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A Prototype of An Automated Farm Monitoring System

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Abstract

The utilization of technology in farming requires a deep understanding of agricultural processes, biology, chemistry, and empirical knowledge. Several parameters are considered and thoroughly investigated when designing a system to support improved, efficient and sustainable farming procedures. The aim of this paper is to propose a prototype of a system for real-time monitoring of environmental and climatic parameters (such as temperature, humidity and soil moisture) in order to provide farmers with accurate, reliable, and on-demand information necessary to make informed decisions. The paper presents the functional requirements, non-functional requirements, block diagram and schematic hardware diagram of the proposed farm monitoring system. A top-down approach is used to design the architectural diagram and the system flowchart. The proposed system is implemented on a Raspberry PI board. It uses the google maps API and the darksky API to obtain the location information (longitudinal and latitudinal coordinates) of the farm environment. Tkinter is used to implement the graphical user interface, while SQL is used to implement the database for storing information collected by the sensors. The environmental and climatic parameters are collected using sensors installed on the farm. The information collected is logged into a database for storage and further processing and analysis by various components of the proposed farm monitoring system. The results of the analysis provide farmers with the information required for accurate, reliable and timely decision making.

Keywords: *automated agriculture, farm monitoring, IoT, smart sensor, WSN*

1. Introduction

Automated agriculture, also known as "*precision agriculture*" is the use of sensor-based technologies to optimize the agricultural cultivation process. The technique is used in research and commercial agricultural projects to monitor crop status, regulate water supply for irrigation, manages fertilizer usage, perform pest control, and carry out automated harvesting. These systems reduce the cost and time of operation. They also enable farmers to monitor their crops and local environmental conditions, while preventing possible hazardous incidents associated with manual monitoring. Automated agriculture relies on accurate capturing and real-time analysis of measurements such as rainfall, temperature, soil condition and humidity. The aggregation and analysis of these measurements provide useful information that guides farmers on the application of fully automated procedures to the crop cultivation process chain (Dong et al., 2013). The way farmers manage farmland and farm animals are also influenced by technologies such as satellite driven geo-positioning systems and sensors. These technologies detect nutrients and water in the soil, which enable tractors, harvesters and planters make decisions on what to plant, when to fertilise, and how much to irrigate.

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Automated monitoring systems are based on wireless sensor networks (WSNs). A wireless sensor network comprises a large number of sensor nodes where each node detects physical phenomena such as light, heat, pressure and humidity. Wireless sensors can be used to collect information on rainfall, water levels and weather conditions and store the information in a centralized database (UDFC ALERT, n.d.). The analysis of real-time data obtained from the fields provides farmers with reliable information and the ability to change strategies as the need arises. This prevents farmers from making decisions based on some hypothetical average condition, which is completely different from what the actual situation in the farming environment (USC Precision Agriculture, n.d.). Wireless sensor networks can be used to monitor rapidly changing climatic and environmental conditions, as well as the growth of crops and animals (Nandurkar et al., 2014). Other applications of wireless sensor technology in precision agriculture include monitoring and control of greenhouse parameters (Devi & Kumari, 2013), monitoring of an outdoor agricultural production environment (Hwang et al., 2010) and video surveillance and data monitoring of crops (Garcia-Sanchez et al., 2011). It is possible to WSN technology based on sensor nodes, surveillance facilities and a base station to communicate and gather information about the farm environment for reliable decision making (Onwuka et al, 2018). This eliminates the need for human monitoring and physical restriction facilities such as fences. The approach also uses technologies such as motion detection, as well as alarm and alert system to provide security.

2. Related Works

Automated irrigation systems use the wireless sensor network technology to provide optimal usage of water (Nisha & Megala, 2014). The sensors obtain real time values of temperature and soil moisture and provide a feedback control mechanism to regulate the flow of water (Manikandan et al, 2016). This provides the farmer with an efficient and inexpensive approach to enhance productivity and effective decision making. A similar work uses smart sensors to measure of physical parameters such as soil moisture content, nutrient content, and pH of the soil (Pryatharshini et al, 2015). The results of the measurement are used to determine the required quantity of green manure, compost, and water that is applied on the farm. A related work proposed a system which uses mobile devices to monitor and control temperature, oxygen level, PH value and water level in a fish farm (Chen et al, 2015). The approach makes the management of a fish farm ubiquitous, easier, more secure and less expensive. The integration of WSN and image processing technologies can be used to monitor the field and detect disease and pest infestation (Jensen et al., 2000)

Smart sensor-based monitoring systems help to improve crop yields by monitoring environmental conditions and providing information to farmers. WSNs are preferred above their wired counterparts due to their flexibility, robustness and the ease of deployment in any type of environment. The use of field-programmable gate array (FPGA) elements provides a system which can be re-configured and re-programmed based on changes in environmental conditions (Mathurkar & Chaudhari, 2013). Hastriyandi et al. (2014) proposed a system which uses multiple temperature sensors placed at several observation positions to monitor the temperature in a greenhouse. The proposed system uses representative and comprehensive observations to achieve optimal analysis and monitoring changes in temperature. A tool developed by Ranch systems (Ranch Ststems, 2018) provides weather and soil moisture monitoring, equipment control and heat index alerts. The farm alarm monitoring system (Farm Alarm, 2018) was designed for environmental surveillance of a farm. The system can detect power failure and low battery and send the information to the phone numbers of up to eight registered users. The system also monitors the temperature, water pressure, power supply, and security. The system is highly customized and allows users to add or remove features. Users can also decide which decision to take when an event occurs. A greenhouse-based WSN uses multiple sensors to monitor daily photosynthetic radiation, electrical conductivity, leaf wetness, temperature, substrate water in real-time (Lea-Cox et al., 2007). The system provides improved plant yield, better water and fertilizer utilization, and reduction in cases of plant diseases caused by unregulated watering. A related study

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proposed a system to monitor and measure greenhouse's temperature, light and soil moisture. (Liu et al., 2007). The data collected by the sensors is sent to a management software for storage and processing.

Internet of Things (IoT) technology has been widely deployed in agriculture to obtain live temperature, soil moisture, humidity and motion data in the farm (Mythili et al, 2019). Such systems perform real-time monitoring and operational control to enhance agricultural productivity. IoT-based farming system also monitors environmental parameters and automates the irrigation system (Ogunti, 2019). A fall below the threshold for optimal crop growth triggers the irrigation system to deliver water into the farm. The system uses a web page dashboard or a mobile app to provide farmers with periodic updates. Intelligent wireless sensors also provide efficient detection and diagnosis of problems in aeroponics. This fully automated technique enables agriculturists to understand the impact of major environmental parameters on plant growth (Lakhiar et al., 2018).

Local farmers in Nigeria can leverage on the availability of NigeriaSat-1 satellite to use remote sensing to support farming activities before, during and after the regular farming seasons (Abdulwaheed, 2019). This is because smart farming promotes efficient use of agricultural equipment, increased productivity and higher return on investment. It also provides better environmental management by preventing excessive application of chemicals such as pesticides, herbicides and fertilizers. A related work suggested that IoT-enabled smart agriculture can provide higher economic benefits and significant improvement in the livelihood smallholding farmers in low- and middle-income countries (Antony et al, 2020). The study used a combination of observation, interviews and surveys to gather information on the challenges related to deployment of smart farm monitoring systems in smallholding farmlands. Findings from the research revealed that the ease with a farm monitoring system can measure relevant environmental parameters and enable users' take decisions based on measured parameters increases the acceptability of such solution. In other words, users are not favorably disposed to tools whose measurements are difficult to interpret or used for decision making.

Alreshidi (2019) observed the absence of research and development in Smart Sustainable Agriculture (SSA), and the challenges resulting from the complexity of devices and processes in smart agricultural farmlands. Hence the author proposed an IoT/AI architecture as a unified model for the development of SSA platforms. The goal is to address issues related to the complexity of components used in precision agriculture and resolve conflicts arising from interactions among these components. A related study proposed a generic reference architecture to provide efficiency by minimizing energy consumption (Triantafyllou, 2019) The model leverages on recent IoT communication technologies and WSN capabilities to integrate the architectural components of a precision agricultural system. An application of the proposed approach on a real-world project showed that the model is efficient and reliable.

A more recent approach to automated farm monitoring is based on the integration of unmanned aerial vehicles (UAV)/remotely piloted aircraft systems (RPAS) and normalized difference vegetation index (NDVI) in small Mediterranean farms (Loures et al, 2020). Analysis of data on seedling failure, differentiated irrigation and differentiated fertilization showed that the technique provides environmental protection, better productivity and higher economic returns. An improved approach is a reference model which addresses challenges (such as high cost of deployment and limited coverage) inherent in current smart farm monitoring systems, which makes them incapable of handling the demands of large farmlands (Saqib, 2020). The proposed solution uses a tree-based communication process to provide a wider coverage for farm monitoring networks. The tool integrates intermediate nodes into existing WSN nodes in farm monitoring systems. It also offers low power consumption (each node requires a minimum 2 mA to operate), reliability (~ 2–5% packet loss

This paper proposes and implements a prototype of an automated farm monitoring system, which uses sensors to obtain relevant data on climatic and environmental parameters. The proposed automated farm monitoring system gathers data related to temperature, humidity, soil moisture content, and soil acidity of the farmland using DHT11 sensor. The sensor has a temperature measurement range of 20-90%RH (0-50°C), humidity accuracy of ±5%RH, temperature accuracy of ±2°C and response time of 6s to 30s. The analysis of these data provides useful information for making informed decisions. This system aims to address the limitations of manual farm monitoring and automate the process to provide efficient operations and enhance productivity. This tool will reduce the amount of time and

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effort required for monitoring and make data gathering and logging faster. The system will also ensure accurate and reliable monitoring of environmental parameters (such as temperature, humidity, soil moisture, and soil pH) to provide farmers with useful data for making informed decisions. Overall, this technology will lead to better smart farming and can be applied to collect large amount of data in other areas apart from agriculture.

3. Methodology

This section presents the requirement specification and design of the proposed farm monitoring system. Requirement specification focuses on system requirements such as functional, non-functional, hardware and software requirements. The design part places emphasis on design principles, design approach, implementation and testing of the system.

3.1 Functional Requirements

A functional requirement (FR) refers to the functionality or service that a system should provide. It also specifies the expected reaction and behaviour of the system in a particular situation. Table 1 presents the functional requirements and a brief description of each requirement.

Table 1 Functional Requirements

ID	Description	Explanation
FR01	Sign up user	A new user should be able to sign up on the system.
FR02	Update user information	Existing users should be able to change or update their information.
FR03	Login farm details	Users should be able to enter information about the farm.
FR04	Update farm details	Allow users to update farm details.
FR05	Display environmental parameters	Allow users view summarized environmental parameters in real-time.
FR06	Infield real-time monitoring	Provide users with the ability to monitor changes in the farming environment in real time.
FR07	Error reporting.	Notification to users in the event of an error.
FR08	Weather forecast.	Provision of at least three days weather forecast.
FR09	Visualization.	Enable users to visualize the outcomes of the system's operations and provide control via a dashboard.
FR010	Feedback.	Provide the means for the user's feedback.

3.2 Non-Functional Requirements

Non-functional requirements (NFR) are constraints on the services which the system offers. Typical examples of NFR are reliability, response time, and storage. Constraints on the system such as I/O device capabilities and the way system interfaces represent data are also elements of NFR. Table 2 lists the non-functional requirements for the proposed automated farm monitoring system.

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Table 2 Non-Functional Requirements

ID	Description	Explanation
NFR01	Similar and easy to use interface	Easy use and navigation of the system. All screens should have similar buttons, menus and layouts. All screens should also have coherent functions and layouts.
NFR02	Provision of clear and detailed notifications to users	The system should use a dialog box.to display a message on the status of an operation to users.
NFR03	Free from bugs and inform the user on any wrong operation	Developers should identify and remove all bugs prior to system release. The system should log errors to enable users detect a wrong operation.
NFR04	Support for portability	The operation of the system on all devices should be based on the same specifications used in this study.
NFR05	Provide scalability	The addition of new features and functionalities without any effect on the overall system performance.

3.3 Design

Fig1 is the design of the automated farm monitoring system.

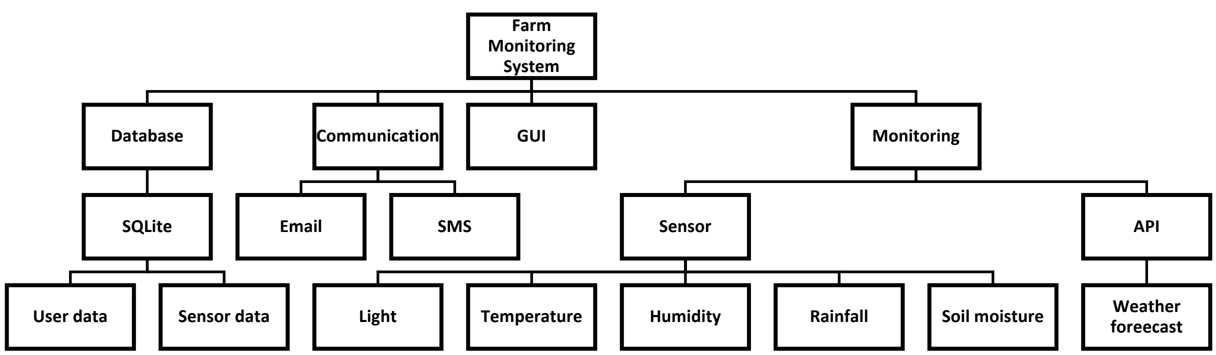

Figure 1. Top-down design of farm monitoring system

The block diagram in Figure 2 illustrates the components of the system such as sensors, microcontroller, database, and the main system which includes python programming environment, server, dashboard, and email accounts. These are the hardware and software components that are interconnected to implement the automatic farm monitoring system

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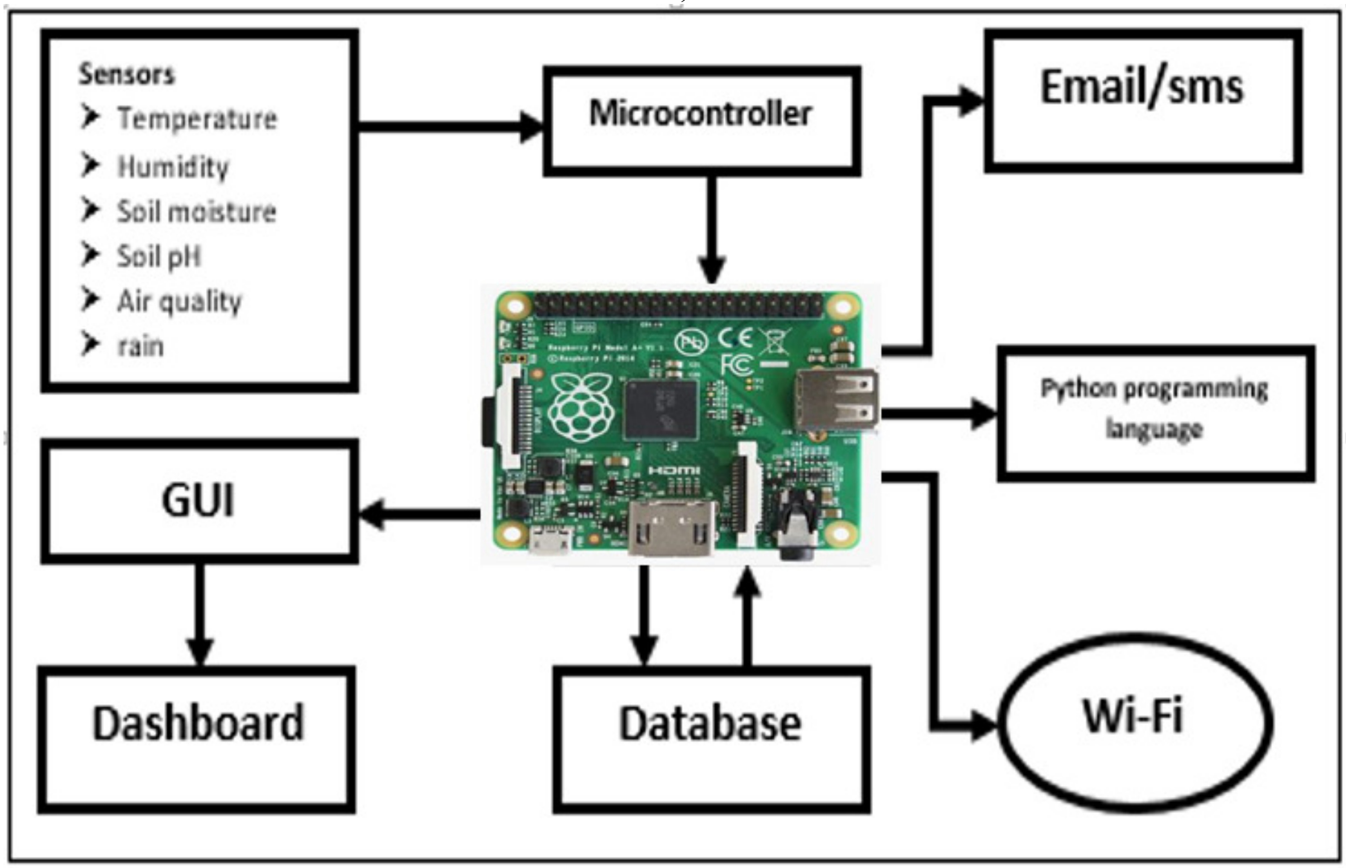

Figure. 2 Block diagram

Fig3 illustrates the system flow chart. The system uses the initialization step to record the current location (using a Geo Positioning System (GPS) technique) as well as powers on and tests sensors to ensure proper operation. The location details enable the system obtain information on the weather conditions on the farmland. The system compares data acquired from the Internet with sensor-based data to analyze and draw conclusions on environmental and climatic variables. The system also presents the statistics of the farming environment and ensures that the data collected tallies with prescribed benchmarks (set by the administrator during system configuration) before such data is saved or exported. Otherwise, the user receives a warning message prompting him to take appropriate actions. Note that the benchmark is based on values of environmental parameters which are known to support high agricultural productivity. Only the farm administrator has a default access to the dashboard, which displays the data collected and statistics of the farmland. However, the administrator can add other users and grant them access rights. Users can download the data in a preferred format such as CSV (Comma Separated Values) or Microsoft Excel and use it for further analysis or research.

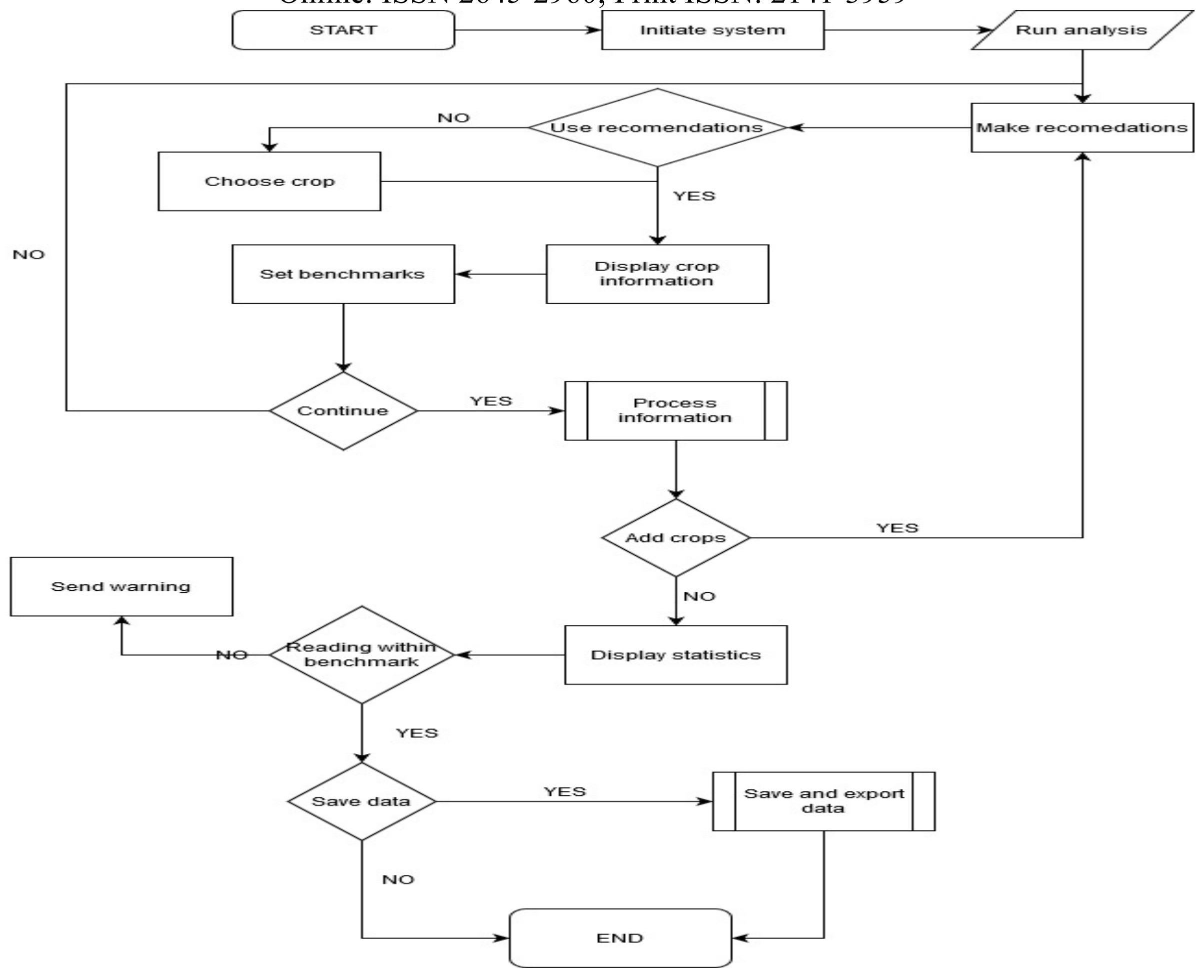

Figure. 3 System flowchart

3.4 Implementation

This section discusses the implementation of the system. The various components are integrated to ensure that the system meets the functional and non-functional requirements stated in sections 2.1 and 2.2.

a) Hardware Setup and Implementation

Figure 4 presents the setup of the hardware and the interconnection of the components used to implement the system.

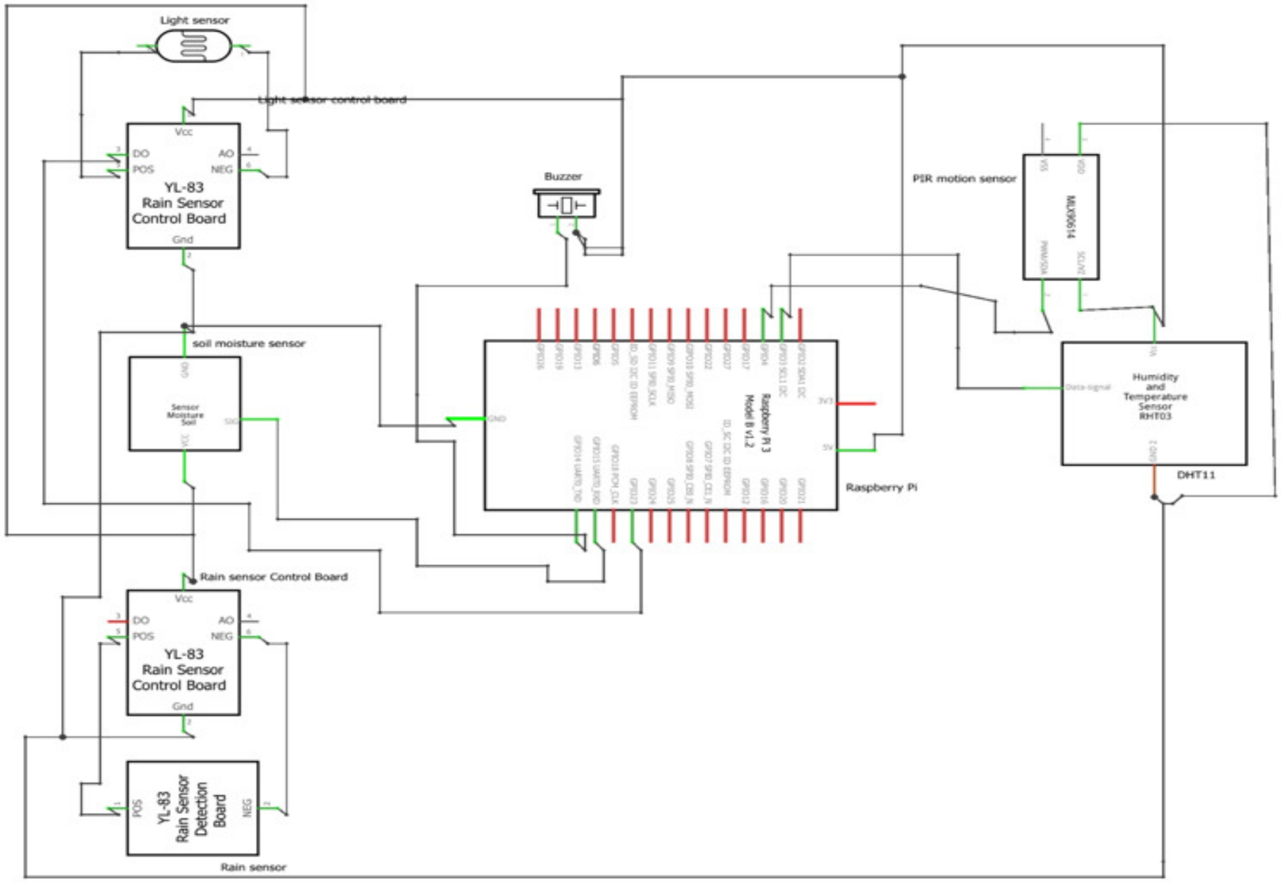

Figure. 4 Schematic diagram of hardware setup

The hardware includes the sensors, Raspberry Pi, and screen, which are used for data gathering, data processing and data visualization respectively. Different sensors perform real-time monitoring of environmental parameters such as temperature, humidity and soil moisture. The information collected by these sensors is transmitted to the Raspberry Pi for processing.

b) Database Implementation

SQLite database engine is used to implement the database of the automated farm monitoring system. Fig5 shows the schema for the SQLite database used to implement the proposed automated farm monitoring system.

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```
CREATE TABLE sensorReadings(
    unix REAL,
    datestamp TEXT,
    temperature REAL,
    humidity REAL,
    light BLOB,
    rain REAL,
    motion BLOB,
    light_duration REAL,
    rain_duration REAL)

CREATE TABLE userInformation(
    first_name TEXT,
    last_name TEXT,
    email TEXT,
    p_number REAL,
    country TEXT,
    states TEXT,
    farm REAL,
    crop TEXT)
```

Figure. 5 Database schema

SQLite is embedded at the end of the program since it is not a client-server database engine like other relational database management systems. The database stores information such as user information, farm information, and sensor readings.

c) API Implementation

The application program interface (API) is used to implement some features and achieve some of the specified functional requirements. The proposed system uses the google maps API and the darksky API. Google maps API enables the system to obtain the longitude and latitude coordinates of any location in the world. The connection to the darksky PI is shown in Fig6.

```
def weather_info():
    url = 'https://api.darksky.net/forecast/845dcb740d63e9ee8d5ae051ac9bf550/9.7999, 8.8667'

    try:
        json_string = urllib.request.urlopen(url).read()
        weather = json.loads(json_string)
    except:
        weather = "Failed to get weather info"
        print ('failed to get infomation')

    return weather
```

Figure. 6 Code snippet for the darksky API

The user enters the farm location and the API queries the location and returns the values of its longitude and latitude. The darksky API, on the other hand, connects the system to the darksky weather forecast system. This provides the farm monitoring system with weather forecasting capabilities as well as future data for enhanced decision making.

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d) Graphical User Interface Implementation

Tkinter is used to implement the graphical user interface (GUI) for the automated farm monitoring system. Figure 7 is the application dashboard.

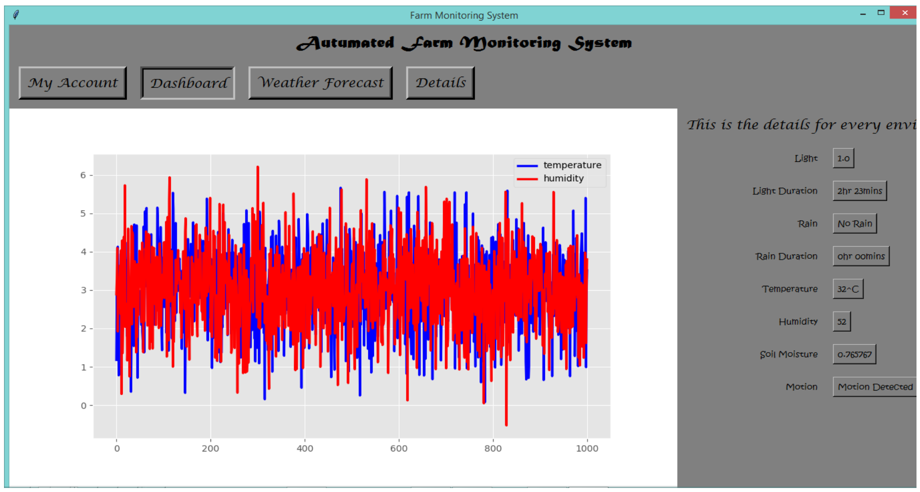

Figure. 7 Application dashboard

The combination of Tkinter with python provides a powerful and easy way to create GUI applications. The GUI provides the visualization to the entire system, making navigation and control easy and user friendly.

e) Working Logic

This describes the logical steps the system uses to achieve the functional and non-functional requirements discussed in Sections 2.1 and 2.2. The pseudocode for the system is as follows.

START
Initialize system
Create database if not exists
Create database if not exists
Get sensor readings
Except sensors not working
  Print sensors not working
  Return to initialize system
Get user information
If new user
  Sign up new user
Else
  Pass
  Except update user information
    Update user information

Log sensor data to database
Except fail to log data to database
    Print fail to log data to database
    Return to create database
Log user to database
Except fail to log user to database
    Print fail to log user information to the database
    Return to get user information
Make API calls
Except fail to make API call
    Print failed to make API call
    Return Make API calls
Print information on the UI
END

4. Results and Discussion

The system is evaluated to determine whether it meets the specified goals. The evaluation criteria include functional requirement testing, non-functional requirement and user interface testing.

3.1 Functional Requirements Testing

This is to ensure that the system meets the functional requirements outlined in Subsection 3.1. The components of the system were tested during and after the implementation. Tables 3 and 4 present the test cases (TS) for signing up and loging the farm details respectively.

Table 3 Test case for sign up

Test reference	TS01
Tested requirement	FR01
Test content	Confirm that the system allows user to sign up
Input	User fill the sign-up form
Pass criteria	The system saves the data and redirects to the homepage

Table 6 Test case for logging farm details

Test reference	TS04
Tested requirement	FR03
Test content	Confirms that the system allows user to log in farm details
Input	User fills the farm details form
Pass criteria	The system saves the data and redirects to the homepage

The GUI in Figure 8 is the sign-up page, where the user enters his personal information and details about the farm.

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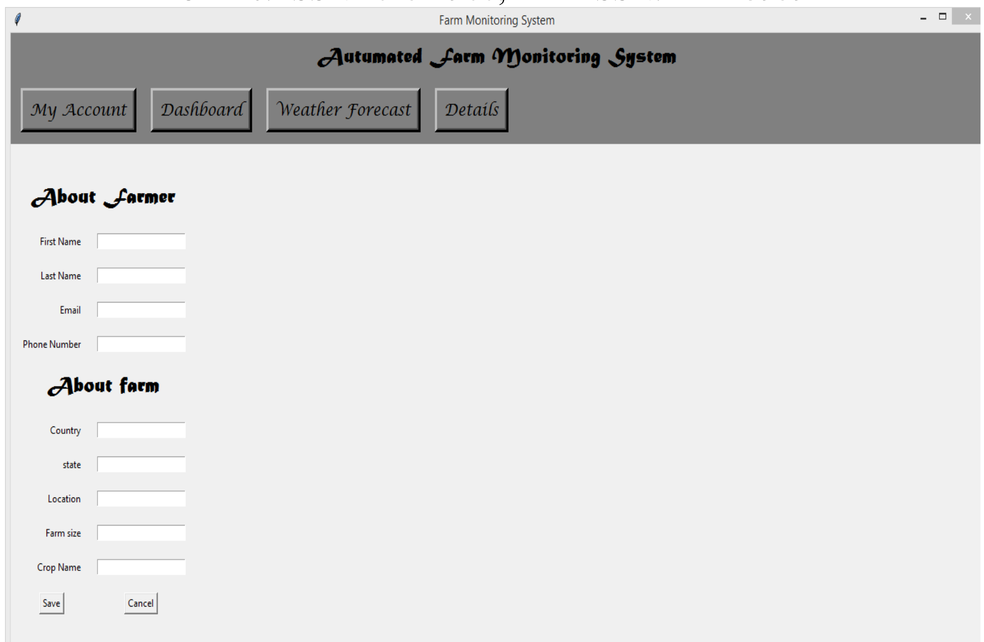

Figure. 8 Sign up page

Table 4 Test case for weather forecast

Test reference	TS02
Tested requirement	FR05
Test content	Confirm that weather forecasting works properly
Input	The user presses the weather forecast button
Pass criteria	The system displays the weather forecast

The GUI in Figure 9 pops up when a user clicks the details button in Figure 8. The GUI shows the ability of the system to provide the user with information on the light intensity, rainfall, temperature, humidity, soil moisture, and human or animal presence.

Table 5 Test case for real-time infield monitoring

Test reference	TS03
Tested requirement	FR06
Test content	Test to check if real-time infield monitoring is working
Input	The user presses the dashboard button
Pass criteria	The system displays real-time parameters obtained from the sensors

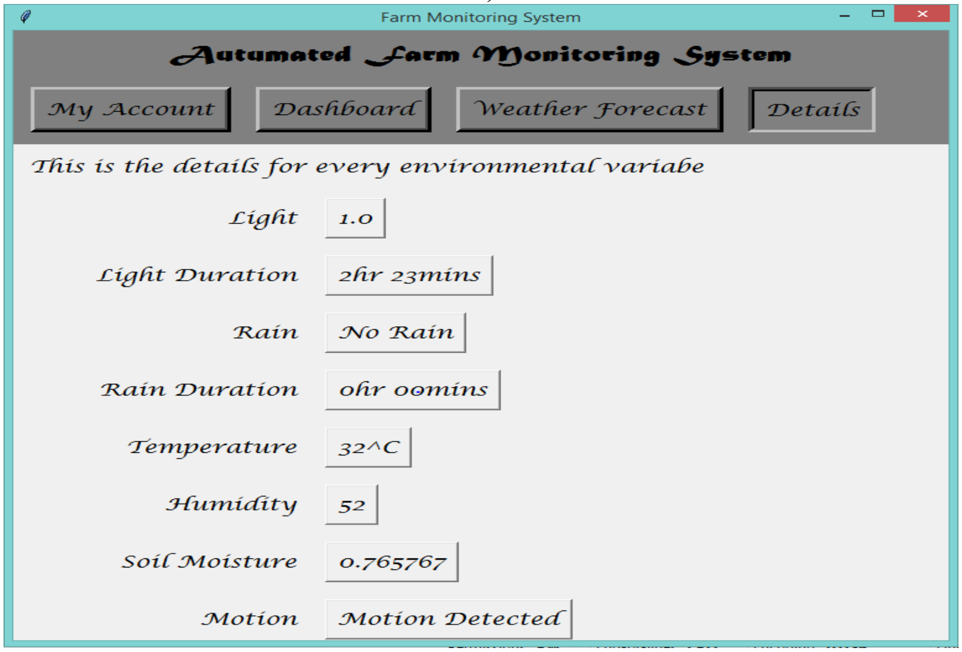

Figure. 9 Sensor readings

The proposed system was tested as shown in Table 5 to determine its ability to perform real-time infield monitoring. The GUI in Fig10 shows the readings for each sensor on start-up.

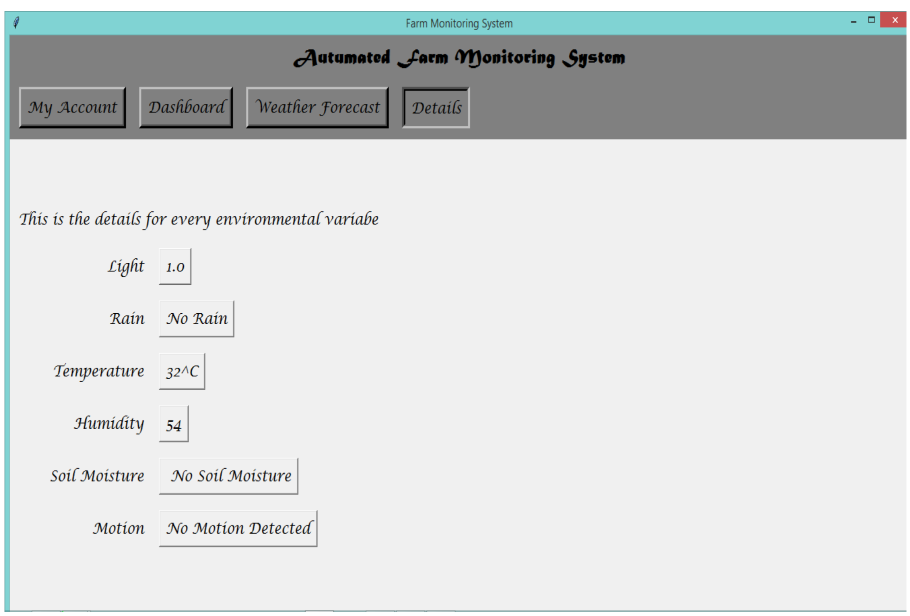

Figure. 10 Sensor readings

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The figure shows the readings for various environmental parameters detected by each of the sensors. The interface in Fig11 displays changes in measurements recorded by the sensors.

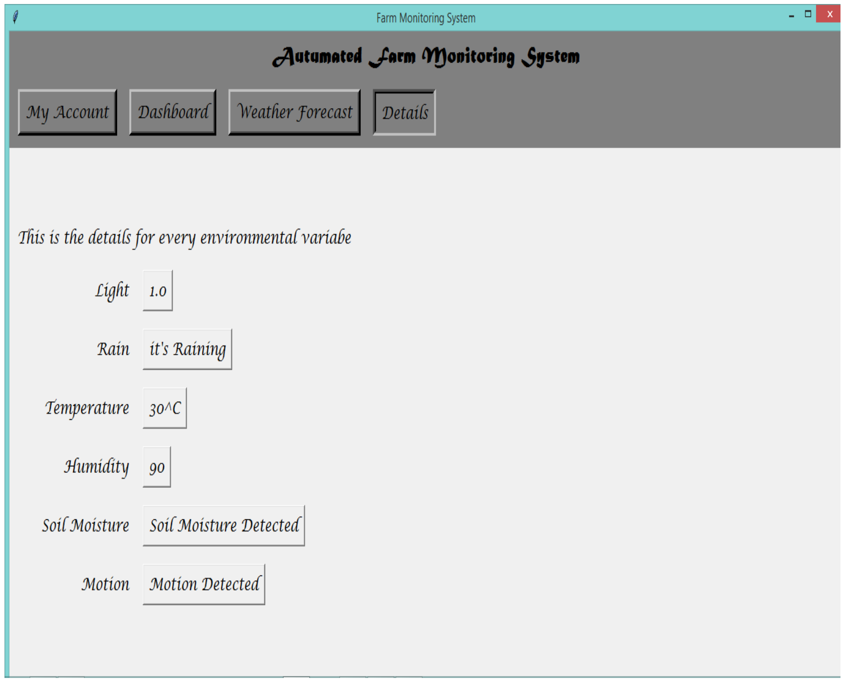

Fig11 Changes in measurements recorded by the sensors

The humidity sensor measures the humidity of the farmland and displays the values on the dashboard. Fig12 shows the reading obtained by the humidity sensor.

Figure. 12 Sensor reading for humidity

The graphical user interface in Figure 13 shows a change in humidity that is being recorded by the sensor installed.

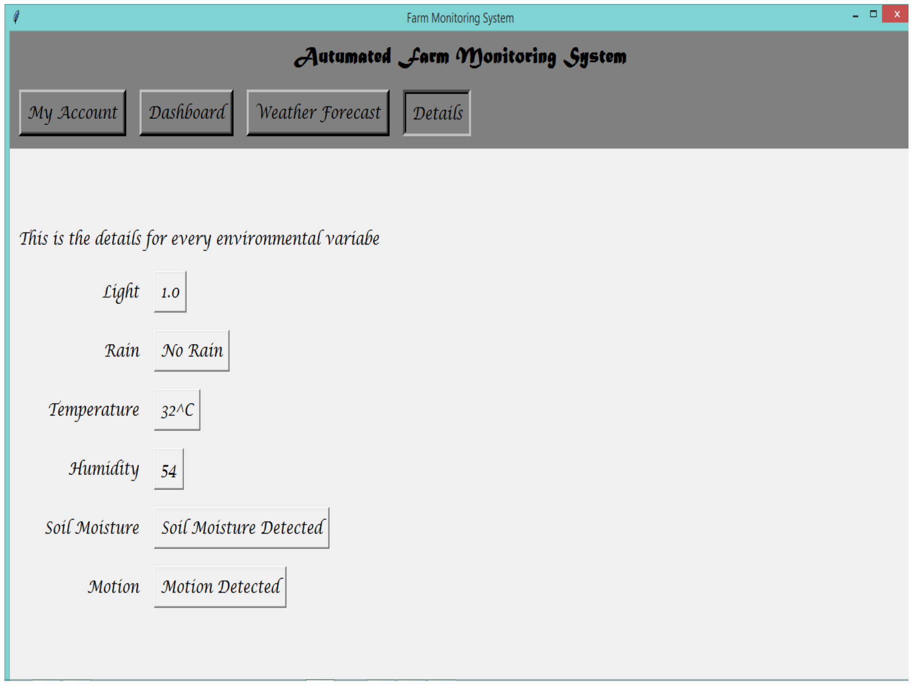

Figure. 13 Change in humidity readings

The light sensor measures the light intensity on the farm. Figure. 114 and 15 illustrate varying values of light intensity in darkness and light respectively.

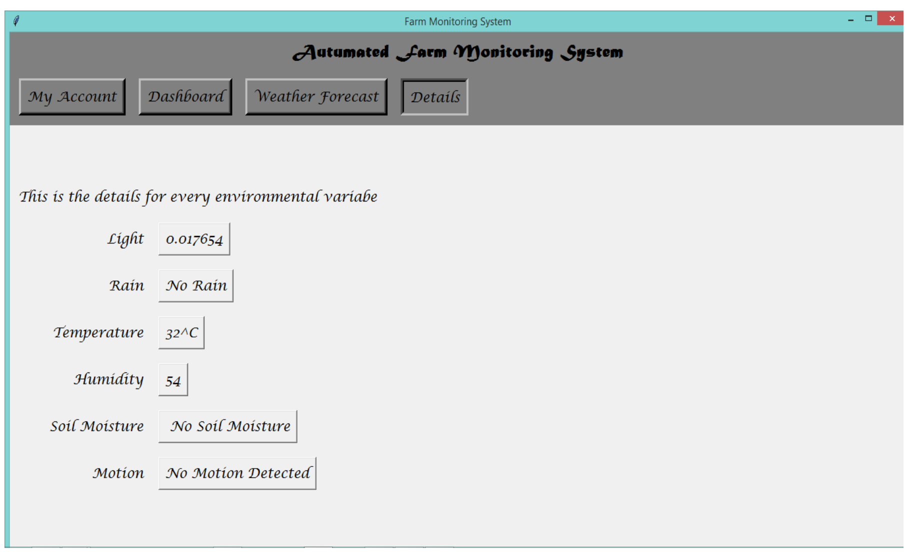

Figure. 14. Light intensity in darkness

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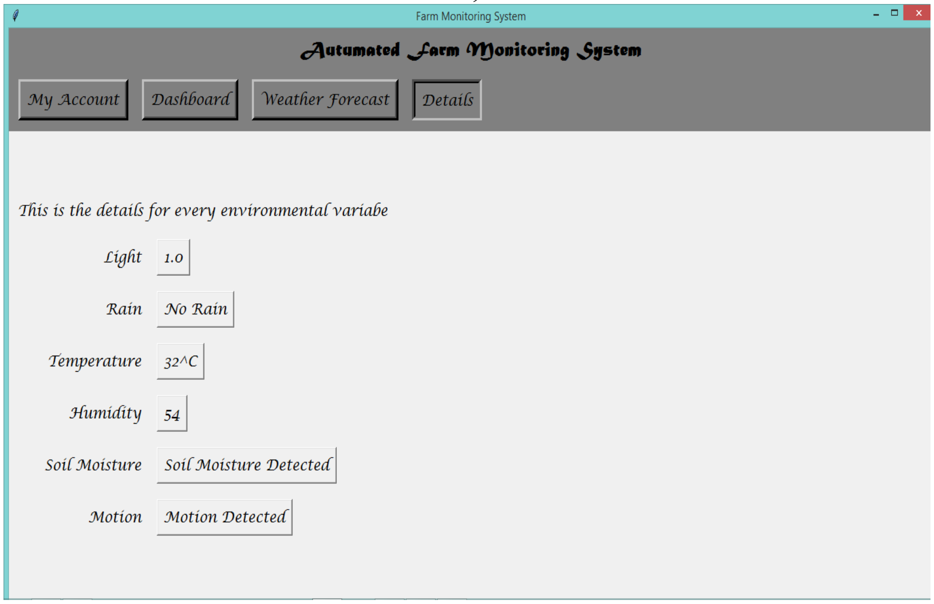

Figure. 15 Change in light intensity from darkness to light

The value ranges from zero when there is absolutely no light to one when there is bright light available.

The rain sensor monitors rainfall and returns a true or false value depending on whether it is raining or not. The graphical user interfaces in Figure. 16 and 17 show the sensor readings when it is raining and when it is not raining respectively.

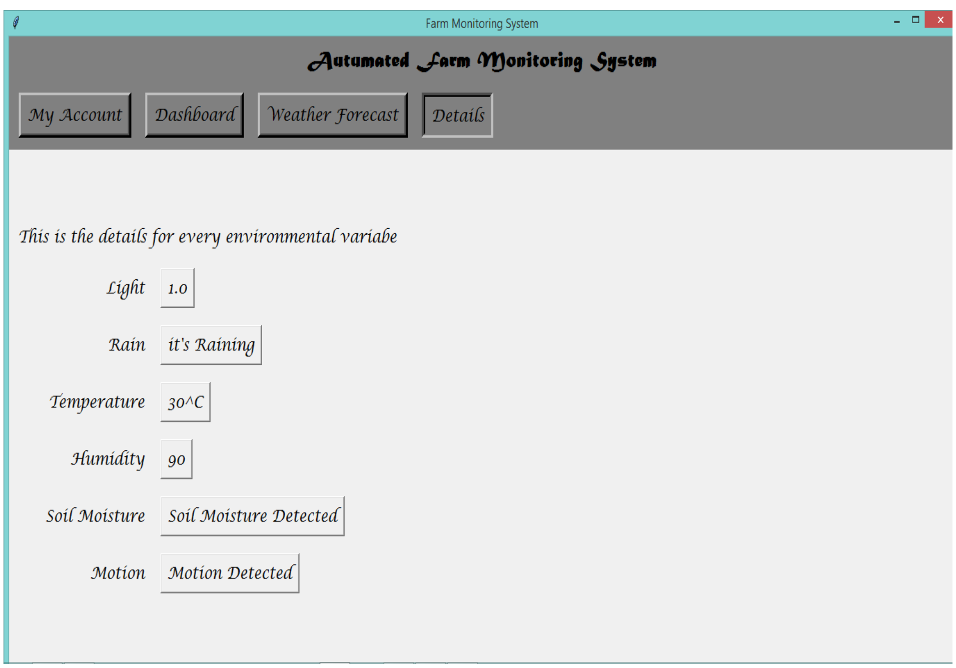

Figure. 16 Sensor reading showing rainfall

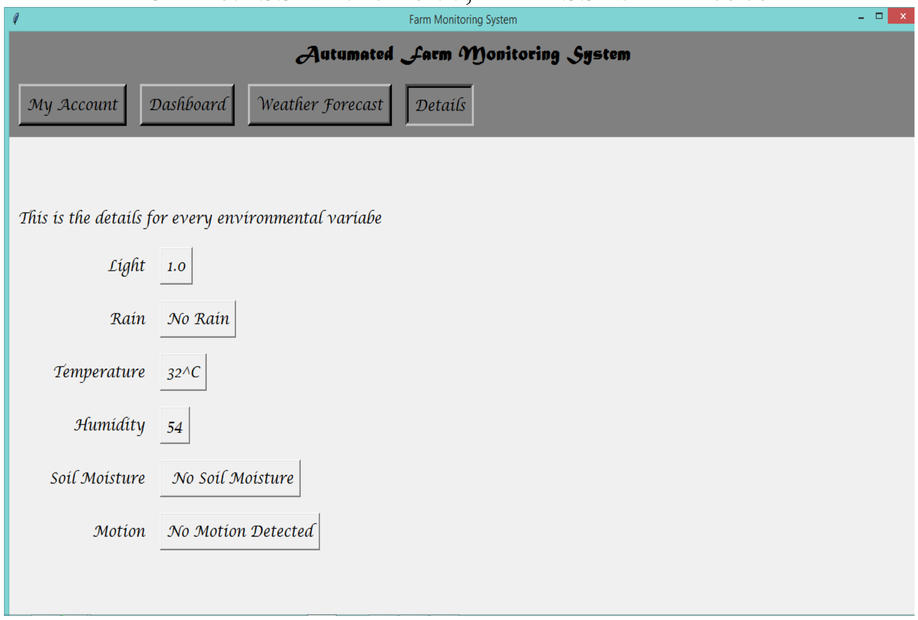

Figure. 17 Sensor reading displaying the absence of rainfall

The value changes when the rain sensor is exposed to rainfall.

The motion sensor detects the presence of moving objects and returns a Boolean value zero or one for when there is no motion and when there is motion respectively. **Error! Reference source not found.**18 and **Error! Reference source not found.**19 show the readings for the motion sensor when a moving object is detected and when there is no motion respectively.

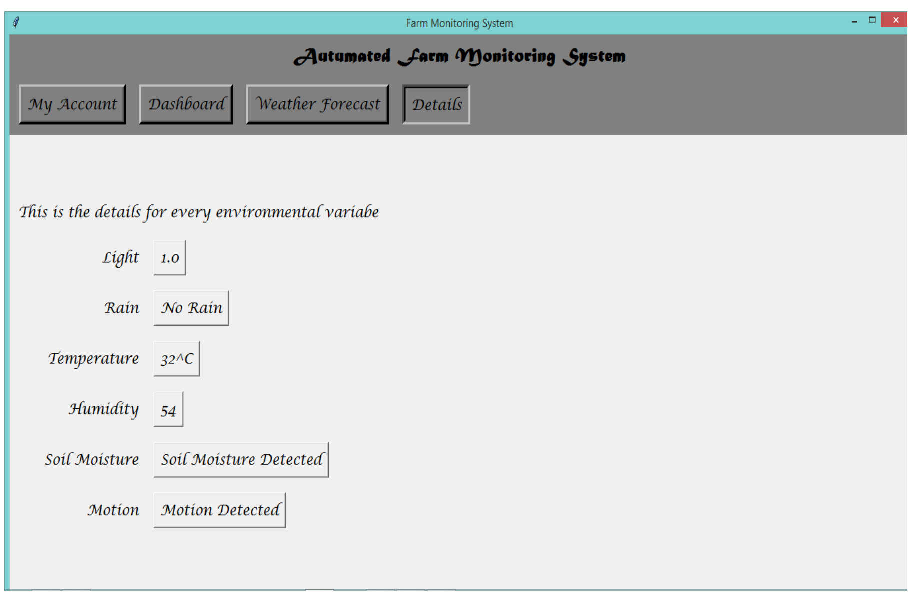

Figure. 18 Sensor reading with motion detected

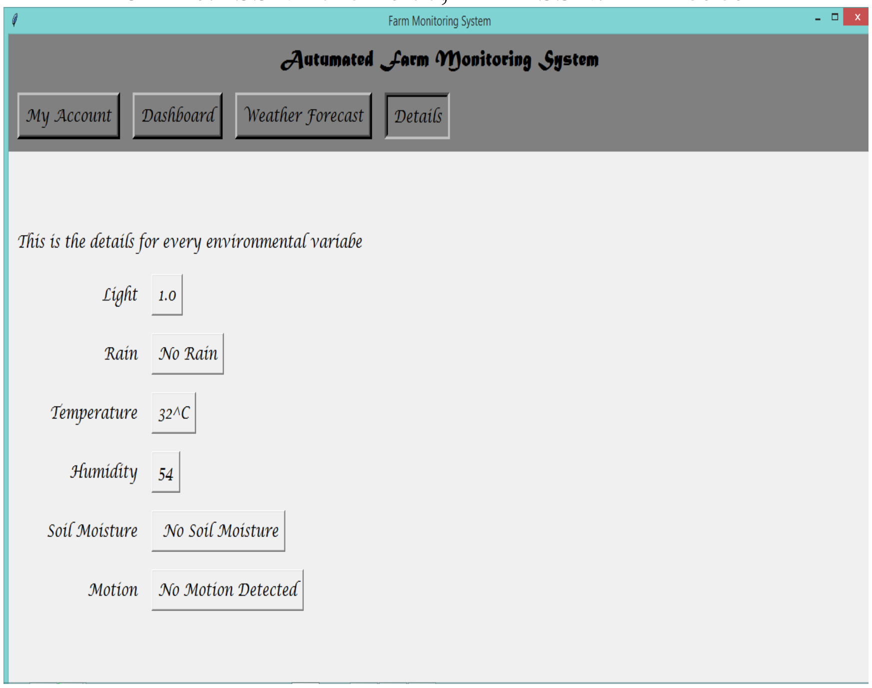

Figure. 19 Sensor reading with no motion detected

The moisture sensor checks for the presence of moisture in the soil and returns the value. The values can either be one for when there is moisture in the soil or zero for when there is no moisture. Figure. 20 and 21 show the values of soil moisture for moist and dry soil respectively.

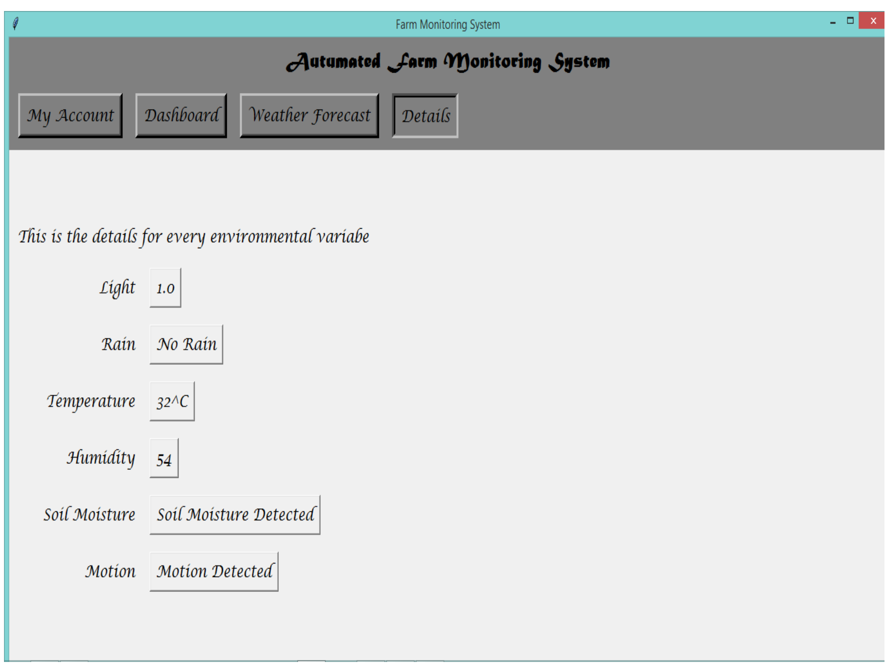

Figure. 20 Sensor reading for moist soil and moisture detected s

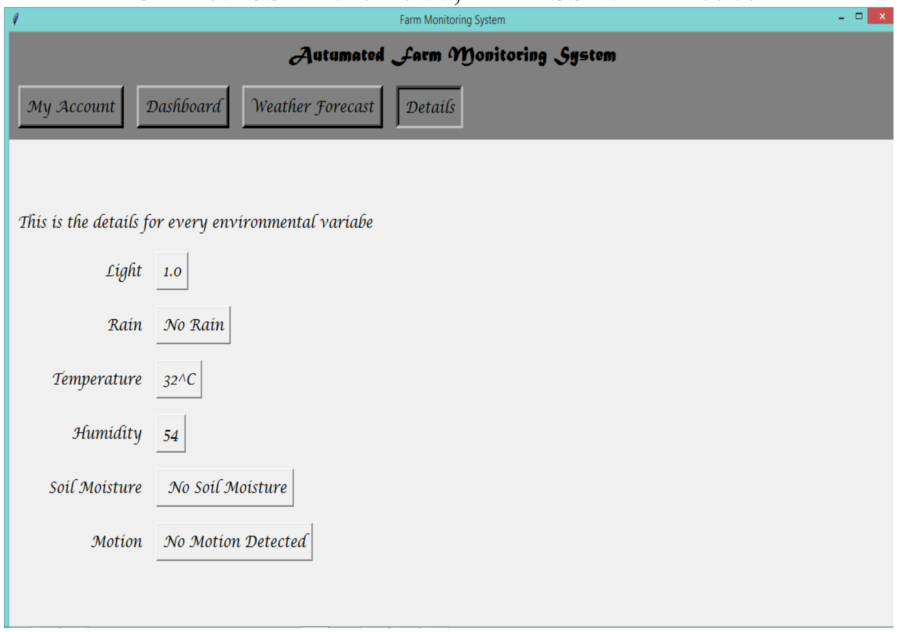

Fig. 21 Sensor reading for dry soil

3.2 Evaluation of Non-Functional Requirements

This section checks whether or not the proposed system satisfies the non-functional requirements highlighted in Section 2.2.

i. **NFR01:** the system provides an identical user interface in all screens, implementing the same style for menus, buttons, and labels as they are presented in the design and implementation phase.
ii. **NFR02:** instructions are clear, detailed and simplified for all screens in the system user interface.
iii. **NFR03:** the system executes all tasks without any error.
iv. **NFR05:** the system allows a seamless addition of new features without affecting the functionality of the system.

a) Testing the System's User Interface

Apart from testing the discrete components of the system, it is also important to test the behaviour of the systems user interface (UI) when the system is running. This ensures that the system's user interface returns the correct user interface output in reaction to a series of user actions on the system. Table 7 shows the test cases for the evaluation of the correctness of the output of the user interface. All the GUIs in this paper show that the system satisfies the UI requirements.

Table 7 User interface test cases

Test Reference	Test contents	Test Results
UI_01	Confirm that the menu is shown across all screens.	PASS
UI_02	Confirm that the user interface shows the keyboard input in all TEXT Objects (e.g., Name, email, phone number, etc.)	PASS
UI_03	Confirm that all buttons are displayed properly in all the screens.	PASS
UI_04	Confirm that the user interface displays images properly on all screens.	PASS
UI_05	Confirm that the user interface displays all screens correctly.	PASS
UI_06	Confirm that the user interface displays errors encountered during execution	FAIL

Table 8 shows the results taken for all the test cases (TS). The test cases refer to activities carried out to validate the functional and non-functional requirements. Each test case references the activities used to validate a corresponding functional or non-functional requirement. TS01 – TS06 refer to the tests carried out to check whether the proposed prototype meets the functional requirements FR01 – FR06 and FR08 – FR10 (see Table 1). Test cases TS07 – TS10 refer to tests carried out to validate non-functional requirements NFR01 – NFR03 and NFR05 (see Table 2). A test case produces a PASS result if the experiment carried out to validate a requirement generates an output which shows that the system meets the tested requirement. In other words, test cases with pass results show that the specified functional requirements and non-functional requirements have been met in the course of implementation and execution of the system. This is demonstrated by the results shown in the GUIs (Figures 7- 21) captured during the implementation and testing of the proposed prototype.

Table 8 Test case result

Test case	Result
TS01	PASS
TS02	PASS
TS03	PASS
TS04	PASS
TS05	PASS
TS06	PASS
TS07	PASS
TS08	PASS
TS09	PASS
TS10	PASS

4. Conclusion and Future Work

A prototype of an automated farm monitoring system provides a template for building large scale computerized devices that make it less difficult for farmers to monitor their crops and local environmental conditions. Such devices minimize the time and effort required for monitoring events in the farm environment while preventing possible hazardous incidents associated with manual monitoring. The prototype proposed in this study provides accurate capturing and real-time analysis of physical phenomena such as rainfall, temperature, soil moisture and humidity. This enables farmers to apply fully automated procedures to the crop cultivation process chain. This paper

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identified and evaluated the essential requirements, features and capabilities of an automated farm monitoring system. The application of the proposed prototype extends beyond farm monitoring to other areas such as environmental monitoring, weather monitoring, and monitoring of animal migration. Possible future extensions of the study will result in an enhanced system with the following features:

1) Control - this study focuses on monitoring farmlands in real-time and relays the information to the central command and control unit for visualization and further processing. Future works should develop an improved system, which is capable of controlling plant watering, shading and application of pesticides and herbicides.
2) Remote access – our prototype uses an onscreen dashboard, which requires the physical presence of a user to observe measured parameters. Future work should enable the system to run on the cloud making it possible for the system to be accessed remotely.
3) Video surveillance - a future extension of the study should provide video footage of the farm in real-time.

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