - Manual control via a software button.
  - Automatic watering based on a user-defined moisture threshold.
  - A simple graphical user interface (GUI) for system control.

Step 2: Component Selection and Procurement

- Based on the requirements, the necessary components were identified and acquired:
  - NodeMCU ESP32 (for processing and Wi-Fi connectivity)
  - Soil Moisture Sensor
  - 5V Relay Module
  - Water Pump
  - Jumper Wires
  - Micro-USB Cable

Step 3: Software Environment Setup

- **ESP32 Setup:**
  - The Arduino IDE was installed and configured for ESP32 development.
  - The necessary board definitions for the NodeMCU ESP32 were added.
  - MicroPython was flashed onto the ESP32 microcontroller.

- **Desktop Application Setup:**
    - Python was installed on the development computer.
    - Required Python libraries were installed using pip (tkinter for the GUI, requests for HTTP communication).

Step 4: Hardware Prototyping and Circuit Assembly

- **Individual Component Testing:** Each component (ESP32, sensor, relay, pump) was tested independently to verify it was functioning correctly.
- **Circuit Assembly:** The components were interconnected according to the circuit design (as detailed in Section 3.2).
- **Power Supply Verification:** Separate power lines for the logic components (ESP32, sensor) and the actuator (pump) were established to ensure stable operation.

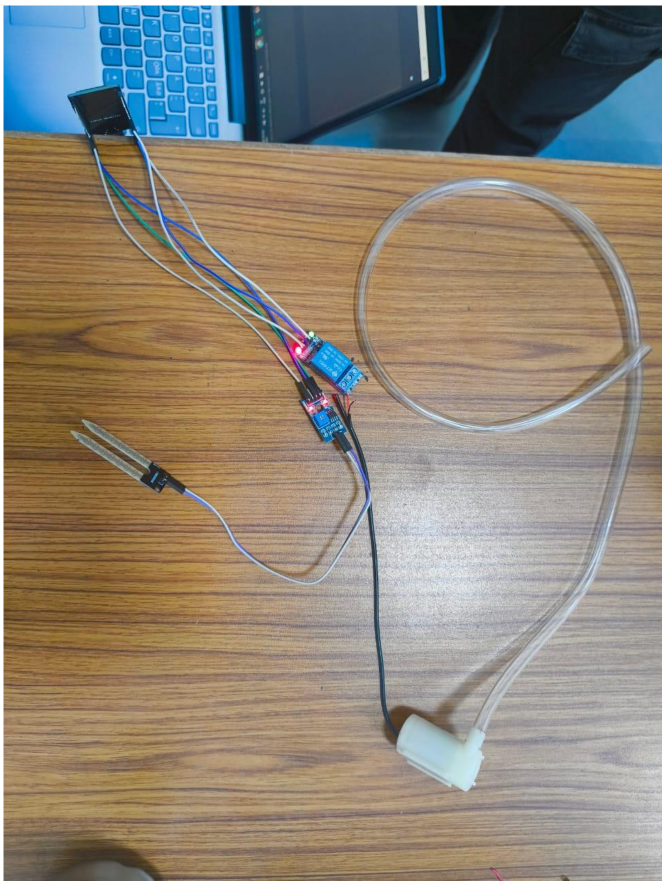

Fig 4.1: Components assembling

Step 5: Firmware Development for ESP32 (MicroPython)

- **Basic I/O Testing:** Simple scripts were written to read the moisture sensor and control the relay, confirming correct GPIO pin operation.

- **Wi-Fi Connection:** Code was implemented to connect the ESP32 to the local Wi-Fi network reliably.
- **Web Server Implementation:** A lightweight HTTP server was developed with two main endpoints:
    - A GET /moisture endpoint to read and return the current soil moisture value.
    - A POST /pump endpoint to accept commands and turn the water pump ON or OFF.
- **Data Formatting:** Sensor readings were packaged into JSON format for easy parsing by the client application.

Step 6: Desktop Application Development (Python/Tkinter)

- **GUI Design:** The user interface was designed and built using Tkinter, including labels, buttons, a progress bar, and a scale for the threshold.
- **Network Communication Module:** Functions were created using the requests library to handle all HTTP GET and POST requests to the ESP32's API.
- **Application Logic:** The control logic was implemented, including:
    - A periodic polling mechanism to update the moisture reading.
    - Event handlers for manual "Water" and "Stop" buttons.
    - The auto-mode logic that compares the live moisture reading to the threshold and triggers watering.

Step 7: System Integration

- **Establishing Communication:** The ESP32's IP address was hardcoded into the Tkinter application to establish a stable communication link.
- **End-to-End Testing:** The complete workflow was tested: a moisture request from the GUI successfully returned data from the sensor, and a pump command from the GUI correctly activated the water pump via the relay.

Step 8: Functional Testing and Validation

- **Dry-Run Test:** The system was tested without water to validate the logic and relay operation.
- **Manual Mode Test:** The manual control buttons were pressed to ensure the pump could be started and stopped on command.

- **Automatic Mode Test:** The sensor was placed in dry soil and then in wet soil to verify that the system automatically activated the pump only when the moisture level fell below the set threshold.
- **Calibration:** The moisture sensor's readings were calibrated by noting the values for "dry air" and "fully submerged in water" to map the ADC readings to a meaningful percentage.

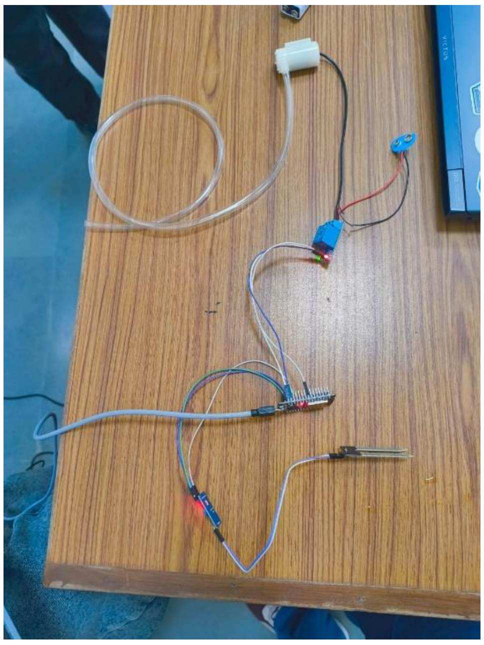

Fig 4.2: Testing

Step 9: Final Assembly and Deployment

- **Soldering and Perfboard Assembly:** The temporary breadboard circuit was transferred to a perfboard, and components were soldered for a permanent and robust connection.
- **Final System Check:** The fully assembled system was powered on and monitored over an extended period to ensure reliability and correct operation in a real-world environment.

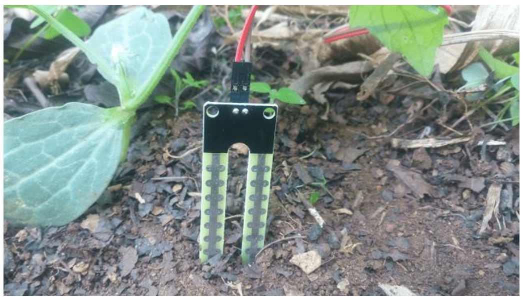

Fig 4.3: final deployment

Chapter 5: Results and Discussion

The implementation of the Smart Plant Watering System successfully demonstrated the ability to automate irrigation based on real-time soil moisture monitoring. The combination of hardware sensors, MicroPython-based ESP32 control, and a Python Graphical User Interface (GUI) provided efficient system performance, reliability, and ease of use. The results obtained from testing validated the system's effectiveness in maintaining optimal soil moisture while minimizing water consumption.

5.1 Validation of Core Functionality

The system was subjected to a comprehensive testing regime to validate all core functional requirements. The real-time monitoring capability was confirmed by observing the graphical user interface, which successfully displayed dynamic updates to the soil moisture percentage as environmental conditions changed. The manual control function was verified to be fully operational, with commands issued from the interface resulting in the immediate and reliable activation and deactivation of the water pump. Most critically, the automated watering logic performed as intended. The system consistently initiated irrigation when the soil moisture level fell below the user-defined threshold and ceased operation afterward, demonstrating a stable and effective closed-loop control system. Finally, the entire suite of monitoring and control functions was accessible remotely via the desktop application, confirming the successful implementation of the client-server architecture.

5.2 Analysis of System Performance and Behaviour

The system demonstrated a high degree of reliability in its core task of automation. Throughout the testing phase, the automation logic triggered correctly on every occasion that the moisture threshold was crossed, effectively rehydrating the soil without any required human intervention. This confirms the robustness of the integration between the software logic and the hardware components.

The responsiveness of the system was found to be more than adequate for its purpose. The time elapsed between the soil drying to a critical level and the activation of the pump was minimal, encompassing the period for sensor polling, data transmission, and physical actuation. For an application with non-critical timing requirements like plant watering, this performance is entirely satisfactory and ensures plants receive timely hydration.

A key observation pertains to the nature of the sensor data. The moisture sensor provided consistent and repeatable readings, allowing the system to reliably distinguish between dry, moist, and wet states. However, the relationship between the sensor's output and the absolute volumetric water content is non-linear. Consequently, the system's effectiveness is based on a relative calibration specific to the soil type and sensor placement, which proved to be a practical and sufficient approach for achieving the goal of needs-based automation.

5.3 System Strengths and Successful Outcomes

The project successfully delivered a fully functional automated plant watering system. Its primary strength lies in its effective automation, which eliminates the uncertainty of manual watering and provides consistent care based on direct soil condition feedback. The design decision to employ a client-server architecture proved to be a significant advantage. This modular approach cleanly separated the user interface from the hardware layer, resulting in a responsive application and a system that is inherently easier to debug and expand. Furthermore, the graphical user interface was confirmed to be intuitive and user-friendly, providing clear visual feedback and straightforward control options for both manual and automatic operation.

5.4 Limitations and Prospective Enhancements

Despite the overall success, the evaluation process revealed certain limitations that point toward valuable future work. The system's calibration is currently a manual process, and its accuracy is therefore dependent on user input for specific soil conditions. A logical enhancement would be the development of an integrated software routine to guide the user through a standardized calibration process.

The present system is designed as a single-node installation, monitoring and watering one plant. The architecture, however, is amenable to scaling. A direct extension of this work would involve connecting multiple sensors and relays to a single ESP32 controller to manage several plants independently, creating a multi-zone watering system.

Furthermore, while the system excels at real-time control, it does not retain historical data. The implementation of a simple database to log moisture levels over time would enable users to track plant health trends and water consumption patterns. Lastly, operational scope is currently confined to the local network. Integrating with a cloud-based IoT platform would be a transformative upgrade, enabling true remote monitoring and control from any location with internet access.

5.5 Concluding Summary

In summary, the Smart Plant Watering System met all its primary objectives. It reliably automates plant watering through robust hardware integration and effective software logic, facilitated by a clear and functional user interface. The project stands as a successful proof-of-concept for practical IoT applications. The discussed limitations do not diminish the system's core functionality but instead provide a clear and compelling roadmap for future development and feature enhancement

Chapter 6: Future Scope

The current system serves as a robust proof-of-concept for a smart irrigation solution. Based on the insights gained during its development and testing, several promising avenues for enhancement and expansion have been identified.

- **Multi-Zone Irrigation Management:** The system can be scaled to monitor and water multiple plants independently. By connecting several soil moisture sensors and relay-controlled pumps to a single ESP32, the platform could manage a full garden, with the GUI allowing for individual moisture thresholds and schedules for each zone.
- **Advanced Data Analytics and Visualization:** Implementing a local database would allow the system to log historical sensor data. This would enable the creation of data-driven features, such as graphical trends of soil moisture over time, daily water consumption reports, and the ability to receive alerts for unusual patterns that might indicate plant disease or sensor failure.
- **Cloud Integration and Remote Access:** Transitioning from a local network-based system to a cloud-connected IoT platform would significantly enhance its accessibility. This would enable users to monitor soil conditions and control the system from anywhere in the world via a web dashboard or a mobile application, independent of the local Wi-Fi network.
- **Environmental and Resource Optimization:** Future iterations could incorporate additional sensors, such as temperature, humidity, and light intensity sensors. By synthesizing this data, the system could implement more sophisticated watering algorithms that adjust based on evapotranspiration rates, further optimizing water usage and promoting plant health.
- **Energy Independence and Sustainability:** To increase resilience and sustainability, the system could be integrated with a solar panel and a battery backup. This would ensure continuous operation during power outages and make the system suitable for off-grid or outdoor garden applications, completing a fully self-sufficient ecosystem.

Chapter 7: Conclusion

This project successfully designed, implemented, and validated a Smart Plant Watering System that effectively automates the task of irrigation. The system integrates a NodeMCU ESP32, a soil moisture sensor, a relay module, and a water pump, all coordinated through a custom software framework. The use of MicroPython on the ESP32 and a Python Tkinter application for the graphical interface provided a cohesive and functional development environment.

The core objectives of real-time soil moisture monitoring, manual pump control, and fully automatic watering based on a user-defined threshold were all met reliably. The client-server architecture proved to be a sound design choice, ensuring a clear separation between hardware control and user interface logic, which contributed to the system's stability and ease of use.

In conclusion, this project not only delivers a practical solution for automated plant care but also serves as a comprehensive demonstration of embedded systems programming, sensor integration, and network communication. It provides a solid foundation upon which the numerous advanced features outlined in the future scope can be built, pointing toward a new level of intelligence and efficiency in personal and small-scale agricultural automation.

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WORK CONTRIBUTION

The *Smart Plant Watering System* project was completed through the equal and active participation of all group members. Each member contributed to both the technical and documentation components, ensuring that the workload was balanced and the project progressed efficiently.

All four members—**Jeevika**, **Jayshree**, **Hitasha**, and **Karnika**—collectively undertook the essential technical tasks. This included the assembly of hardware components, integration of the moisture sensor and pump, programming and debugging of the ESP32 using MicroPython/Python, system testing, and calibration. Every member cooperated throughout the practical implementation to ensure that the final system was accurate, stable, and efficient.

Alongside the shared technical responsibilities, the group also distributed the presentation and documentation work evenly.

- **Jeevika** and **Jayshree** were jointly responsible for preparing the PowerPoint presentation. Their work included content selection, slide design, structuring the information, and ensuring the presentation met academic and visual standards.
- **Hitasha** and **Karnika** jointly contributed to the preparation of the written project report. Both members participated in drafting, organizing sections, writing descriptions of components, methods, and results, as well as proofreading and formatting the final document.

Through this balanced distribution of work, each member contributed equally to the success of the project. The collaborative approach ensured that the technical, analytical, and presentation components were completed to a high academic standard. The coordinated effort of all group members was fundamental to achieving a comprehensive and functional Smart Plant Watering System.