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Early Detection of Crop Disease: Plant Health Monitoring Robot

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ABSTRACT

This aim of this project was to develop a prototype plant's health-monitoring robot capable of assessing environmental conditions and benchmarking them against a standard plant's parameters. This modern system serves as an indicator of plant vitality, gauging factors such as soil moisture, ambient temperature, and humidity levels. We constructed a simulated environment to facilitate the robot's operation and showcase its functionality. The robot's design enables it to capture sequential photographic frames of the plant, allowing for real-time health assessments. These images are analyzed to determine leaf texture, with health indications expressed as percentages. For easy robot control and real-time sensor monitoring, we created a user-friendly Android app that connects via Bluetooth. The app lets you command the robot's movements and view sensor data directly on your screen. The robot efficiently navigates a predetermined route, visiting various plants within the field. Its hardware comprises an array of sensors, motors, and associated components. This research study demonstrates the potential of robotic technology in the agricultural sector and sets a precedent for future developments in the assessment of environmental conditions and early detection of plant's diseases.

Keywords: plant; health-monitoring**;** robot; environment; android

1. INTRODUCTION

In 1947, agriculture stood as the primary contributor to Pakistan's GDP. However, today, two other sectors surpass agriculture in GDP share. The service sector now leads, with agriculture trailing in third place. Initially agrarian, Pakistan diversified with industrialization, diminishing the prominence of agriculture. Despite its decline due to industrial development, the sector remains vital, especially considering rural areas, which accommodate 62% of the population. Agriculture not only sustains rural livelihoods but also serves as a major employment source. Studies, such as the World Development Report (2008), highlight the effectiveness of agribusiness in reducing poverty, emphasizing its role in bridging the rural-urban income gap in Pakistan (Wing, 2014).

Pakistan, primarily agrarian, relies heavily on agriculture for its economic sustenance. However, farmers face increasing challenges, including inflation, jeopardizing their livelihoods and driving them away from farming. Struggling to break even, farmers seek solutions to reduce costs and labor. To address these issues, the PHIMR robot was developed, aiming to alleviate the burden on farmers and ensure fair returns on their investments.

The Plant Health Indication and Monitoring Robot (PHIMR) is outfitted with an array of sensors designed to evaluate a range of plant health metrics. Visual sensors, including high-resolution cameras, take intricate photographs of leaves. These photographs undergo scrutiny through image processing methods and machine learning models to identify pest infestations ,disease markers like discoloration, droopiness, or speckles . Moreover, PHIMRs utilize multispectral imaging technology to record wavelengths outside the visible range, offering valuable data on plant distress, and nutritional shortfalls (Dour et al., 2017; Hajare et al., 2023; Kamilaris et al., 2017; Manjunath et al., 2019).

A significant benefit of Precision Health Informatics Mobile Robots (PHIMRs) lies in their capability to oversee extensive farming activities both effectively and economically. Operating independently, these robots navigate across agricultural expanses, gathering detailed images and sensor readings from various perspectives. Utilizing advanced machine learning techniques and data analysis (Vázquez-Arellano et al., 2016), PHIMRs can detect minute variations in crop health markers, which are typically imperceptible to human observation. This facilitates the prompt identification of potential issues such as disease, infestations, or adverse environmental conditions (Mahlein, 2016) (Sankaran et al., 2010).

In our efforts to enhance agricultural productivity and alleviate farmer hardships, PHIMR focuses on two key functionalities:

1. Accurate Monitoring: PHIMR provides precise readings of temperature, humidity, and soil moisture, aiding farmers in optimizing growing conditions.

2. Health Assessment: By observing plant leaves, PHIMR assesses plant health, enabling early detection of issues and proactive interventions to maximize crop yield.

Optimal temperature is crucial for the proper functioning of a plant's biological processes, such as photosynthesis. During photosynthesis, plants utilize light and CO_2 to fuel their growth mechanisms, which operate optimally within specific temperature ranges. Variations in temperature can lead to abnormal growth, diminishing productivity. Warm-season vegetables and flowers typically thrive between 60 to 75°F, while cool-season plants like spinach and lettuce require temperatures ranging from 50 to 70°F for optimal production (Hussain et al., 2014).

Humidity, defined as the presence of water vapor in the atmosphere, also significantly impacts plant growth and productivity. Humidity levels, ranging from 0% to 100%, play a vital role in monitoring plant health. Low humidity can cause plant tissues to wilt, while high humidity promotes fungal and bacterial growth. Ideal humidity ranges from 50% to 70% for vegetable plants and 50% to 60% for flowering plants.

Soil moisture, the third critical factor, profoundly affects plant growth. It's essential to regulate the amount of water supplied to plants, as excessive watering can be harmful. For instance, a mature tomato plant typically requires one gallon of water per day. Insufficient water supply leads to root damage and prolonged recovery periods, directly impacting productivity.

The leaf serves as the primary indicator of a plant's health, with its color revealing valuable insights into its nutrient status. Chlorophyll, the green pigment in leaves, is particularly informative in assessing plant health. Farmers typically favor a dark green hue in their plants. For the past two decades, the SPAD-502 meter has been employed to measure leaf chlorophyll levels. Renowned for its accuracy, it has been widely utilized in research, with over 200 studies featuring its application (Uddling et al., 2007).

The aim of this study is to create a robotic system to for early detection of plants health by evaluating key environmental parameters such as temperature, humidity, and soil moisture levels. The ultimate goal is to increase crop yield and reduce production cost.

Scope of the PHIMR

• The robot's tracked chassis enables it to traverse uneven terrains effectively.

• Plant health accuracy will be assessed through continuous monitoring.

• The robot facilitates estimation of optimal harvesting times and watering schedules for crops.

• Its precise sensor readings are particularly beneficial for high-maintenance plants requiring close attention.

• In greenhouse settings, our robot aids in regulating atmospheric conditions.

• Biologists can leverage this robot in research laboratories, where precise detection of plant health is crucial.

2. LITERATURE REVIEW

2.1. Agriculture history

Agriculture, a practice dating back roughly 10,000 years, has evolved significantly. The history of agriculture reflects a relentless pursuit to satisfy our society's increasing food demands by enhancing crop productivity. For millennia, farmers have selectively cultivated plants that yield more and are resilient to drought and disease, thanks to vigilant monitoring. Numerous strategies have been employed to protect vulnerable plants, including the construction of canals for irrigation, the creation of terraces to prevent soil erosion, and the application of various fertilizers. However, the consistent identification of diseased plants posed a challenge for many years (Mueller et al., 2021).

In the 20th century, with the world population surging dramatically, projections suggest that the global population will rise from an estimated 6.9 billion in 2010 to 9.2 billion by 2050, predominantly in less developed regions. Consequently, approximately 70% of the global population will reside in urban areas, escalating the demand for food and necessitating a substantial increase in crop production. Ensuring plant health is paramount to meet these demands.

The advent of automation became widespread in the 20th century, revolutionizing tasks previously performed by human labor. This shift introduced robots capable of executing various operations, thereby simplifying human efforts.

2.2. Modern technology

Numerous studies have been conducted on systems for monitoring plant health, employing two primary detection methods: destructive and non-destructive. The destructive approach relies on laboratory analyses, where plants are dissected to examine their nutrient content through various chemical tests. This method, while accurate, requires advanced equipment and is notably time-intensive.

Conversely, the non-destructive method is expedited but sacrifices some precision. It includes Digital Image Processing, which analyzes the shape, color, and texture of plant leaves to detect diseases. These diseases can originate from pesticide use or environmental factors and are identifiable by the leaves' physical state.

The HIS color model is instrumental in transforming images into three distinct models for disease identification. The research presented here focuses on maize plant diseases, with a database compiled from images of healthy and diseased plants captured in Maharashtra, India. A camera records images from the fields, which are then processed by an algorithm that extracts hue, saturation, and intensity components. The algorithm selects the optimal component, isolates green pixels, and converts the remaining image into a binary format. This binary matrix is then analyzed by a Neural Network that identifies the disease, referencing a pre-established database. Finally, an SMS is generated to inform the farmer about the crop's condition (Gokulakrishnan, 2014).

The leaf is a critical indicator of plant health, with its color reflecting nutrient levels. Chlorophyll, the green pigment, is particularly telling of a plant's well-being. Farmers typically favor a darker green hue in their crops. For over two decades, the SPAD-502 meter has been a popular tool for measuring leaf chlorophyll, and it has been the subject of over 200 published research studies.

The RGB color model is a fundamental element of digital image processing. Diverse cameras have been utilized to capture images of foliage. These images facilitate the detection of RGB values. From these values, various formulas can be extrapolated to assess plant health. Historically, numerous researchers have contributed to the development of RGB-based formulas. Such formulas are instrumental in identifying leaf components, providing valuable indicators of plant vitality.

Another proposed image processing technique for analyzing plant chlorophyll content is OPILEAF. This method utilizes a handheld, portable scanner called the Pico Life. The scanner features a reference plate measuring 40 x 22 centimeters and is designed specifically for scanning plant samples. The scanning process involves placing a detached leaf on a white background for the Pico Life to capture the image. The captured data, containing RGB (red, green, blue) values, is then transferred for analysis using MATLAB software. By analyzing the relationship between these RGB values, OPILEAF estimates the chlorophyll content within the scanned leaf tissue (Cai, 2006). Different robots used to monitor plant's health are mentioned below:

2.2.1. Koubachi Wi-Fi sensor

KUAOBACHI Wi-Fi sensor is a robot which is renowned for its houseplant care capabilities. It is equipped with comprehensive sensors that monitor humidity and soil moisture levels, seamlessly transmitting this data to the Koubachi web platform. Upon specifying the plant species under observation, the platform provides tailored care instructions to ensure optimal plant health (Ahmad & Sharma, 2023).

Figure 1: KoubachiWi-Fi Sensor robot

2.2.2. HarvestGeek

The HarvestGeek system employs a network of soil sensors that relay data to a central processor, which in turn, tracks plant conditions in real-time. This comprehensive system operates with soil sensors and dubbedBots that transmit data to the base station and its cloud network. Subsequently, this information can be shared via social media or email notifications. It maintains a log of water temperature and utilizes this data to formulate a strategy for the plants' optimal growth (Srivastava & Das, 2022).

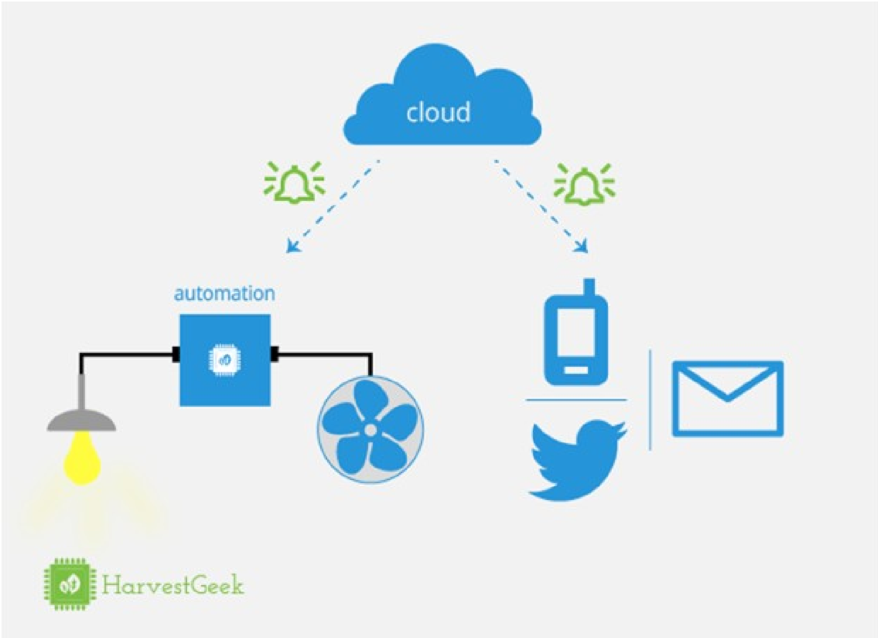

Figure 2: HarvestGeek system

2.2.3. GardenBot

GardenBot is a comprehensive, open-source system powered by Arduino for soil condition monitoring. It aims to provide a full-fledged solution for garden surveillance and management. The Beta version of GardenBot allows you to keep track of your garden's environmental parameters and offers graphical representations for better understanding of these metrics. Additionally, it includes a feature that enables electronic regulation of your watering system, allowing for easy activation of water flow with a simple switch action.

Figure 3: GardenBot

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3. METHODOLOGY

3.1. Requirements Specification:

3.1.1. Non-functional requirement

Platform: Arduino

Operating system: Windows

Application: Android application

Portability: Efficient movement and easy use.

Design: Compactly designed**.**

Safety precautions: Specific area movement of the robot

Efficiency: Ideal performance in a given field**.**

Development method: No immoral material should be used developing the robot.

Security: The robot can be accessed only through the android application for its movement.

3.1.2. Functional Requirements

Bluetooth Connectivity: Arduino receives characters from android application through the Bluetooth module.

Sensors Reading: Sensors sends reading to arduino which sends it to the application through Bluetooth module.

Camera: Camera images transferred to windows for analyzing using open Computer Vision library.

3.2. Design creation

3.2.1. Designing of artificial field

An artificial field has been created to showcase the functionality of robots. It features four distinct plants chosen for their prominent leaves over stems. The soil composition is tailored to suit sensor detection, and the plants are arranged in a compact tray. The height of the plants is determined by the robot's size and the camera's range. Demonstrations are conducted on this 5x5 square feet field.

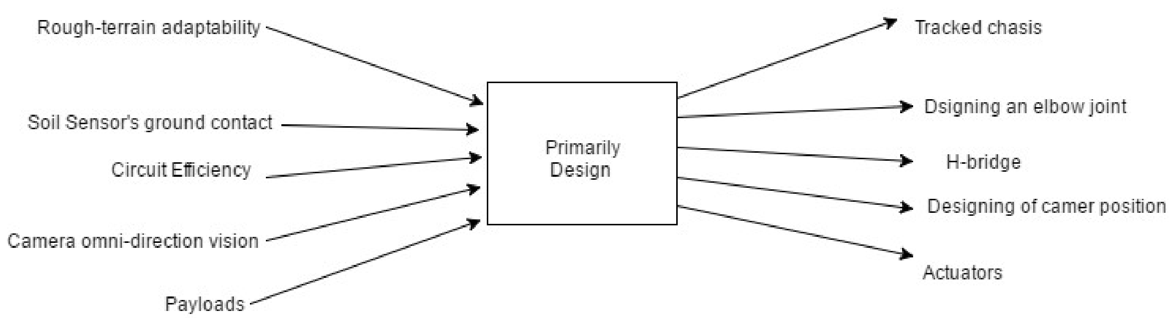

Figure* 4*: Primarily design of robot

3.2.2. Design of Elbow Joint for Soil Moisture Sensor

The design of the elbow joint for the soil moisture sensor has been a critical task. Through extensive brainstorming and precise calculations, we determined that the elbow should measure 8 inches and be positioned laterally. Additionally, it is essential for the elbow to incorporate a large servo motor to manage the pressure effectively.

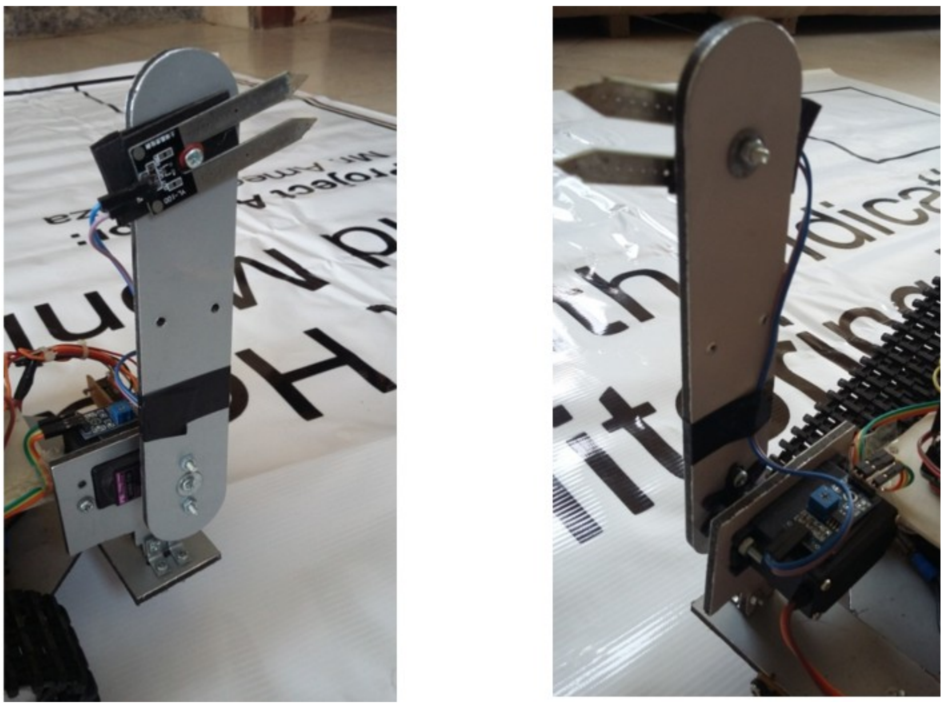

Figure 5: Elbow joint showing both sides

3.2.3. Circuit Efficiency

To enhance the circuit's efficiency in conjunction with the motors and to ensure the delivery of suitable pulses to the Arduino board, a Dual H-Bridge is utilized. Different circuit specifications are mentioned below in table 1.

Table 1: Circuit specifications

Parameter	Value
Double H bridge Drive Chip	L298N
Logical voltage	5V
Drive voltage	5V-35V
Logical current	0-36mA
Drive current	2A (MAX single bridge)
Max power	25W

Weight	26g

3.3. Hardware and Software implementation

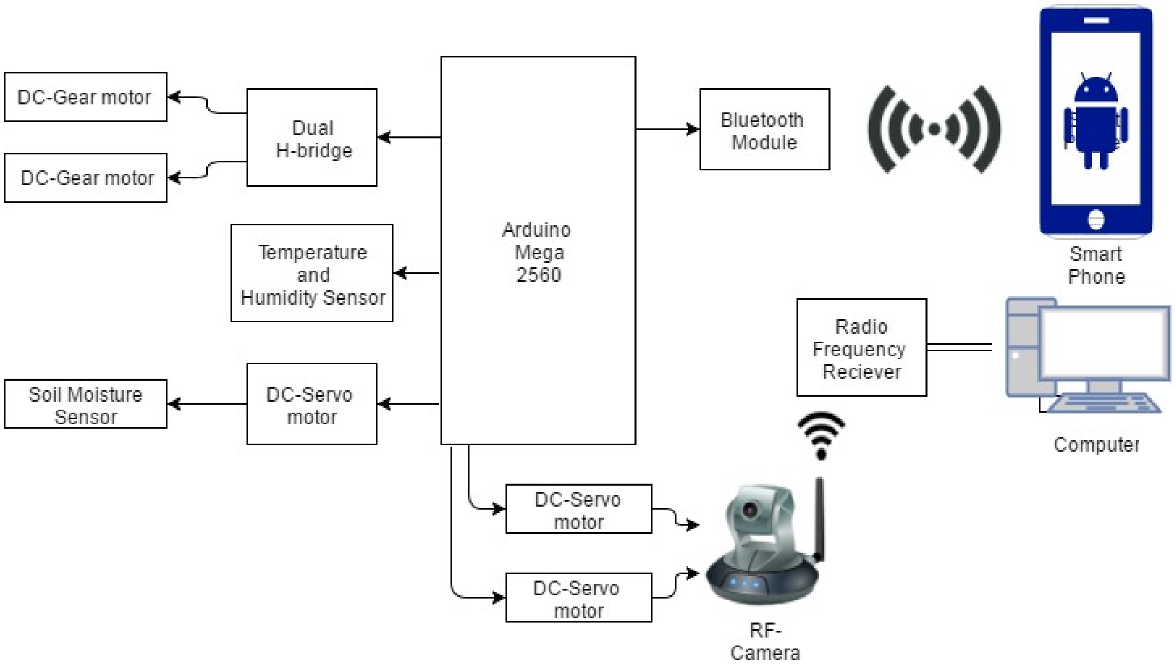

Figure 6: Block diagram of complete model

The project integrates hardware and software components. The hardware includes a Bluetooth module (HC-05) for robot control, various sensors (DHT-11, Soil moisture, IR-Sensors) for environmental monitoring and distance measurement, and actuators (5 servo motors, including 2 DC-gear motors) for movement and camera control. The Arduino Mega 2560 serves as the central processor, interpreting sensor data and directing actuators.

The software comprises an Android app developed with MIT-App Inventor 2, providing a user interface for command input and sensor data display. The robot's semi-autonomous functions are coded in C on the Arduino platform, with a color detection algorithm processed via Digital Image Processing and C# in Visual Studio.

3.3.1. Sensors working with Arduino Mega

The Arduino Mega is connected to DHT-11 and soil moisture sensors. Soil moisture levels are set using “s+value”, humidity with “h+value”, and temperature with “t+value”. The Arduino transmits these values

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via TX data, and a Bluetooth module packages and sends them to an Android app. The app identifies the values based on the initial character (‘t’, ‘h’, or ‘s’) and updates the respective text box.

Humidity is measured in percentages, temperature in Celsius, and soil moisture also in percentages. The system reads analog signals, digitizes them, and sends them serially. Soil moisture measurement is based on electrode conductivity, with 3.3 volts representing the maximum range for calculating percentage values.

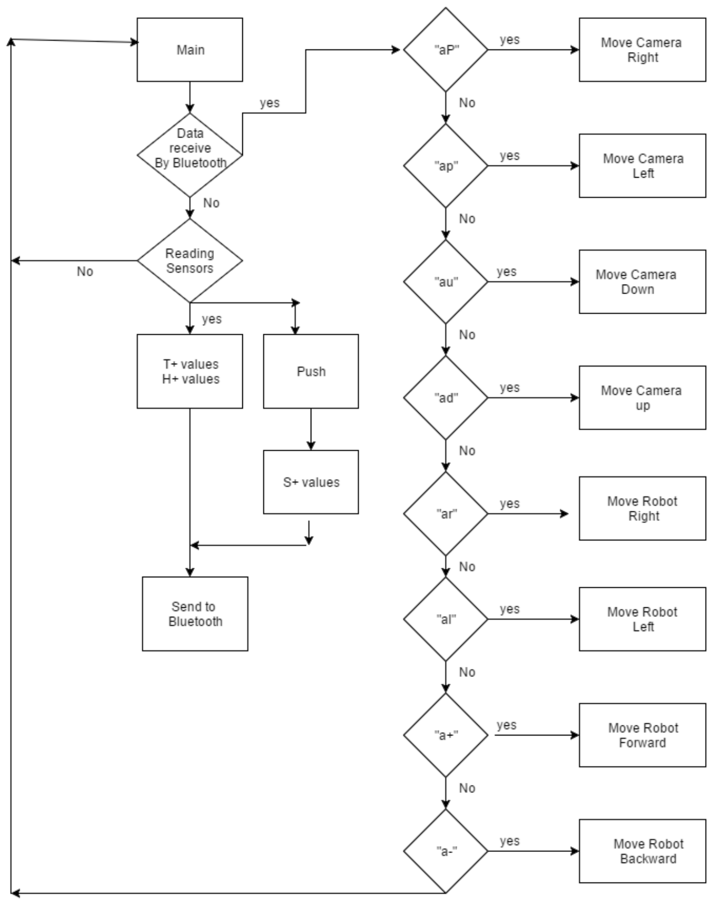

Figure 7: Sensors working with arduino(flow chart)

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3.3.2. Motors Working with H-bridge and Arduino Mega

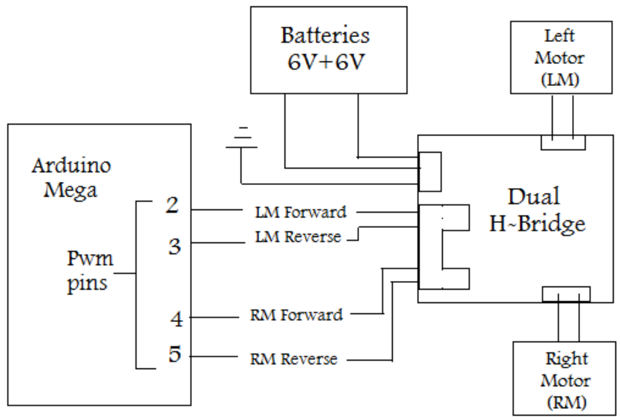

Figure 8: Motor and H-bridge interference with Arduino

The Arduino is connected to a dual H-bridge using 4 PWM pins, enabling robot locomotion. It sends square wave signals with a period of T, where the rising edge halts operation and the falling edge commands the motor to spin. Motor speed is regulated by varying the duration of these signals, with a value range of 0-255; setting it to 125 results in half-speed operation.

The robot's movement is directed by alternating the motors' rotation: both motors moving forward propels the robot ahead, both reversing causes it to back up. For turning, the right motor advances and the left reverses for a right turn, and vice versa for a left turn.

3.3.3. Bluetooth Module working with Arduino Mega

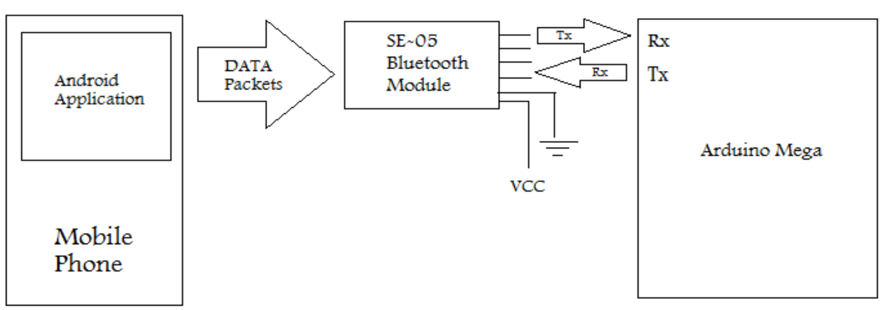

Figure 9: Bluetooth module interference with Arduino

The HC-05 Bluetooth module, featuring 6 pins, was utilized. It has TX/RX pins for data transmission and reception with Arduino. The Arduino's TX connects to the module's RX, and vice versa. Data is transmitted at 9600bps. An Android app sends data like "aP" and its ASCII value to the module, which then forwards it to the Arduino. Upon recognizing the 'a' identifier, the Arduino confirms the data is from an Android app and processes the subsequent characters.

3.3.4. Image processing technique through camera

We utilize the Open-Source Computer Vision Library for image processing tasks. This library allows the integration of image processing features into various programming languages through a compiler. An RGB image is composed of pixels, each with three components:

- **R (Red):** 0-255
- **G (Green):** 0-255
- **B (Blue):** 0-255

The image is scanned for green color, which is then matched pixel-by-pixel against a reference image of healthy plant greenery. The comparison yields a ratio that is converted into a percentage. This percentage, indicative of the plant's health, is then assessed using a GUI-based greenness analyzer that employs the described method to display the greenness level of the captured image.

4. RESULTS AND ANALYSIS

Robot testing involves checking hardware and software with specific inputs and expected outputs. During assembly, individual components are tested to ensure they function properly. Each component receives its designated input, and the output is analyzed for quality. R-C servo motors are tested with recommended voltages to verify their torque output. This individual testing is repeated for all hardware components, with results documented below in table 2.

Table 2: Input and output results of different components

Components	Input	Output
DC Gear Motors	Voltage	Torque
DC Servo Motors	Voltage	Torque
DHT-11 Sensor	Temperature, Humidity	Voltage
Soil Moisture Sensor	Moisture in soil	Voltage
IR-Sensors	Light Reflections	Voltage
RF-Camera	voltage	Live feed

3.1. Sensor testing

The DHT-11 sensor underwent two temperature tests: the first with ice to gauge the minimum temperature, and the second with fire for the maximum. Data was logged via an Android app, showing readings of **12°C** and **60°C** for the respective tests.

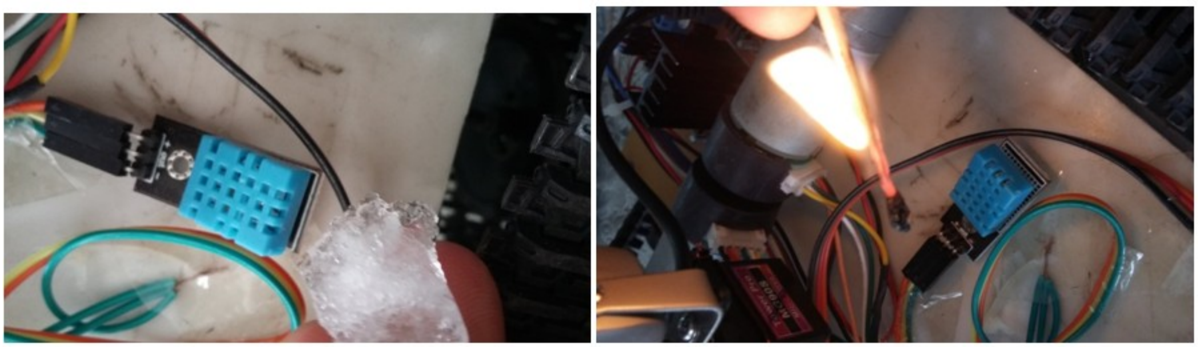

Figure 10: DHT-11 sensor testing in presence of ice and fire

The humidity levels were tested by creating a vacuum over the DHT-11 sensor and by generating high water vapor levels within a glass jar. Both the hardware and software components, including an Android application, were thoroughly evaluated. The humidity readings ranged from **10%** to **80%** under these conditions.

Soil moisture levels (%) were measured in three experiments. Conditions ranged from dry soil to moist soil, and water without soil. These tests set minimum and maximum moisture thresholds. Following images show moisture percentage differences, comparing to ideal conditions, with a column showing practical variance.

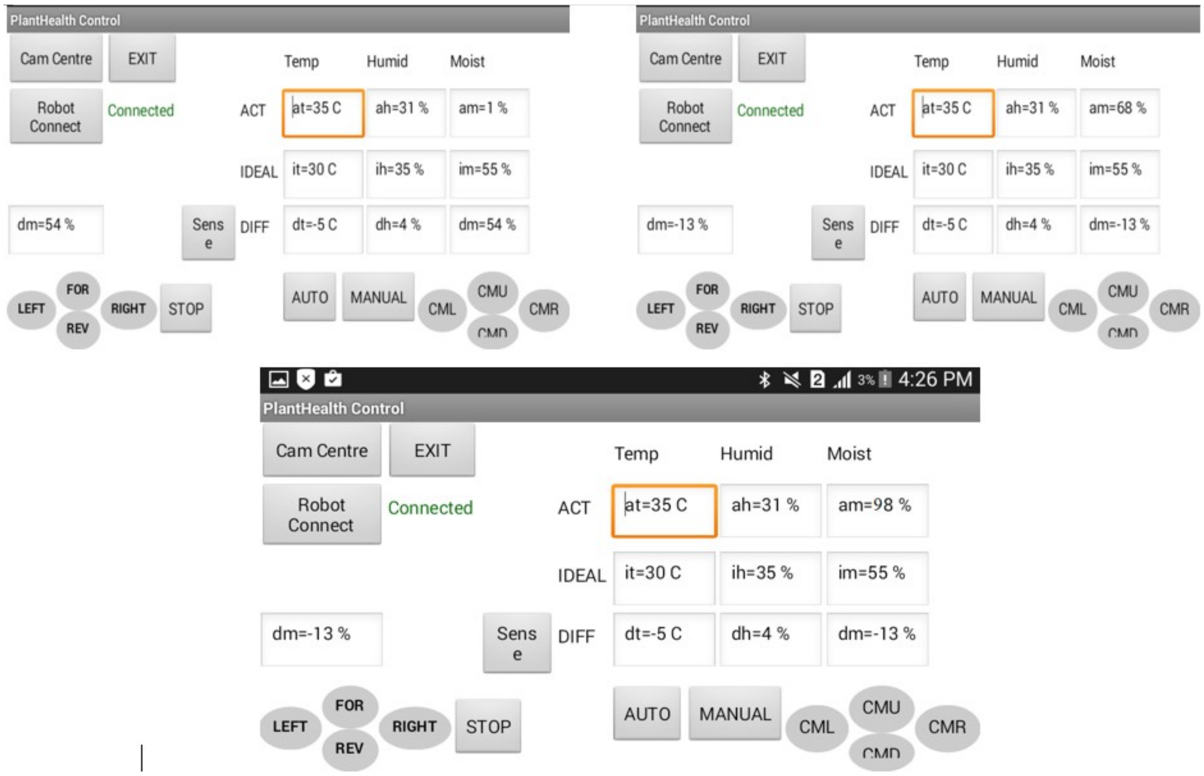

Figure 11: Result samples on android application

The camera serves the purpose of delivering image frames to the laptop. A series of test experiments were conducted on these images. To assess the effectiveness of the digital image processing technique, three different plant species were used as subjects.

Figure 12: Plant image samples

4.2. Control testing

Control testing primarily targets Actuators. The Android app features various buttons to manually operate motors, including an 'auto' button for autonomous navigation using a predefined array. Manual control is tested through app buttons that direct dc-gear motors: forward, backward, right, and left. Similarly, buttons for camera pan servo motors are included. Pressing these enables testing of the entire black box control system, which comprises multiple hardware and software components.

Figure 13: Robot movements during work

The robot's second control method is an array-based system, utilizing IR sensors and an 'auto' button in the app, alongside a preset array in the software. Various software tests led to the selection of an optimal array for the robot's movement. The long-distance array is utilized for the control of IR sensors and the detection of obstacles. The long-angle array enables the robot to execute lateral movements, allowing it to navigate to the left and right.

5. CONCLUSION AND RECOMMENDATIONS

In conclusion, this study successfully achieved its goal of developing a prototype health-monitoring robot designed to evaluate environmental conditions and compare them with the standard parameters of a healthy plant. This innovative system acts as a reliable indicator of plant health, accurately measuring critical factors such as soil moisture, ambient temperature, and humidity levels. This project showcases the capabilities of robotics in agriculture while also establishing a model for upcoming advancements in environmental evaluation and plant maintenance.

6. LIMITATIONS AND FUTURE STUDIES

The prototype robot may have been tested in a controlled environment with only specific plant varieties, which may limit its applicability across different species or environmental conditions. Expanding this technology for use in broader agricultural or horticultural applications could encounter unforeseen challenges that are not addressed in this study.

In future, further studies can be conducted on this robot as mentioned below:

- The robot's application is Android-based, which is more prevalent globally and in lower-income regions. An iOS app could be developed in the future to reach a broader audience.
- The robot can autonomously spray pesticides, reducing health risks for workers in hot, humid greenhouses. Protective gear only minimizes, not eliminates, exposure to chemicals, which can penetrate gloves within 30 minutes. The robot's spraying system, equipped with a tank, pump, valves, and controlled by a microprocessor and infrared sensor, ensures precise application and avoids human contact with toxins.
- The robot could be adapted for fruit picking and cutting. A mounted camera would identify fruit locations for harvesting. Current technology cannot outperform human labor in cost-effectiveness for tasks like picking oranges, which requires mapping the trees and fruit positions. The robot's arm, possibly with a camera for dynamic situations, would follow a pre-determined picking sequence, even in clustered or moving conditions.

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Author contributions: All authors equally contributed to this study
Ethical Statement:
Consent to Participate: Before conducting this research study, the researcher has taken permission from the host department at XXX University. The researcher explained the objectives of the study before interviewing the respondents. The respondents were assured that the information would only be used for research purposes. The respondents were told that they could withdraw at any stage from the interview if they felt uneasy or did not want to continue the interview.
Competing Interests: The author declares that this work has no competing interests.
Grant/Funding information: The author declared that no grants supported this work.
Data Availability Statement: The associated data is available upon request from the corresponding author.
Declaration Statement of Generative AI: The author(s) of this work used the [name of tool or service] to [reason or the parts of the manuscript prepared with the assistance of AI tools, remember: Grammar checking tools and Referencing tools do not require to declared]. After using this tool or service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the publication's content. OR Author's declared for not using AI during preparation of this study

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