Botany Buggy: An IoT-Integrated Smart Farming Robot with ESP32 for Agricultural Efficiency

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***Abstract*—The agricultural sector contributes 13.28% to Indonesia's national income, highlighting its critical role in the country's economy. To enhance the quality and quantity of agricultural products, the development of innovative technologies is essential. The Botany Buggy represents a breakthrough in this endeavor, designed as a fully autonomous plant-maintaining robot aimed at revolutionizing farming practices in Indonesia. This advanced robot is engineered to increase productivity by performing essential agricultural tasks such as watering and monitoring crop health, thereby reducing the reliance on manual labor. By integrating cutting-edge technologies, the Botany Buggy ensures precision and efficiency, leading to higher yields and improved crop quality. This innovation not only addresses the challenges faced by Indonesian farmers but also aligns with the nation's goal of achieving sustainable agricultural growth. Through its deployment, the Botany Buggy is poised to significantly contribute to economic growth by boosting agricultural output and ensuring food security. The development and implementation of this autonomous robot underscore a commitment to modernizing agriculture and fostering a resilient, prosperous farming industry in Indonesia.**

I. INTRODUCTION

A. Background

In Indonesia, one of the most significant and most important sources of supplies is the agriculture department, providing the foundation for the nation's food. However, in the recent years a lot of problems had arisen in the agriculture department, the most significant problem being the rapid growth in population in Indonesia causing the increase in need for food supplies. This problem heavily impacts the farmers in Indonesia requiring them to increase the production of crops, which proposes a new problem which is the decline in interest among the younger generations to pursue farming as a vocation [1]. Moreover, the agriculture land needs to be in a specific location and requires an individual with the adequate knowledge about plants. These problems create a significant obstacle for the agriculture sector's sustainability and economic viability in Indonesia [2].

Over the years as technologies continue to get more advanced, their implementation in agriculture could offer vital solutions to these problems. Despite that, According to the research done by the students at University of Muhammadiyah Malang, the use of technologies in Indonesia's agricultural sector is at medium to low level, which results to the inefficiency and declining production in the agriculture sector. On the other hand, other countries that have adopted higher levels of agricultural technology have seen significant increases in production efficiency and improved system security. This proves that utilizing technologies in Indonesian agriculture could also increase productivity and safeguard the sector's future [3].

In response to these challenges and the rapid advancement of technologies, the integration of technological solutions emerges as a promising approach. One such innovation is the development of agricultural robots, exemplified by the Botany Buggy. This robot is designed to monitor and maintain crucial parameters essential for plant growth, such as humidity and soil moisture. The Botany Buggy utilizes simple yet effective sensors to gather real-time data on these variables and takes actions accordingly. The collected data is transmitted to a dedicated application via a Firebase database, allowing users to monitor environmental conditions with precision and immediacy. This integration of technology facilitates efficient and responsive plant care, addressing the needs of modern agriculture

B. Project Purpose

Expanding its scope, Botany Buggy aims to simplify farming practices through an advanced robotic solution. By deploying a meticulously engineered robot capable of autonomously tending to crops, Botany Buggy seeks to alleviate labor-intensive responsibilities traditionally shouldered by farmers. This innovative approach streamlines cultivation, offering efficiency gains and resource optimization. Through advanced automation, Botany Buggy redefines farming paradigms, fostering enhanced productivity and sustainability

C. Project Benefits

1. Increases the efficiency of agricultural production
2. Enhanced Crop Management

D. *Scope of Problem*

1. Diminishing Interest Among Younger Generations in Farming
2. Declining Agricultural Production Output

II. Literature Review

Prior to making this project, there has been some other projects and research on creating a fully autonomous farm/agricultural robot.

The project "Farming Bot" by S. Kautsar aims to create a robot that utilizes Computer Numerical Control (CNC) technology to operate efficiently. The "Farming Bot" features a fixed design positioned above the crops, allowing it to move along the X, Y, and Z axes to perform necessary plant maintenance tasks. The robot's central control system is an Arduino UNO R3/ATMega328, which manages three limit switches (one for each axis) and five stepper motors (two for the Y axis, two for the X axis, and one for the Z axis). Additionally, it controls two pumps—one for water and one for fertilizer. These actuators operate based on data from a humidity sensor, with readings displayed on an OLED screen. This design ensures precise and efficient care for the crops [4].

Building on the "Farming Bot," the "Botany Buggy" aims to further enhance agricultural robot technology. The Botany Buggy features a more compact, car-like drone design, reducing production costs. It also includes a quality-of-life improvement, allowing farmers to monitor sensors in real-time from anywhere using a dedicated application. Additionally, the Botany Buggy tracks more parameters, including humidity, enabling it to maintain the optimal environment for plant growth. These advancements make the Botany Buggy a significant step forward in agricultural technology

III. Ease of Use (main Components)

A. *ESP32*

The ESP32 is an affordable and versatile microcontroller, highly regarded for its advanced features and robust wireless connectivity options. It boasts a 240 MHz microprocessor and includes built-in components such as antenna switches, an RF balun, a power amplifier, a low-noise receive amplifier, filters, and power management modules. These features make the ESP32 a powerful and efficient choice for a wide range of applications [5].

B. *DHT11 Temperature & Humidity Sensor*

The DHT11 sensor is a cost-effective digital device used for measuring temperature and humidity, known for its reliable and precise readings. It features an integrated thermistor and capacitive humidity sensor, making it ideal for basic weather monitoring and environmental control systems due to its simplicity, compact size, and low power consumption [6]. The humidity sensor consists of two electrodes with a moisture-holding substrate, and changes in capacitance are processed into digital form by the IC. The temperature sensor uses a Negative Temperature Coefficient (NTC) thermistor, which decreases resistance as temperature increases, ensuring high sensitivity. The DHT11 operates within a temperature range of 0 to 50 degrees Celsius with ±2 degrees accuracy, and a humidity range of 20% to 80% with ±5% accuracy. It samples data at 1Hz, operates on 3 to 5 volts, and consumes a maximum of 2.5mA during measurement [7].

C. *Soil Moisture Sensor*

The soil moisture sensor accurately measures the volumetric water content in soil by detecting changes in its dielectric constant. This real-time data is crucial for optimizing water usage in agriculture, environmental monitoring, and irrigation systems. Typically, these sensors use two probes inserted into the soil to transmit electrical signals and measure moisture levels, with advanced models also assessing temperature and salinity [8].

D. *TCS 3200 Color Sensor*

The TCS3200 color sensor detects and measures object colors by analyzing light intensity with an 8x8 matrix of 64 photodiodes, which are divided into groups with red, green, blue, and clear filters. Illuminated by super-bright white LEDs, it captures reflected light and converts these readings into frequency signals for microcontroller processing. This sensor can record up to 25 different color data points and is commonly used in microcontroller applications to detect and monitor object colors. The sensor operates by reading the light intensity values emitted by the LEDs onto the object; the reflected light, varying in wavelength based on the object's color, is processed by the photodiodes to determine the color [9].

E. *Botany Buggy Application*

The Botany Buggy application provides comprehensive monitoring of a plant's environment by tracking soil moisture, humidity, and temperature. Users can visualize fluctuations in these parameters through an interactive line graph, ensuring they stay informed about their plant's conditions. This feature also helps users verify that the robot is functioning correctly, offering peace of mind and optimal plant care

IV. Project Design

A. *Botany Buggy Components*

- Two ESP32
- Three soil moisture sensors
- One DHT11 sensor
- One Mist actuator
- Two servos
- Two DC motors
- Five 6V batteries
- Four Relays
- One TCS 3200 color sensor
- One water pump
- Two IR sensors

B. Botany Buggy Design

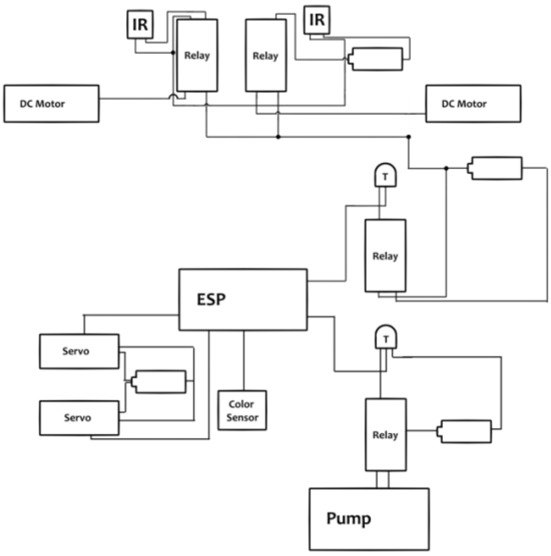

Figure 1 (Robot Block Diagram)

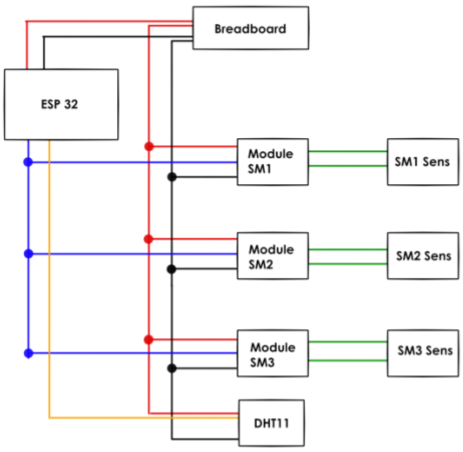

Figure 2 (Station Block Diagram)

The Botany Buggy employs two ESP32 microcontrollers to manage environmental monitoring and robotic operation. The first ESP32 is the station which is dedicated to gathering data from two sensors: a soil moisture sensor and a DHT11 humidity and temperature sensor. This data is then transmitted to a Firebase database. The second ESP32 retrieves the data from Firebase and controls the robot accordingly. Based on the sensor readings, it determines which plants require watering and whether the mist actuator should be activated. This system ensures precise and responsive care for the plants, based on real-time environmental data.

C. Working Process

To further understand the working of the Botany Buggy here are the explanation for each of the system.

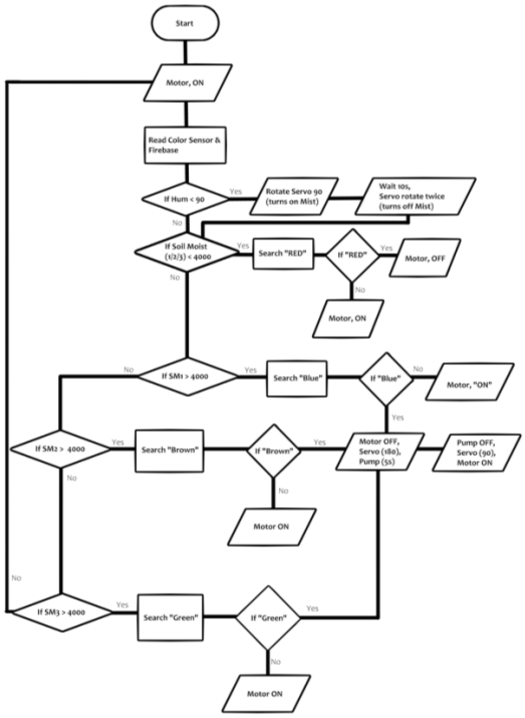

Figure 3. Robot Flowchart

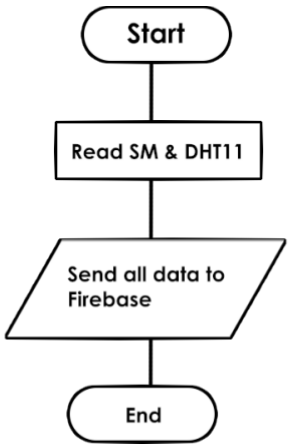

Figure 4. Station Flowchart

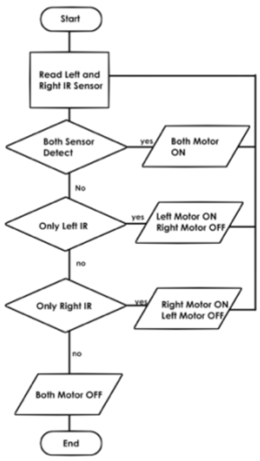

Figure 5. Robot Drivetrain Flowchart

1. Humidity Control Sub-system

The humidity control system utilizes a DHT11 sensor to measure the environmental humidity, with data collection managed by an ESP32 microcontroller located at the monitoring station. This ESP32 transmits the humidity readings to a Firebase database. A second ESP32, located on the robot, retrieves the humidity data from Firebase. If the humidity falls below a predefined threshold that could jeopardize plant health, a servo motor activates a mist actuator for 10 seconds. The servo then rotates twice to deactivate the mist actuator. This process repeats, with the servo reactivating the mist actuator for subsequent 10-second intervals, until the humidity reaches the required level. This automated cycle ensures that optimal humidity conditions are consistently maintained to protect the plants.

2. Soil Moisture Control Sub-system

The soil moisture control system employs three soil moisture sensors, each placed in a different plant pot. The sensor readings are collected by an ESP32 microcontroller located at a central station, which transmits the data to a Firebase database. A second ESP32, situated on the robot, retrieves the soil moisture data for all three plants from Firebase. To facilitate plant identification, each plant is assigned a specific colour plant one (sensor one) is blue, plant two (sensor two) is brown, and plant three (sensor three) is green.

When the soil moisture reading for plant one falls below the required threshold, the robot searches for the colour blue. Upon detecting blue, the robot's DC motor halts, and a servo rotates from its initial 90 degrees to 180 degrees. The water pump then activates for five seconds to irrigate the plant. After watering, the servo returns to its initial 90-degree position, and the DC motor resumes movement.

A similar process occurs for plant two and plant three, with the robot searching for brown and green, respectively, when their soil moisture readings fall below the required levels. If all soil moisture readings meet the required values, the robot searches for the colour red, which indicates the station where the robot will remain until further watering is needed. This system ensures precise and efficient irrigation of each plant based on real-time soil moisture data.

3. Robot Drivetrain Sub-system.

The robot's drivetrain employs two DC motors, one on each side, enabling it to operate similarly to a line-following robot and navigate its designated track. Control of the drivetrain is achieved through two IR sensors, each paired with one of the DC motors, rather than through a microcontroller. When an IR sensor detects the black line of the track, it deactivates the corresponding DC motor. This allows the robot to adjust its movement and follow the track accurately by turning in response to the sensor inputs

Identify applicable funding agency here. If none, delete this text box.

V. RESULT & DISSCUSSION

A. *Plant Growth Data & Result*

In this study, the Botany Buggy was deployed to monitor and support the growth of a tomato plant under controlled conditions. Optimal growth parameters for tomato plants include maintaining soil moisture levels between 60% and 80%, achieved by applying 100 ml of water to the plant, and maintaining humidity levels between 60% and 85%, accomplished through the creation of a misted environment [10], [11]. The growth of the tomato plant was systematically recorded at three-day intervals to ensure accurate and consistent data collection and analysis.

Day1	
Day 4	
Day 7	
Day 10	

Day 13	
Day 16	
Day 19	
Day 22	
Day 25	

B. *Testing The Whole Working Of The System*

The testing of the system was conducted in a series of structured phases to ensure comprehensive evaluation. The first phase involved assembling the drivetrain of the Botany Buggy using two DC motors and three relays. In the second phase, an ESP32 microcontroller, located outside the Botany Buggy, was set up to read humidity and soil moisture levels, transmitting the data to Firebase. The third phase focused on configuring the ESP32 to retrieve data from Firebase and the color sensor, and subsequently control the Botany Buggy's internal actuators, including the DC motor, servos, and water pump. The fourth phase involved constructing a track for the Botany Buggy to ensure consistent testing conditions. The fifth and final phase was dedicated to testing the entire system on the track. The results of these five phases are summarized in the table below.

Sensor	Parameter	requirement	Actuator	Performance
Soil Moisture & Color sensor	Soil Moisture & color	X1 > 4000 & color "Blue" // X2 > 4000 & color "Brown"// X3 > 4000, color "Green"	DC motor OFF Servo Rotate 180° Pump ON 5 second Pump OFF Servo Rotate 90° DC motor ON	✓
		X1 & X2 & X3 < 4000 & color "red"	DC motor off	✓
DHT11	Humidity	Hum < 90	Servo Hum rotate 90° (wait 10s) Servo rotate 90° twice	✓
		Hum > 90	Servo Rotate 0°	✓

C. Botany Buggy Prototype

The Botany Buggy prototype is designed in the form of a car-like drone, as illustrated in the images below.

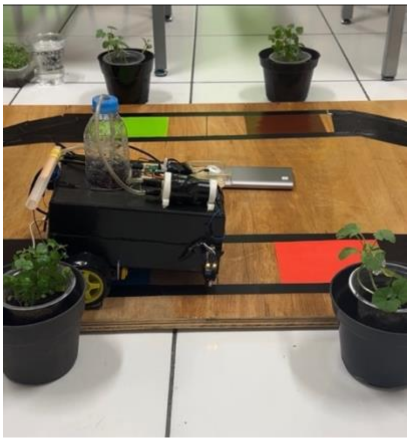

Image 1

Image 2

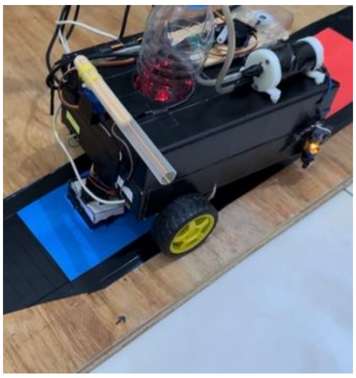

Image 3

D. Expenses.

No	Item	Jumlah Item	Harga per item	Sub total
1	Box 50 x 40	1	40.000	40.000
2	Water pump	1	35.000	35.000
3	Servo	2	30.000	60.000
4	Mist actuator	1	45.000	45.000
5	Jumper cable	120 (3 Pack)	10.000	30.000
6	DC motor & wheels	2	15.000	30.000
7	Caster wheel	1	9.000	9.000
8	Alkaline Battery	4	20.000	80.000
9	18650 lithium Battery	2	30.000	60.000
10	Ice cream stick	1	5.000	5.000
11	Glue gun refill	1	15.000	15.000
12	IR sensor	2	15.000	30.000
13	ESP32	2	50.000	100.000
14	Colour sensor tcs 3200	1	70.000	70.000
15	5V relay	4	5.000	20.000
16	Duct tape	2	25.000	50.000
17	Electrical tape	1	15.000	15.000
18	Lead	1	40.000	40.000
19	Wooden board 70 x 130	1	40.000	40.000
20	Origami	1	10.000	10.000
21	Soil moisture sensor	3	6.000	18.000
22	DHT 11	1	11.000	11.000
23	Flower Pot	3	3.000	9.000
Total				792.000

E. Scope of Problems in Development

1. Uneven water distribution from the hose.
2. Ineffectiveness and wastefulness of Alkaline and Lithium batteries as power sources (DC power source is recommended).
3. Lengthy calibration process for color sensors (alternative approaches is suggested).
4. Inability to achieve optimal sensor parameters due to sensor limitations

VI. CONLUSION

Based on the design, construction, and testing of the Botany Buggy, the following conclusions can be drawn.

1. Primary Systems
   The Botany Buggy is composed of three main systems: humidity control, soil moisture control, and the robot drivetrain
   a. Humidity Control System: Utilizes a DHT11 sensor to monitor humidity levels. The sensor's readings control a servo motor, which activates the mist actuator.
   b. Soil Moisture Control System: Employs a soil moisture sensor in conjunction with a color sensor. The readings from these sensors control the DC motor, the servo motor positioning the pump hose, and the water pump.
   c. Robot Drivetrain System: Uses two IR sensors to create a line-following robot, enhancing movement consistency.

2. Considerations for Larger Scale Implementation:
   a. Power Supply: A larger-scale Botany Buggy requires a more powerful and consistent power source. The prototype's power source depletes quickly, resulting in suboptimal performance due to insufficient voltage for certain components.
   b. Detection System: The current color sensor's performance is affected by varying lighting conditions. A more reliable detection system is necessary to improve consistency.

In conclusion, scaling up the Botany Buggy involves addressing several critical aspects, particularly regarding power supply and sensor reliability. Further research and cost analysis are essential for the successful implementation of a larger-scale Botany Buggy.

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