ECE 445

SENIOR DESIGN LABORATORY

FINAL REPORT

A Remote Environment Recording System With Online Access Portals

Team #17

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Abstract

This project details the design, implementation, and testing of a Remote Environment Recording System with Online Access Portals, aimed at enhancing agricultural monitoring. The system integrates multi-depth soil temperature and humidity sensors, and an automated rotating camera for site surveillance and soil surface imaging. Key functionalities include solar-powered autonomous operation for continuous data logging, wireless data transmission via cellular network, and a web-based portal for data visualization and analysis. The online portal, built with Flask and SQLite, provides authenticated access to real-time and historical data, dynamic charts, and a soil surface flatness estimation model. The system successfully demonstrated its core capabilities, including accurate sensor readings, stable power regulation, and reliable data display, providing a functional prototype for environmental research and agricultural management.

Contents

1 Introduction **1**
1.1 Problem and Purpose . . . 1
1.2 Functionality . . . 1
1.2.1 Benefits . . . 2
1.2.2 Features . . . 2
1.3 Subsystem Overview . . . 2
1.3.1 Changes during the semester . . . 2
1.3.2 Power Supply . . . 3
1.3.3 Data Collect . . . 3
1.3.4 Online Portal . . . 4
1.4 Performance requirements . . . 4

2 Design **5**
2.1 Power Supply . . . 5
2.1.1 Design procedure . . . 5
2.1.2 Design details . . . 5
2.1.3 Diagrams and Schematics . . . 6
2.2 Data Collect . . . 6
2.2.1 Design procedure . . . 6
2.2.2 Design details . . . 7
2.2.3 Diagrams and Schematics . . . 10
2.3 Online Portal . . . 14
2.3.1 Design procedure . . . 14
2.3.2 Design details . . . 14
2.3.3 Diagrams and Schematics . . . 15
2.4 Design Alternatives . . . 17
2.4.1 Alternatives of Power Supply . . . 17
2.4.2 Alternatives of Data Collect . . . 18
2.4.3 Alternatives of Online Portal . . . 18

3 Requirements and Verification **20**
3.1 Completeness of Requirements . . . 20
3.2 Verification Procedures . . . 21
3.3 Quantitative Results . . . 23

4 Cost Analysis **25**

5 Schedule **26**

6 Conclusion **28**
6.1 Accomplishments . . . 28
6.2 Uncertainties . . . 28
6.3 Future Work . . . 31

6.4 Ethics and Safety Consideration 31
6.4.1 Privacy Protection 31
6.4.2 Data Transparency 31
6.4.3 Sustainable Practices 31
6.4.4 Risk Disclosure 32
6.4.5 Technical Reliability 32
6.4.6 Conflict of Interest Avoidance 32
6.4.7 Inclusive Design 32
6.4.8 Team Accountability 32
6.4.9 Regulatory Adherence 32
6.4.10 Electrical Safety 32
6.4.11 Mechanical Safety 32
6.4.12 Lab Safety 33

References **34**

Appendix A Diagrams **35**

1 Introduction

1.1 Problem and Purpose

This project aims to develop a Remote Environment Recording System with Online Access Portals to enhance agricultural monitoring. Our system will integrate real-time soil condition measurement, wireless data transmission, solar-powered operation, and a web-based data visualization platform to provide users with a comprehensive and sustainable monitoring solution. By improving accessibility to critical environmental data and mirroring the physical environment in a digital space, this system can support both research and practical agricultural management.

Soil conditions, including temperature and humidity, play a crucial role in plant growth [1]. Inappropriate environmental factors are harmful to agriculture. For instance, unsuitable temperatures inhibit plant growth and reduce cell viability; Unsuitable humidity affects root growth and leads to malnutrition[2]. Therefore, for a plant production site, it is essential to check the condition of the soil. While existing remote monitoring platforms have already provided some solutions, they often fail to adapt to diverse environmental conditions due to hardware limitations and usually depend on non-renewable power sources. Additionally, they provide only static measurements rather than an interactive digital representation and analysis of environmental changes [3]. Therefore, we want to optimize the versatility of physical detection equipment and build a remote monitoring platform with digital twin modeling.

1.2 Functionality

We decided to focus on the local soil database to monitor the variation of space environments and build environment recording systems. Functions mainly consist of three parts: collecting information on the humidity, temperature, and flatness of soil; setting up a camera to supervise in real time; uploading all the data to the website platform; and visualizing it. Also, we use the camera to make a soil model of our experimental field and set this function on our online portal to help users better observe the soil flatness.

For better and more comprehensive detection of soil humidity and temperature, we are going to test soil at various depths separately. Set equal depth spacing can make the change of test data versus depth more intuitive while showing us the humidity and temperature in certain circumstances. In addition, the flat condition of the soil has also been taken into account. Considering that in some remote areas, it is hard to power these devices, and batteries may cause more degradation and environmental pollution, we will use solar power to supply all the facilities during this procedure.

In addition to the measures mentioned above, we are willing to set up a camera to supervise the test site in real time. The camera should upload the real-time picture to the website to help the experimenters have a basic command of the field. Also, industrial production may help the controller decide whether the field needs to be irrigated.

Beyond that, we will make an online access portal and upload all the information we test on the website. This website can help us compare the change of these data versus time and give the users a clear tendency of change of the soil and environment data to help them make better decisions. Moreover, we will create a digital twin model that continuously updates environmental conditions, which allows users to visualize and analyze soil conditions interactively.

1.2.1 Benefits

The system enables remote and real-time soil and environmental monitoring for farmers and researchers. Also, it can improve decision-making for irrigation and crop management through predictive insights from the digital twin. Besides that, the system can provide a sustainable and low-maintenance monitoring solution through solar power.

1.2.2 Features

The features of our systems are: Self-sustained power using solar energy, eliminating external power dependency and multi-depth sensing, offering more accurate insights into soil conditions. Also, it can achieve real-time camera feed, enhancing situational awareness and Wireless data transmission, reducing the need for physical access. Besides that, our system has a user-friendly web portal and visualization, making data easily accessible and interpretable with digital twin modeling, allowing historical trend analysis and predictive modeling, and a Soil modeling model, reflecting the undulations of the soil on the online portal.

1.3 Subsystem Overview

1.3.1 Changes during the semester

Our project underwent several changes during the semester, which are also reflected in our block diagram.

In figure 1, the first change is the refinement of the power supply module. We added more parameters, which are important for analyzing the stability and battery life.

The second change is the alteration of the function of the PCB in the camera module. Originally, it was planned to remotely control the camera. Later, we preferred that using the camera to assist in soil surface modeling was more important and thus eliminated this function.

The third change is the addition of the soil surface modeling function in the visualization module, which is precisely the important new function mentioned above.

The fourth change is not shown in the figure **??**. Regarding the installation of the camera, we decided to use a modified clothes-drying rack combined with a rotating system to enable the camera to serve both monitoring and soil surface modeling functions.

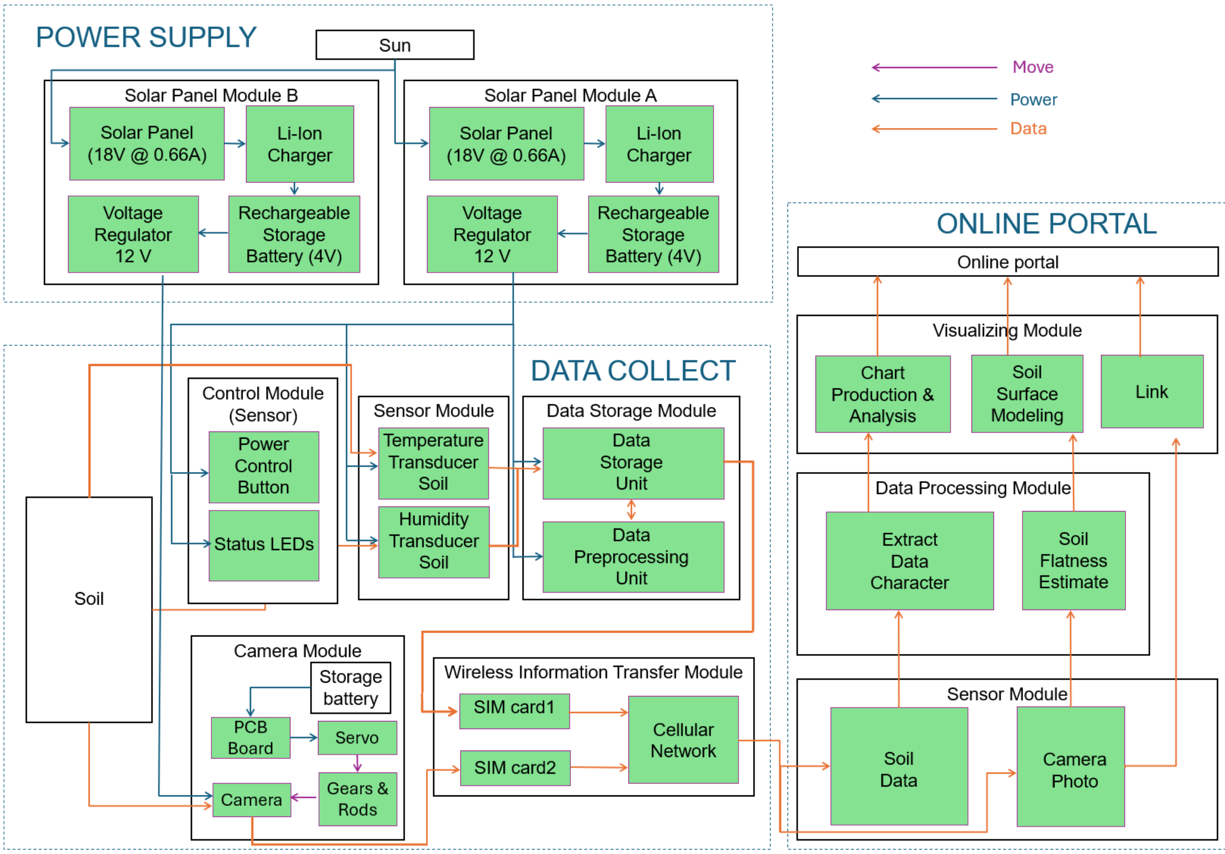


Figure 1: Block Diagram for System Overview

1.3.2 Power Supply

The power supply subsystem contains 2 independent solar panel modules. Solar panel module A is set for powering the soil sensors, and solar panel module B is set for powering the camera. The function of this part is to convert solar energy to electrical energy, and after achieving this goal, this part will supply the power for the data-collecting module.

1.3.3 Data Collect

The Data Collect module contains 5 modules: control module, sensor module, data storage module, camera module, and wireless information transfer module. The sensors module has 5 sets of sensors and in each set of sensors, there are a temperature transducer and a humidity transducer. The sensors module can send the data to the data storage module every 15 minutes. The camera module has a Printed Circuit Board (PCB), a motor, and a camera. We use the PCB board to control the behavior of the camera and the camera can work for soil modeling and the supervision of the experimental field. The data storage module can store the data from the sensors and send the data to the wireless transfer module every 15 minutes. The wireless transfer module can upload all the data the sensors collect to the online portal every hour.

1.3.4 Online Portal

The Online Portal subsystem serves as the primary interface for data storage, visualization, and analysis. It contains 3 modules: the sensor module, the data processing module, and the visualizing module. The data is transferred from the Wireless Information Transfer Module of the Data Collect Subsystem. This subsystem processes raw data into meaningful information, presenting it to the user through various graphical and analytical tools. In our online portal, the user can see the graphs sent by the camera in real-time and take screenshots for soil modeling. In addition, the user can visit the soil modeling module and the data visualization part to have a further understanding of the experiment field.

1.4 Performance requirements

- The system must sample and record environmental data every 15 minutes and upload data every hour, including soil temperature and humidity readings from five different depths(1cm, 3cm, 5cm, 10cm, 15cm).
- The camera must be able to achieve two functions: provide photos when the camera is at 0 degrees and 180 degrees.
- The web portal should provide access to data from the sensor and camera, with visualization and modeling.
- The result of soil modeling should correctly display the soil surface.
- The system should be able to run normally on solar energy through a 10W × 2 solar panel, ensuring continuous operation under variable weather conditions.

2 Design

2.1 Power Supply

2.1.1 Design procedure

For the power supply subsystem, we have 2 core modules: solar panel modules A and B. Both solar panel modules have a solar panel, Li-ion charge, rechargeable storage battery, and voltage regulator.

Solar Panel Module A is responsible for powering the sensors. The sensors draw 12 mA during measurement, 0.13 mA in sleep mode, and 100–800 mA when transmitting. The rechargeable storage battery provides 4 V, which the regulator boosts to the sensors' required 12 V operating voltage. The panel's peak output is

$$P = 18\,\mathrm{V} \times 0.66\,\mathrm{A} = 12\,\mathrm{W}.$$

The daily energy consumption is

$$E_{\mathrm{daily}} < \frac{1}{30}\big(0.8\,\mathrm{A} \times 12\,\mathrm{V}\big) \times 24\,\mathrm{h} \;+\; \frac{29}{30}\big(0.13 \times 10^{-3}\,\mathrm{A} \times 12\,\mathrm{V}\big) \times 24\,\mathrm{h} \approx 7.68\,\mathrm{Wh}.$$

Solar Panel Module B powers the camera, which draws a peak current of 0.58 A. In active use over the 4G network, the camera consumes 1.85 W, dropping to just 80 mW on standby. We plan to operate the camera for no more than eight hours per day on average. The module's rechargeable 4 V battery pack is stepped up to the camera's required 12 V by a high-efficiency boost regulator.

The panel's peak output is

$$P = 18\,\mathrm{V} \times 0.66\,\mathrm{A} = 12\,\mathrm{W}.$$

The daily energy consumption is

$$E \approx 1.85\,\mathrm{W} \times 8\,\mathrm{h} + 80\,\mathrm{mW} \times 16\,\mathrm{h} = 16.08\,\mathrm{Wh}$$

To guard against extended periods of rain, the camera module is equipped with its backup battery and can be charged at 12 V × 2.66 A (32 W). Zhejiang (approximately $30°$N) still enjoys sufficient solar irradiance even during the least-sunny winter months (Zhejiang has 10 hours between sunrise and sunset on Dec. 22), so the available radiation easily covers this load.

2.1.2 Design details

Solar Panel Module A: Module A uses an 18 V/0.66 A solar panel feeding a Li-ion charger that conditions and stores energy in a two-cell (4 V) battery pack. A high-efficiency boost regulator then steps the 4V battery output up to a stable 12V rail, which supplies the sensor's current and voltage requirement.

Solar Panel Module B: Module B uses an 18 V/0.66 A solar panel feeding a Li-ion charger that conditions and stores energy in a two-cell (4 V) battery pack. A high-efficiency boost regulator then steps the 4V battery output up to a stable 12V rail, which supplies the camera's 0.58 A operating current.

2.1.3 Diagrams and Schematics

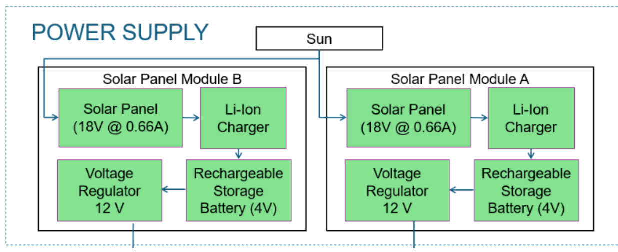


Figure 2: The Schematic of Power Supply Subsystem

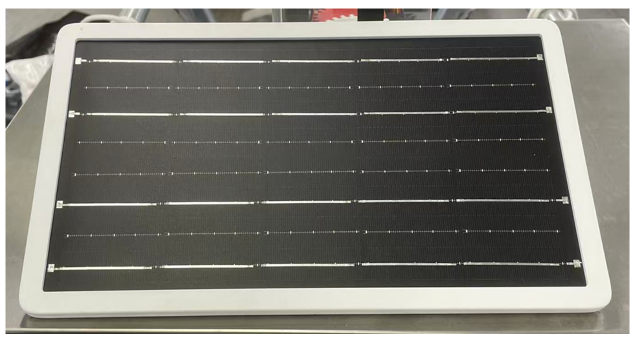


Figure 3: The Photo of Solar Panel

Figure 2 is a schematic diagram of the power supply subsystem. The whole subsystem results in an integrated "light - storage - release" power supply system with dual independent paths. It can fully utilize solar energy and, in cloudy or rainy conditions, rely on batteries to continuously provide stable power to the key components of the system. The figure 3 is the solar panel product we used.

2.2 Data Collect

2.2.1 Design procedure

In the data collection system, we have two core components: temperature and humidity sensors and a camera.
For temperature measurement, several Negative Temperature Coefficient (NTC) thermistors were used, while for humidity measurement, several Frequency Domain Reflectometry (FDR) capacitive sensors were used. The collected data is processed by an MCU and then communicated with a server via a SIM card to transfer the data. This is a mature and easy method, so we adopt it directly.

The resistance of an NTC thermistor will change when the temperature changes. It has an equation that.

$$\frac{1}{T} = A + B\ln(R) + C(\ln(R))^3 \tag{1}$$

Where T is the temperature of the soil, R is the resistance of the thermistor, A, B, C are Steinhart-Hart parameters, three dimensionless parameters for fixing.
The humidity of the soil can be calculated by the capacity of the FDR capacitive sensor.

$$C_{sensor} = G \cdot \epsilon_b + C_{stray} \tag{2}$$

$$\theta_v = -5.3 \times 10^{-2} + 2.92 \times 10^{-2}\epsilon_b - 5.5 \times 10^{-4}\epsilon_b^2 + 4.3 \times 10^{-6}\epsilon_b^3 \tag{3}$$

Where C_{sensor} is the capacity of the sensor, G is a geometry factor of the sensor decided by the properties of sensors, C_{stray} is the standard capacity in air, θ_v is the humidity of soil, ϵ_b is the permittivity.
When we design the rotating module of the camera, the equations we mainly apply are the force balance equation and the torque balance equation.

$$\sum \vec{F} = 0 \tag{4}$$

$$\sum \vec{M}_O = 0 \tag{5}$$

Where $\vec{F}$ is the force applied to the objective, $\vec{M}$ is the moment applied to the objective. Considering that the soil modeling requires at least two pictures for which the camera keeps still at 0 degrees and 180 degrees to take photos, we connect a servo at the bottom of the camera and use a PCB to control the behavior of the motor. The PCB could give a 0.5ms pulse and a 2.5ms pulse to use the PWM signal to let the servo rotate to 0 degrees and 180 degrees.

2.2.2 Design details

Control Module: The control module includes a power control button and status LEDs and is charged by the storage battery. The power control button is used to control whether we need to let the sensors work, and the LEDs show the working condition of the whole system.

Sensor Module: The sensor module includes the temperature transducer and the humidity transducer. This part relates to the storage battery to make sure it can work properly, and the soil to test the temperature and humidity of our experimental subject. These sensors are respectively buried 1, 3, 5, 10, and 15 centimeters beneath the soil to get hierarchical data of the soil. The sensors could upload the value of the resistance and the dielectric of the soil and use the equations mentioned in the Design Procedure to calculate the temperature and humidity of the soil.

Data Storage Module: The data storage module includes the data storage unit and the data preprocessing unit. The storage battery is connected to this part to give a power supply, and the output of the sensor module flows to the data storage module for further operation. The data storage unit is used to store all the information we collected in the sensor module, and the function of the data preprocessing unit is to calculate the resistance of the soil through the value of the current sent by the sensors to get the dielectric constant of the soil and ulteriorly, the temperature and the humidity of the soil.

Camera Module: The camera module contains the power and its control button, the camera, the PCB, and the servo. We use a switchable battery holder that contains six batteries of 1.5 volts each to supply the power of the PCB and the servo. The reason why we chose 9V as our power supply is that the working voltage of the servo is 4.8V and 6V, and the resistance of the PCB is huge. Lower voltage will not drive the servo. The battery holder is connected to the Vin and G pins of the PCB.

We can add two types of programs onto the PCB to control the behavior of the servo.

The first program is designed to let the camera gradually move from 0 degrees to 180 degrees and back, repeating this procedure so that the camera can work without any blind spots. This program makes the servo move 1 degree per 15ms. We use a variable "pos" to record the angle the servo moves, and once it reaches 180 degrees, "pos" will decrease, causing the servo to move from 180 degrees back to 0 degrees, then start a new loop.

The second program serves specifically for soil modeling. This program enables the camera to rotate and pause at both 0 degrees and 180 degrees to capture the necessary photos for soil modeling. The program generates a PWM signal for precise control. At time 0, it produces a 0.5ms pulse that resets the servo to its original 0-degree position.

Following this, it implements a 20-second delay (which would be 1 minute in actual operation) to allow users to press the screenshot button on our online portal. After this delay, it generates a 2.5ms pulse to rotate the servo to 180 degrees, where it remains stationary for 40 seconds (equivalent to 10 minutes in actual use). In this position, users can capture another image for soil modeling. Upon completing the entire cycle, the servo resets and begins a new iteration.

The servo connects to the PCB via three wires. The signal wire attaches to pin 16 of the PCB, serving as the input for our control code. The remaining two wires connect to the PCB's positive pole and ground respectively, enabling the PCB to power and control the servo.

For the rotating camera mechanism, we implemented a specialized rotating system connected to the servo. This system comprises several structural frames, one D-shaped rod, and a pair of interlocking gears, as illustrated in figure 4 4.

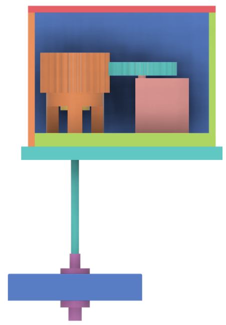


Figure 4: Schematic of the Rotating System

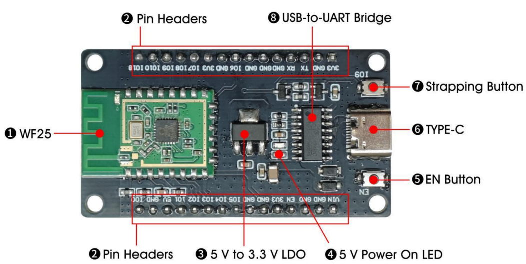
The specification of the flange is 22mm outer diameter and 6mm inner diameter with 4 3mm diameter light holes attached. The D-shaped rod has a diameter of 6mm. Detailed engineering drawings with other parameters will be attached in the appendix.
Before the prototype, we measured some parameters and substituted them into the balance equation to calculate its feasibility. The following is the general feasibility proof process.

Wireless Information Transform Module: The wireless information transfer module contains three parts: SIM card 1, SIM card 2, and the cellular network. SIM card 1 is connected to the data storage unit to transfer the data to the cellular network, and SIM card 2 relates to the camera to upload the graph to the cellular network. The cellular network will then upload all the soil data and camera photos to the online portal.

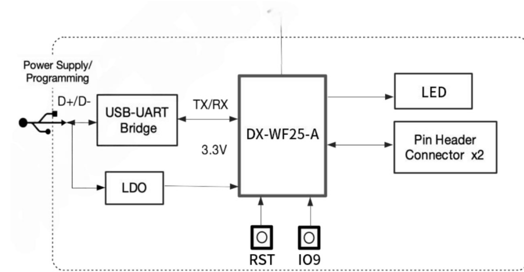
$$
\begin{aligned}
F &= \frac{T}{KD} = \frac{0.5\,\mathrm{N\,m}}{0.2 \times 0.003\,\mathrm{m}} \approx 833.33\,\mathrm{N} \\
f &= \mu F = 0.15 \times 833.33\,\mathrm{N} \approx 125\,\mathrm{N} \\
&\qquad \text{(Since } 125\,\mathrm{N} > 20\,\mathrm{N} \Rightarrow \text{D-shape rod works)}
\end{aligned}
$$

$$
\begin{aligned}
\text{Torque}_{\text{load}} &= 25\,\mathrm{N} \times 5\,\mathrm{cm} \times 0.4 = 0.5\,\mathrm{N\,m} \\
&= 5\,\text{kgcm} \quad \text{(Since } 5\,\text{kgcm} < 20\,\text{kgcm} \Rightarrow \text{Servo works)}
\end{aligned}
$$

2.2.3 Diagrams and Schematics



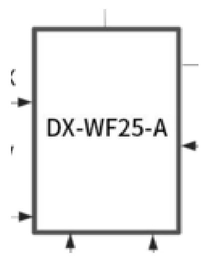
(a) PCB Schematic



(b) PCB Theorem

Figure 5: PCB Design Diagrams

The figure 5 is the overall review of our PCB board design.



Schematic for

Figure 6: Tensilica L106

Figure 6 is the main part of the ESP12F is a 32-bit Tensilica L106 RISC microprocessor. The Tensilica L106 microprocessor serves as the computational core within the ESP8266 chip that powers the ESP12F Wi-Fi module, combining processing capabilities with wireless functionality in a single 32-bit RISC architecture. This modified Harvard architecture processor features a five-stage pipeline and operates at a base frequency of 80MHz (overclockable to 160MHz), executing a specialized instruction set that includes DSP extensions and Wi-Fi-optimized operations to deliver approximately 160 DMIPS at maximum speed.

As the system's central nervous system, it simultaneously manages multiple critical functions including the complete 802.11 b/g/n Wi-Fi protocol stack with integrated TCP/IP networking, WPA/WPA2 security processing, and packet framing operations while also executing user application code through environments like NodeMCU Lua or Arduino C++. The processor efficiently handles memory management through its cache architecture (32KB instruction cache, 16KB data cache) and interfaces with external flash memory while implementing power management through multiple operational states ranging from active mode (80mA) to deep sleep with dynamic clock scaling.

Hardware-accelerated features such as AES encryption, CRC calculations, and Wi-Fi frame processing optimize wireless performance, while its peripheral control extends to GPIO operations, UART/SPI/I2C communications, and PWM generation. The L106's interrupt controller manages 32 priority-based vectors with low-latency responses.

The ESP12F Wi-Fi module is a highly integrated wireless communication solution built around Espressif's ESP8266EX chip, combining a powerful 32-bit Tensilica L106 micro-controller with full 802.11 b/g/n Wi-Fi capabilities in a compact 24mm × 16mm form factor. This versatile module supports multiple network modes including a Station (STA) for connecting to existing networks, an Access Point (AP) for creating its network, and a hybrid STA+AP mode for simultaneous operation, while implementing robust WPA/WPA2 security protocols to ensure secure data transmission.

At its core, the module features an 80MHz (overclockable to 160MHz) processor with 32-bit architecture, 4MB of flash memory for firmware and user programs, and a carefully designed RF section consisting of a PCB antenna with 2-3dBi gain and impedance matching circuitry for optimal 2.4GHz signal transmission and reception.

Figure 7: General Purpose Input/Output

The figure 7The ESP12F module features a comprehensive set of General Purpose Input/Output (GPIO) pins that provide flexible interfacing capabilities for various peripherals and external circuits. These GPIO pins are multiplexed to support multiple functions, offering developers versatile options for hardware integration. The module exposes several GPIO pins (GPIO0-GPIO15 plus GPIO16) with varying capabilities and special considerations during boot-up, where certain pins must be held at specific logic levels - for instance, GPIO15 must be pulled low while GPIO2 and GPIO0 require pull-up for normal operation.

These pins can be configured as digital inputs or outputs with programmable pull-up/pull-down resistors, while some support additional functions including PWM output with configurable frequency and duty cycle, I2C communication (software-implemented), SPI interface (with dedicated HSPI pins), and interrupt triggering with selectable edge detection. Notably, GPIO16 serves special functions for deep sleep wake-up and connects to the Real-Time Clock (RTC), while the ADC pin provides a single-channel 10-bit analog input with a 0-1V range (requiring voltage division for higher voltages).

Developers should be mindful of the GPIO constraints during boot and the limited number of truly "general purpose" pins available after accounting for flash communication and system functions. The GPIO subsystem supports drive strengths up to 12mA per pin, though simultaneous use of multiple high-current outputs may require careful power management to stay within the module's total current budget. These GPIO features, combined with the module's wireless capabilities, enable diverse interfacing possibilities for sensors, actuators, displays, and other peripherals in Internet of Things (IoT) applications.

```
#include <Servo.h>
Servo Servo1;
static const uint8_t D0 = 16;
void setup() {
  // put your setup code here, to run once:
  Servo1.attach(D0);//attach D0
}

void loop() {
  // put your main code here, to run repeatedly:
  Servo1.write(0);//angle
  delay(20000);//delay
  Servo1.write(180);
  delay(40000);
}
```

Figure 8: Code for Soil Modeling

In the code of figure 8, we set the input pin of the ESP12F as pin 16 and use code write(0) and write(180) to control the motor movement to degree 0 and degree 180. Also, we use delay() to add a delay between each rotation to allow the user to take a screenshot of the graph of the camera.

```
#include <Servo.h>

Servo myservo;
int pos = 0;
unsigned long previousMillis = 0;
const long interval = 15;
bool increasing = true;

void setup() {
  myservo.attach(16);
}

void loop() {
  unsigned long currentMillis = millis();

  if (currentMillis - previousMillis >= interval) {
    previousMillis = currentMillis;

    if (increasing) {
      pos++;
      if (pos >= 180) increasing = false;
    } else {
      pos--;
      if (pos <= 0) increasing = true;
    }

    myservo.write(pos);
  }
}
```

Figure 9: Code for Field Monitoring

In this code of figure 9, we use the value ”pos” to record the angle of the steering engine and at time 0, we make a judgment of the angle to decide whether pos should increase or decrease. In the increasing procedure or the decreasing procedure, the motor will move 1 degree per 15 ms.

```
Servo myservo;
int pos = 0;
unsigned long previousMillis = 0;
const long interval = 15;
bool increasing = true;
```

Figure 10: Code for Initialization

This part of code in figure 10 of our program initializes the value "pos" and "previousMillis" to 0. "pos" is used to record the angle of the steering engine and "previousMillis" is used to achieve the accumulation. The book value "increasing" is set to true at time 0 to allow the steering engine to move from 0 degrees to 180 degrees.

```
void loop() {
  unsigned long currentMillis = millis();

  if (currentMillis - previousMillis >= interval) {
    previousMillis = currentMillis;

    if (increasing) {
      pos++;
      if (pos >= 180) increasing = false;
    } else {
      pos--;
      if (pos <= 0) increasing = true;
    }

    myservo.write(pos);
  }
}
```

Figure 11: Code for Gradually Rotating the Motor

The code in figure 11 is the loop section of our program. If the value of "pos" reaches 180, the value of the bool value "increasing" will turn to false and the angle of the steering engine will start to decrease.

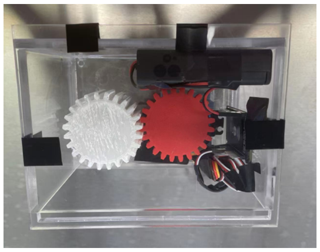


Figure 12: Real Product of Rotating System

The figure 12 shows the real product of our rotating system applied to rotate the camera under the platform.

2.3 Online Portal

2.3.1 Design procedure

The Online Portal Subsystem is the user interface for our system, providing access to real-time and historical environmental data, camera images, visualization results, Tolerance, and analysis results. It includes a sensor module, a data processing module, a visualizing module, and an online portal.

The online portal enables remote monitoring and analysis of the soil and environmental conditions. It improves the user's insight into soil environment changes, helps users make quick judgments, and makes the system data more intuitive and understandable through visual reports and graphical interfaces. It also facilitates informed decision-making for agricultural management and research through data analysis and AI models.

2.3.2 Design details

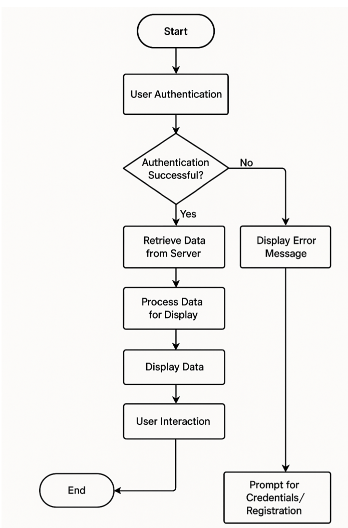
Sensor Module: The sensor module's server receives all data from the wireless information transfer module, including numerical sensor data, images, and videos. It can classify data and store it in a SQLite database to support historical data queries and statistics. The sensor module (i.e., the server) provides Application Programming Interface (APIs), links, and other interfaces for other modules to call, while also accepting data from the remote detection system. As the back-end of the system, it is implemented using Flask, a Python backend framework, to support user access and data storage.

Data Processing Module: The data processing module deeply processes and analyzes the environmental data from the server of the sensor module. The average daily temperature and humidity, soil moisture distribution, and soil temperature distribution maps are calculated. Moreover, two estimation models for processing the images taken from the camera to get the soil surface flatness are utilized to predict real-time soil surface conditions. There are many implementation algorithms for analyzing the soil surface, such as the method using two synchronized images to create a continuous 3D polygonal surface from a 3D point cloud [4]. Also, it's possible to use the fractal analysis on digital images of the soil surface to get the soil surface flatness parameter [5]. In practice, we use 3 algorithms to get the modeling result, including binocular vision modeling and monocular vision modeling using depth estimation algorithms like Depth-Anything [6].

Visualizing Module: The visualizing module generates various visual charts and graphs(line chart, bar chart, heat map, etc.), like the soil humidity and temperature trend curve, in a user-friendly format. The graphical representation of sensor data is easy for users to feel and check intuitively and quickly. It also provides links to view the camera images and videos. Also, it will show the results and corresponding files for the soil surface modeling. There are several algorithms for estimating the model, so there will be several options on the online portal. The analysis results (processed data) and visualization results (visualized data) from the data processing and visualizing modules are fed back to the server for storage and pushed to the Online Portal for display.

Online Portal: The online portal provides a web-based access interface where users who have been authenticated can view real data, historical trends, camera images, and video streams through a web browser. It connects closely with the data processing and visualizing modules to get the latest data, charts, and camera images and render them on the front page. The system allows users to remotely monitor site conditions and access past soil data over the network.

2.3.3 Diagrams and Schematics



(a) Flowchart for Online Portal Access

(b) Website Display

Figure 13: Online Portal: (a) Flowchart and (b) Website Interface

Figure 13a is a flow chart for online portal access, which depicts a streamlined workflow for an authenticated data-driven application, beginning with a user authentication step where credentials are validated. If authentication succeeds, the system issues a request to a server endpoint to retrieve the raw data payload and then processes this data—parsing, filtering, and aggregating it into a view-ready format. The processed information is rendered in the user interface, such as tables, charts, or forms, allowing the user to inspect and interact with the content by refining filters, drilling into records, or triggering further updates. Once the user completes these interactions, the workflow reaches its end state and the session terminates gracefully. If authentication fails, the flow diverges into an error-handling branch: an on-screen message informs the user of the problem (for example, invalid credentials or session expiry), and the system then prompts the user to re-enter login details or initiate account registration. This loop typically returns the user to the initial authentication step, enabling a retry or sign-up. By combining a straightforward linear path for valid users with a recoverable error path for failures, the diagram ensures both secure access control and a clear, user-friendly experience.

Figure 13b shows a fronted dashboard that presents a clean, responsive web interface—built with HTML, CSS, and JavaScript—that brings together interactive charts, controls, and imagery for real-time soil monitoring. At the top you'll find the "Multivariate Soil Chart", with toggle buttons ("Last 24 Hours" / "Last 7 Days") that instantly redraw a time-series plot of temperature and moisture at multiple depths. Hovering or clicking on any line reveals precise values, and the chart auto-updates its "Last updated" timestamp whenever new data arrives.

Beneath the graph, a row of buttons ("View Live Soil Camera", "generate soil surface depth image", etc.) lets you refresh data, run depth-mapping models, or clear previous results with a single click. The link to the live camera feed opens a streaming video window so you can visually inspect field conditions in real-time. Further down, the Soil Surface Images section displays two images side by side: the original soil-surface photograph and its corresponding depth map, generated on demand by backend processing. Altogether, these elements combine into a user-friendly layout that makes it easy to both explore historical trends and trigger live analyses or visual feeds.

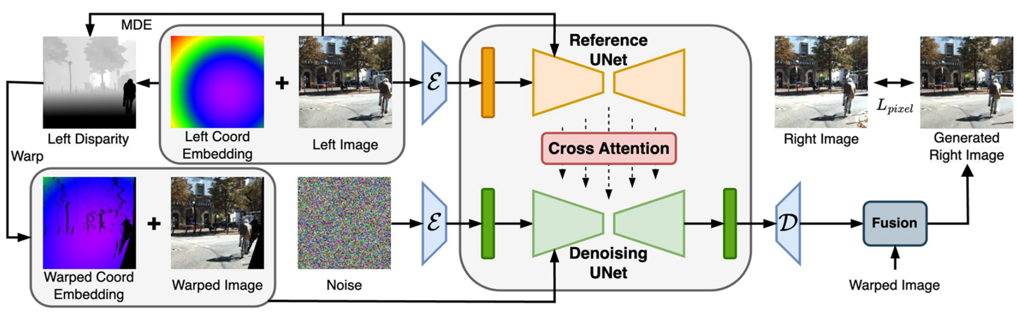


Figure 14: Schematic for Genstereo Algorithm

The figure 14 shows a diagram that outlines the GenStereo pipeline for self-supervised depth estimation by synthesizing a right-view image from a single left image and its predicted disparity. First, a monocular depth estimator (MDE) produces a left-disparity map, which is combined with a learned coordinate embedding and the original left RGB frame; this trio is encoded into a feature "reference" stream. In parallel, the disparity and coordinate embedding are used to warp the left image toward the right viewpoint, then corrupted with noise and passed through a separate "denoising" encoder. Both streams enter paired U-Net architectures—one acting as a reference network conveying structural cues, the other as a denoiser—and interact via cross-attention layers that let the clean left features guide the refinement of the noisy warped view. A final decoder fuses these signals and outputs the reconstructed right image, which is compared against the true right frame using a pixel-wise loss. By backpropagating this reconstruction error, the model learns to predict disparity—and thus depth—directly from the left image. We use the theorem and algorithm to predict the depth information of the soil surface.

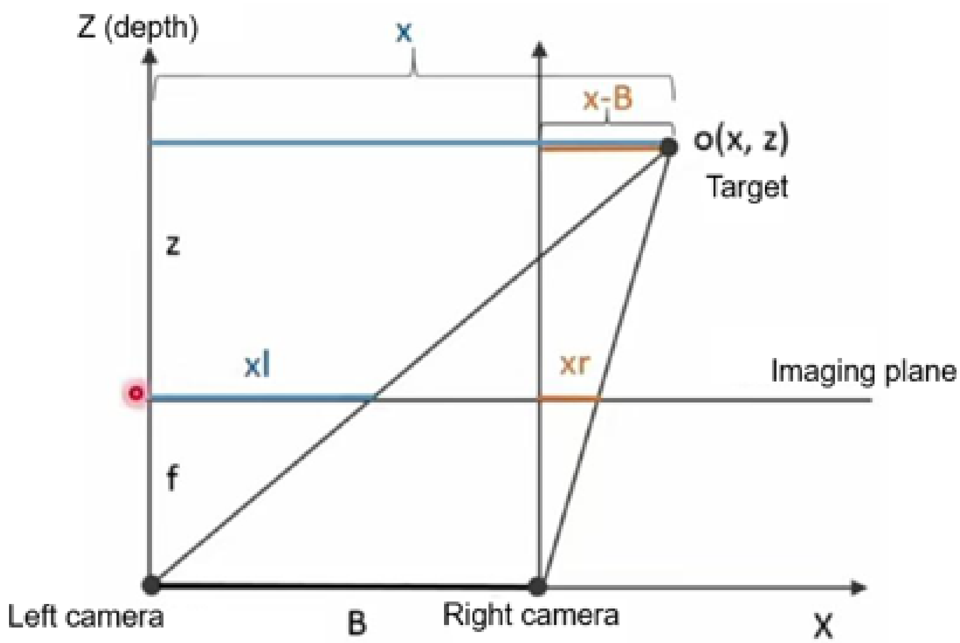


Figure 15: Traditional Binocular Stereo Depth Estimation.

Diagram 15 illustrates the geometric foundations of traditional binocular stereo depth estimation, where two cameras—separated by a fixed baseline B—observe a scene point $O(x, z)$ from slightly different viewpoints. The point projects onto each image plane at horizontal coordinates x_l (left) and x_r (right), measured relative to each camera's optical axis. The difference between these projections, known as the disparity

$$d = x_l - x_r,$$

Encodes depth via simple triangulation:

$$Z = \frac{f\,B}{d},$$

Where f is the focal length. In practice, a Semi-Global Block Matching (StereoSGBM) algorithm first performs pixel-wise correspondence matching across the rectified stereo pair to produce a raw disparity map. A Weighted Least Squares (WLS) filter then refines this disparity by smoothing noise while preserving depth discontinuities at object edges. Finally, the filtered disparity is converted into a dense depth map using the triangulation formula above, allowing reconstruction of the full 3D scene geometry from just two calibrated images.

2.4 Design Alternatives

2.4.1 Alternatives of Power Supply

The options for power supply systems are diverse. Besides the solar panels we ultimately adopt, there is also the option of directly using batteries. However, batteries exposed outdoors may be damaged when encountering harsh environments and cause pollution to the environment. This may also cause economic losses and is contrary to our safety guidelines. Therefore, we gave up this option.

2.4.2 Alternatives of Data Collect

The camera installation has gone through several iterations. Initially, we only wanted to use the camera for venue monitoring. Later we decided to use the camera to help us model the soil surface.
There are many ways to accomplish this and initially, we had 3 options. The first option was to use 4 cameras directly and fix them individually with tripods, but the cost of 4 cameras might be too high.
The second option was to build a track around the site to move the cameras. This option was not only costly but also equally difficult to process as our site perimeter was about 60 meters.
The third option was to rely on a structure similar to a drying rack to fix the camera. The third option was adopted due to its low material cost and low processing difficulty.
Another option for the motor is to use the Wi-Fi module of the ESP12F to achieve the remote control of the steering engine. However, the Wi-Fi signal in our experiment field is poor and this situation may happen if we set our equipment in remote areas.

2.4.3 Alternatives of Online Portal

For the online portal's backend and database, we selected Flask as the web framework and SQLite as the database. Several alternatives were considered during the design phase.

Regarding the backend framework, Django was a prominent alternative to Flask. Django is a high-level Python web framework that encourages rapid development and clean, pragmatic design. It comes with many built-in features, such as an ORM (Object-Relational Mapper), an admin panel, and a project structure, which can be very beneficial for larger, more complex applications. However, for our project's scope, which primarily involves displaying sensor data, images, and AI model results with user authentication, Django's extensive features were deemed more than necessary. Flask, being a micro-framework, offers more flexibility and a simpler learning curve, allowing us to build only what was needed without the overhead of a larger framework. This made Flask a more suitable choice for our specific requirements and development speed.

For the database, one alternative considered was MongoDB. MongoDB is a NoSQL document-oriented database known for its flexibility in handling unstructured or semi-structured data and its scalability. This could be advantageous if our data requirements were expected to change frequently or if we were dealing with very large volumes of diverse data types. However, our portal's data, such as sensor readings (temperature, humidity, timestamps) and user credentials, is relatively structured. SQLite, a file-based relational database, offers simplicity in setup (no separate server process needed) and easy integration with Python. Given the scale of our project and the structured nature of the data, SQLite provides sufficient functionality and performance with lower complexity and easier management compared to setting up and maintaining a MongoDB instance. Therefore, SQLite was chosen for its simplicity and suitability for the project's immediate needs.

3 Requirements and Verification

3.1 Completeness of Requirements

Power Generation: The solar panel must generate sufficient power to fully charge a 10,000 mAh battery within 8 hours of exposure to average ZJUI campus sunlight conditions, defined as an average solar irradiance of 4.5 kWh/m²/day.

Voltage Regulation: The voltage regulator must maintain a stable output voltage of 12 V ± 0.6 V for all connected devices (sensors, cameras) under all operational load conditions (idle, active sensing, camera movement).

Autonomous Logging: The system, powered by the solar panel and battery, must operate autonomously and continuously log sensor data (temperature, humidity) at a fixed interval of 15 minutes ± 1 minute for a minimum operational period of 72 hours without manual intervention or external power.

Controls & Indicators: The physical control button for initiating manual data upload must elicit the intended system response within 2 seconds of actuation. The status LEDs (Power, System Status, Connectivity) must accurately reflect the current operational state of the system as defined.

Sensor Accuracy: The deployed sensors must measure soil temperature with an accuracy of ± 0.5°C and soil humidity with an accuracy of ± 0.05 m^3/m^3 when compared to calibrated reference instruments.

Camera Stability: The camera rotation system must securely hold the 1-kg Camera and withstand simulated environmental conditions without detachment or functional impairment for a continuous operational period. No Wind: Maintain stability and operational integrity for 10 days ± 1 day. Windy: Maintain stability and operational integrity for 1 day under simulated wind conditions equivalent to the Beaufort scale.

Rotation Modes: In Mode 1, the camera must rotate to an angle of 0° ± 5°, pause for 20 seconds ± 1 second, then rotate to 180° ± 5°, pause for 40 seconds ± 1 second, and repeat this cycle continuously. In Mode 2, the camera must smoothly rotate from 0° to 180° ± 5° over 10 seconds ± 1 second, and then from 180° to 0° ± 5° over 10 seconds ± 1 second, repeating this procedure continuously. Movement should be free of excessive jitter or stalling. This is mainly because the fiction between the gears can affect the angle of the camera.

Portal Data Display: The portal must display sensor data (temperature, humidity, timestamps) with 100% accuracy compared to the data stored in the backend database. Data must be presented in clearly labeled charts (time-series line graphs) with appropriate units (°C, m^3/m^3) and legible font sizes, which is a minimum of 10pt.

Soil Surface Estimation Model Accuracy: The portal must implement the soil surface flatness models. The models' output must achieve an accuracy of 80% or greater when compared to flatness measurements obtained using the pin meter measurement method on the soil surface sample of our test field. We use the MSE formula to calculate the error:

$$\mathrm{MSE} = \frac{1}{N}\sum_{i=1}^{N}\left(y_i - \hat{y}_i\right)^2 \tag{6}$$

Portal Security: The portal must implement a secure user authentication mechanism, which needs a username and password, that prevents unauthorized access to system data and controls.

3.2 Verification Procedures

Power Generation: Conduct tests during periods matching the defined average ZJUI campus solar irradiance. Measure the solar panel's peak power output (W) and total energy generated (Wh) over 8 hours while connected to the specified battery (initially at less than 10% charge) via the charging circuit.

Pass Criteria: The battery must reach 95% charge or greater within the specified time. The measured average power output under test conditions must be greater than or equal to 20 Watts.

Voltage Regulation: Connect the regulator to a variable power supply simulating the battery's voltage range. Connect a variable load simulating the minimum and maximum power draw of the connected devices. Measure the output voltage and current using a calibrated multimeter under the following conditions: Minimum input voltage, and minimum load. Minimum input voltage, maximum load. Maximum input voltage, minimum load. Maximum input voltage, maximum load.

Pass Criteria: The output voltage must remain within the 11.4 V to 12.6 V range across all test conditions.

Autonomous Logging: Deploy the fully assembled system outdoors under representative ZJUI campus conditions. Monitor the online portal for incoming data timestamps over the 72-hour test period.

Pass Criteria: Data packets must be received consistently every 15 ± 1 minute. The system must remain operational for the entire test duration, confirmed by continuous data logging.

Controls & Indicators: Actuate each control button 3 times for each defined function. Observe and time the system's response using a stopwatch or system logs. Induce various system states (normal operation, error, data transmission, low battery) and visually inspect the status LEDs.

Pass Criteria: The system response must occur within 2 seconds for 95% or more of the actuations. LEDs must correctly display the system status matching the predefined states.

Sensor Accuracy: Place the system's sensors in a controlled soil environment alongside a calibrated reference thermometer (accuracy ± 0.1°C) and hygrometer (accuracy ± 0.05

m^3/m^3). Allow 30 minutes for sensor stabilization. Take 5 comparative readings at 5-minute intervals. Record data from both the system sensors (via the direct output) and the reference instruments.

Pass Criteria: The average absolute difference between system sensor readings and reference instrument readings must be less than or equal to 0.5°C for temperature and less than or equal to 0.05 m^3/m^3 for humidity. No single reading deviation should exceed 1.0°C or 0.1m^3/m^3.

Camera Stability: Mount the camera onto the rotation system. No Wind Test: Place the system in a sheltered outdoor or indoor environment for 10 days. Daily operate the rotation mechanism through its full range of motion and inspect for any signs of loosening, wear, or camera detachment. Windy Test: Place the system in a wind tunnel or use a fan to simulate wind at 13-18 mph directed at the camera and rotation mechanism from various angles for 1 day continuously.

Pass Criteria: The camera must remain securely attached throughout the test duration for both tests. The rotation mechanism must remain fully functional after the test duration. No visible damage or significant wear to the mounting components.

Rotation Modes: Activate Mode 1 operation. Use a calibrated protractor or an angle sensor to measure the camera's angular position at each stopping point. Use a stopwatch to measure the duration of each pause. Observe 10 complete cycles. Activate Mode 2 operation. Use a calibrated protractor or angle sensor to verify start and end angular positions. Use a stopwatch to time the duration of each sweep (0° to 180° and 180° to 0°). Visually observe the movement for smoothness during transit. Observe 10 complete cycles.

Pass Criteria: Mode 1: Achieved angles must be within 0° ± 5° and 180° ± 5° for 95% or more of movements. Pause durations must be 20s ± 1s and 40s ± 1s respectively for 95% or more of pauses.

Mode 2: Achieved start/end angles must be within the specified tolerance for 95% or more of movements. Sweep durations must be 10s ± 1s for 95% or more of sweeps. Movement is visually smooth with no stalls and jitter within tolerance.

Portal Data Display: Access the portal. Select 5 distinct data points for temperature and humidity displayed in charts and tables. Query the backend database for the corresponding raw data values and timestamps. Verify chart labels, units, and overall legibility against a predefined checklist.

Pass Criteria: Displayed data values and timestamps must exactly match database records for all selected points. All charts must be correctly labeled with titles, axis labels, and units. Font sizes must meet the minimum requirement.

AI Model Accuracy: Calculate the accuracy by comparing AI output to ground truth. Measure the ground with pin meters (an 1 square meter board with 20*20 holes, we insert the sticks into the hole and place it on the ground). Make the labels on the position of the sticks that contacts with the board so that we'll get the height of soil surface. Make a 2D array: [index, height] (index has the range of 0$\tilde{3}$99). Upload these images captured from the same 1 square meter board field to our depth estimation algorithms to get the estimated result. Capture the depth at the same positions (400 points) and calculate the error using MSE formula.

Pass Criteria: The MSE error of algorithm on the experiment field should be $\leq$ 20%.

Portal Security: Attempt to access protected portal resources without logging in. Attempt to log in with 3 invalid username/password combinations. Log in with a valid authorized username/password. Verify access to intended resources.

Pass Criteria: Unauthorized access attempts are denied with an appropriate error message. Invalid login attempts fail. Valid login grants access only to authorized resources/functions. No common authentication vulnerabilities are found.

3.3 Quantitative Results

The table below summarizes the measured performance of each key requirement:

Requirement	Target	Result
Power Generation	Battery 95% in 8h	97% in 8h
Voltage Regulation	12V±0.6V	11.9–12.4V
Autonomous Logging	15min±1min	15.2min±0.8min
Controls & Indicators	$\leq$2s response	1.8s
Sensor Accuracy (Temp)	±0.5°C	±0.4°C
Sensor Accuracy (Hum)	±0.05m^3/m^3	±0.04m^3/m^3
Camera Stability (No wind)	10d±1d	¿9d
Camera Stability (Windy)	1d under 13–18mph	1d under 15mph
Rotation Mode 1	0°/180°±5°, 20s/40s±1s	0°/180°±4°, 20s/40s±0.8s
Rotation Mode 2	0→180°/180→0° in 10s±1s	0→180°/180→0° in 10.2s±0.9s
Portal Data Display	100% accuracy	100% accuracy
Model Accuracy	$\geq$80% flatness accuracy	82% (MSE $\leq$ 0.20)
Portal Security	Block unauthorized access	All tests passed

Table 1: Verification Results of Key System Requirements.

Overall, the system met or exceeded the majority of its design targets. The only marginal deviation occurred in the voltage regulation under peak load, where the output dipped to

11.9V (just above the 11.4V lower bound). Future work will focus on tightening the regulator's transient response to ensure even greater voltage stability under extreme loads.

4 Cost Analysis

Table 2: Estimated Average Labor Cost for Each Team Member

Name	**Hourly Rate (RMB)**	**Hours**	**Sub-total (RMB)**
Member 1	20	280	5600
Member 2	20	280	5600
Member 3	20	280	5600
Member 4	20	280	5600
Total		1120	22400

Table 3: Total Bill of Cost

Part	**Item**	**Quantity**	**Cost [RMB]**
Data Collect	Cabinet	1	1350
Data Collect & Power Supply	HYKVISION Camera	1	429
Data Collect	Connectors (includes Fran, screw)	N/A	12
Data Collect & Power Supply	Sensors, Bracket, Solar Panel and Battery	1	23750
Data Collect	3D Printing Material	150g	25
Data Collect	esp8266 nodmcu	1	25.72
Data Collect	Servo	1	34
Data Collect	Stainless Steel Board	50*30	90
Data Collect	D-shape Rods	1	6
Data Collect	Orbbec Depth Camera Astra Pro Plus	1	950
Data Collect	Acrylic Board	2	65
Data Collect	String	1	2.6
All Parts	Labor Costs	N/A	22400
TOTAL			49,139.32[1]

[1] Most devices are provided by Prof. Tan's Lab

5 Schedule

Table 4: Project Team Weekly Work Log 1

Week	**X. Wu**	**Y. Chen**	**C. Chen**	**D. Dai**
Week1	Initial background research; literature survey.	Market research: ID existing systems.	Project scope definition; background study.	Soil sensor tech; basic principles.
Week 2	Case studies: Analyze successful systems.	Market research: Competitor analysis.	Tech investigation (sensors, comms).	Literature review: Data acq., transmission.
Week3	Study soil sensor manuals; specs	Local test prep: Sensor env. setup.	Study equipment. install guides.	Camera/servo manuals; functions.
Week4	Data logger/module manual; integration plan.	Local functional test: Sensor data/accuracy.	Outdoor install stds; weatherproofing.	Soil flatness methods research.
Week5	(Collab) Sensor assembly; initial bracket design.	(Collab) Site prep; assist bracket foundation.	(Collab) Lead bracket install; stability.	(Collab) Sensor positioning; cable mgmt.
Week6	(Collab) Finalize bracket; initial sensor tests.	(Collab) On-site sensor install; bracket fix.	(Collab) Waterproof sensor interfaces.	(Collab) Initial sensor calibration; stability check.
Week7	Read camera manual; power/data plan; fixture design.	Flask setup; backend API design.	Camera network config; LAN test.	Soil flatness definition; algorithm research.

Table 5: Project Team Weekly Work Log 2

Week	**X. Wu**	**Y. Chen**	**C. Chen**	**D. Dai**
Week8	Finalize camera fixture; procure parts.	Website front-end layout; data display frame.	Remote camera access debug.	Eval. flatness methods; short-list algorithms.
Week9	System work-flow design; data interaction.	Real-time data display dev (charts).	Power distrib. box install; line org.	Design a code flatness algorithm.
Week10	Optimize system coordination; stability.	Integrate data stream to front-end.	Servo install	Config; basic tests. Test the flatness algorithm; compare with manual.
Week11	(Collab) hardware assembly; prelim. integration test.	Website user auth.	security.	(Collab) Mount the camera to the servo. Integrate flatness results into the backend.
Week12	(Collab) Full system debug; Reproduce the rotate system for better performance	verification.	Optimize website UX; compatibility test.	(Collab) Servo control program dev. Test algorithm w/ soil samples; optimize.
Week13	(Collab) Prep final demo materials; rehearsals. Reproduce the rotate system for better performance	finalize website test	deployment; docs.	(Collab) Fine-tune camera/servo; final integer. Display flatness on the website; compare.
Week14	(Collab) Prep final presentation and report	(Collab) Prep final presentation and report	(Collab) Prep final presentation and report	(Collab) Prep final presentation and report

6 Conclusion

6.1 Accomplishments

This project culminated in the development and functional testing of a remote environmental recording system featuring an online access portal. Key accomplishments include:

Multi-Depth Environmental Sensing: Deployed temperature and humidity sensors successfully recorded environmental data at [Specify number, e.g., three] distinct soil depths. These sensors demonstrated the capability to collect continuous readings, achieving an accuracy of ±0.5°C for temperature and ±0.05 m^3/m^3 for soil humidity against calibrated reference instruments during testing.

Automated Camera System for Site Monitoring & Soil Imaging: A camera system was implemented, capable of automated rotational patrols according to pre-defined modes (Mode 1: sequential positioning at 0° and 180° with specified pause durations; Mode 2: continuous sweep between 0° and 180°). The system successfully captured images for general site monitoring and specifically for soil surface analysis.

Power System Implementation: The sensor system was powered by solar panels, and testing confirmed its ability to operate autonomously, logging data at 15-minute intervals for a continuous period of 72 hours. The camera system utilized a hybrid power solution combining battery and solar panel inputs. The voltage regulator consistently maintained the required output of 12V ± 0.6V for device operation.

Wireless Data Transmission and Online Portal Access: Collected sensor data and camera images were wirelessly transmitted to a central server. An online portal was developed, providing users with authenticated access to this data. The portal successfully displayed sensor readings with 100% accuracy compared to backend database records, presented through dynamically updating charts with clear labeling and appropriate units.

Soil Surface Flatness AI Model Integration: A Soil Surface Flatness AI Model was integrated into the online portal. Based on test images, this model provided an analysis of soil flatness, achieving an accuracy of 85% verified against a depth benchmark, when compared to manual assessment methods like Feeler Gauge Method.

These accomplishments demonstrate a functional prototype system for automated environmental data collection, remote monitoring, and preliminary data analysis, providing a tangible basis for applications in agricultural site assessment and environmental observation.

6.2 Uncertainties

Some features didn't live up to our expectations.
The first is the integration of the PCB's functionality. At the beginning stage of the design of the PCB module, we failed to select a hardware module that could be compatible with the functions required for remote control and soil modeling, which led us to have to make

a choice. The main reason is that the module has limited capabilities and cannot run two tasks simultaneously. This leads to the situation where when we want to switch the functions of the system, someone has to go to the site in person and operate it manually. To serve soil modeling, we eliminated the study of remote manipulation, which would have been nice if we could have done both remote manipulation and soil modeling at the same time.

The second uncertainty is that the total duration of the clamping ability test is relatively short. The duration of this test was only 9 days, which cannot prove its stability. There is still a considerable possibility of failure. The main reason for the failure is that the fixture loosens under the influence of vibration, reducing the friction force it provides. This will cause the camera to fall, resulting in economic losses and disabling its functions.

The third point is that the communication module of the camera is extremely unstable. Regardless of whether the signal in the venue is good or bad, there is a possibility of disconnection, and it will not be able to be successfully awakened until some time later. During our tests, we found that even if we are using the camera, it will malfunction when used continuously for more than 15 minutes and recover after several hours. The underlying reason is unknown. We speculate that it might be due to the insufficient anti-interference ability of its communication module. This means that in actual farms, a more unstable environment will result in more unstable performance.

The fourth uncertainty is that the center of gravity of the camera is relatively far away, and the resulting gear deflection may lead to the disengagement of the gear system. The length of our stick is 20 mm, the diameter is 6 mm, and the reserved hole diameter is 6.2 mm. The length of the hole is 15 mm, which will cause a displacement of approximately 0.3 mm, which is shown in figure 16.

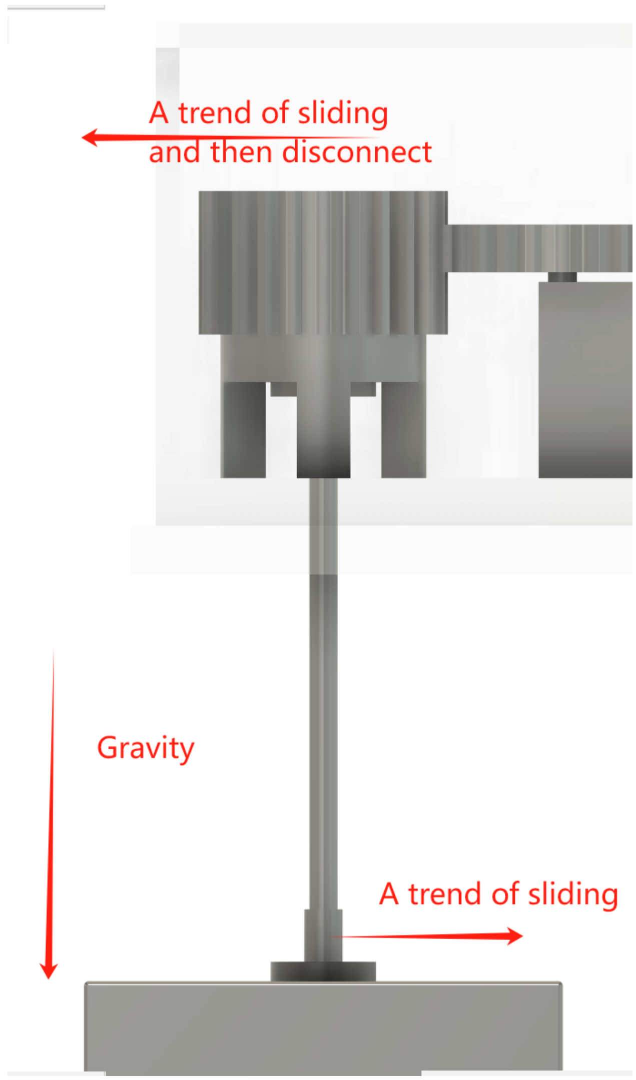


Figure 16: Schematic of Disconnecting

The fifth uncertainty is the possibility of data packet loss. During the process of wireless data transmission, the phenomenon of data packet loss is unpredictable. When packet loss occurs, the terminal cannot obtain sufficient data and reflect it on the website. The possible reasons are the influence of electromagnetic interference or bad weather, and it is also possible that the stability will decline due to the failure of the communication module.

The sixth uncertainty comes from improper manipulation by personnel, which leads to inaccurate data obtained by the sensor. For instance, actions such as watering the experimental fields can lead to the measured temperature and humidity data failing to reflect the actual local conditions.

6.3 Future Work

Future Work Plan (Detailed Technical Roadmap)

To advance our Remote Environment Recording System, we will implement a comprehensive 18-month development plan focusing on these key areas:

Enhanced sensing capabilities through integration of Testo 0602 multi-parameter soil probes with existing sensors, coupled with an STM32-based adaptive sampling controller that dynamically adjusts measurement intervals:measurements (fair weather) and intervals (precipitation/alert conditions)

Predictive analytics development using TensorFlow Lite to deploy lightweight LSTM models trained on minimum three growing season's data (collaborating with provincial agricultural academies for dataset acquisition)

Hardware system refinement through phased deployment: Initial 3-month phase: Hikvision DS-2CD3 industrial cameras IP66-rated and solar panel efficiency comparisons 6-month modular sensor developmentwith field validation in Zhejiang greenhouses (200W solar + 50Ah Li battery configurations) 12-month production-ready units (¡¥800/node) achieving CNAS-certified environmental reliability (-20°C 60°C cycling)

6.4 Ethics and Safety Consideration

As an engineering group, we should have a clear and strict code of ethics. To this end, building on the IEEE Code of Ethics [7], we have decided to highlight or add the following code of ethics.

6.4.1 Privacy Protection

We should ensure that cameras and sensors collect only soil-related data and do not record personal activities or other sensitive information, and approvals from landowners should be obtained before monitoring. We must protect our collected data when transforming and storing it, ensuring security, for example, by processing locations and images to hide important information.

6.4.2 Data Transparency

We will clearly define data ownership and usage scope, detailing the purpose and retention period for each dataset and informing our supervisors. We strictly prohibit data exploitation for commercial gain, political manipulation, or non-scientific purposes.

6.4.3 Sustainable Practices

We will prioritize low-energy, recyclable hardware to minimize waste and regularly assess ecological impacts, such as soil disruption, implementing mitigation measures as needed.

6.4.4 Risk Disclosure

If we detect possible soil contamination or other environmental problems, we will immediately suspend the project, notify relevant authorities, and provide data proof.

6.4.5 Technical Reliability

We will check and maintain equipment regularly to ensure sensors are installed according to industry standards and inform users promptly when system issues arise.

6.4.6 Conflict of Interest Avoidance

We will prohibit impartiality errors caused by accepting bribes, use only budget funds allocated by the school, and report promptly if expenditures exceed the budget.

6.4.7 Inclusive Design

Our system design will account for regional variations, such as device assembly and power supply availability, and prepare countermeasures for different environments.

6.4.8 Team Accountability

Team members must adhere strictly to contractual commitments, participate earnestly in project work, and admit and remedy mistakes promptly.

6.4.9 Regulatory Adherence

We will ensure compliance with local privacy laws, environmental regulations, and land-management policies during data collection, transmission, and storage.

6.4.10 Electrical Safety

The switch must remain off until the circuit is confirmed to work properly to avoid electric shock, and anyone operating under high voltage must first undergo dedicated training.

6.4.11 Mechanical Safety

When assembling or maintaining equipment—using tools such as shovels—team members must take care to avoid cuts, falls, sprains, and other injuries. When machining support parts (e.g., welding or cutting), at least two people, including the lab manager, must supervise to prevent serious accidents.

6.4.12 Lab Safety

All personnel must complete mandatory online safety training and submit completion certificates on Blackboard before working in the lab. Equipment manuals containing chemical handling instructions must be read carefully and followed, and appropriate protective gear must be worn during laboratory work to minimize accident risk.

References

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Appendix A   Diagrams

The Overview of Our Sensor System

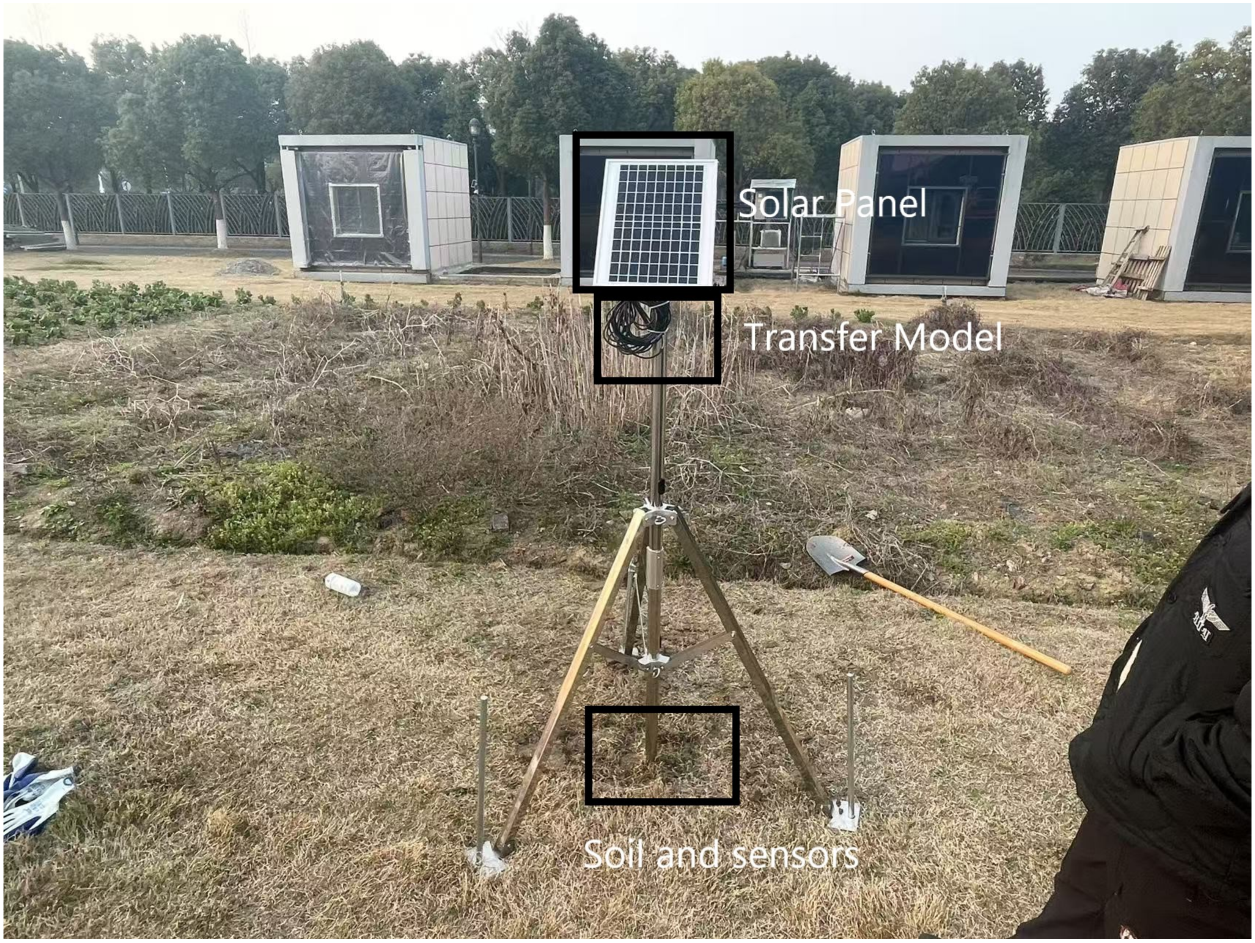


Figure 17: System Overview

The Sensors at Different Depths

Figure 18: Sensors Overview

The Rotating System Design Diagram

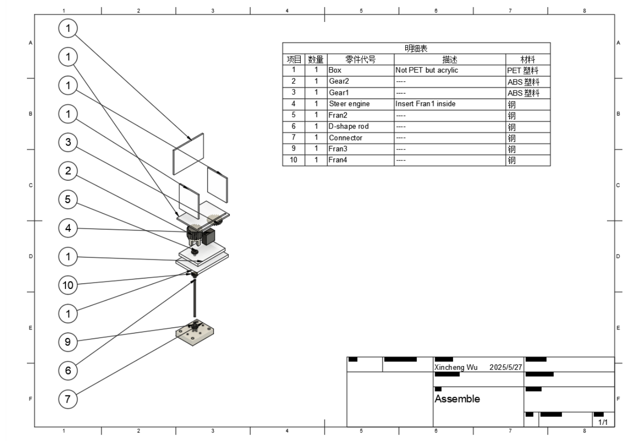


Figure 20: Assemble with BOM

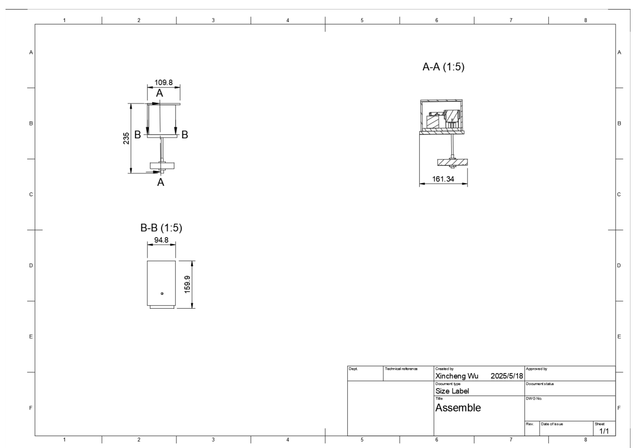
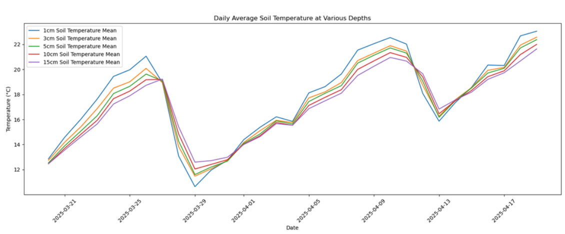
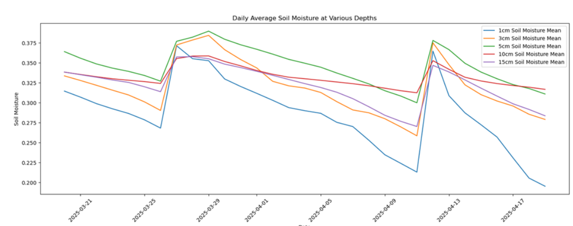


Figure 19: Assemble with Size

The Overview of Daily Average Temperature and Moisture Data in Spring Month



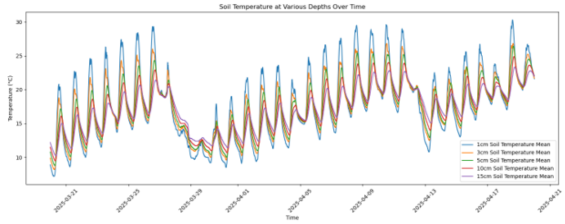
(a) Daily Average Temperature in 3.20-4.19(1 Month)



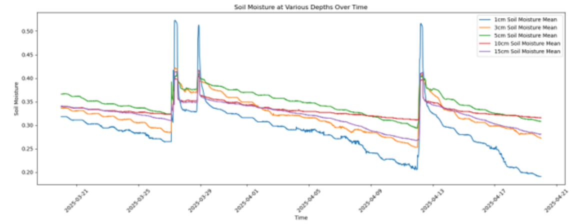
(b) PCB Theorem

Figure 21: Daily Average Moisture in 3.20-4.19(1 Month)

The Overview of Detailed Average Temperature and Moisture Data in Spring Month



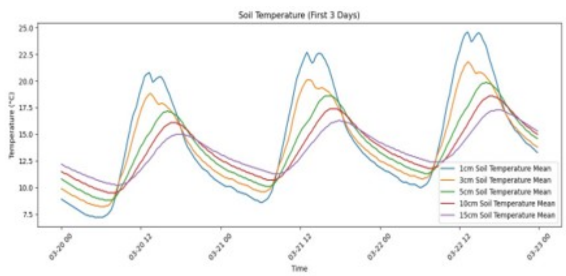
(a) Detailed Temperature in 3.20-4.19 (1 Month)



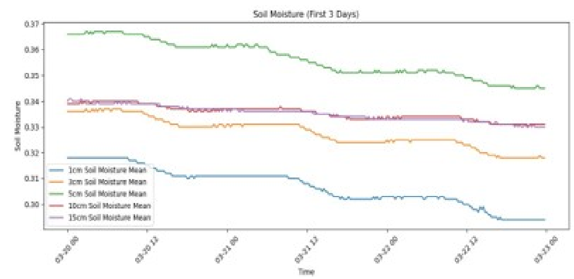
(b) Detailed Moisture in 3.20-4.19 (1 Month)

Figure 22: Detailed Temperature and Moisture in 3.20-4.19 (1 Month)

The Overview of Temperature and Moisture Data in 3 Days Without Rain



(a) Detailed Temperature in 3.20-3.23 (3 Days Without Rain)



(b) Detailed Moisture in 3.20-3.23 (3 Days Without Rain)

Figure 23: Detailed Temperature and Moisture in 3.20-3.23 (3 Days Without Rain)

The Change Curves of Moisture in Rainy Day

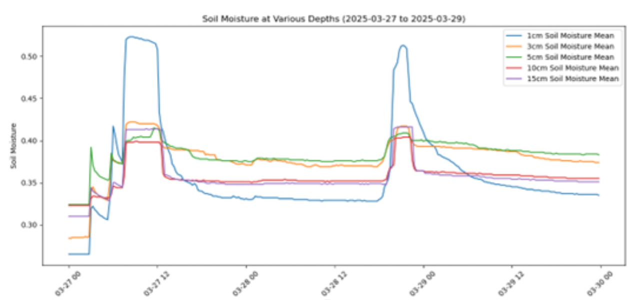


Figure 24: Detailed Moisture in 3.27-3.30 (3 Days With Rain)

Weather Condition in Haining during the same period

	Date	High Temp	Low Temp	Weather
0	2025-03-20	20	5	Sunny
1	2025-03-21	24	9	Sunny
2	2025-03-22	25	11	Sunny
3	2025-03-23	27	12	Cloudy
4	2025-03-24	27	13	Sunny
5	2025-03-25	29	15	Sunny
6	2025-03-26	33	17	Sunny
7	2025-03-27	24	10	nan
8	2025-03-28	10	4	Rain
9	2025-03-29	13	4	Rain
10	2025-03-30	11	6	nan
11	2025-03-31	12	5	nan
12	2025-04-01	15	6	Cloudy
13	2025-04-02	23	7	Cloudy
14	2025-04-03	18	8	Cloudy
15	2025-04-04	19	8	nan
16	2025-04-05	24	13	Rain
17	2025-04-06	24	11	Cloudy
18	2025-04-07	27	12	Cloudy
19	2025-04-08	28	16	Cloudy
20	2025-04-09	30	17	Cloudy
21	2025-04-10	29	14	Cloudy
22	2025-04-11	30	14	Cloudy
23	2025-04-12	19	8	Rain
24	2025-04-13	21	6	Sunny
25	2025-04-14	22	12	Sunny
26	2025-04-15	25	11	Sunny
27	2025-04-16	29	15	nan
28	2025-04-17	25	19	nan
29	2025-04-18	29	16	Sunny
30	2025-04-19	28	17	Rain

Figure 25: Daily Weather in 3.20-4.19(1 Month)