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Design and Development of an Automated Plant Monitoring and Care System Using IoT Sensors.

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ABSTRACT
The global agricultural sector faces challenges in ensuring food security and sustainability with problems of climate change and a growing population. In Zambia, farming is the foundation of the country's economy, but most small-scale farmers are at risk because of unpredictable rainfall and traditional farming methods that lead to waste of resources and result in poor harvests. The emerging of the Internet of Things (IoT) offers a great solution, but the systems available today are usually too expensive and complicated for the average Zambian farmer.

This thesis presents the design and development of an automated system to monitoring and care for plants using IoT sensors, specifically tailored for the needs of small-scale farmers. The system integrates a network of low-cost sensors to remotely monitor and collect data for the user with information about the environmental parameters, such as soil moisture, temperature, humidity and light intensity. The data collected is sent wirelessly to a central processing unit, which then analyses the information by providing real-time data and insights to the user. The system is designed to be user-friendly, with an interface for monitoring crop conditions, as well as automated functions for basic plant care, such as introducing an irrigation system when soil moisture levels drop below a specific limit.

The study will bridge the technological gap by providing farmers a low-cost solution that will help them transition from traditional guesswork to making smart decisions based on real information. The study will increase the potential to enhance food security, improve agricultural productivity, and promote economic empowerment by increasing crop yields and reducing financial risks associated with crop failure. This project shows how a localized technological innovation can contribute to national development goals and create a more secure and sustainable future for farming in Zambia.

Keywords: Internet of Things, Smart Agriculture, Automated Plant Monitoring, Small-Scale Farmers, Food Security.

I. INTRODUCTION

Agriculture remains one of the most critical sectors for global food security. In Zambia, it is more than just an economic activity, it is the foundation of the country's growth and provides a living for most citizens. It contributes a large part of the country's Gross Domestic Product (GDP) and employment, with small scale farmers playing a central role in food production (Central Statistics Office, 2022). However, it continues to face major challenges such as unpredictable rainfall patterns, prolonged droughts, optimal resource utilization, and low productivity. (Zambia Meteorological Department, 2024).

In response to these challenges, the integration of modern technologies in farming has become essential. Similar to how modern defense operations utilize IoT sensors and web-based dashboard to monitor infrastructure and respond rapidly to threats, agriculture can benefit from systems that provides real-time insights and automated control. IoT based technologies allow farmers to remotely monitor and control farm conditions through interconnected sensors and devices, facilitating data driven decisions that enhance productivity and sustainability (Patil et al.,2022).

This study focuses on the design and development of an automated plant monitoring and care system that integrates IoT sensors with a user-friendly web-based interface to support smart farming. The system automates key functions such as soil moisture detection, temperature and humidity tracking, and light regulation. By doing so, it aims to improve plant growth, minimize resource waste and provide an affordable, scalable and reliable solution tailored to the needs of small-scale farmers.

The significance of this study lies in its potential to bridge existing gaps in traditional farming practices through IoT and web-based technologies. By providing accurate, real-time data and enabling proactive interventions, the system promotes sustainable farming practices and improved productivity. Ultimately, this research contributes to the goals of precision agriculture, enhancing efficiency, strengthening food security and promoting a more resilient agricultural future.

1.1 Background

Despite Zambia possessing considerable arable land and a large farming population, productivity has struggled to keep pace with the rapid growth of urban areas and the country's expanding population. Studies indicate that agriculture engages a high share of employment but contributes only modestly to GDP, reflecting deep structural constraints. (Tandiwe Ngombe, et al, 2024)

The challenges facing Zambian agriculture, particularly for small-scale farmers, the most critically being climate change which is causing more frequent and severe droughts as well as increasingly unpredictable rainfall patterns. These weather shocks directly impact crop yields and food-security. (Bornface M and Georgina M, 2025) For these farmers, the rising risk associated with reliance on traditional rain-fed methods is very high. They also deal with social and economic limited access to affordable credit, high cost of farming supplies, and poor infrastructure that make it hard to get products to markets. These problems have historically prevented farmers from adopting of modern, higher-yielding techniques and appropriate technologies. (Petros chavula, 2022)

In recent years, the global agricultural landscape has been changed by the emerging of Internet of Things (IoT) also referred to as "smart farming" which involves the deployment of interconnected sensors and devices to collect and analyze real-time data from the field data. This allows farmers to carefully monitors environmental conditions of plants such as soil moisture, temperature and light enabling them to make data-driven decisions that optimize resource use. The benefits of IoT in farming are well documented, with studies demonstrating its effectiveness in improving efficiency, reducing water waste and ultimately increase crop productivity. (United Nation Development Programme, 2021)

Whilst IoT holds huge potential for transforming agriculture in Zambia, implementation remains very limited. The barrier does not lie in the technology alone, but rather in its availability, affordability, and fit for the small-scale farmer context. Most commercial IoT solutions are expensive, complex to operate, and designed for large-scale commercial farms making them impractical for small-scale farmers who lack capital, technical expertise, and supportive infrastructure. (Miyanda Malambo, et al, 2023)

The Zambian Government has shown increasing interest in using technology for national development evidenced by strategic documents and plans that emphasize sustainable farming systems, efficient resource use, and digital innovation. For example, the revised Zambia National Agricultural Policy 2012-2030 emphasizes sustainable production and resource efficiency. Therefore, the development of an automated, accessible and affordable plant-monitoring and care system is not only a technological innovation, but also a strategic step in supporting Zambia's development goals and building a more resilient and sustainable agriculture sector.

1.2 Problem Statement

There is a lack of affordable, accessible, and user-friendly IoT-based systems tailored to the needs of small-scale farmers in Zambia for real-time plant monitoring and automated care, that can help overcome climate-related risks and improve their resource, thereby enhancing crop yields and securing their livelihoods.

1.3 General Objective

To design and develop an Automated plant monitoring and care system using IoT Sensors to provide real time data and automated care.

1.3.1 Specific objectives

i. To develop a user-friendly interface that allows users with different levels of technical expertise to easily interact with the system, access real-time data and managed plant care.
ii. To establish an automated irrigation control system that uses sensor data to make intelligent decisions
iii. To evaluate the potential impact of the developed system on key agricultural outcomes. Such as to improve crop yields, conserve water, and reduce the manual labor required for plant care, with a view to demonstrating its economic and environmental benefits for small-scale farmers in Zambia.

1.4 Research Questions

i. How can a user-friendly interface be developed to reliably collect and send sensor data in environments with potentially unstable or limited internet connectivity?

ii. How can the automated irrigation system be programmed to respond effectively to real-time soil moisture data, ensuring ideal watering schedules that prevent both over- and under-irrigation?

iii. To what level does the developed prototype system accurately monitor the environmental parameters compared to traditional manual methods?

1.5 Scope of the study

This study will involve the design, development, and implementation of a prototype for an automated plant monitoring and care system using Internet of Things (IoT) sensors. This research will focus on creating a cost-effective and user-friendly solution designed for small-scale farmers in Zambia.

The study will involve the following key functionalities:

- Sensor Integration: The system will integrate a network of sensors to collect real-time data.
- Data Transmission and Processing: The collected sensor data will be sent wirelessly from the field to a central microcontroller. This microcontroller will then process the data and send it to a cloud-based platform for storage and analysis.
- Automated System: The core of the system is an automated mechanism. Based on the data from the sensors, the microcontroller will trigger a pump to irrigate the plants when the soil moisture level drops below a set standard, trigger a ventilation fan when the temperature rises above the set standard or trigger a heat source when the temperature drops below the set standard.
- User Interface and Alerts: A simple user interface (web dashboard) will be developed to allow farmers to view real-time and historical sensor data, receive alerts when specific conditions are met and to set specific standards and schedules.
- This study's practical application is a pilot implementation such as a small greenhouse within a controlled environment. It will focus on a single common crop to make sure the system works well. While the system is designed to be used for different crops and larger farms in the future, my initial testing will be small-scale.

Limitations

Initial Prototype Focus: The project will deliver a prototype, not a fully commercialized product. Further development, and large-scale testing would be required for wider adoption.

- Dependence on Connectivity: The system relies on reliable Internet or cellular connectivity to transmit data to the cloud and for remote monitoring. This could be a challenge in some rural areas with poor network coverage.
- Limited Environmental parameters: While the system monitors key environmental parameters like water and temperature, it may not account for all factors affecting plant growth, such as nutrient levels, or pest infestations. These are areas for potential future improvements.
- Cost of Implementation: While the aim is to be cost-effective, the initial expense for the sensors and hardware, might still be a barrier for some farmers to afford.

1.6 Conceptual framework

This research is based on the concepts of the Internet of Things (IoT) and Automation Theory, which collectively form the basis for developing a smart system for monitoring and caring for plants. The IoT framework highlights the interconnection of physical devices though sensors and the internet to collect, process and transmit data in real time (Israel Mendonca, et al, 2023). This concept enables continuous environmental monitoring and smart decision-making without requiring human involvement. In this context, IoT enables the integration of sensors like temperature and humidity, soil moisture, light, and gas sensors with microcontrollers such as Arduino and NodeMCU to develop a responsive and data-driven plant management system. (N.S.Abu, et al, 2022)

The design of the system is also guided by Control Systems Theory, which illustrates how feedback mechanisms are used to maintain preferred conditions in a changing environment. According to this theory, sensors function as feedback elements that track environmental conditions and transmit data to the controller. The controller then compares the measured values with set thresholds and activates actuators like water pumps or lights when deviations occur. This feedback loop ensures that plants receive optimal care conditions automatically. (Sairoel Amertet Finecomess, et al, 2023)

The conceptual framework of this research therefore integrates IoT connectivity, sensor-based data collection, and automated control principles to achieve effective and smart plant care. The interaction between the sensors, microcontrollers, web interface, and actuators creates a closed-loop system that ensures optimal growing conditions for plants. This framework not

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only showcases the application of modern technological theories but also provides a practical model adaptable to small-scale agricultural contexts in Zambia.

II. LITERATURE R EVIEW

2.0 Overview

This chapter discusses relevant literature regarding the research and addresses the existing challenges, embracing advancements in sensor technology as well as the gaps associated with the challenges.

2.1 Review of the Literature

This literature reveals that the development of automated plant monitoring and care systems using IoT sensors is a well-established area of research, with numerous studies demonstrating their effectiveness in improving agricultural outcomes.

Research by (Baharudin, et al, (2024) demonstrates that IoT systems, which integrate sensors and microcontrollers, can provide real-time insights into environmental conditions such as soil moisture, temperature, and humidity. These systems can automate critical tasks like irrigation, reducing manual labor and human error (Kumar et al., 2024). The primary benefits identified in these studies are to enhance resource efficiency, which is water conservation, and improved crop yield through data-driven decision-making.

Multiple sources highlight the unique challenges faced by small-scale farmers in Zambia. A study by the (United Nations Development Programme, 2024) talks about how the nation is highly prone to climate change effects, including an increase in the frequent and intensity of droughts and unpredictable rainfall. These climatic disruptions affect rain-fed agriculture, which is the common practice among small scale farmers. The literature also points to a lack of access to financing, poor infrastructure, and limited agricultural support services as the major barrier to modernization (Consumer Unity & Trust Society, 2020. Climate change and its implications on agriculture productivity in Zambia. CUTS Lusaka.). These factors mean technology needs to be affordable and reliable to be useful.

This literature confirms that IoT-based systems are effective tools for modern agriculture, particularly in promoting resource efficiency and increasing productivity. However, this research is important because it will create a technology that combines smart farming principles with real life needs of Zambia's small-scale farmers. The goal is to provide a solution for the country's most pressing farming problems which are water shortage and the effects of climate change. The study will not only add to scientific knowledge but also help improve the lives and livelihood of Zambian farmers.

2.2 Related Works

IoT for Intelligent Agriculture

Mbale and Phiri (2025) proposed an IoT-based system for intelligent agriculture in Zambia that monitors and controls automated irrigation temperature, humidity, soil moisture, and light intensity. As it demonstrates the possible application of IoT in farming practices. The strength of this system lies in contextual relevance, as it addresses local agricultural challenges and demonstrates the feasibility of IoT in Zambian farming practices. However, this system limitations include restricted range of sensors, lack of scalability, and insufficient focus on the design of the interface for the end-user. Its reliance on basic monitoring functions without broader integration of data sources also restricts its long-term usefulness.

This research advances beyond this by incorporating gas sensors, and providing modular design for scalability as well as web-based interface for better accessibility and visualization. These improvements allow the system to handle larger deployments and deliver more extensive decision support tool for farmers

Cloud-Enabled Precision Agriculture Platform

Patil and Kale (2023) developed a cloud-enabled platform for precision agriculture which integrates IoT sensors with cloud servers for data storage, analysis, and predictive insights. Its key strength is scalability, as it can handle large datasets across multiple farms, providing predictive analysis of soil conditions, crop disease risks, and weather changes. However, its reliance on reliable internet connectivity, technical expertise, and costly infrastructure limits its adoption in developing regions.

This research adopts a hybrid approach by utilizing local processing through microcontrollers while maintaining web-based visualization. This approach reduces cost and technical barriers, making real-time monitoring more accessible for small- and medium-scale farmers without compromising on data accessibly or sensitivity.

Green house monitoring system

An additional relevant work is the Automated Greenhouse Monitoring System by Li and Wang (2023), which uses IoT sensors and cloud integration to monitor environment and plant growth parameters. This system is particularly useful for the provision of predictive alert and data analytics features for greenhouse management. However, the system analytics, which are advanced, are heavily dependent on cloud computing which may be problematic in inconsistent internet connectivity areas, especially in rural farming areas. Also, the interface is not user-friendly on multiple devices.

In contrast, this research focuses on a web interface that is lightweight and accessible on multiple devices and in low bandwidth scenarios, still providing real-time alerts and notifications.

This review confirms that although the technology for an automated plant monitoring system is well-established, there's still a huge gap in adapting it for Zambia's small-scale farmers. This study will use the technical successes of existing projects while focusing on the specific problems that have stopped technology adoption in the past, such as affordability, connectivity, and user experience.

2.4 Gaps in the literature

There is a significant gap in the research of using IoT sensors to automatically monitor and care for plants in developing nations like Zambia. While the technology's effectiveness is well-documented, they are usually designed for large commercial farms. This leaves a few key problems that my study will address.

Most existing research are designed for large-scale, commercial farms and are very expensive for small-scale farmers in Zambia (Akyazi G, Akbari A, 2022). There isn't much research on how to build a good system that focuses on a cost-effective, readily-available component-based approach that makes IoT technology financially accessible to the majority of farmers. The (Zambia ICT Journal, 2025) directly showcases that current systems are "too complex and expensive for widespread adoption" by small-scale farmers (Jameson M, Matthews P, 2025). My study will fill this gap by designing a system using low-cost, open-source hardware.

Smart farming systems usually need reliable electricity and strong internet connection these are often not available in most areas of Zambia due to load shedding issues. There is a lack of research that focuses on designing systems for unstable power, intermittent connectivity, and harsh environmental conditions. A report by (Anish Paul Antony, et al, 2020) further emphasizes that poor infrastructure is a major barrier to the utilization of IoT in small scale farming. My study will address this by designing a system that can operate effectively with limited infrastructure.

Many of the existing systems focus on the technological aspects of the system rather than the users experience. There is a huge gap in research on how to create a system that is ease to use even with less technical knowledge. A successful solution must be simple to install and operate, without requiring advanced technical knowledge. The research implies that the lack of user involvement in the design process is a major reason for the failure of new technologies (Soeker,j et al, 2021). My study will bridge this gap by developing a system that requires minimal technical knowledge and designing a simple user-friendly interface to operate.

While many studies claim to that smart technology can improve crop yields, there's limited research that provide strong, quantitative data on how it actually helps small scale farmers in developing countries financially (ResearchGate, 2025). This includes evaluating the system's effect on a farmer's income, labor savings, or how they improve their daily lives. A study by (Wanjiku, S.T, Waithaka,S.K, 2022) found that while smart technologies have potential, there is limited research on their actual usage and how they could support the lives of small-scale farmers in Southern Africa. My study will address this by conducting a test project to see and measure the real impact of the system

III. RESEARCH METHODOLOGY

3.0 Overview

This chapter provides a structured approach which emphasizes the methods used to conduct the research, data collected, analyzed and interpreted to achieve the study. As well as the development of the application, system design, context diagram and the system architectural design.

3.1 Research Design

This study follows a design science research approach, which is a structured way to design and evaluate an innovative solution into a real-world problem. It involves three phases which are Design, Development, and Evaluation.

Design Phase

This is the planning stage where the system's requirements and structure are defined. It ensures the final product will be practical and address the identified problems.

Development Phase

This is the practical phase where the system is built based on the design plans. It involves putting the hardware and software together.

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Evaluation Phase
This is the final stage where the system is tested to see if it works as planned and resolves the problem effectively

3.2 Baseline Study

The baseline study provides critical factors by detailing the current agricultural practices, existing technologies, and the challenges faced by Zambian small-scale farmers. This enables a clear comparison to be made between traditional farming and the IoT-based system to illustrate its effectiveness.
The baseline for this study is represented by the dependence on traditional, rain-fed farming methods. Small-scale farmers mostly use manual techniques for planting and irrigation, which is time consuming and often inefficient (Shaan R, 2024). This reliance on rainfall makes farming very risky, especially with the increasingly unpredictable weather patterns caused by climate change.
In the current setup, small scale farmers have very little access to modern technology even with its existence in Zambia. The most common forms of technology are large-scale commercial irrigation systems (Zambia National Farmers' Union, 2021). However, the baseline shows a lack of use for smart, data-driven technologies for small scale farmers this due to the high-cost of imported IoT and agriculture solutions that are not financially or technically within reach for most farmers (Nkumbu Nalwimba, 2024).

3.2.1 Data Collection

To Data collection for this study will involve both quantitative and qualitative methods to provide a comprehensive prospective of the system's performance and usability.

Quantitative Data Collection
This data will be the main source for evaluating the system's technical performance and efficiency. It involves collecting numerical data from the system's components.
Sensor Data: The IoT sensors will automatically and continuously collect data at set intervals. This includes soil moisture data the readings from the soil moisture sensor, measured in analog or digital values, temperature data the readings from the ambient temperature sensor measured in degrees Celsius, light intensity data Readings from the light sensor, measured in lux, and soil TDS data the reading from the dissolved salts/nutrients measured in milligrams per liter.
Performance Measures: Data will be collected on the system's operational efficiency, including power consumption to determine the system's sustainability for remote use, latency the delay time between a sensor reading and its appearance on the user interface as well as system reliability the percentage of successful data transmissions and automated control actions.

Qualitative Data Collection

This data is necessary for evaluating the system's user-friendliness and overall functionality, as it provides insights from potential end-users. It will be collected after the prototype has been built and tested.
Usability Testing: Interviews, surveys, and direct observations will be used to gather feedback from a small group of potential users, such as greenhouse operators, small-scale farmers and home gardeners.
User Feedback: Questions will focus on the system's operation, the usefulness of the alerts, and the potential for a system like this to be adopted in their day-to-day farming practices.

3.2.2 Research Approach

The study will adopt a mixed-methods approach, combining both quantitative and qualitative techniques to evaluate the system from technical and a user experience perspective. This approach ensures that the findings are both accurate and relevant within the Zambian agricultural settings.
Quantitative Data Analysis
This section focuses on the numerical data collected from the prototype's sensors and performance logs, with the aim of assessing the system's efficiency, reliability, and accuracy.
Descriptive measures: Key measurements including average soil moisture, temperature, humidity, light intensity and Soil TDS readings, will be calculated over the testing period to provides a baseline understanding of the controlled environment.
Performance Measures*:* The system's performance will be evaluated through:
Accuracy*:* Sensor readings will be compared against manual measurements taken with standardized instruments to determine the percentage of accuracy.
Reliability*:* The systems reliability will be assessed by recording the number of successful data transmissions and automated control actions such as successful pump activations.
Power Consumption*:* Battery usage will be monitored and analyzed to estimate the system's operational duration per single charge or a solar cycle.
Data Visualization*:* The collected data will be represented using charts and graphs to highlight

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trends and patterns in environmental conditions and systems responses.

Qualitative Data Analysis

This section focuses on the non-numerical data collected from usability testing and surveys, aiming to evaluate user experience and the system's practicality.

Thematic Analysis: Open ended survey responses and interview transcripts will be systematically analyzed to identify key themes and common viewpoints related to the system's usability, design, and perceived value.

Sentiment Analysis: User feedback will be categorized as positive, neutral, or negative to assess overall sentiment towards the system.

Comparative Analysis: The qualitative feedback will be compared with baseline study results to determine whether the system effectively addresses the challenges such as affordability, complexity, and resource inefficiency.

3.2.3 Development of the Application

The development of the application for this system involves creating two main parts, the front-end what the user sees and the back-end what makes it work.

Back-End Development

The back-end is responsible for handling all the data and decision making. It is the core of the system

Data Processing: This is set up to receive real-time sensor data from the microcontroller. A communication protocol will be used to ensure transfer of data from the microcontroller to the server is efficiently done. Once received, it will make the data easy to understand.

Storing information: This will be done by creating a database which will be set up to store all the sensor data. This is important so that the user can track their plants health and environmental conditions over time.

Automation: This is the core logic for the system's automation. It will constantly analyze incoming sensor data against set standards. For example, if the soil moisture levels drop too low, it will automatically send a command to the microcontroller to turn on the water pump. And if the temperature rises too high it will automatically turn on the fan.

API Development: An Application Programming Interface (API) will be developed to serve as the bridge between the data and the user interface, by allowing the back-end to communicate with the front-end.

Front-End Development

The front-end is the application on the user's phone. It is designed to present data in a simple and easy way.

User Interface Design: The UI will be designed with a simple layout. It will include a dashboard where the user will be able to see real-time sensor data visualization, through simple charts and graphs and will be able to manual control automated functions using toggle buttons. This will make it easy even for users with limited technical experience as they can check plants status at a glance.

Mobile and Web Application: The application will be developed as a mobile application, which will be accessible on smartphones.

Notifications and Alerts: The application will be programmed to send automatic alerts to the user's mobile phone if there's a problem, such as the soil being too dry or the temperature being too high. This ensures the farmer always knows their plants' needs, even when they are not actively using the application.

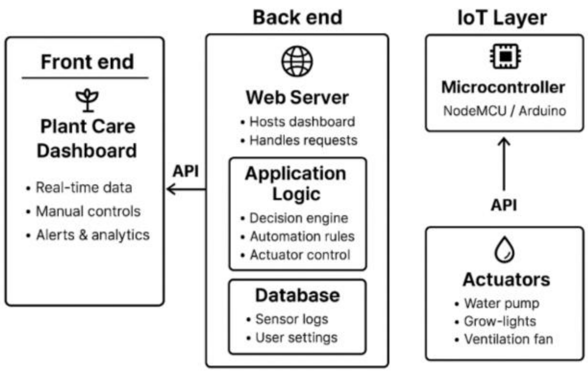

Figure 1 Development of Application

3.2.4 System Design

This system was designed using an open-source hardware kit with a microcontroller and software development environment. The Arduino Uno R3 development board was selected for its simplicity and versatility. It features 20 digital input/output pins, 6 analogue input pins, a 16 MHz crystal oscillator, USB connectivity, a power jack, and a reset button. Programs can be uploaded to the board using the Arduino Integrated Development Environment (IDE). The ESP32 was selected for its integrated Wi-fi capability and low cost, it can communicate directly over the internet making it ideal for the projects goals of creating an affordable and accessible IoT system.

The schematic diagram of the automated monitoring and care system is shown in Figure 3. The main components of the system include an Arduino R3 microcontroller, an ESP32 wi-fi module, a soil moisture sensor, a DHT11 temperature and humidity sensor, a light intensity sensor, a TDS conductivity sensor, a Gas sensor, an LCD display, an ultrasonic sensor, a water pump, relays and a fan.

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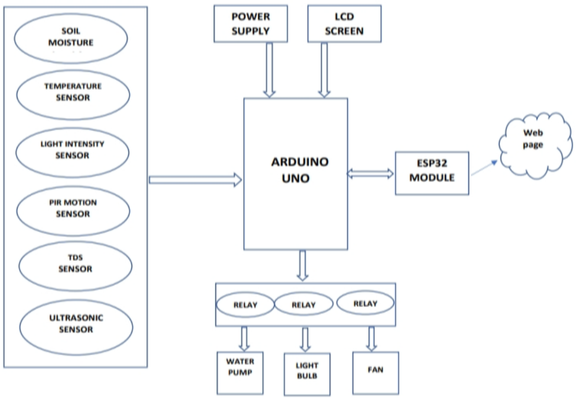

Figure 2 Schematic System Design

Circuit Diagram

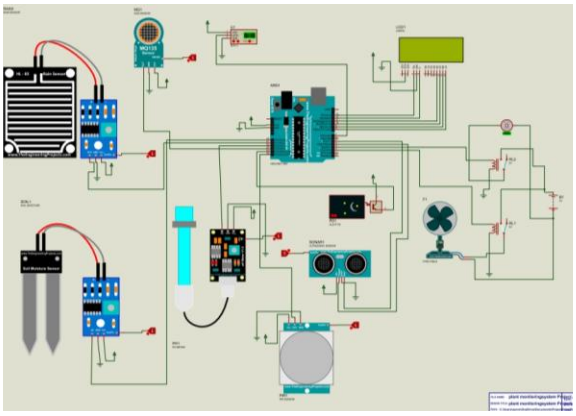

Figure 3 Circuit Diagram

The complete circuit diagram of the system, as illustrated in Figure 3 comprises
several key components each component plays a specific function in the plant
monitoring system:

- The Arduino Uno R3 serves as the main microcontroller, providing a user-friendly interface for programming and interfacing with various sensors and actuators. It is the central unit of the system, controlling the functions of the other components and processing the data collected by the sensors.
- The ESP32 provides Wi-fi connectivity for the system, sends sensor data to the web interface for remote monitoring and receives control commands from the web interface like turning the pump on/off
- The LCD is a display screen that displays plant monitoring data, such as temperature, humidity, soil moisture, and light levels, allowing quick on-site monitoring.
- The temperature sensor measures the ambient temperature and humidity of the plants and their surroundings and maintains suitable environmental conditions for plant growth.
- The soil moisture sensor measures the moisture content of the soil where the plants are growing and triggers irrigation when moisture levels are below the required standard.
- Gas sensor monitors air quality by detecting harmful gases such as carbon dioxide, ammonia, or smoke to ensure a safe environment for the plants.
- PIR motion sensor detects human or animal movement near the plant area, providing security by alerting the user to possible intrusions.
- Light intensity sensor measures the intensity of light reaching the plants to determine whether additional artificial lighting is required
- TDS Conductivity sensor measures the total dissolved solids in the water quality, ensuring that the irrigation water is suitable for plant growth.
- Ultrasonic sensor uses sound waves to measure distance in this system it is used to detect tank water levels.
-
- The fan acts as an actuator to regulate air circulation and temperature around the plants by turning on when high heat or poor ventilation is detected.
- The water pump functions as the actuator for the irrigation system, by automatically watering the plants when soil moisture is below the requires standard.

Working Principle

The working principle of this system is based on a continuous, automated feedback loop that monitors and controls the environmental parameters for the setup smart greenhouse. The system is capable of operating in two distinct modes, automated and manual operation. The system enables the user to have full control and monitoring capabilities. It operates by sensing, processing, and acting to maintain optimal conditions.

The process begins with the sensing phase, where the sensors constantly collect data from the environment. The soil moisture and TDS conductivity sensors check the soil's condition and nutrient level, while the ultrasonic sensors monitor the water tank to ensure sufficient water is available. Simultaneously, the temperature and humidity sensor track the air conditions, and the gas sensor detects any harmful pollutants by evaluating air quality. The light intensity sensor measures sunlight, and the PIR sensor enhances security by detecting movement near the plant area. All these sensors work together to convert physical conditions into electronic signals.

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This data is then sent to the Arduino Uno, which acts as the main controller, it processes the data and makes decisions based on its programmed logic by triggering actuators to maintain optimal conditions and compare sensor readings against specified thresholds. An ESP32 module provides Wi-Fi connectivity, allowing the system to send sensor data and receive commands over the internet.

Based on the decisions made by the Arduino the system activates various components to correct the environmental conditions. If the soil is too dry the water pump turns on to irrigates plants, when the temperature is too high the fan is activated to regulate temperature and airflow, and a light bulb is turned on to supplement natural light when required. These Real-time readings are displayed on the LCD screen to provide a quick way for the user to have on-site monitoring without needing a phone.

This entire process forms a continuous feedback loop, where the system senses a change, processes the data, acts to correct the condition, and then senses the new state, ensuring the environment remains controlled and stable.

Flowchart

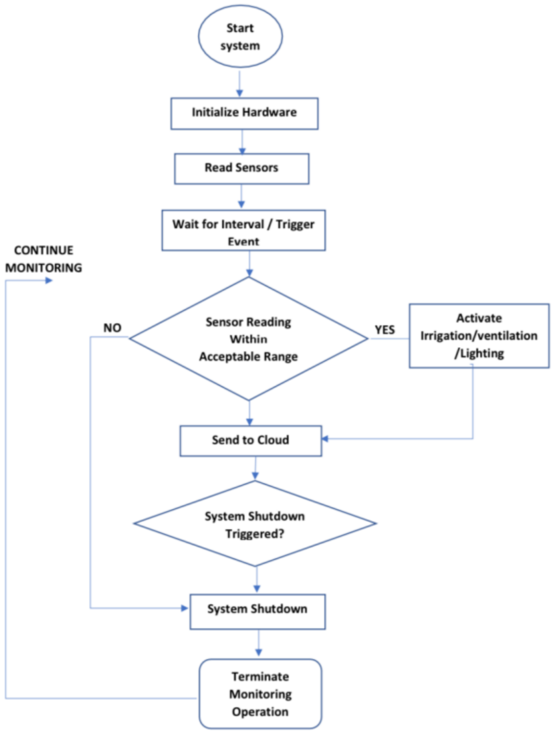


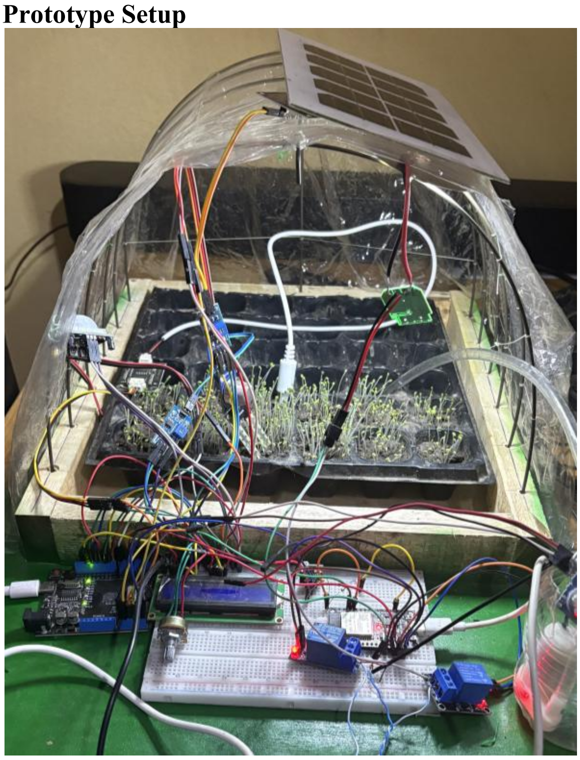
Figure 4 flowchart

The operation of the system starts with initializations of the sensors, preparing them for the beginning of the operation. After achieving the status of operational, the system proceeds to collect readings from different sensors, these sensors monitor soil moisture, temperature and humidity, light intensity and gas concentration. These readings are constantly taken and compared with set metrics.

When the system detects that soil-moisture has fallen below the level, it automatically activates the water pump to irrigate the plants. If the soil has enough moisture, the system performs the next check by assessing the light level. If the light intensity is below the set standard, the system turns on the artificial light source. Once the system activates the light source, it performs further checks on temperature and humidity, If the temperature and humidity are in the set safe range, it will notify the user. After temperature and moisture checks, the system performs gas checks. If gas concentration within the system exceeds the safe level, it is programmed to trigger an alert which makes sure that gas concentration is taken care of. Following these steps, the system processes the collected data and sends it to the web interface to facilitate remote monitoring of the plant's condition and the system's operational status.

In conclusion, the system runs continuously in a loop. After the conditions are checked and data is sent, it returns to the beginning to read the sensors. This guarantees that the monitoring and care system delivers real-time, automated plant management until the user decides to turn it off.

Prototype Setup



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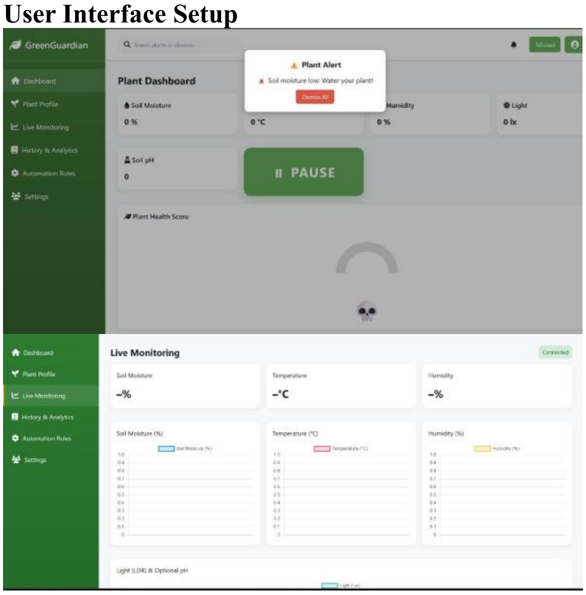
User Interface Setup



The baseline reveled that the monitored parameters were significant variable, as a result the health of plants was at risk. Manual methods of observation were time consuming and prone to inaccuracies. These results justified the necessity of an automated IoT based monitoring and control system to maintain optimal growing conditions consistently and efficiently.

IV. RESULTS

4.0 Overview

This chapter presents the results obtained from the design and implementation of the automated plant monitoring and care system using IoT sensors. The findings include data from the baseline survey conducted with target users (urban gardeners, farmers, and agricultural students), the system implementation test results, and subsequent data analysis.

4.1 Baseline study and testing

A baseline study was conducted before the development of the system in order to evaluate the traditional plant care practices and identify the key environmental factors affecting plant growth. The effectiveness of the IoT based system was assessed using this baseline guide.

Plants were carefully observed manually over a period of seven days during the baseline assessment. Measurements of soil moisture, temperature, humidity, light intensity and air quality were recorded. The data collected established the environmental condition of the test plants before the integration of IoT sensors.

Parameter	Minimum	Maximum	Average	Remarks
Temperature (°C)	22	33	28	Fluctuated due to daytime heat
Humidity (%)	34	67	50.5	Moderate, but inconsistent
Soil Moisture (%)	18	65	36.2	Dried quickly during midday
Light Intensity (Lux)	4500	12500	8300	Varied with cloud cover
Gas Concentration (ppm)	380	680	520	Slight increase near polluted areas

Table 1 Observed Environmental Parameters

4.2 Survey Results and Discussion

A user survey was conducted among selected respondents, which included small scale farmer, home gardeners, green-house operators and agricultural students. The objective was to understand existing practices, challenges and expectations regarding automated plant care systems, as well as to evaluate the usability, effectiveness and performance of the developed prototype.

Statement	Yes (%)	No (%
Have you ever heard of IoT-based plant care systems?	70	30
Have you used any plant monitoring devices before?	25	75
Do you believe automation can improve plant health?	90	10

Table 2 awareness and use of automated systems

Despite their lack of practical experience, the majority of participants were aware of IoT systems. This indicates that if the technology is made accessible and easy to use, there is a significant potential for it to be adopted.

Perception of the Developed System

After demonstrating the prototype, the respondents were requested to evaluate the system based on usability, accuracy, and reliability.

Evaluation Parameter	Excellent (%)	Good (%)	Fair (%)	Poor (%)
Ease of Use	50	43	7	0
Accuracy of Readings	47	40	13	0
System Responsiveness	53	37	10	0
Design and Interface	60	33	7	0

Table 3 user perception

The survey results highlight a positive sentiment regarding the adoption of IoT technologies in plant monitoring and care. The main benefits to respondents were the real time data feedback provided by the sensors and the automatic actuation mechanisms.

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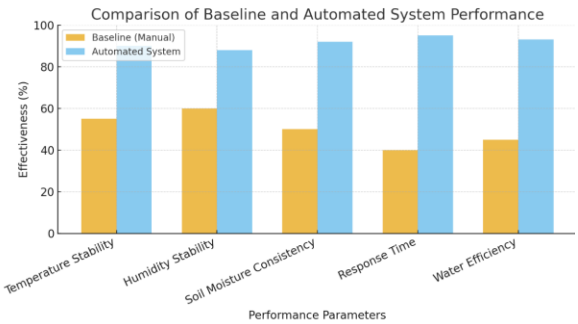
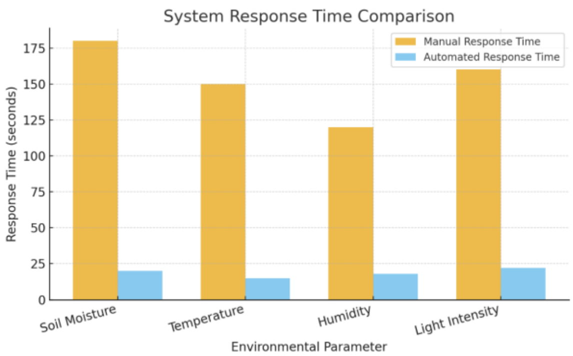
4.3 System Implementation Results

Implementation results showed stable sensor performance, reliable wireless communication, and accurate irrigation control. The web interface effectively displayed live readings and system status, enabling user-friendly supervision of plant conditions. Overall, the system demonstrated its potential to enhance plant care by improving monitoring accuracy, reducing manual labour, and supporting data-driven decision-making.

4.4 Data Analysis

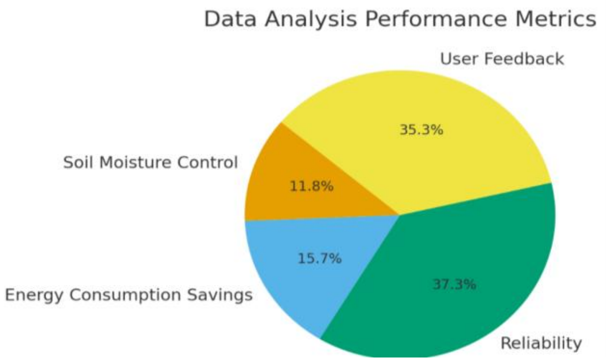
The results showed clear improvement in environmental stability after the automated system was introduced.





The analysis confirms that the developed IoT based system achieved the following goals effectively, accurate monitoring was improved by maintaining real time readings, the system was able to reduce human error and delayed responses in plant care, environmental stability (soil moisture, humidity and temperature) was improved and the system got positive user feedback in terms of usability and efficiency.

Overall, the results show that the system has the technical capability, energy consumption savings, is reliable, and meets with user-acceptance, successfully meeting the objectives of the study.



V. DISCUSSION AND CONCLUSION

5.0 Overview

This chapter interprets the results obtained from the baseline study and implementation, discusses the role of technology, compares with related systems, and outlines applications, summary, and future directions.

5.1 Discussion

The study aimed to design and develop an automated plant monitoring and care system using IoT sensors to overcome the challenges of traditional/manual plant care practices. The results obtained from the survey, baseline study and system testing provide strong proof of the system's effectiveness and reliability

5.2 The Baseline Study

The baseline study offered a foundation for understanding the challenges associated with traditional plant monitoring and care methods. The discussion of the baseline study shows that the IoT based approach successfully addressed the weakness of traditional plant care techniques, validating the systems design objectives and proving its role in promoting more efficient, data driven plant management

5.3 Use of Technology

The study demonstrated that the integration of technology, particularly internet of things IoT devices, played a critical role in improving plant care and monitoring practices. The system utilized Arduino and ESP32 microcontrollers as the central processing units connected to the sensors, these sensors ensured real-time monitoring of the plant environments and accurate measurements, which were previously unachievable with manual methods.
Remote monitoring and control were made possible by the web-based interface, which allowed users to

observe environmental conditions and initiate activities like watering or lighting adjustments without being physically present. This illustrated how technology in plant management can reduce human error, increase productivity and save time. Based on sensor readings, automation ensured that plants consistently received optimal care possible
Utilizing these technologies also make data driven decision making easier because historical sensor data can be stored, analyzed and utilized to predict future plant needs. Both home gardeners and small-scale farmers can benefit from this technological approach's precision, consistency, and scalability when compared to traditional plant care.

5.4 Development of the System as a Solution

The development of the system was driven by the need to solve the challenges outlined in the baseline study such as inconsistent monitoring, delayed response to changing environmental conditions and the traditional, time consuming methods of caring for plants. The results of this study demonstrate how the systems automation, precision and real time control successfully offer a technological answer to these issues.

5.5 Comparison with Other Similar Works

The systems performance aligns with findings from related IoT based agricultural projects, which have also shown enhanced crop monitoring effectiveness, reduced human error and optimal resource use. However, this study contributes a unique approach by integrating several sensors with a simple web-based platform that enables real-time visualization and alert notification, making it user-friendly and more accessible.

5.6 Possible Applications

- Small-Scale Agriculture
- Greenhouses and Nurseries
- Home Gardening
- Urban Farming
- Educational and Research Purposes

5.7 Summary

In summary, the IoT based automated plant monitoring and care system successfully addressed the challenges of manual plant management by offering a reliable, accurate and user-friendly solution. The system adds to the growing field of smart agricultural and showcases how demonstrated effective integration of IoT in agriculture. Baseline results confirmed high user interest, while implementation validated the solution's practicality. The findings reinforce the need for scalable, affordable IoT agricultural systems.

5.8 Conclusion

The main goal of the research, which was to use internet of things to design and develop an automated plant monitoring and care system, was accomplished. The prototype demonstrated accuracy, responsiveness and dependability in maintaining optimal environmental conditions for plant growth.
Real time monitoring, automated control and data visualization via a web interface were made possible by the combination of Arduino and NodeMCU32 microcontrollers with soil moisture, temperature, humidity, light and gas sensors. The system minimized manual effort, reduced errors, and improved the consistency of plant care activities. It achieved reliable monitoring of soil moisture, temperature, humidity, and light, while automating irrigation and providing real-time updates via cloud and mobile platforms.
Furthermore, user feedback validated that the system is practical and has high potential for deployment in both home and small-scale agricultural settings. The study shows how IoT technologies can be applied in precision agricultural to help manage resources in sustainable and effective ways.

5.9 Future Works

Based on the results, the following recommendations are proposed
- Integration of a LORA module to allow data transmission in areas without WI-FI connectivity
- Integration of GSM module to enable SMS based alerts when WI-FI connectivity is unavailable.
- The use of advanced sensors for higher accuracy
- The development of a mobile application in addition to the web interface for much easier accessibility.

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