DESIGN, DEVELOPMENT AND PACKAGING OF IOT MONITORING AND INTELLIGENT CONTROL SYSTEM FOR CROP HEAT STRESS

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ABSTRACT. *This paper proposes an IoT-based precision agriculture system aimed at mitigating crop yield losses due to drought in the Philippines. The system integrates wireless technology to transmit soil and environmental data related to farmland stress conditions. This information aids farmers in adopting responsive strategies, helping improve water management. The collected data is stored in both local and remote databases and relayed via WiFi to an automated device. This device, comprising a programmable circuit connected to a solenoid, controls water flow in the fields. A pilot of this system was implemented in Zamboanga City, with 24 sensor and automation units installed across three 12x16m2 lots. The units' enclosures were 3D-printed using ABS plastics for protection against environmental extremes. MQTT and HTTP protocols facilitate data transfer to an Android app, enabling remote monitoring. The system uses a Neural Network for intelligent analysis of sensor data, enabling effective irrigation scheduling. The results validate this system as an efficient, scalable solution for smart farming.*

Keywords: Precision Agriculture, IoT Monitoring, Intelligent Control System, Crop Heat Stress, Neural Network Analysis

I. INTRODUCTION

The anticipated increase in the Philippine population to 142 million by 2045, as per the 2010 Census-based projections [1], presents an alarming challenge. The current food availability is inadequate, highlighting an urgent need for transformative farming approaches. Traditional farming methods prove inadequate for effective crop care and monitoring. The situation is worsened by limited technology aids for farmers and the high cost of such technologies. Data collection for analytics, research, and development in Philippine agriculture is labor-intensive and laggard, with limited access to data for more sophisticated farming practices.

Farmers' concern about drought conditions, particularly during the El Ni√±o phenomenon [2], underscores the need for effective water management. Drought poses a significant risk to crop growth, survival, and yields due to high-temperature levels. As such, a paradigm shift in water management and crop monitoring practices is warranted to increase agricultural productivity and sustain the country's growing population.

The food and agriculture sector is a substantial consumer of water resources, utilizing quantities of hundredfold our personal consumption [3]. Seventy percent of water resources come from rivers and groundwaters, with nearly half of 3600 km3 of freshwater lost during evaporation and transpiration from crops. For many global communities, groundwater, stored underground in porous rock formations called aquifers, is crucial for irrigation, livestock, and drinking water. Thus, effective water management strategies become increasingly pivotal in achieving sustainable agriculture.

Water Stress Sensor Network (WSN) technology could offer a viable solution for farmers grappling with water management issues. WSN advancements have facilitated environmental data monitoring, independent of geographical location [4]. In current implementations, disparate sensors measure data. Apart from its environmental conservation benefits, WSN can assist farmers in complying with state and federal water regulations, potentially reducing water consumption by up to 25% with the help of IoT technology, networks, and data collection [5].

Existing literature presents a wealth of knowledge on leveraging technology in smart agriculture. Some studies have optimized water usage using solar-powered WSN during drought seasons [6]. Others proposed mobile-integrated and IoT-based smart irrigation systems [7], low-cost irrigation monitoring, and control systems with scheduling in cotton [8], and targeted WSN for mango and apple orchards [9]. A survey of WSN in agriculture revealed an overview of ZigBee-based network applications for ambient, soil, and plant condition monitoring [10].

A synergetic approach of Precision Agriculture (PA) and IoT for data collection and decision-making has been demonstrated [11], using sensed data comparison with thresholds for decision-making. However, this paper proposes the use of neural and Evapotranspiration (ET) based methods according to past and current water needs. Similar work has been shown in automatic greenhouse parameter observation and control using PA [12]. With machine learning, there is the added benefit of automatic learning and programming, enhancing water management decision support systems [13].

Currently, irrigation systems estimate water requirements through fuzzy logic, with parameters such as ambient temperature, humidity, and soil moisture not having a significant relationship with crop needs. Through Neural Networks (NN), these parameters can be utilized to decide on irrigation. Mimicking the human brain's information processing, NN solves problems through its neural nodes. This paper explores this technology, particularly for Filipino farmers, to address drought issues through modern and specific crop water management solutions.

The proposed intelligent crop monitoring and automated irrigation system aim to:

1. Assemble incorporated transducers and embed them into a central system to gather environmental and soil data, transmitting these data to the cloud via MQTT.
2. Fit the circuitry to defined enclosures to protect it from the harsh environment.

3. Estimate irrigation schedules for a complete season and automatically irrigate based on NN.

This system offers infield farm monitoring and intelligent irrigation with crop heat stress status determination through soil sensors deployed in the ground and environmental sensors strategically located on the farm. The system can send commands to automation boxes for triggering irrigation flow when thresholds and decisions are satisfied. This data, stored for historical reference, can contribute to effective water resource utilization through automated irrigation during crop needs.

Abiotic and Biotic stresses affect crop growth, development, and productivity [14]. Abiotic stress includes drought, flooding, extreme temperatures, salinity, and mineral toxicity [15], while Biotic stress includes disturbances from living organisms such as fungi, bacteria, nematodes, or harmful insects [14]. This work considers parameters causing Abiotic stress, such as ambient temperature, humidity, luminosity, rainfall, wind direction, soil moisture, soil temperature, and pH.

The remainder of this paper discusses system deployment in Section 2, the results of the modular system in Section 3, and the conclusions in Section 4. References are included at the end.

2. METHODOLOGY

Research Design

Our study utilized a design based on a theoretical framework that models the input, processes, and output of a system for monitoring and managing crop conditions as shown in Figure 1. The inputs include login information, GPS coordinates, sensor and automation box registration, farm details, and environmental data measurements. The processes encompass sending data to cloud-based analysis, environmental data analysis through neural networks, prediction models, crop monitoring, and irrigation control. The outputs derived include crop and environmental parameters, crop stress status, and automation of irrigation.

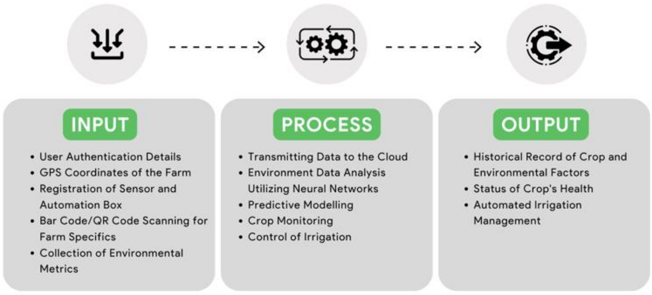

Figure 1. Theoretical framework

Implementation

The study's system architecture, illustrated in Figure 2, mainly consists of a sensor box, automation box, central device, gateway, IoT platform, and client. The system monitors the environmental stress of crops, analyzes and processes collected data, and controls the irrigation flow automatically. This architecture allows for reliable and cost-effective data collection, analysis, and automation.

Algorithm Design

In the algorithm, there are two main parts, the central device, and the automation box. Here's a more expanded version:

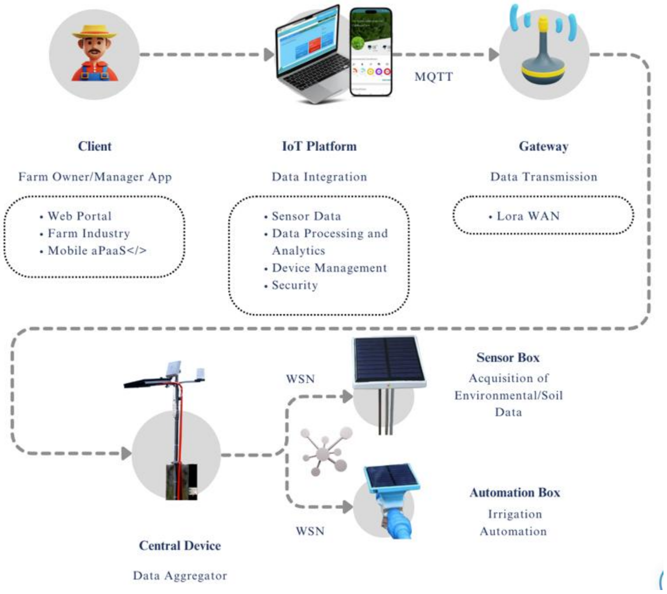

Figure 2. System Implementation

<u>Central Device Algorithm</u>

1. Inputs: Crop type, Date of Crop Plantation, Farm coordinates
2. Output: Irrigation request based on Neural Network decision
3. Begin loop:
    a. **Setup Phase**
        i. Admin Mode: Select the type of crop, date of crop plantation and farm coordinates.
        ii. Load thresholds for each environmental stressor.
        iii. Compute the crop coefficient and evapotranspiration using the data obtained from sensors and based on the selected crop type.
        iv. Estimate an irrigation schedule based on the calculated crop coefficient and evapotranspiration. This schedule suggests when irrigation should take place.
        v. Send the calculated schedule to the cloud for storage and future reference.
    b. **Non-Setup Phase**
        i. Read the current environmental and soil parameters from sensors.
        ii. Connect to the MQTT broker and send data to it for further analysis and real-time remote monitoring.
        iii. Depending on the environmental conditions, the device will operate in one of two modes:
            1. If in Normal Mode, send irrigation requirement computations to the IoT Unit (IU) using the evapotranspiration method.
            2. If in Adaptive Mode, use Neural Networks to model environmental data

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            and compute the irrigation
            requirements based on this model.
    4. End loop when all irrigation requirements are met
       or when a stop condition is met.
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Automation Box Algorithm

```
1. Inputs: Unique identifier, Irrigation Trigger
2. Begin loop:
   a. Setup Phase
      i. Define the port mode: set up the system to
         send or receive data from specific ports.
      ii. Assign ports: assign specific ports for data
          transmission and receiving.
      iii. Configure the automation box: this includes
           settings like network configuration, data
           processing speed, etc.
      iv. Assign a static IP: the automation box has a
          static IP address so that the central device
          can easily find and communicate with it.
   b. Client Phase
      i. Continuously read incoming data: the box
         checks for incoming data from the central
         device.
      ii. Parse the data into a unique identifier ID
          and an irrigation trigger: the box processes
          the incoming data to understand what task it
          needs to perform.
      iii. Write to the port: based on the parsed data,
           the box sends a signal to the specified port
           to control the solenoid valve.
      iv. Repeat the loop until a stop condition is met.
3. End loop when all irrigation requirements are met
   or when a stop condition is met.
```

The pseudocode provided describes the basic operational algorithm for the central device and automation box. It represents a simplification of the full program, which would need to account for error handling, network connection issues, and other potential problems. However, it should provide a good understanding of how these components interact to achieve the goal of automated irrigation.

4. DATA GATHERING PROCEDURE

Data is gathered from the sensor boxes and the central device, which collectively measure soil conditions and environmental parameters. This data is temporarily stored in the device's local database and transferred to the online database when an internet connection is available. Other relevant data for computations, such as the stressor thresholds, are loaded during the setup. The system also connects to the MQTT broker to publish sensor data for further analysis and real-time remote monitoring.

5. DATA ANALYSIS

The system uses a 2-layer Neural Network, trained using MATLAB's 'tool', for data analysis. It employs weights and biases post-training along with the inputs to generate the final decision about irrigation. This decision is sent to the automation box, actuating the corresponding areas. The system also analyzes the sensor data in the cloud-based IoT platform, which facilitates real-time remote monitoring and system management.

6. RESULTS AND DISCUSSION

Assemble incorporated transducers and embed them into the main system that will gather the environmental and soil data and send these data to the cloud via MQTT.

This data was then transmitted to the cloud through MQTT. Prior to the final fabrication of the PCB board, three prototype iterations were developed. The use of surface-mount device (SMD) components facilitated a miniaturization process, resulting in a final production board that was 23% smaller than the preceding prototype. The latest version of both sensor and automation circuitry boards is depicted in Figure 3.

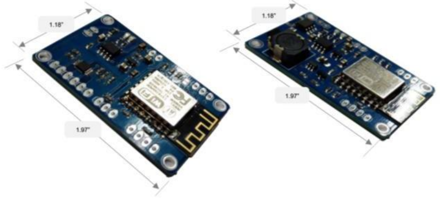
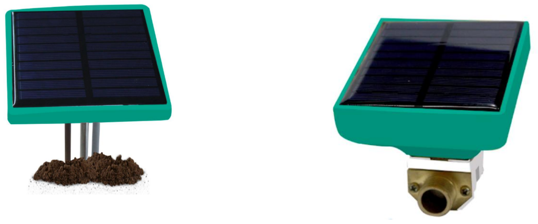


Figure 3. Sensor Box (Left) and Automation Box (Right) Circuitry, Prototype Final Version.

These final boards for the sensor and automation box will be incorporated with soil temperature, soil moisture, ph, and the solenoid valve. The whole circuitry powered with a 2200mAh battery will be properly placed in their 3D-printed enclosures. Also, the assembly of the metallic rods made of coppers which serves as conductors of electrical signals from the soil for the sensors specifically soil temperature, moisture, and pH to read and might as well serves as support when injected into the soil. The rod's length is based on the standard length to get accurate results. The rods must be properly inserted with tight contact with the enclosure to counteract the pressure applied when inserting it into the ground. Silicon sealant is applied to this contact to adhere to the rod and the plastic and at the same time the minimize risk related to long-term exposure to rain/moisture that may lead to water being absorbed into the gaskets.



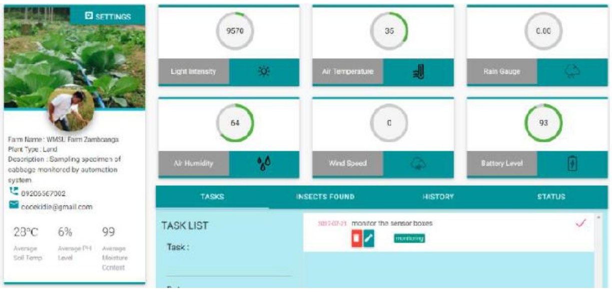
Sensor Box Automation Box

Figure 4. Sensor and Automation Box

Environmental Sensors were integrated into the central device as shown in figure 5. The final setup has a capacitive touch LCD screen to allow interaction with the farmer in the environmental and soil conditions of the crop. Active sensors and automation boxes are also displayed on the screen along with their registered serial numbers.

Figure 5. Central Device with the Sensors and LCD screen along with the readings from the sensors.

The monitoring of environmental and soil parameters is shown in Figure 5. There are 18 sensor boxes deployed in every row of the experimental lot.



Farm Name : WMSU Farm Zamboanga
Plant Type : Land
Description : Sampling specimen of cabbage monitored by automation system
09205567002
cocekidie@gmail.com

23°C Average Soil Temp
6% Average PH Level
99 Average Moisture Content

TASK LIST
Task :

monitor the sensor boxes

Figure 6 Web Platform for Monitoring conditions of the crops.

As shown in Figure 6 are the active sensor boxes connected in the system with their corresponding reading from the sensors. Also, 18 Automation Boxes are installed in every pipe of the 16 rows. Before these devices get online, a simple registration of their identification by scanning the barcode using the mobile phone. When data is sent from every sensor box, the system is performing a quadratic regression, so that a single piece of information should reflect in the system that represents the whole farm's soil condition.

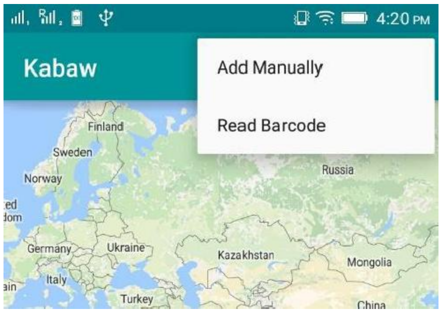
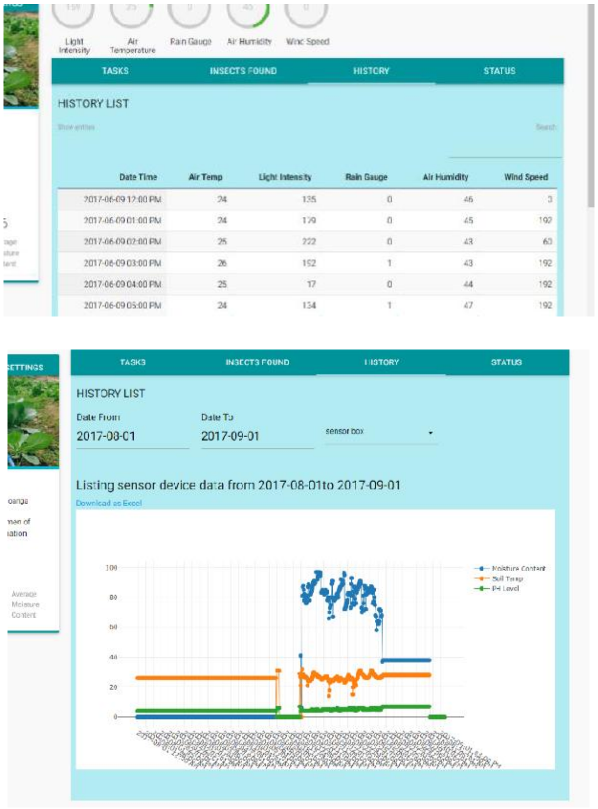


Figure 7 Barcode scanning for Sensor and Automation Box registration.

Figure 8 Active 18 sensor boxes deployed in the field.

A graphical representation of the battery's health of the central device is provided so that farmers are aware of its power capabilities. Figure 9 below shows the history tab that provides farmers with a comprehensive condition of their crops — subscription to the proper topic by the user where the parameters can be noticed.



HISTORY LIST

Date Time	Air Temp	Light Intensity	Rain Gauge	Air Humidity	Wind Speed
2017-06-09 12:00 PM	24	135	0	46	3
2017-06-09 01:00 PM	24	179	0	45	192
2017-06-09 02:00 PM	25	222	0	43	63
2017-06-09 03:00 PM	26	152	1	43	192
2017-06-09 04:00 PM	25	17	0	44	192
2017-06-09 05:00 PM	24	134	1	47	192

HISTORY LIST
Date From 2017-08-01
Date To 2017-09-01
sensor box

Listing sensor device data from 2017-08-01to 2017-09-01
Download as Excel

Figure 9 History of the gathered data from the environment and soil parameters.

To represent the data in an understandable visual that is useful for engineers and scientists, the proponents used a free and open-source graph API from Plotly. Users may also download their raw data in an Excel file.

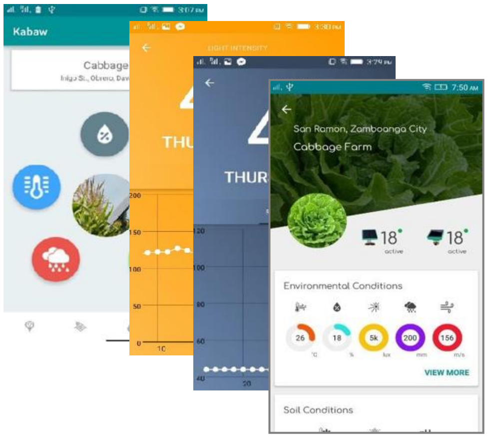


Figure 10 Android Mobile Application reading the sensed data.

The monitoring of the environment and soil parameters can be accessed on mobile phones as shown in Figure 10. The user interface (UI) is considered to address the usability and accessibility of the app. The app presents brighter and bigger fonts, buttons, and interfaces, considering the age of the target users.

The sensor data can be remotely seen by initiating a connection to the MQTT broker. The HTTP server running on the same machine allows users to log in to their farms/gardens and monitor the ambient plant situation, its moisture level, irrigation status, and the irrigation schedule as well. Based on the collected data and one-time setup of the system, the irrigation schedule will automatically be programmed usually based on neural networks.

Fit the circuitry to its defined enclosures free from the effects of a harsh environment.

Figure 11 presents the placement of the chip with the 2200 mAh Lithium-ion and testing the functionality of the sensors. The whole setup is then covered by the 5V, 1W, Monocrystalline solar panel. The photovoltaic solar panel is used as an energy-harvesting component of both the sensor and the automation box. The enclosure of the boxes is 3D printed and takes 6 to 7 hrs. to complete.

Figure 11 Circuitry Placement in the enclosure

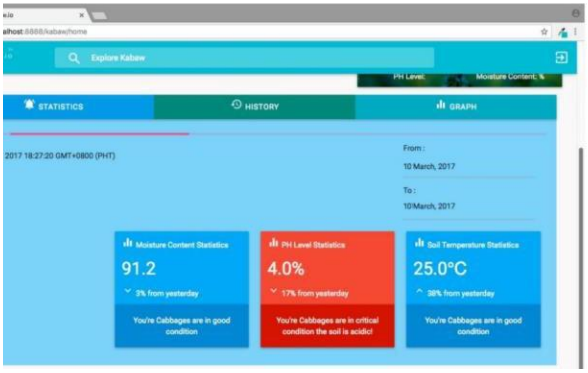
Along with the progress is the fabrication of the stainless-steel enclosure of the central device, as shown in Figure 12, with 610 cm x 377 cm in size. One careful consideration, aside from the ventilation and rigidity, is the addition of wire systems for path/route planning. Taking this into account during product design rather than adding them later accelerates the development process, saves time and rework costs, and helps to ensure efficient product assembly and serviceability.

Figure 12 Central device Stainless Steel Fabrication

After multiple designs and trials in 3D printing and steel fabrication, the final design is considered, especially because it must withstand harsh conditions and satisfy beauty and strength.

Estimates the irrigation schedule for a complete season and automatically irrigated based on NN.

Though the soil water availability can be controlled using irrigation, the ambient conditions are still uncontrollable, thus creating a complicated relationship between them. This implies that the decision taken based on these values does not entirely reflect the needed one. To relate the required output with the sensor inputs, simple equations are not enough, and so here, NN is employed for getting the precisely accurate output. A crop IN requirement database is used to train the NN shown in Figure 13. The bayesian regularization algorithm is used in training done by the network. Weights and biases obtained post-training are used to compute the output and typical mode outcome on the selection of the Adaptive mode.



2017 18:27:20 GMT+0800 (PHT)

10 March, 2017

10March, 2017

Moisture Content Statistics
91.2
3% from yesterday
You're Cabbages are in good condition

PH Level Statistics
4.0%
17% from yesterday
You're Cabbages are in critical condition the soil is acidic!

Soil Temperature Statistics
25.0°C
38% from yesterday
You're Cabbages are in good condition

Figure 13 Results of crop condition and evaluation

After setting the inclusive dates, the application will show the summary of the environmental and soil condition of the crops. Thus, giving the farmer a clearer picture of what's going on the farm, as shown in Figure 13. The said results of evaluation based on the algorithm will influence sending a request to the automation box to trigger the irrigation flow.

7. CONCLUSION

In this work, the researchers were able to meet the objectives of this study for farm monitoring and automatic irrigation. The system has sensor boxes equipped with sensors and WSN connectivity, which continually communicate with the central device to gather environmental and soil data. The central device computes the initial farm details and current reading of the parameters to estimate the irrigation schedule, and change depends on current data trends. Data are sent to the cloud through the MQTT broker to allow remote monitoring for the farmers. Also, it will enable effective water utilization and online monitoring provides smart solutions in water scare areas and people away from their farms. The future study may consider the deployment of the system to multiple farms and observe in a longer period of time how WSN sensor Boxes and Automation Boxes sense and actuate the irrigation. Further improvement could be done in extending the life shell of the Sensor boxes and Automation Boxes by using optimized communication technologies and minimal battery usage. A farm management feature could be added where farmers could consult online for different problems in the farm like pest control and application of fertilizers.

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