Climate Adaptation and Sustainable Water Management in Small-Scale Agriculture an IoT-Based Monitoring Prototype

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ABSTRACT

Environmental monitoring is important in small-scale agricultural activities, particularly for managing soil moisture, temperature and water availability. However, regular manual monitoring can be time-consuming for farmers who are unable to attend to their farms continuously. This study presents the development and preliminary evaluation of an Internet of Things (IoT)-based environmental monitoring and automated irrigation system using an Arduino microcontroller. Preliminary testing was conducted to evaluate temperature readings, soil moisture response to watering and water tank notification functions. The results showed that the DHT22 recorded 31°C during night-time observations while the weather application indicated temperatures ranging from 28°C to 25°C. The LM35 sensor recorded a roof temperature of 48°C compared with a weather reference of 32°C. Soil moisture readings increased following repeated watering, while water-level notifications were displayed at 20% and 100% tank conditions. These findings demonstrate the basic functionality of the prototype in monitoring environmental parameters and supporting automated control operations. From a socio-technical perspective, the developed system has potential applications in assisting small-scale farmers with routine environmental monitoring and irrigation management. However, its practical benefits for agricultural productivity, water conservation and farmer workload were not evaluated in this study.

Keywords: smart agriculture; smart farming; climate adaptation; Arduino; water management; Internet of Things.

INTRODUCTION

Agriculture supports food security and rural livelihoods in Malaysia, but farmers are increasingly exposed to unexpected weather conditions. Changes in temperature and rainfall can disturb planting activities and create additional pressure on people who depend on farming as a source of income [1]. High temperature also affects poultry by increasing heat stress. For farmers who work alone, are elderly or cannot always visit the farm, monitoring the growing area becomes another daily responsibility.

This study looks at the farm as both a working environment and a place where families invest time and money. A missed watering period may create additional stress for the farmer, while an unnecessarily running pump can waste water. Monitoring technology is therefore useful only if its information can be understood and translated into simple action. It should help the user manage the farm, instead of creating another complicated task.

Traditional watering and cooling usually depend on farmers observing the condition of the soil and shelter. This can take time and may lead to late action when the weather changes. Hiring extra help during absence also increases operational costs. The problem is therefore not only technical: it concerns labour, access to suitable technology and the ability of small farmers to manage resources in a practical way.

The objectives of this project are to develop an IoT-based prototype for monitoring environmental parameters, including soil moisture, air temperature, shelter roof temperature and water tank level, for small-scale agricultural applications; to implement automated irrigation and roof-cooling control using predefined sensor thresholds, together with real-time monitoring and notifications through the Blynk application; and to conduct a preliminary evaluation of the prototype's functionality by analysing sensor readings, soil moisture response to watering, automatic control operations and water-level notifications. The scope is a small prototype based on Arduino and Blynk, rather than a large commercial installation. The proposed system is intended to make environmental information easier to obtain while reducing repeated checking of the farm.

LITERATURE REVIEW

Climate Risks and Rural Livelihoods

Climate variability brings uncertainties to planting, water supply and agricultural income. Malaysian studies connect changes in rainfall and temperature with risks to food security and farmers' livelihoods [1,2]. Heat is also important in poultry shelters because high surrounding temperatures may affect animal welfare. These conditions increase the need for farmers to monitor their surroundings, especially when they are unable to visit the farm regularly.

Smart Agriculture and Water Stewardship

IoT monitoring brings soil moisture, air temperature and water availability into one system. Earlier studies describe sensor-guided irrigation and remote monitoring as ways to improve decisions about watering [3–5,7,8]. Rainwater harvesting can provide a supplementary water source, while tank-level alerts help users know when the supply is low. However, monitoring by itself does not establish a reduction in water consumption; the volume used must also be measured.

Socio-Technical Frameworks

A socio-technical approach looks beyond equipment and considers the people, routines and conditions surrounding its use. Geels [9] explains the links between technologies, users and institutions, while Klerkx et al. [10] examine the social questions raised by digital agriculture. Rose and Chilvers [11] also argue for responsible innovation involving farmers. For this project, these ideas provide a way to consider whether sensor information fits the daily work and resources of small farmers.

Technology Acceptance among Small Farmers

Davis [12] identifies perceived usefulness and ease of use as factors in technology acceptance. A Malaysian study by Aziz et al. [13] further highlights the importance of institutions in encouraging climate-smart technology adoption. Such work suggests that smartphone alerts are useful only when the farmer can interpret them and keep the equipment working. Connection quality, maintenance costs and digital confidence therefore matter alongside the correct operation of sensors.

Research Gap and Project Positioning

Many irrigation studies emphasise technical performance, but small farmers also face limits in labour, time and access to support. This prototype combines crop-area monitoring, shelter roof sensing and tank notifications in one arrangement. It does not include farmer interviews, surveys or adoption measurements; the socio-technical framework is used to discuss potential user needs, not to claim that these needs were empirically tested.

METHODOLOGY

Research Design and Development

A design-and-development approach was used. The work included planning, simulation, circuit construction, Arduino coding, Blynk configuration and prototype checks. The study examined how environmental sensing

and automatic responses could be combined for small farming activities. It was an engineering prototype study, with a socio-technical interpretation of its potential use, rather than a field study of farmer behaviour.

Prototype Architecture and Control Rules

An Arduino Uno received data from the DHT22, four LM35 roof sensors, two soil moisture sensors and an HC-SR04 tank-level sensor. Two relays controlled the watering and cooling pumps. The soil pump was programmed to operate below 30% moisture if water level was above 20%. Roof cooling was triggered when at least two LM35 readings exceeded 45°C. Blynk displayed the readings and generated low-level (20%) and full-tank (100%) alerts. The overall process and the arrangement of inputs and outputs are shown in the project flowchart as depicted in Figure 3.1. The circuit diagram for all sensor inputs and outputs connected to the microcontroller are shown in Figure 3.2.

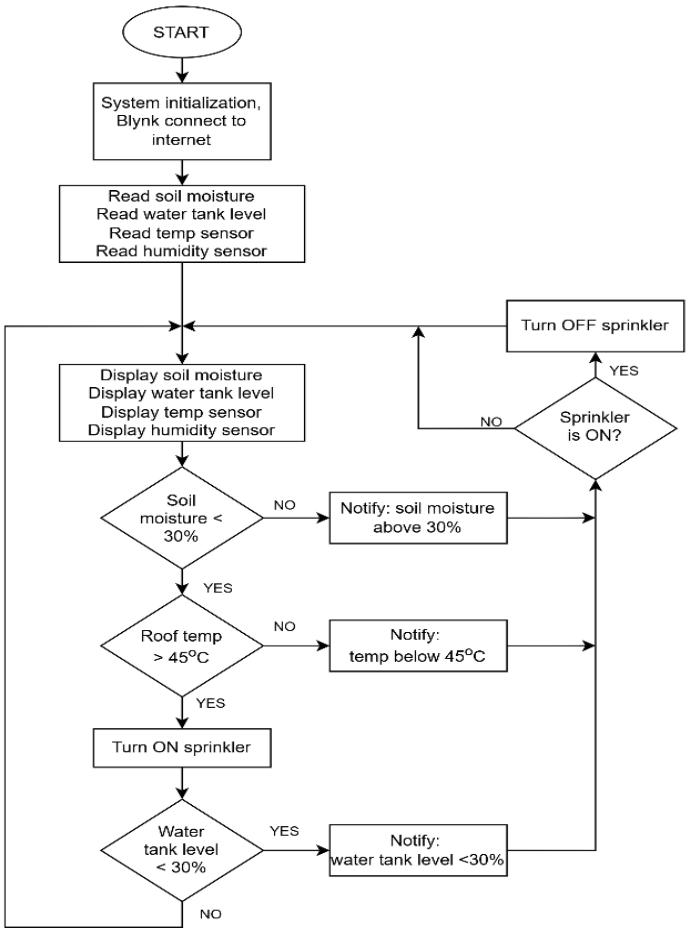


Figure 3.1. Project flowchart

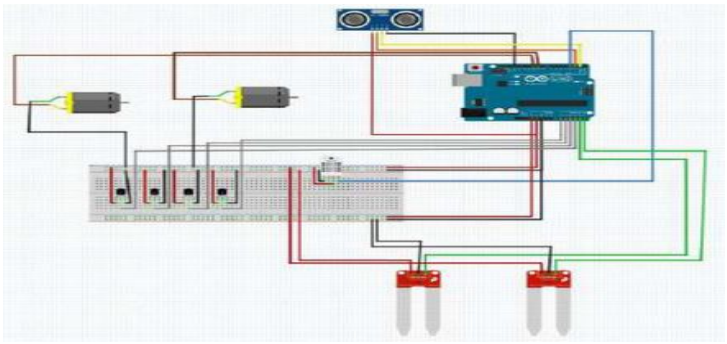
Observation and Prototype Testing

The prototype was checked using Arduino simulation and hardware observations. Local DHT22 readings were compared with a phone weather application at selected day and night times. Roof temperature, changes in soil wetness and tank notifications were also recorded. Results were described in tables and screenshots. Since the mobile weather display represents a wider area, this comparison is not equivalent to laboratory sensor calibration.

Social and Sustainability Assessment Scope

The socio-technical concepts were used to interpret possible implications for farmer workload, ease of access, maintenance and water use; no social data were collected. The design relates conceptually to SDG 2 (food security), SDG 6 (water), SDG 12 (responsible consumption), SDG 13 (climate action) and SDG 15 (land).

These links are intentions of the design, not measured impact indicators.

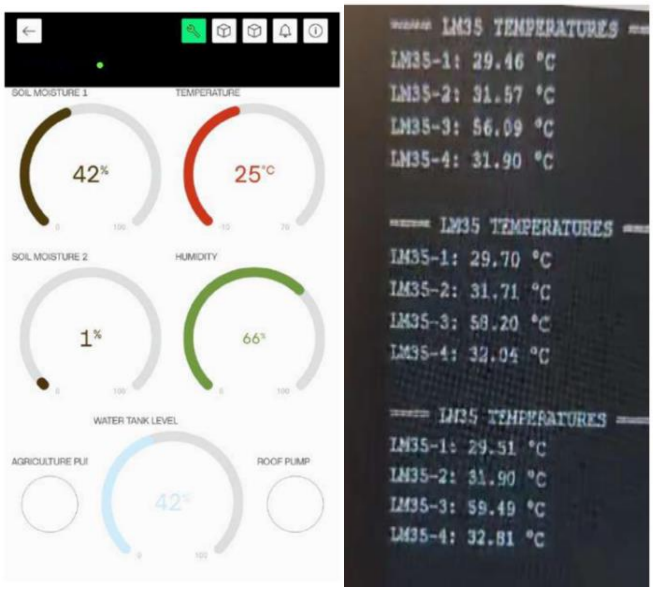


Figures 3.2. Project circuit diagram.

RESULTS

Prototype Operation and Mobile Interface

The prototype was assembled using the sensors, two relays, Arduino controller and Blynk mobile interface. Figures 4.1–4.3 show the simulation output, dashboard, hardware prototype and junction box. In the reported tests, the microcontroller received the sensor readings and operated the relay outputs according to the programmed control rules. The soil pump was designed to activate when the soil moisture fell below 30% and the tank water level was above 20%. The cooling output operated when at least two LM35 roof readings exceeded 45°C. These observations support the basic functioning of the sensor-to-actuator system, although switching delay, long-term reliability and electricity consumption were not measured.



(a) (b)

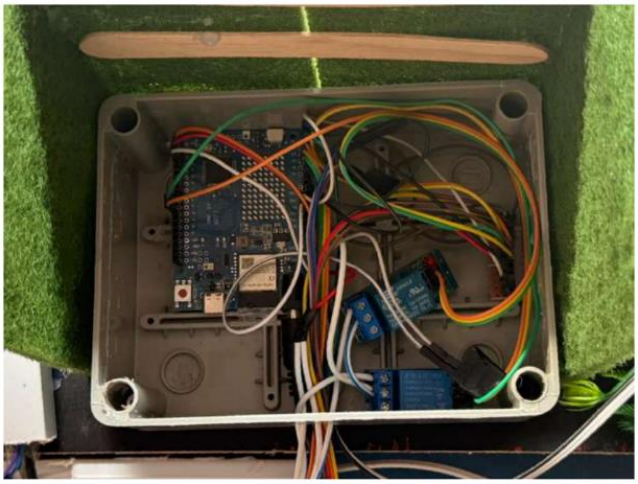
Figures 4.1. (a) Blynk information display. (b) Simulation output.

Air and Roof Temperature

Night-time and daytime DHT22 observations were compared with the readings of a mobile weather application. As shown in TABLE 1, the evening weather reference decreased from 28°C to 25°C between 7:57 am and 10:57 am, while the DHT22 remained at 31°C. The resulting difference increased from 3°C to 6°C. In the afternoon, the DHT22 recorded 32–34°C against weather reference values of 32–34°C; three readings were identical and one differed by 1°C. This comparison indicates differences between local measurements and the wider-area weather display, but it is not a calibration against a certified thermometer.



Figures 4.2. Project prototype



Figures 4.3. Circuit's junction box.

Roof measurements showed stronger local heat variation. At 12:37 pm, the LM35 recorded 48°C while the weather application showed 32°C, a difference of 16°C as presented in TABLE 2. The roof readings were 38°C and 45°C at the next two observations, demonstrating that local readings did not simply follow the general weather trend. The last reading was 34°C on the roof against 38°C in the roof-comparison table. As the LM35 devices were installed near the metal roof, these readings describe a monitored roof location, not the core body temperature of poultry or the air temperature throughout the shelter.

TABLE 1

TEMPERATURE OBSERVATIONS OF DHT22 SENSORS

Time	Weather app (°C)	DHT22(°C)	Difference (°C)
7:57 AM	28	31	3
10:57 AM	27	31	4
12:37 PM	26	31	5
1:37 PM	25	31	6
2:37 PM	32	32	0
3:37 PM	33	34	1

Soil Moisture and Watering Response

A watering trial examined how the two soil sensors responded as water was sprayed repeatedly. TABLE 3 shows that Soil Sensor 1 rose from 21% before spraying to 60% after 20 presses and reached a displayed value of 100% after 25 presses. Soil Sensor 2 increased from 33% to 74% and then also reached 100%. Both sensors showed an increasing response, although the readings were not identical at intermediate stages. The spray-press count indicates the number of actions performed; the experiment did not measure the volume of water delivered per press.

TABLE 2

TEMPERATURE OBSERVATIONS OF LM35 SENSORS

Time	Weather app (°C)	LM35 Roof (°C)	Difference(°C)
12:37 PM	32°C	48°C	+16°C
1:37 PM	33°C	38°C	+5°C
2:37 PM	34°C	45°C	+11°C
3:37 PM	38°C*	34°C	−4°C



Figures 4.4. Blynk information compared to online readings on temperature.

TABLE 3

SOIL MOISTURE DISPLAY VALUES FOLLOWING REPEATED SPRAYING

Spray presses	Soil Moisture Sensor 1	Soil Moisture Sensor 2
0	21%	33%
5	24%	35%
10	28%	40%
15	40%	49%
20	60%	74%
25	100%	100%

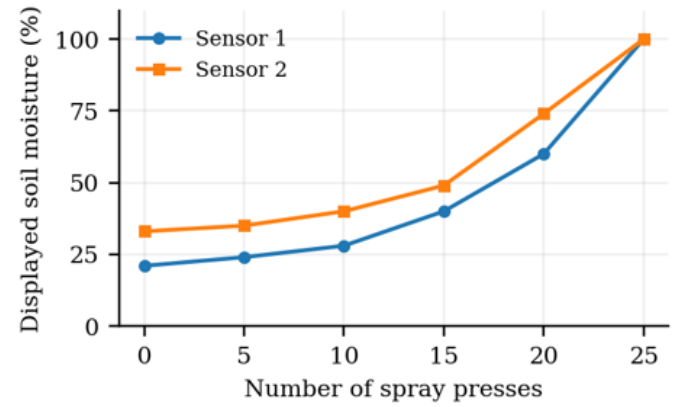


Figure 4.5. Soil moisture readings versus number of spray presses; water volume was not measured.

A second observation checked the displayed moisture readings over the afternoon after wetting the soil. At 12:01 pm, Sensor 1 displayed 100% while Sensor 2 displayed 32% as tabulated in TABLE 4. By 1:01 pm, Sensor 2 had increased to 100% and remained at that value for the remaining readings. Meanwhile, Sensor 1 varied between 94% and 97% after its initial 100% reading. The difference may be related to sensor placement, sensitivity or calibration, but the study did not isolate these factors. The readings show why more than one measuring position may give useful information before an automated decision is made.

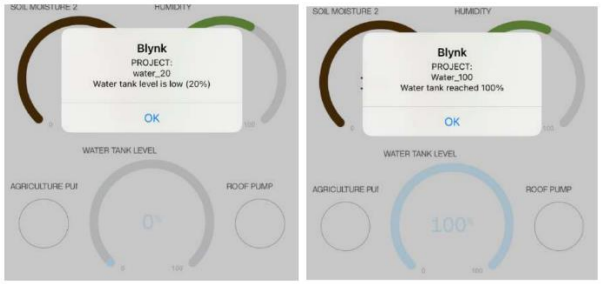
TABLE 4

AFTERNOON SOIL MOISTURE OBSERVATIONS AT TWO SENSOR LOCATIONS

Time	**Soil Moisture Sensor 1**	**Soil Moisture Sensor 2**
12:01 PM	100%	32%
1:01 PM	97%	100%
2:01 PM	94%	100%
3:06 PM	97%	100%
4:01 PM	96%	100%

Water Tank Level and Smartphone Alerts

The ultrasonic water-level system was checked for low- and full-tank notification states. The displays showed the 20% low-water condition and the 100% full-tank condition as depicted in Figures 4.5, with the mobile notification visible in Figure 4.6. This indicates that the prototype can show water availability to a person who is away from the tank and may help plan refilling or water use. However, the study did not measure notification latency, distance accuracy, false alerts or how farmers responded to the messages.



(a) (b)

Figures 4.5. Smartphone notifications for 2 different cases of water tank level. (a) tank level at 20%, (b) tank

level at 100%



Figures 4.6. Smartphone notifications for 2 different cases of water tank level. (a) tank level at 20%, (b) tank level at 100%

DISCUSSION

Farmers' Work and Socio-Technical Usefulness

The Blynk interface brings environmental readings together and may reduce the need for repeated manual checking. From the socio-technical view [9–11], the usefulness of this feature depends on the farmer's routine and available support, not only on whether it works electronically. This possibility is relevant to part-time or older farmers, but workload changes and user acceptance were not measured in this study.

Microclimate Readings and Data Interpretation

The DHT22 showed 31°C throughout the night even though the phone's weather value fell. Differences in sensor position, shielding and source of the weather reference may explain some variation; these were not isolated experimentally. The metal roof also recorded temperatures above the surrounding weather reading. A roof measurement must not be taken as a direct measure of the temperature experienced by the chickens.

Water Stewardship and Practical Sustainability

The soil moisture changes and water tank notifications show how the prototype can provide information for irrigation and refilling decisions. Linking watering to soil condition and available stored water is relevant to responsible water use. However, no flow meter, water-use baseline or comparison with manual irrigation was reported. The prototype therefore demonstrates monitoring and control, not quantified water savings or improved crop yield.

Adoption Barriers and Limits of Evidence

Before use on working farms, issues such as power supply, internet connectivity, sensor maintenance, installation cost and understandable alerts need attention. Perceived usefulness and ease of use [12], together with local support [13], could be examined through farmer interviews or a small pilot study. The present findings are limited to prototype tests; poultry welfare, labour hours, user acceptance and economic benefits remain untested.

CONCLUSION

This study developed and conducted preliminary testing of an Arduino-based environmental monitoring and automated irrigation prototype for small-scale agriculture. The system monitored air and roof temperature, soil moisture and rainwater tank levels. The Blynk application displayed real-time readings and water-level notifications, while predefined thresholds controlled irrigation and cooling. The results demonstrated basic sensor functionality, soil moisture response to watering and successful tank-level notifications. However, improvements in water-use efficiency, crop productivity and poultry welfare were not established.

From a socio-technical perspective, the prototype has potential applications in supporting small-scale farmers through easier access to environmental information and automated control. Nevertheless, its practical benefits for farmers, sustainable water management and climate adaptation remain unverified. Further evaluation of system reliability, resource consumption and farmer acceptance would help determine its suitability for practical agricultural use.

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