ECE 445

SENIOR DESIGN LABORATORY

DESIGN DOCUMENT

Design Document: A Remote Environment Recording System With Online Access Portals

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Team #17

XINCHENG WU
(xw80@illinois.edu)
YIZHOU CHEN
(yizhouc7@illinois.edu)
CHANGWEN CHEN
(cc105@illinois.edu)
DINGYUAN DAI
(ddai10@illinois.edu)

TA: Cao Zhijiao

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1 Introduction

1.1 Problem and Solution Overview

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 the 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 often 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.

To monitor the variation of space environments and build environment recording systems, we decided to focus on the local soil database. Functions mainly consist of three parts, including collecting the information on the humidity, temperature, and the surface roughness of soil; setting up a camera to supervise in real time; uploading all the data to the website platform; and visualizing it.

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 degression 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, in industrial production, this may help the controller to 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.

1.1.1 Benefits

1. The system enables remote and real-time soil and environmental monitoring for farmers and researchers.
2. The system improves decision-making for irrigation and crop management through predictive insights from the digital twin.
3. The system provides a sustainable and low-maintenance monitoring solution through solar power.

1.1.2 Features

1. Self-sustained power using solar energy, eliminating external power dependency.
2. Multi-depth sensing, offering more accurate insights into soil conditions.
3. Real-time camera feed, enhancing situational awareness.
4. Wireless data transmission, reducing the need for physical access.
5. User-friendly web portal and visualization, making data easily accessible and interpretable.
6. Digital twin modeling, allowing historical trend analysis and predictive modeling.

1.2 Visual Aid

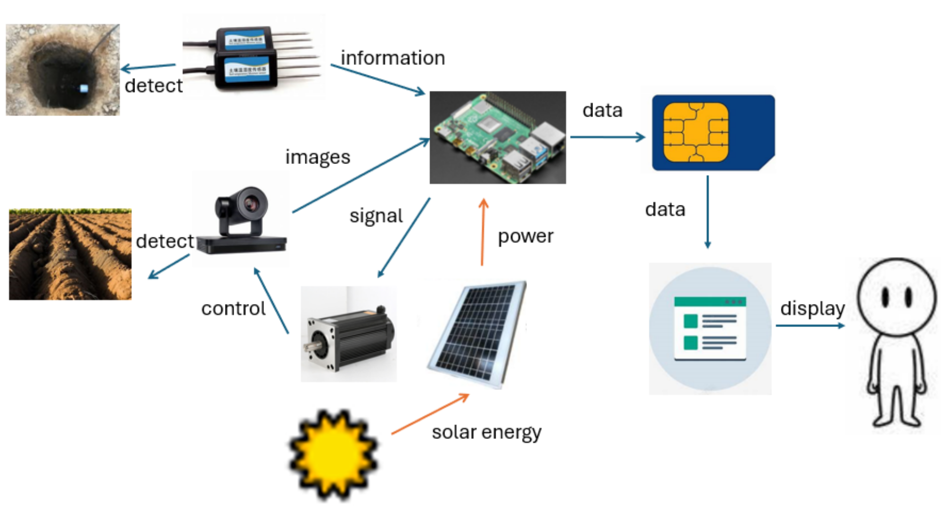

Figure 1: Visual Aid

1.3 High-level requirements list

1. 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).
2. The camera must provide real-time ground condition monitoring (≤ 1 min latency on the web portal).
3. The web portal should provide the access to data from the sensor and camera, with visualization and a digital twin modeling.
4. The entire 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 Block Diagram

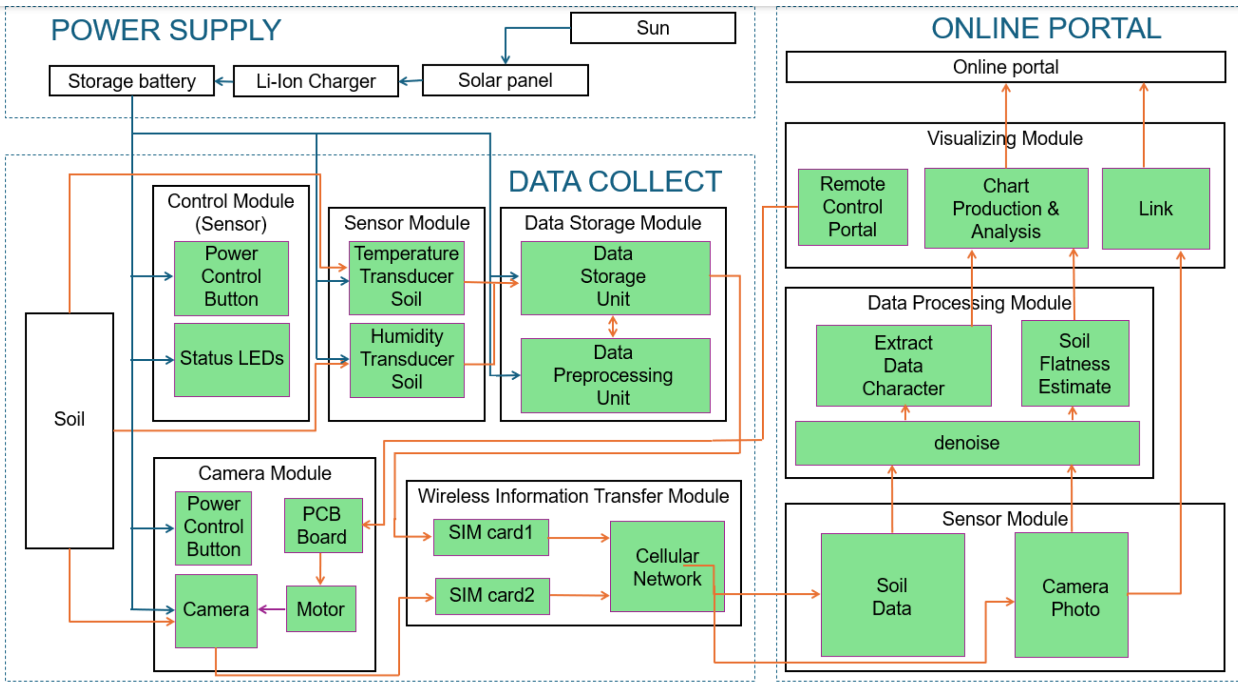

Figure 2: Block Diagram

2.2 Physical Design Drawings

The team has designed three physical models in this project, the first is a cabinet for storing tools of experiment and safety keeping, the second and third is a clamping device for fixing the surveillance camera, and there are two related plans in the future, respectively, a plate for fixing the camera support arm and an electric rotation system for rotating the camera arm.

For the first one, after discussion, we directly purchased a distribution box.

Figure 3: Cabinet

For the second one, the clamping device for fixing the surveillance camera is a combination of sucker and air exhaust. Considering about the difficulty in manufacture the sucker, directly buy one might be a good idea.

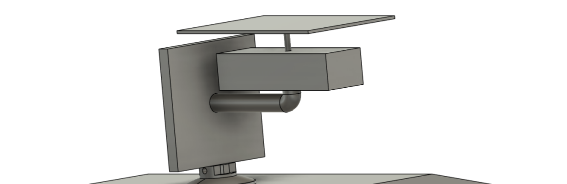

Figure 4: Sucker

For the third one, the second clamping device for fixing the surveillance camera is a combination of clamp and rod for sliding.

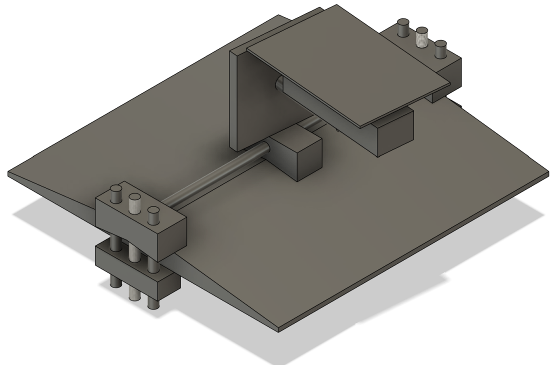

Figure 5: Clamp up-side

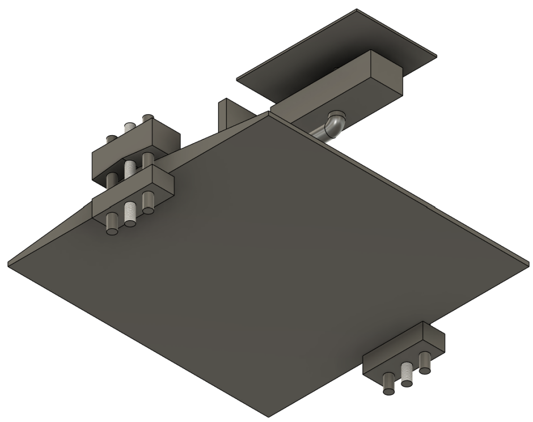

Figure 6: Clamp down-side

2.3 Block Design

2.3.1 Power Supply

Description & Interface Definition: The Power Supply Subsystem is responsible for providing stable and reliable power to all components of our system. It includes a storage battery, a Li-Ion charger, a solar panel and the sun. The solar panel utilizes the photovoltaic effect to convert solar energy from the sun into electricity, providing the main energy source for the remote environment detecting system. This enables the sensors to work continuously in areas away from mains or where electricity is unstable. Its output is connected to the Li-Ion Charger through a cable, and the converted DC energy is sent to the charger for voltage regulation and charge management. It makes the system capable of sustainable and green energy supply, especially for the remote environment detecting system, which is hard to be powered by the outer power network.

The Li-Ion Charger receives the power from the solar panel, and carry out protection measures such as voltage regulation and current limiting to ensure the safe and efficient charging of the energy storage battery. Its input will be connected to the solar panel to receive its output direct current. Output will be connected to the Storage battery and provides power to the battery. It can extend the life of the energy storage battery to avoid excessive loss or safety hazards during charging, which help with the steady of system.

The Storage Battery stores the electricity provided by solar panels and chargers to provide continuous power to the system at night or in rainy weather when enough solar energy is not available, satisfying the power needs of the micro controller, sensors, camera and the Wireless Information Transfer Modules with about 12 V working voltage. It is associated with a lithium battery charger, accepts charging, and supplies power to each power module. And through the voltage control module to adjust the output voltage to the appropriate range, supply to the subsequent components. It provide continuous, stable power for the data collecting module in the system.

Justification: Solar power reduces reliance on grid electricity, making the system more environmentally friendly and potentially cost-effective in the long term. The storage battery ensures uninterrupted operation, crucial for continuous data collection and transmission.

Requirements and Verification:

Requirement	**Verification Method**
The solar panel must provide sufficient power to charge the battery under the average sunlight conditions on ZJUI campus.	Measure the solar panel's output voltage and current under various sunlight conditions.
The battery must provide at least 24 hours of backup power when fully charged.	Discharge the battery at the system's typical current draw and measure the discharge time.
The Li-Ion charger must regulate the charging current and voltage to prevent overcharging and damage to the battery.	Monitor the battery charging process to ensure the charger operates within safe limits.
The power supply must deliver stable voltage within 12V to all modules.	Measure the output voltage of the power supply under varying load conditions.

Schematics, Software Flow Charts, Calculations, and Simulation: The recording system's working vlotage is 12 V.

When the recording system is in sleep State, Current $I_{sp} = 0.03mA = 0.00003A$, Power

Consumption $P_{sleep} = V * I_{sp} = 12V * 0.00003A = 0.00036W$.

When the recording system is in operating State for Sensor Data Acquisition, Current $I_{collect} = 4mA = 0.004A$, Power Consumption $P_{collect} = V * I_{collect} = 12V * 0.004A = 0.048W$.

When the recording system is in operating State for Data Transmission, Current $I_{transmitmin} = 30mA = 0.03A$, $I_{transmitmax} = 500mA = 0.5A$,Power Consumption $P_{transmitmin} = V * I_{transmitmin} = 12V * 0.03A = 0.36W$, $P_{transmitmax} = V * I_{transmitmax} = 12V * 0.5A = 6W$.

The average daily sunlight in Haining is about 6 hours. The $10W * 2$ solar panel can provide sufficient power for the recording system.

2.3.2 Data Collect

Control Module:

Description & Interface Definition: The control module includes 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:

Description & Interface Definition: 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 soil to test the temperature and humidity of our experimental subject. These sensors are respectively buried 1, 3, 5, 10, 15 centimeters beneath the soil to get hierarchical data of the soil.

Data Storage Module:

Description & Interface Definition: 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.

Requirements and Verification:

Requirement	**Verification Method**
The solar power should supply enough energy to the sensor and the supporting system to make sure that they can work 24 hour per day.	check the online portal to see if we can have the data every 15 minutes

The control button should work immediately and the status LEDs should reflect the correct status.	press the button and check on the online portal to see if the system still work and check the status LEDs at the meanwhile.
The sensors should give correct temperature and humidity to the wireless transform module	set a thermometer and a hygrometer under the soil and compare them with the data we get from the sensor

Camera Module:

Description & Interface Definition: The camera module contains the power control button, the camera, the PCB board and the motor. Both elements are connected to the storage battery. The power control button is used to open or cut off the power supply and the camera is used to observe the soil to get the graph. In further research study, we will use the graph to the get the flatness of the soil. The PCB board is used to control the motor and the motor is used as a steering engine to let the camera rotate 0 to 180 degrees horizontally.

Requirements and Verification:

Requirement	**Verification Method**
The solar power should supply enough energy to the camera to make sure it can work well	Check the LED of the camera and the graph it upload to the website.
The camera should give correct picture of the soil and upload them to the online portal.	Take a picture of the soil in real life and make a compare between the picture and those uploaded by the camera.
The photos taken by the camera should be clear enough.	Check the picture on the online portal and use our algorithm of flatness to see if we can use the picture to find the flatness.
The steering engine should let the camera move 0 to 180 degrees horizontally	Use our code to let the motor move and observe.

Wireless Information Transform Module:

Description & Interface Definition: The wireless information transfer module contains three parts: SIM card 1, SIM card 2 and 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 then will upload all the soil data and camera photos to the online portal.

2.3.3 Online Portal

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

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 database to support historical data query and statistics. The sensor module (i.e., the server) can provide APIs, links and other interfaces for other modules to call, while also accepting data from the remote detecting system. As the back-end of the system, it supports multi-user access and data storage.

The data processing module deeply process and analyze the environmental data from the server of the sensor module. The average daily temperature and humidity, soil moisture distribution and soil temperature distribution map are calculated. Moreover, a estimation model for processing the images taken from the camera to get the soil surface flatness is utilized to predict real-time soil surface condition. 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 points cloud [4]. Also, it's possible to use the fractal analysis on digital images of soil surface to get the soil surface flatness parameter [5].

The visualizing module generates a variety of 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 the links to view the camera images and videos. Moreover, it contains a remote control portal to control the PCB board associated with the steering engine in camera module, which enables users to adjust the camera's scope.

The analysis results (processed data) and visualization results (visualized data) from data processing module and visualizing module are fed back to the server for storage and pushed to the Online Portal to display.

The online portal provides a web-based access interface where users can view real data, historical trends, camera images and video streams through a web browser. It connects closely with the the data processing module and visualizing module to get the latest data, charts, and camera images and render them on the front page. In the system, it allows users to remotely monitor site conditions and access past soil data over the network at any time.

Justification: The online portal enables remote monitoring and analysis of the soil and environment 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 model.

Requirements and Verification:

Requirement	**Verification Method**
The portal must display sensor data in a clear and understandable format.	Access the portal and verify that the sensor data is displayed correctly in the charts and graphs.
The portal must provide access to the captured camera images.	Access the portal and verify that the camera images are displayed correctly.
The portal must implement the Soil Flatness AI Model and display its output.	Access the portal and check the performance of the Soil Flatness AI Model by comparing the output result of the AI model with the soil flatness measured by the traditional Straightedge and Feeler Gauge Method.
The portal must be accessible through a web browser on various devices (computer, mobile).	Access the portal with different web browsers and devices to test its compatibility.
The portal should have the user authentication mechanism.	Access portal with authorized and unauthorized usernames to test the user authentication mechanism.

Schematics, Software Flow Charts, Calculations, and Simulation:

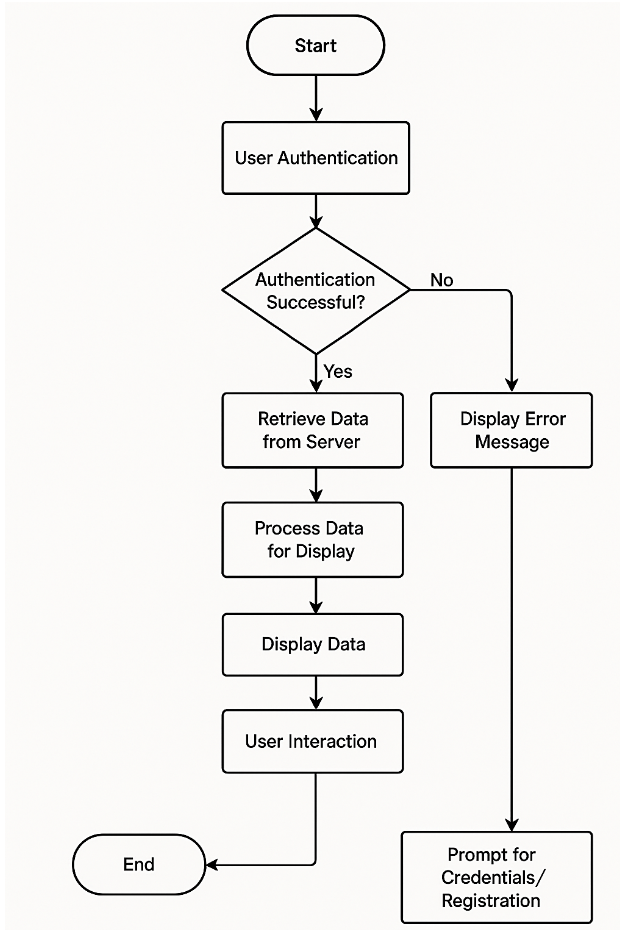

Figure 7: Flowchart for Online Portal Access

2.4 Tolerance Analysis

For the three physical models, only the third model, clamping requires tolerance analysis.

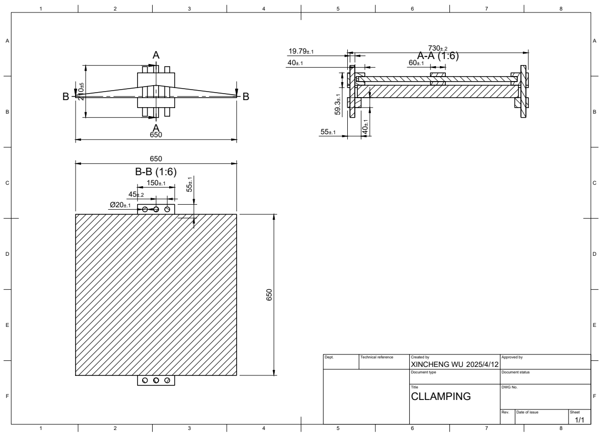

Figure 8: Engineering drawing of the clamp

This picture is an engineering drawing of the physical model, including dimensions, sections and tolerances. The reason for the tolerance is mainly the measurement and the rapid prototyping method planned to be used during production.

For rapid prototyping products, a certain amount of error can not be avoided, and for our clips, our requirements and tolerances focus on the rods and the holes for rods.

For the combination of hole and rod, the requirement of torllerance is indeed strict within 0.1mm. In the engineering drawing, we can infer that the worst condition will be 0.2 mm by the equation $d_{rod}+t_{rod}+t_{hole}-d_{hole}=0.2mm$, which is terrible. So when we are making our products, we will modify its size, make the rods more coarse.

For the sensors, the tested temperature and humidity at 5 p.m. The 13 April is 20.900 (1 cm), 0.298 (1 cm), 20.000 (3 cm), 0.335 (3 cm), 20.000 (5 cm), 0.359 (5 cm) while the data we collected using thermometer and hygrometer is 20.1 (1 cm), 0.291 (1 cm), 19.8 (3 cm), 0.328 (3 cm), 19.7 (5 cm), 0.361 (5 cm). The error is relatively small compared to the data it self and is within our acceptable range.

For the estimation of soil flatness, there will be errors between the estimated value and real one. We will evaluate the soil flatness through algorithm using images, which will have some error and we get the real value using the pin meter 9 [6], which will have tolerance in the measuring part since the soil is soft and the pin meter has intervals among the pins. There are also errors when we measure the length of the outline with the algorithm.

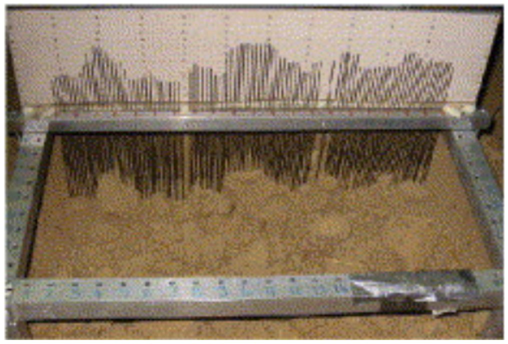

Figure 9: Pin Meter

3 Cost Analysis

Table 5: Bill of Cost

Part	**Item**	**Quantity**	**Cost [RMB]**
Data Collect	Cabinet	1	1350
Data Collect	HYKVISION Camera	1	429
Data Collect	Sucker	1	97 (OPTIONAL)
Data Collect	M4 Screw	LOTS	3
Data Collect & Power Supply	Sensors, Bracket, Solar Panel and Battery	1	23750
Data Collect	3D Printing Material	?	?
Data Collect	esp8266 nodmcu	1	25.72
Data Collect	steering engine	1	34
Online Portal	Cloud Server Rental	2 months	60
TOTAL			25689 (Most provided by Prof Tan)

4 Schedule

Time	Xincheng Wu	Yizhou Chen	Changwen Chen	Dingyuan Dai
2.17-3.3	Background checks, case studies	Do market research on existing remote environment and soil monitoring systems	background investigation	Background investigation
3.4-3.17	Read the product manual	Locally test on my computer whether the soil sensor's transmission and detection functions are normal	installation instructions for research equipment	Read the product manual. Review some literature about the project.
3.18-3.31	All members work together to build the sensor and bracket	dig soil to install senors and help set up the bracket	set up the bracket of sensor and add the waterproof	set up the sensors and bracket.
4.1-4.14	Read the instructions of the surveillance camera and design the fixtures of it	Set up the online website portal using Flask	connect the camera to the network correctly	Discover details of soil flatness, including the definition, usual detecting methods, and so on
4.15-4.28	Design and optimize the monitoring work system	Display and visualize the real-time data on the website portal	set up the distribution box and the steering engine	Design and apply the algorithm to measure the soil flatness, compare it with real measurement result.
4.29-5.19	Complete the assembly and commissioning of the entire monitoring system and prepare for the final demo	Finalize the website's user authentication mechanism and optimize the user's interaction experience	set the camera to the steering engine	Integrate the soil flatness algorithm and result to the website. Compare it with other typical soil samples

5 Ethics

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.

5.1 Privacy Protection

- We should ensure that cameras and sensors collect only soil-related data. We should not record personal activities or other sensitive information. Also, approvals from landowners should be obtained before we start to monitor.
- Protect our collected data, when we are trying to transform and store them, make sure they are secure. For example, the locations and images should be processed to hide important information.

5.2 Data Transparency

- Clearly define data ownership and usage scope. For every group of data, we describe in detail our purposes and the retention periods of the data. Also inform our supervisors.
- Prohibit strictly data exploitation for commercial gain, political manipulation, or nonscientific purposes.

5.3 Sustainable Practices

- If we can, use low-energy recyclable hardware firstly to minimize waste.
- Regularly assess ecological impacts, for example, the soil disruption. And implement mitigation measures.

5.4 Risk Disclosure

- When we find possible soil contamination or other environmental problems, we immediately suspend the project, notify the relevant authorities and provide data proof.

5.5 Technical Reliability

- Check and maintain equipment regularly to ensure that sensors are set up in accordance with industry standards. Inform users clearly and quickly when there are problems with the system.

5.6 Conflict of Interest Avoidance

- We will strictly prohibit impartiality errors caused by accepting bribes, use only the budget funds allocated by the school, and report timely when the budget is exceeded.

5.7 Inclusive Design

- System design needs to take into account the characteristics of different regions, such as the assembly of the device, whether the supply of power systems is adequate. Prepare countermeasures for various environments

5.8 Team Accountability

- Team members need to strictly abide by the content of the contract, seriously participate in the work of the project, and promptly admit mistakes and compensate when they make mistakes.

5.9 Regulatory Adherence

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

6 Safety

In order to protect the safety of students and users, we also need to follow safety rules and avoid risks.

6.1 Electrical safety

- The switch must be kept off until the circuit is confirmed to work properly to avoid electric shock.
- In the case of high operating voltage, you must first undergo high voltage environment training before you can operate.

6.2 Mechanical safety

- When assembling and checking maintenance equipment, due to the need to use tools such as shovels to work on the land, you need to be careful of cuts, falls, sprains and other physical injuries.
- Machining equipment such as welding and cutting may be used when processing the support parts of the equipment, and at least 2 people, including the laboratory

manager, must supervise the use of these equipment to avoid unremediable accidents.

6.3 Lab safety

- Everyone must complete a mandatory online safety training in order to be allowed to work in the lab. Certificates of completion must submitted on Blackboard.
- Read the instruction manual carefully before using the equipment containing chemical substances and follow its instructions.
- Complete equipment must be worn when performing laboratory work to minimize the possibility of accidents.

References

[1] R. C. Hood and, "The effect of soil temperature and moisture on organic matter decomposition and plant growth," *Isotopes in Environmental and Health Studies*, vol. 37, no. 1, pp. 25–41, 2001.

[2] Md. Noabur Rahman, Ryan Hangs, and Jeff Schoenau and, "Influence of soil temperature and moisture on micronutrient supply, plant uptake, and biomass yield of wheat, pea, and canola," *Journal of Plant Nutrition*, vol. 43, no. 6, pp. 823–833, 2020.

[3] HOBOnet Wireless Sensor Network, "hobonet-sensor-network-remote-monitoring-system," *https://www.onsetcomp.com/hobonet-sensor-network-remote-monitoring-system*, 2025.

[4] Karolina Herodowicz-Mleczak, Jan Piekarczyk, Cezary Kaźmierowski, Jakub Nowosad, and Mateusz Mleczak, "Estimating soil surface roughness with models based on the information about tillage practises and soil parameters," *Journal of Advances in Modeling Earth Systems*, vol. 14, no. 3, pp. e2021MS002578, 2022.

[5] Kamal Marandskiy and Mihai Ivanovici, "Soil roughness estimation using fractal analysis on digital images of soil surface," in *2023 International Symposium on Signals, Circuits and Systems (ISSCS)*, 2023, pp. 1–4.

[6] Werner Jester and Andreas Klik, "Soil surface roughness measurement—methods, applicability, and surface representation," *Catena*, vol. 64, no. 2-3, pp. 174–192, 2005.

[7] IEEE, "Ieee code of ethics," *https://www.ieee.org/about/corporate/governance/p7-8.html*, 2016.

Appendix A Example Appendix

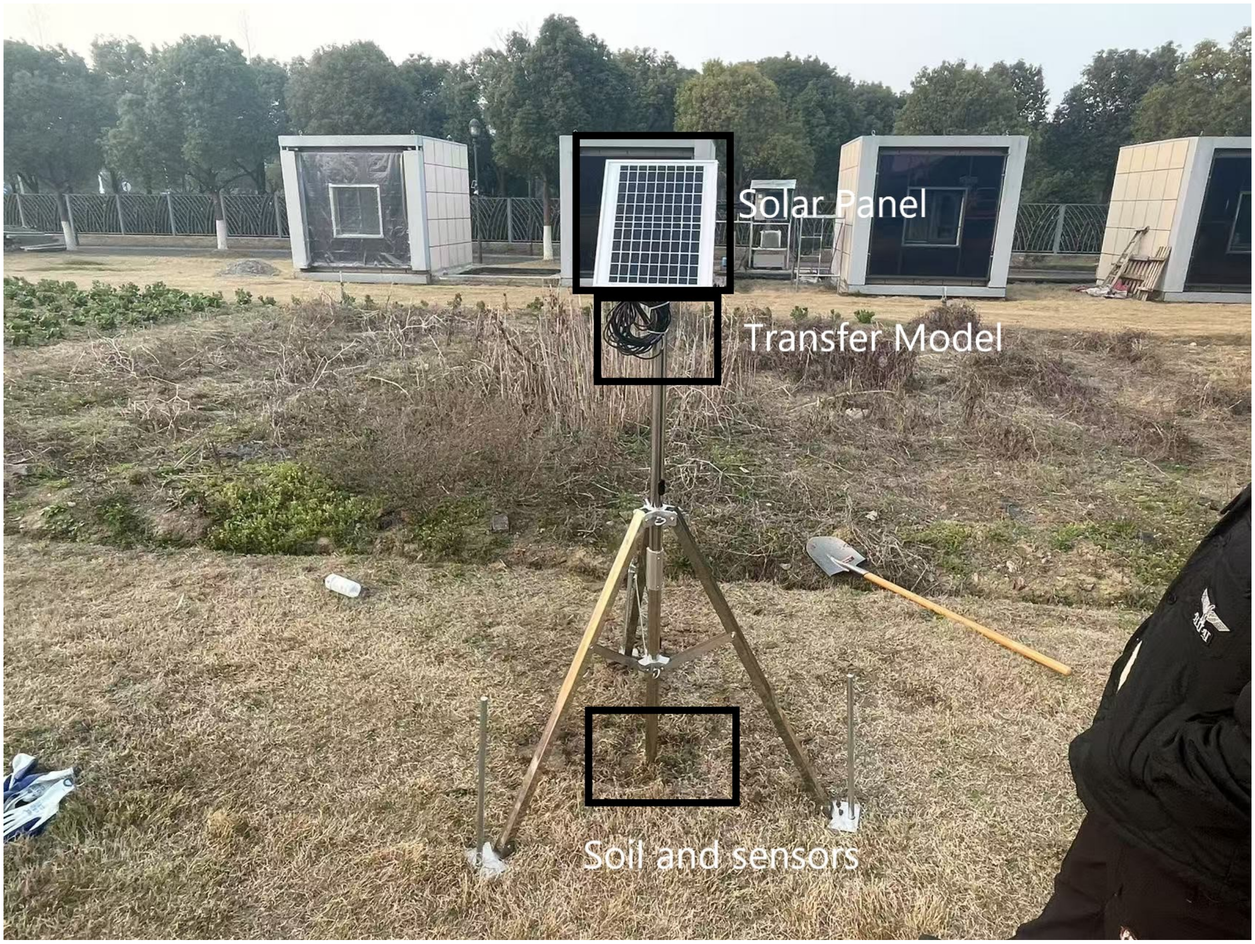

Figure 10: System Overview

Figure 11: Sensors Overview