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Enbat: Automated Farm Monitoring and Controlling System for Sustainable Agriculture

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Abstract

In modern agriculture, challenges along with aid optimization, climate trade model, and the growing demand for food production require modern solutions. Farmers, in particular those working in arid regions including Saudi Arabia, encounter sizeable demanding situations in identifying suitable water and soil assets for cultivating lots of plants, whilst concurrently striving to put into effect sustainable agricultural practices. This research gives an automated farm tracking and manage

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gadget that leverages Internet of Things (IoT) generation to deal with these challenges. The proposed device integrates computerized drip irrigation and dynamic sunlight shading to enrich crop productiveness, conserve water sources, and maintain healthful soil situations. By making use of temperature, humidity, and soil moisture sensors, the gadget continuously video displays units environmental situations and triggers automatic responses through an Arduino microcontroller (ESP32). The gathered records from the sensors are compared with predefined database values to optimize irrigation and shading mechanisms in real-time. Additionally, a mobile utility, advanced using Flutter, offers farmers with real-time farm facts, manage capabilities, and more suitable decision-making support. The device was tested through a prototype, demonstrating a 10.45% reduction in water intake and improved plant fitness. Compared to existing IoT-primarily based agricultural solutions, this system uniquely consists of a dynamic shading mechanism to protect crops from excessive heat, a feature not formerly addressed in similar studies. Conclusions indicate that this smart agricultural system can improve work effort, improve accurate agriculture while improving efficiency and stability, making it a promising solution for future sustainable agricultural development.

Keywords: IoT-Based Agriculture, Smart Agriculture, Automatic Irrigation, Sustainable Agriculture.

1 Introduction

The agriculture sector plays a crucial role in the economic and social development of the Kingdom of Saudi Arabia. As part of Vision 2030, the Saudi government prioritizes agricultural advancement to achieve economic diversification and sustainability. The Kingdom's diverse climate enables the cultivation of various crops, contributing significantly to national food security (Bosco et al., 2018). To support this vision, the Ministry of Agriculture emphasizes sustainability, efficient water management, and innovative solutions for resource optimization.

To enhance agricultural sustainability, Saudi -Arabia integrates advanced technologies such as the Internet of Things (IoT), Artificial Intelligence (AI) and Wireless Sensor Network (WSNS) (Nambiar & Varma., 2023). These technologies are consistent with the goal of Vision 2030 (Saudi Vision, 2030) to reduce oil addiction and promote a diverse economy (Qiu et al., 2021). However, many challenges such as water management face, adaptation of sunlight and resource efficiency (Alsheddi, 2020) in the agricultural sector.

Traditional agricultural methods, which depend on manual monitoring of environmental factors such as soil moisture, temperature and humidity, are disabled and incorrectly exposed (Khakimov et al., 2022). IoT-based solutions address these boundaries, changing agriculture in Saudi Arabia, integrating environmental sensors and microcontrolls (Monica Nandini, 2024). These innovations enable surveillance of real -time, adapt to water use and improve productivity when retaining resources. Therefore, this research develops and enforces a prototype of an automated agricultural system that fits the specific challenges and opportunities of Saudi Arabia. In addition, the proposed system aims to increase productivity, reduce resource waste and support permanent agricultural development.

2 Related Works

Several studies have shown integration of IoT and wireless sensor networks (WSN) in agriculture to enhance efficiency, sustainability and productivity. Early work of Nayyar & Puri, 2016 introduced an IoT-based agricultural system using temperature and soil sensors through DS18B20 to provide real-time data for farmers, causing crop monitoring and productivity. Similarly, the Institute of Technology (I-SMAC, 2017) proposed a farm automation system using the Raspberry Pi 2 Model B, connected to several sensors, where a mobile robot collected and sent environmental data, which reduced the need for extensive sensor placement.

When it comes to smart agriculture, developed IoT-based prototypes to help rice farmers and reduced land shortages due to population growth. These systems use soil moisture, pH, water level, moisture and temperature monitoring of cost -effective sensors and raspberries PI while offering real -time data visualization through mobile applications. Similarly for monitoring agricultural parameters (moisture, temperature, intensity, pH and soil moisture) integrated with IoT to monitor the agricultural parameters to focus on a solar powered smart agricultural platform with a study with IoT, a solar -operated smart agricultural platform, 2019.

Other studies examined the role of IOT in irrigation and resource optimization. (Farooq et al., 2020; Firebase, 2024) Research underwent major IoT trends, highlighted Wi-Fi, Zigby and WSN as an important communication protocol for accurate agriculture. Further studies of (Khan et al., 2020; Goel, 2026), further IoT-based mobile robotics and sensor networks for automatic monitoring, weed detection and permanent irrigation practice stated to achieve high accuracy and improve farm productivity.

Machine learning and AI are also included in IoT-operated agricultural solutions. (Mohan et al., 2023; Suanpang, 2019) Research developed an IoT structure by integrating supervised learning to predict crop productivity based on the soil nutrients and environmental factors (Almotairy et al., 2024). In addition, Chan et al. (2015) introduced a smart agricultural model that combines IoT, cloud computing and mobile application for crop production, decision -making in agriculture. Overall, the results of IoT and machine learning demonstrated to increase agricultural results.

In addition, several studies (Zheng et al., 2016) have focused on affordable IoT-based smart agricultural systems to improve irrigation efficiency, reduce water consumption, increase crop productivity, increase the remote farm monitoring and provide a solution (Vasudevan et al., 2022). The study highlighted the benefits of IoT and AI in accurate agriculture, including initial disease detection and sustainable crop health management. Similarly, (Moshashai et al., 2020; Vadapalli et al., 2020; Visconti, 2020; Abhiram et al., 2020). The results indicated that the integration of IoT improved the status of the farm, ecosystem and monitoring of production efficiency.

Some research centered precise agricultural challenges, which includes sustainable water control the use of the SKU soil moisture sensor (Chaudhary et al., 2011; Jagannathan, 2015), drone-assisted precision farming the use of sensors together with SHT71, SHT75, and 107-L (Shafi et al., 2019), drones and AI for precision agriculture (Ionescu et al., 2024; Joseph et al., 2020), and automated irrigation scheduling the usage of soil moisture sensors and Zigbee era (Shavkidinova et al., 2025). Other research advanced clever structures leveraging IoT and AI to display soil conditions, control irrigation, optimize pesticide application, and enhance agricultural efficiency and productiveness. In the look at, (Mishra et al., 2019) proposed a smart farming system the usage of IoT technology linked to NodeMCU and advanced a smart system integrating IoT connected to an ARM7 board (Naresh & Munaswamy, 2019). Conclusions emphasize the effectiveness of integrated smart agricultural systems (IoT, AI and remote measurement) in agricultural challenges, accurate measurement, efficient irrigation automation, reduction of water consumption, improvement of resource adaptation, improvement of energy efficiency, and enhanced crop production while minimizing pesticide usage and labor requirements (Ptashchenko et al., 2025; Channe, 2025).

Despite this remarkable progress of using IoT and automation for agriculture, existing studies lack a comprehensive approach to corresponding to the unique environmental conditions of the Saudi Arabia or the Gulf region (Hester, & Harrison, 2012). Most reviewed literature focuses on general accurate agriculture, which is without tackling challenges such as exposure to excessive sunlight and climate water conservation (Mustapha et al., 2017). In order to bridge this difference, this research proposes an automated agricultural system, which integrates IoT with a dynamic shadow mechanism, aims to increase crop productivity and efficiency by adapting resource use under Saudi -Arabia's unique agricultural conditions.

3 Methodology

The implementation relies on several main methods; A Firebase database stores plant-specific environmental factors across different seasons. The DH sensor measures air humidity and temperature, while soil moisture sensors assess soil moisture levels. An ESP32 microcontroller processes real-time sensor data, comparing it with predefined database conditions to Arduino trigger necessary actions. Automatic shading mechanisms activate when sunlight levels exceed the tolerance of certain plants, while a drip irrigation system optimizes water usage and maintains soil health. Additionally, a mobile application developed using Flutter provides user interaction and system control.

3.1 The Analytical Vision of the Current System

The Royal Commission for Jubail and Yanbu, established by the royal decree, operates independently to develop the Jubail and Yanbu regions (Hasan, 2020; Barradas et al., 2024). As part of this initiative, the Royal Commission's nursery in Jubail Industrial City specializes in growing plants and flowers for public and private landscaping. The nursery comprises 14 shaded houses, three glass houses, and a research center focused on afforestation and horticulture, housing various trees, shrubs, and soil covers. A key component of the nursery is its seasonal flower production line, which utilizes a cork-wasting machine (Figure 1). The process includes soil mixing, seed placement, and water spraying for stabilization before the plants are transferred to greenhouses for manual watering (Chungade et al., 2021; Al Shehai, 2015). The machine is equipped with two sensors: one regulates soil filling and the other controls the sprinkler system. This system achieves a daily production capacity of 200,000 seeds. The greenhouses are equipped with an automated climate control system, where fans regulate humidity based on temperature readings from thermometers (Go et al., 2015). Cooling filters supplied with water pipes help maintain optimal growing conditions for these types of plants. The limited sensor integration in this existing system highlights the opportunity for comprehensive IoT implementation in our proposed solution.

Figure 1: Cork Waste Machine

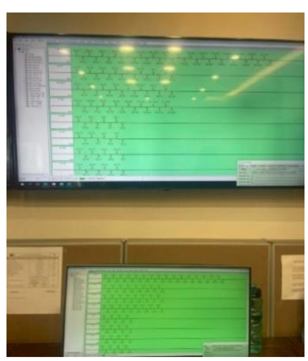


Figure 2: SCADA System's Monitoring Screen

Figure 3: Flow Transmitter Sensor

To manage Jubail's irrigation system, a SCADA-based central control system (Figure 2) regulates water distribution via a network of pipes acting as timers. These open and close at scheduled intervals based on plant requirements. Accordingly, some areas use radio frequency signals while others have adopted fiber optics for improved control. Monitoring is conducted through sensors placed at critical points to measure water flow and pressure (Figure 3), preventing pipe damage from excessive or insufficient pressure. If an abnormality occurs, employees manually adjust the system via monitoring screens. This system has significantly improved irrigation efficiency and ensured a consistent water supply for plants. However, further improvements are needed to optimize performance and reduce employee workload. The proposed system expands upon this foundation by connecting water management directly to plant needs through integrated soil moisture sensing and automated response mechanisms, and the testing demonstrated that when the sensor's data was compared against plant-specific parameters in the database, it successfully triggered appropriate system responses under varying conditions, confirming its effectiveness for Saudi Arabia's challenging climate.

3.2 The Analytical Vision of the Proposed System

The proposed automated system consists of hardware and software components, enabling monitoring and control functionalities. Hardware includes a DHT sensor, a soil moisture sensor and a microcontroller. Sensors collect environmental data and compare them with ideal values stored in the database. Based on this comparison, the microcontroller tasks trigger as opening/closing or adjusting shading. For example, if the DHT sensor detects high temperatures, the microcontroller activates colors for the safety of plants. Similarly, if the soil moisture is sufficient, the system prevents irrigation.

The system deals with the most important problems seen in the Royal Commission in Jubil, KSA, such as manual irrigation using a fixed timer who disregards seasonal variations, causing overwater or underwater. By integrating the moisture sensor into the soil, the system ensures that watering only occurs when necessary, to automatically use seasonal changes. In addition, the traditional manual checkout method used in the Royal Commission is inefficient, as plants must be transmitted to adjust the sunlight contact. The proposed system automates this process by adjusting shades based on temperature levels. For example, if the temperature exceeds 30°C, the shades open, and they close when it drops below this threshold. Beyond automation, the system will provide real-time plant data and generate daily farm reports, enhancing efficiency and reducing human intervention.

3.3 Data Collection

Data was collected from the Royal Commission in Jubail, including plant names, types, temperatures, and seasonal water requirements. Water measurements were converted from gallons to liters to fit the system's prototype. Since humidity levels were unavailable, independent research provided data for 75 plants, which was then extrapolated to the rest. Plants were ultimately grouped based on suitable humidity levels.

3.4 Tools Used in the Study

3.4.1 Hardware Components

- ✓ **DHT Sensor**: Measures temperature and humidity levels, providing essential environmental data for decision-making within the system (Figure 4).
- ✓ **Soil Moisture Sensor**: Monitors soil moisture levels to ensure optimal irrigation based on real-time data (Figure 5).
- ✓ **ESP32 Microcontroller**: The central processing unit of the system, responsible for connecting and controlling all devices, including sensors, the water pump, and the shading mechanism. It

compares real-time sensor data with predefined values in the database to trigger actions such as opening/closing the irrigation system or adjusting shading (Figure 6).

- ✓ **Automatic Shading Mechanism**: A 3D-printed shading system that automatically adjusts to protect plants from excessive sunlight, operated by a servo motor (Figure 7). This component directly addresses a critical gap identified in our literature review, where previous studies neglected sunlight management despite its significant impact on plant health in arid regions. Additional components include a Water Pump for transferring water from the storage tank to the irrigation system, tank for water storage, silicon pipes for drip irrigation, a relay for switching mechanisms, an adapter for power supply, a voltage reducer for managing electrical loads, this component highlights the system's design considerations for stable long-term operation. (Figure 8), as well as wires and a breadboard for system connectivity.

Figure 4: DHT Sensor

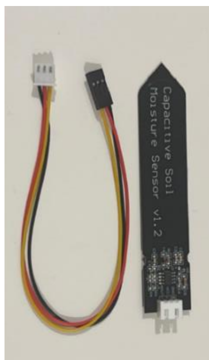


Figure 5: Soil Moisture Sensor

Figure 6: ESP32 Microcontroller

Figure 7: Shading Mechanism

Figure 8: Voltage Reducer

3.4.2 Software Components

- ✓ **Flutter Programming Language:** An open-source framework powered by Dart, optimized for fast cross-platform application development. It will be used in this project for building the mobile application (IDAACS, 2019).
- ✓ **C Programming Language:** A famous and fundamental programming language will be used to configure the ESP32 microcontroller and manage hardware interactions (Alwin, 2024).
- ✓ **Firebase Platform:** A cloud-based NoSQL database providing real-time data storage and retrieval. It ensures secure, serverless data access and enables farmers to view daily reports via the mobile application.
- ✓ **Arduino IDE platform:** An integrated development environment used for writing and uploading code to microcontrollers, including ESP32, to program system sensors.

Additional software tools include Visual Studio as the development environment for Flutter applications and Database ERD to illustrate database structure and entity relationships.

3.5 Experimental Controls and Baseline Measurements

Controlled experimental conditions were implemented to compare the traditional irrigation system and the proposed automated system to establish a valid performance comparison. Baseline measurements were established by monitoring water consumption and plant health indicators under the traditional irrigation system at the Royal Commission Nursery in Jubail.

3.5.1 Baseline Parameters Included

Plant Species: Two plant species were selected: *Vitex Agnus-Castus* during the summer season, and *Epipremnum N' Joy* during both summer and winter seasons.

Measurement Tools

The study utilized standardized measurement tools to ensure accurate and reliable data collection. Water consumption was quantified using calibrated flow sensors, while soil moisture levels were monitored via SEN0193 digital soil moisture sensors. Ambient temperature and relative humidity were recorded using DHT22 sensors to account for environmental conditions. Plant health indicators, including leaf color and overall appearance, were assessed through qualitative visual inspection.

These methods enacted accurate monitoring of plant reactions during irrigation efficiency, substrate moisture dynamics and controlled experimental conditions.

Baseline Water Consumption was Determined as Follows

Vitex Agnus-Castus 6 liters per square meter (traditional method), while Epipremenum N 'Joy 0.5 liters per pot per week (traditional method). After implementing the proposed automatic system, the measurements were repeated under equal environmental conditions.

Comparative Analysis

Comparison between traditional and automatic water consumption is shown in Table (1). Comparative analysis revealed a continuous reduction of 10% in the water consumption of both plant species when using an automated irrigation system versus traditional methods. In particular, *Vitex Agnus-Castus* demonstrated a deficiency of 6.0 to 5.4 liters/m/day, while Epipremnum N'joy showed a lack of 0.5 to 0.45 liters/pot/week. These findings were accompanied by the optimal limitations and continuous healthy plants' levels of soil moisture levels with optimal sustained healthy plant conditions, looked at through visual indicators.

Table 1: Water Consumption Comparison Between Traditional and Automated Irrigation Systems for Different Plant Species

Plant Species	Traditional system water consumption	Automated system water consumption
Vitex Agnus-Castus	6 liters/m²/day	5.4 liters/m²/day
Epipremnum N' Joy	0.5 liters/pot/week	0.45 liters/pot/week

4 Workflow and Implementation

This section provides the workflow and implementation of the database, application, hardware, and the prototype provided with a test case.

4.1 Database Workflow and Implementation

A Cloud Fire store database (Firebase) was used to implement the system database. It organizes user data and stores essential plant information, including optimal conditions and group classifications linked to the Groups table. When a user establishes a farm, their plant selections are recorded in the Farm table. Real-time environmental readings from sensors are logged in the Reading table, while the system monitors irrigation and shading states in the Action table, with '1' indicating open and '0' indicating closed. This data generates daily reports, providing insights into efficient farm management.

4.2 Application Workflow and Implementation

The mobile application, developed using the Flutter framework supported by Google, is designed to be compatible with both iOS and Android devices. Upon launching the app, users are presented with an initial page (Figure 9) where they can either sign in or sign up. If a new user chooses to sign up, they are redirected to the registration page to create an account. Additionally, if a user forgets their password, they can select "Forgot Password" which leads them to a password recovery page, where they must enter their email to receive reset instructions. Subsequently, the reset message is sent to the user’s email, while Figure 10 displays the sign-in page, enabling users to log into their registered accounts. Once signed in, users are directed to the home page (Figure 11), which provides access to the system's services.

Figure 9: Main Page

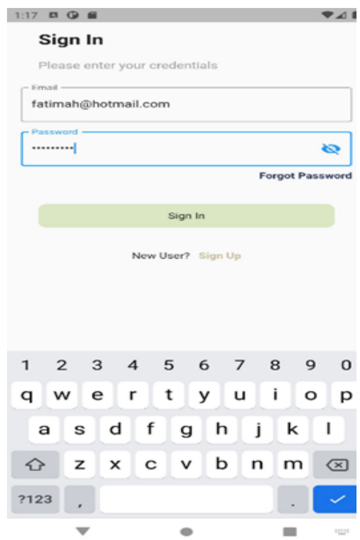


Figure 10: Sign-in Page

Figure 11: Home Page

Furthermore, the profile page (Figure 12) contains the farmer’s information and two key buttons: "My Farms" and "Daily Reports." By selecting "My Farms", users can view a list of their farms and have the option to add a new farm. In addition, Figure 13 shows the page that displays all the plants within a selected farm. To add a new farm, users can enter relevant information in the designated interface (Figure 14), which is then stored in the system. Moreover, Figure 15 presents a comprehensive list of all plants available in the database, including popular plant species from the Jubail Royal Commission nursery. If a user clicks on a specific plant, they can access detailed information.

Additionally, users can assign any plants to a specific farm. When accessing the "Daily Reports" section via the profile page (Figure 16), users can select the desired farm to generate its daily report. This report (as depicted in Figure 17) includes plant groupings along with corresponding sensor readings and action statuses.

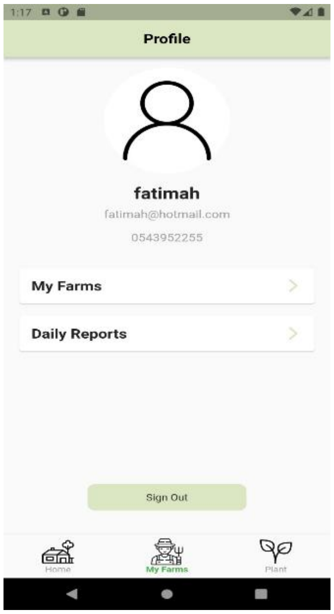


Figure 12: User's Profile Page

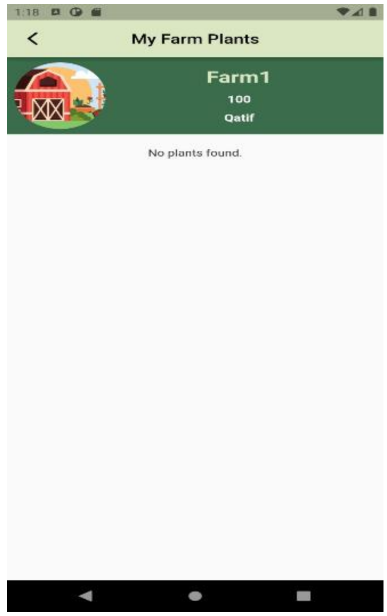


Figure 13: Farm's Interface Page

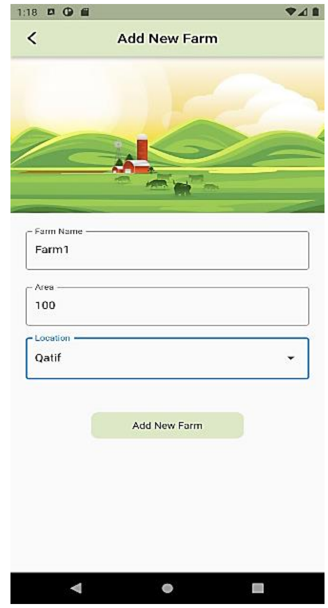


Figure 14: Add New Farm Page

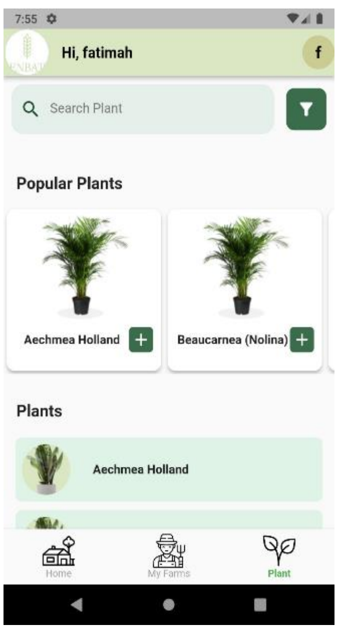


Figure 15: Plants Page

Figure 16: Category of the Daily Reports Page

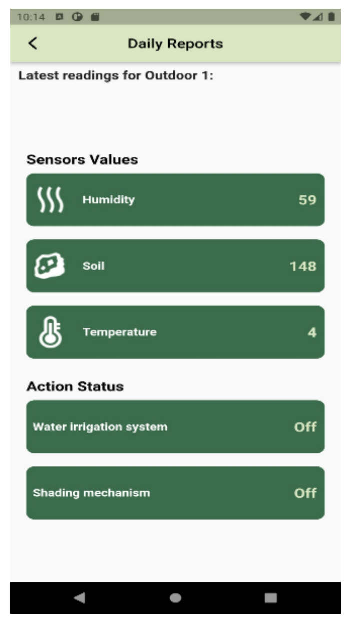
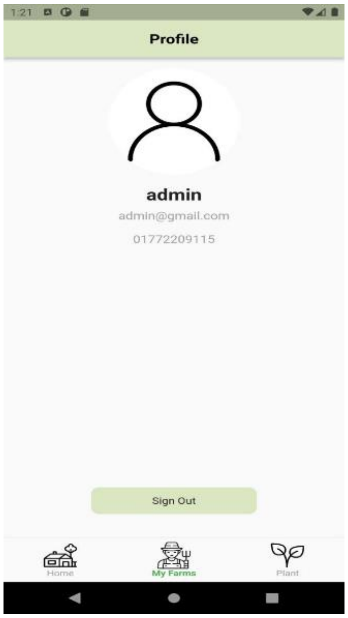
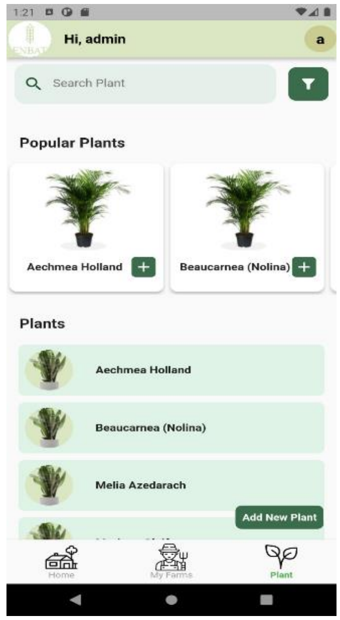


Figure 17: Daily Reports Page

From an administrative perspective, the following interfaces are exclusively available to administrators. First, the admin profile page (Figure 18) displays essential details. Unlike the user version, the plant interface (Figure 19) includes an "Add New Plant" button, allowing the admin to expand the plant database.

Next, the process of adding a new plant where the admin completing the required plant details. Finally, when the admin selects a plant from the list (Figure 20), they can view its details. Unlike the user interface, the admin version does not include the "Add to My Farm" button, ensuring a distinction between user and admin functionalities.





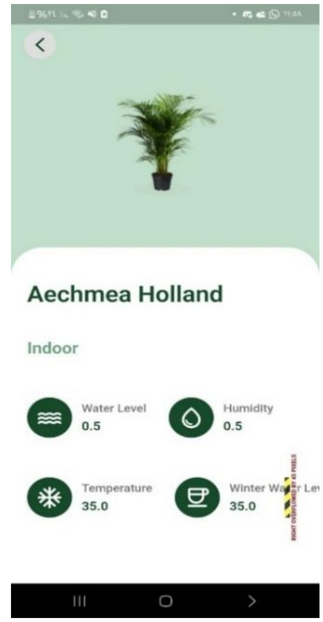


Figure 18: Admin's Profile Page

Figure 19: Admin's Plant Page

Figure 20: Admin's Plant Details Page

Accordingly, this interface features streamlined authentication and a centralized dashboard that provides easy access to monitoring and control functionalities. Farm management capabilities include user profiles, plant inventory viewing, and setup tools that support gradual adoption and system expansion. The platform offers comprehensive plant databases, reporting tools for data analysis, and administrative interfaces for system maintenance and development, successfully balancing functionality with user-friendliness for users with diverse technical expertise.

4.3 Hardware Workflow and Implementation

As illustrated in Figure 21, each sensor was initially tested individually to ensure proper functionality before being integrated into a unified electrical circuit, thereby preventing potential damage. During this phase, calibration was required for the soil moisture sensor, as it does not measure in standard units, despite the database storing values in liters. To address this, practical experiments were conducted to determine the moisture thresholds for "wet," "dry," and "medium-wet" conditions, which were then standardized to align with the database (code presented in Figure 22).

Furthermore, the DHT and soil moisture sensors were connected to three essential circuit components: positive (red), negative (black), and the ESP32. To ensure circuit protection, a voltage reducer was also integrated with the ESP32 to prevent overvoltage or connection errors. Additionally, the pump was linked to a relay and a silicon pipe, while a servo motor was connected via a relay to regulate the shading system based on sensor readings. To avoid operational errors, each ESP32 pin was assigned specific inputs or outputs, as detailed in Figure 23, since altering pin assignments could interfere with sensor readings.

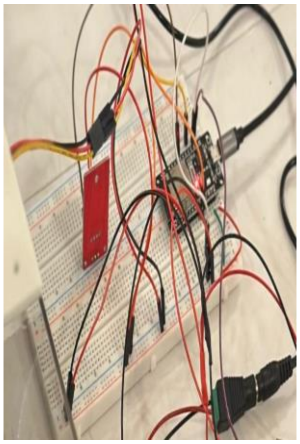


Figure 21: Circuit Connection

```
void read_soil()
{
  // read the analog / millivolts value for pin 2:
  soilReading = analogRead(SOIL_PIN);
  if (soilReading > 4000 )
  {
    soilReading = 10;
  }
  else if (soilReading > 3000 )
  {
    soilReading = 6;
  }
  else
  {
    soilReading = 3;
  }
```

Figure 22: Soil Moisture Readings Code

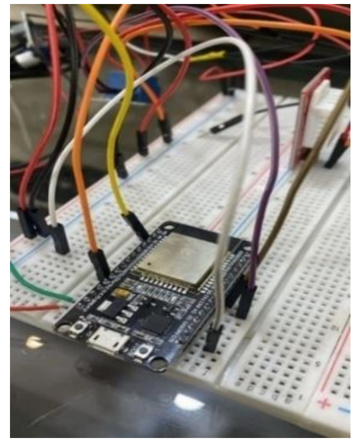


Figure 23: Connected Pins in ESP32 Microcontroller

The ESP32 was programmed using C within the Android IDE. The system operates by retrieving plant data, measuring air temperature and humidity through a DHT sensor, and adjusting shading based on predefined temperature thresholds. Simultaneously, soil moisture levels are continuously monitored, with seasonal adjustments to water levels informed by meteorological data. If the soil moisture falls below the designated threshold, the pump is activated. Throughout the process, sensor readings and system statuses are stored in the database, ensuring continuous monitoring, with the cycle repeating every three seconds.

4.4 Prototype Workflow and Implementation, and Test Case

The prototype was constructed using the proposed design, utilizing a single ESP32 microcontroller programmed in C to connect sensors with the water drip irrigation system, shading mechanism, and database. A servo motor, positioned at the top of the basin, controls the 3D-printed shading mechanism. A DHT sensor and a soil moisture sensor measure temperature, humidity, and soil moisture levels. The components were integrated using two soldering boards, with a relay to control water flow and a pump to draw water from the tank to the hose. Figures (24 and 25) illustrate the developed prototype. This prototype demonstrates the practical application of our design, showing the integration of sensors, shading mechanisms, and irrigation components.

Figure 24: System Protype (1)

Figure 25: System Prototype (2)

The system was tested with *Vitex Agnus-Castus*, using the plant's details provided in Table 2. The testing involved two scenarios: first, activating the water pump, and second, adjusting the plant's weather temperature to 20 °C to observe if the shading mechanism would activate. The outcomes of these tests are summarized in Table 3.

Table 2: Vitex Agnus Castus (Green) Plant Details as a Test Case

Plant Name	Vitex Agnus Castus (Green)
Type	Outdoor
Weather temperature	55 °F
Humidity level	50 %
Winter water level	3.5 L Weekly
Summer water level	3.5 L Weekly

Table 3: Test Cases for Plant Information Retrieval and System Actions Based on Temperature and Soil Moisture Readings

Test Case	Case	Input	Shade Control	Season Determination and Pump Control
Test Case 1	First case: Retrieve plant information (Table 1)	Temperature reading, Soil moisture reading	If temperature reading > 21.2 and Weather temperature > 55, then close shade	If temperature reading > 30, then it's summer (no actions specified for summer) Else, it's winter. If soil moisture reading < winter water level, then turn pump on.
Test Case 2	Second case: Retrieve plant information (Table: 1) with weather temperature change to 20	Temperature reading, Soil moisture reading	If temperature reading > 21.2 and Weather temperature = 20, then open shade	If temperature reading > 30, then it's summer (no actions specified for summer) Else, it's winter. If soil moisture reading < winter water level, then turn pump on.

5 Results and Discussion

An automated farm monitoring and control system was created using Internet of Things (IoT) technology to address the challenges faced by farmers, particularly in determining the appropriate amount of water and protecting temperature-sensitive plants from high heat. The system was developed using the Flutter programming language for user interfaces, and the Firebase was used to link sensors and the application for comparison purposes. A prototype was created to simulate the automated farm system for the proposed sustainable agriculture system.

The system successfully met its objectives, and the project was presented to the Royal Commission in Jubail. Their feedback was highly positive, as they found the system impressive. Water consumption in the Royal Commission nursery in Jubail was calculated to be 4 liters per 6 square meters, which was compared to the proposed system's consumption of 0.15 liters per 0.25 square meter. The results showed that the proposed system would reduce water consumption by 10.45%. The project team hopes that it will be implemented by the Royal Commission in the future.

When comparing the proposed system with other systems reviewed in the literature, it was found that the proposed system shares the benefit of using a drip irrigation system. However, the proposed system stands out in several ways, making it unique, useful, and effective. It integrates an application linked to the automated farm system, along with the use of sensors to monitor high temperatures and provide full shading protection for plants that are sensitive to heat. This new feature of full shading protection has not been used in previous studies. In addition, the presence of the system will make farmers' work easier and more enjoyable without the challenges of traditional agricultural methods.

6 Conclusion

Automatic agricultural monitoring and control system marks significant progress in agricultural technology, and provides an innovative solution that reduces labor, water consumption and costs by simultaneously increasing efficiency and productivity. Its adaptability for different plant types enables efficient resource care, reduces the necessary time and effort from farmers.

Although the system has shown positive results, promotion in the future can further improve functionality. Possible upgrades involve integrating a seasonal system to adjust watering automatically on the basis of prognosis, such as disabling watering during rainfall. In addition, a heating mechanism can be introduced to protect temperature -sensitive plants from extreme cold. Inclusion of a pH sensor will allow continuous monitoring and adjustment of the soil's pH levels to ensure optimal conditions for plant growth.

In order to increase the versatility, the system may contain a hallmark that can enable farmers to propose new plant species, subject to the approval of an administrator. In addition, the expansion of the application in a full-service platform will allow farmers to order simple distribution and additional hardware components for integration in their fields. This will make the improvement system effective to promote more extensive, user -friendly and durable agricultural practices.

7 Challenges and Future Work

The smart agricultural system shows strong performance in prototype -controlled tests. However, scaling commercial deployment faces challenges in IoT agricultural systems, including hardware capacity constraints, network dependencies, and environmental protection requirements. Moving forward, planned enhancements include implementing distributed architecture with edge computing, integrating solar power systems, and incorporating machine learning algorithms for predictive analytics. Additional improvements, such as expanded sensor capabilities, drone integration, and computer vision, will create a comprehensive monitoring solution. API development will ensure seamless integration with existing agricultural systems, building on the prototype's proven success to deliver an advanced management solution optimized for arid regions.

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