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Solar Powered Autonomous RC Robot

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Abstract: Modern farming using sensor and control technology, renewable energy, and agricultural robots aim to produce higher-quality products at lower cost, reduce labor workload, and enhance efficiency and safety compared to traditional methods. The study aimed to develop a robot that used Photo-voltaic (PV) panels for low-power recharging and efficient sustainability while integrating a reliable wireless link for seamless robot-controller communication and monitoring. This paper discussed new strategies for replacing humans in agricultural operations, including structural design, robot control systems, and experimental results on renewable energy, mobility, durability, and safety. The robot system used a battery and PV module for power supply, with the L298N motor driver and Raspberry Pi 4B controller. The system software, Thonny IDE, drove the robot in either automatic or manual mode and transported the harvested product to the collection area. Besides, it has been tested in several experiments to ensure the PV panel was reliable and sustainable source of low-power recharging for the robot, the robot's durability to transport the 10kg weight and the runtime of the robot during a given task was also evaluated. From the result, it shows that the robot can automatically charge using the PV module and transport harvested products weighing 10kg or less. However, the runtime of the time working can be extended if using a proper battery. Further improvements included adding sensors for accurate movement measurements and strengthening the robot's body chassis for stability and future lifting capabilities over 10kg.

Keywords: Agriculture, Renewable Energy, Transporting, Solar Powered

1. Introduction

Malaysia's agriculture industry contributes 12% to Gross Domestic Product (GDP) and employs 16% of the population. Natural factors like mineral-rich soil, rainfall, and water supply drive its rapid development. Malaysia exports cocoa, gum, palm oil, pineapple, banana, coconut, durian, and

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rambutan. As the world's population grows, agricultural demand is expected to rise by 50% by 2050 [1].

Today's technology continually evolves, which enhances both farmers' ability to produce more food and the continuous innovation of robotics and automation [2]. The agriculture sector demands easy-to-understand technology for automation in various fields. Robots must work dynamically, accurately controlling crops and surroundings, reducing impact while increasing efficiency. However, the complexity of what are known as unstructured settings and unpredictable activities hinders the use of industrial robotic systems in agriculture [3].

Autonomous agricultural robots utilize advanced tools, sensors, and control technologies, offering significant advantages in modern farming. These breakthroughs resolve nonlinear navigation difficulties, making robots more accessible and reducing travel time for various tasks [4]. Modern agriculture faces challenges in monitoring crops, and livestock due to labor-intensive methods. Mobile robots can perform critical outdoor tasks but face energy constraints. Photovoltaic solar panels can extend their battery life, making them suitable for day-only outdoor agricultural robots. This environmentally dependent solution benefits the environment by providing power and preventing pollution [5], [6]. PV has high initial costs, large robot surface area, and energy storage requirements [7].

A Solar-Powered Autonomous RC Robot (SPARB System) is designed and implemented with the integration of PV solar panel, wireless control, and sensor technology, to provide farmers with real-time information and optimize resources. This study focuses on extending mobile robot battery life using solar panels. Different conditions are tested on energy-efficient paths planning, to determine optimal solar power usage in the operating environment.

2. Previous Research for Solar Powered Autonomous RC Robot

This section provides an overview of autonomous robot mechanisms. A few researchers had implemented 40W PV panel to power a lawn mower robot, with a charging time of over 8hours [6]. During a short pass (2-3sec) under shadows, the agricultural robot's solar panel charging process may be reduced, however on a sunny day, the solar energy stored can ensure up to 10 hours of operation [5]. Using a PV panel as an energy source, an automated harvesting bot with a line tracking mechanism and four degrees of freedom arm robots improved the fruit harvested crop by differentiating the crop colour [8]. Other researchers design a solar-powered robot to execute seed sowing, pesticide spraying and grass cutting tasks, as well as controlling mechanism and robot movement without human intervention [9].

Most of the researchers used a Convolutional Neural Network (CNN) technique to detect edges, lines, and steering prediction, whereas ultrasonic sensors were used for front collision avoidance mechanism [10]– [12]. When there is a sudden disturbance in the vision sensor, low light, or no light at all, a LiDAR sensor is obtained for navigation and 2D grid map conversion [13]. The proposed SPARB System prototype was examined in this study, based on solar panel implementation and a weight system, ensuring effective harvest product transport[14]. The mechanism is designed to work in automated and remotely controlled mode, potentially reducing labor requirements while assuring safe transportation.

2.1 Hardware Details

The SPARB System consists of a Raspberry Pi 4 Model B CPU, GPU, RAM, HDMI, USB connections, a camera interface, and GPIO pins. It is a versatile platform suitable for general-purpose computing, while Arduino is specialized for embedded systems and physical computing. The system can run a full operating system like Linux, providing a familiar development environment for complex software development. A 30W 12V monocrystalline silicon PV module converts solar radiation into electrical energy, powering the system and charging the battery. The RC Car Crawler chassis allows for smooth movement and navigation.

The HC-SR04 Ultrasonic sensor detects distances using sound waves, while the load cell ensures accurate weight readings. The brushless DC 12V gear motor, controlled by an L298N motor driver, provides efficient and long-lasting performance. The HX711 module stores and processes weight load data from the load cell, providing precise weight readings. A 16x2 character I2C LCD display provides visual feedback on the weight burden of carried objects. These hardware components provide a strong foundation for obstacle recognition, precise weight measurement, and efficient movement to achieve the project's goals.

2.2 Software Details

Aside from the hardware components, the effective implementation of the SPARB System is dependent on the use of well-designed and efficient software. Software details are critical in programming the system's behavior and capabilities, allowing it to execute tasks like obstacle detection, weight measurement, and controlled movement. Each software component is carefully selected and tailored to ensure seamless integration and optimal performance, from the operating system running on the Raspberry Pi 4 Model B to the programming languages and libraries used for sensor integration, navigation algorithms, and user interface development. Table 1 shows the software used in this development project.

Table 1: List of software

No.	Component	Description
1.	Raspberry Pi OS	It offers a user-friendly interface, extensive software support, and pre-installed applications. It enables users to run software, develop projects, and maximize the Raspberry Pi's capabilities.
2.	Blynk Application	Blynk is an IoT platform that allows users to control and monitor connected devices using a mobile app.

3. Materials and Methods

3.1 SPARB System flowchart

Figure 1 shows the first part of the flowchart for the system. The flowchart's goal is to outline the step-by-step methods for carrying out the software task. The variable declaration is necessary for the program to understand which representative is used in the algorithm. Figure 2 shows the second part of the system flowchart that defines the obstacle avoid mechanism, while Figure 3 demonstrates the third part of the system flowchart for the weighing system.

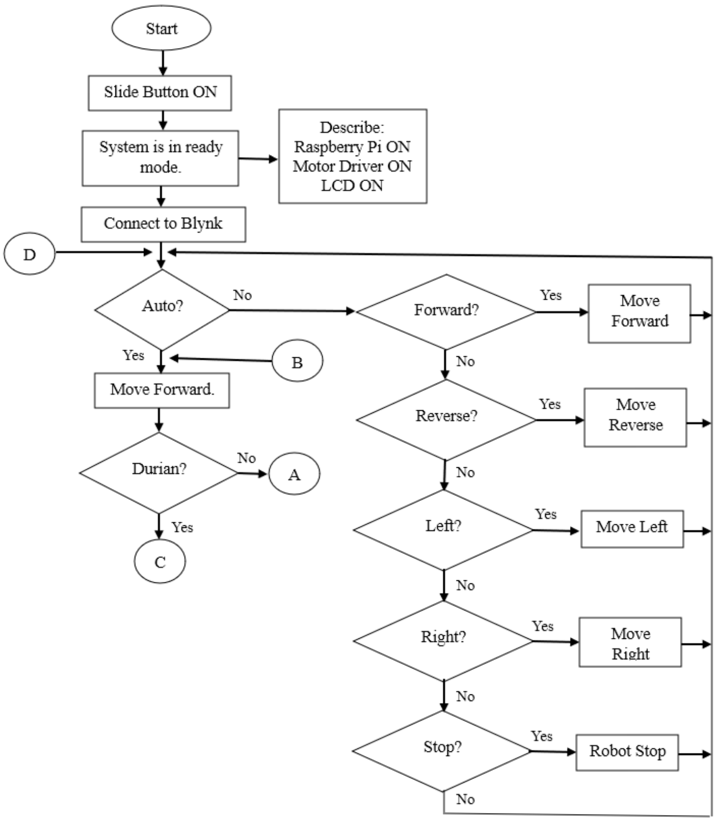

Figure 1: First part of SPARB System flowchart

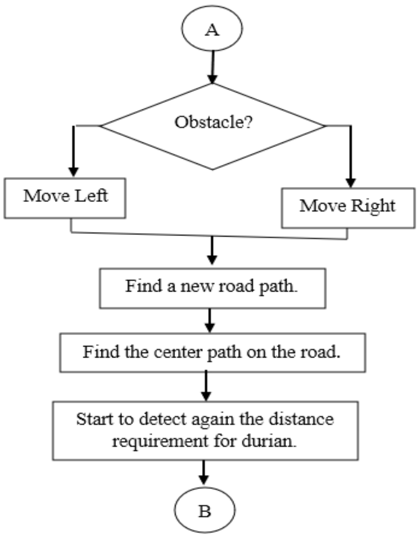

Figure 2: Second part of SPARB System

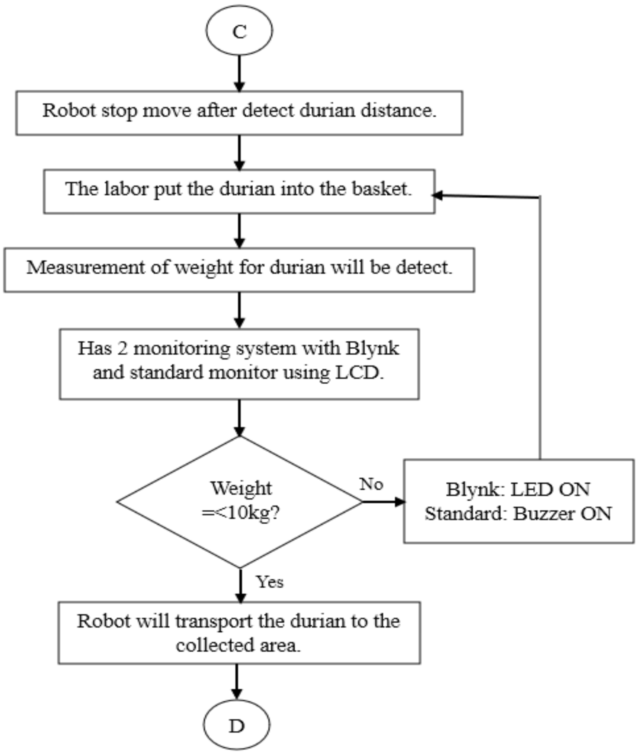

Figure 3: Third part of SPARB System flowchart

3.2 SPARB System block diagram

A block diagram is used to represent the layout and structure of the system in question. The project's design was thoroughly discussed and planned during its development phase. The connectivity of the subsystems employed in the robot system is illustrated using the block diagram displayed in Figure 4. As the heart of the robot, the main control unit consists of one Raspberry Pi 4B unit. It is divided into two sections: autonomous harvest detection in automatic mode and control of the complete robot in remote manual mode. Besides, the Raspberry Pi 4B and sensors module are used to regulate the outputs of weighing system. In contrast, the Blynk application is utilized to control all aspects of the robot system.

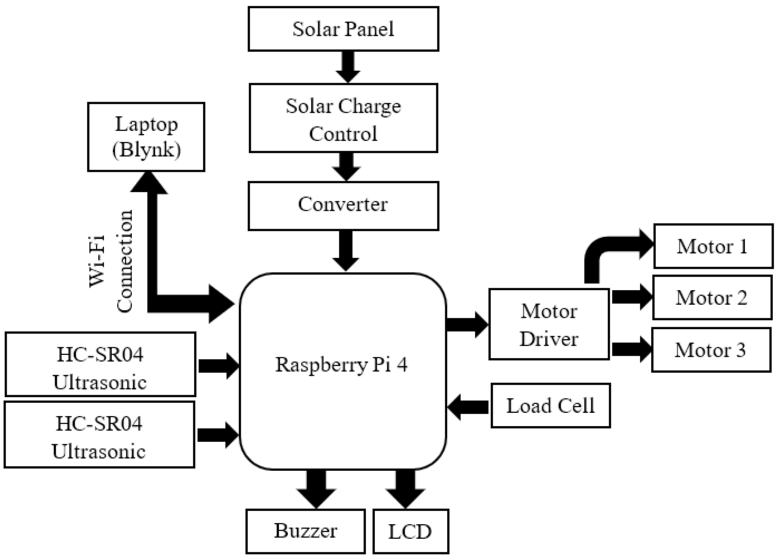

Figure 4: SPARB System block diagram

3.3 Hardware configuration

3.3.1 System construction

Figure5 illustrates the SPARB System, designed for durian farms, has dimensions of 27 cm and a height of 80 cm. The design is created using the Tinkercad software, and the SPARB System is developed from the design. Table 2 shows the APSR prototype requirements, and the design generated with Tinkercad software. The navigation system and weighing system are two elements of the SPARB prototype development.

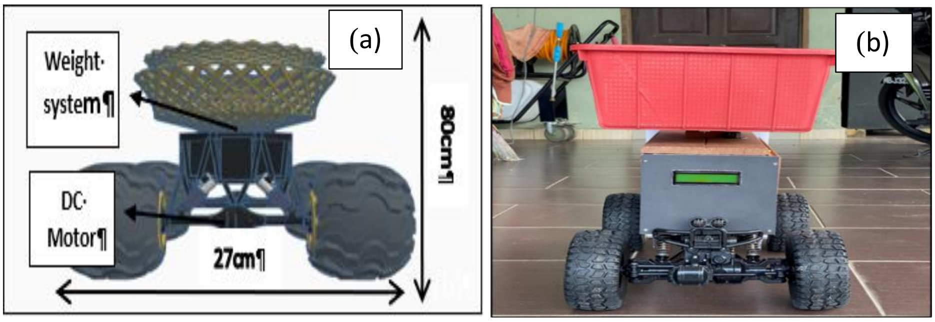

Figure 5: SPARB prototype (a) design; (b) developed.

Table 2: SPARB System specification

Item	Specification
Robot dimension	50 cm x 27 cm x 80 cm (L x W x H)
Robot Weight	3kg without payload
Drive system	4-wheeled drive system
Power supply	Solar panel and 12V DC rechargeable battery
Ground clearance	6 cm from the ground
Payload	Max 10 kg
Control type	Automatic and remote manual

Figure 6. illustrates the SPARB prototype's overall connection. The connectivity of the required components in the proposed robot is critical, and it plays a key role in ensuring that the robot operates as expected. Misconnections between the electronic components might cause the developed system to fail, preventing the project's objectives from being met.

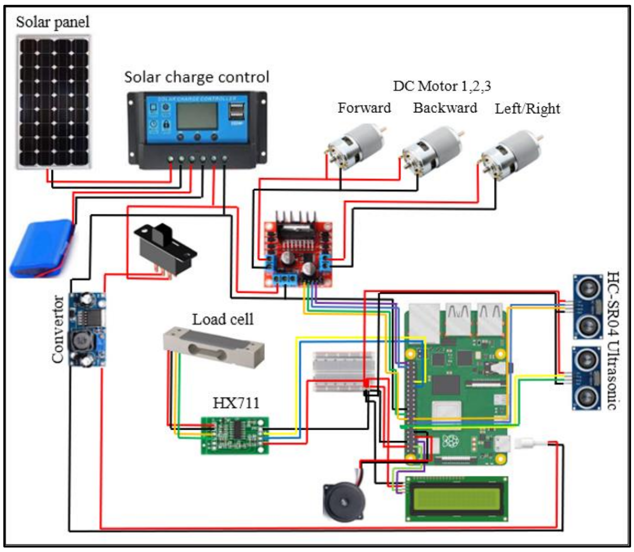

Figure 6: APSR System circuit diagram

3.3.2 Navigation system

The navigation system for SPARB prototype consists of two ultrasonic sensors (HC-SR04), a Raspberry Pi 4B microcontroller, three units of 12 VDC brushless gear motor (200 rpm), one motor drivers (2 Amp 7V-30V L298N), and a 12 VDC 2.6 AH rechargeable battery. The microcontroller is the system's brain, where programs are developed in python using the Thonny IDE and then uploaded to control the prototype's sequence and operation.

The navigation system has two operating modes: automatic and remote manual. The sensor is critical in automated mode for the robot's mobility and navigation without human interaction. Using the Blynk application interface on the laptop, farm workers may easily browse and manage the robot's movement and monitor the system when in remote manual mode, as shown in Figure. 7.

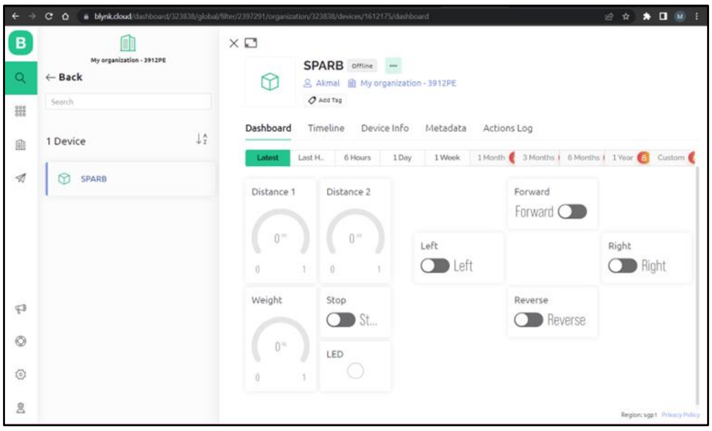

Figure 7: Blynk application of the SPARB System

3.3.3 Weighing system

A load cell with HX711 module was chosen to measure the weight load of harvested products. Besides, by using LCD display and buzzer, it makes the weighing system has a local monitoring and safety mechanism. This safety mechanism will be generated when the weight of load is over 10kg. The condition for the weighing system will be considered while the microcontroller implements the condition in the navigation part. A suitable basket is required in addition to the 10kg weight standard to weigh the harvest. Additionally, this system also can be monitored by using a Blynk application whether it is autonomous mode or remote manual mode.

4. Results and Discussion

This chapter examines the data gathering procedure and analysis of the SPARB System, which was tested on four sites of durian fruits collected from orchard areas. The system was tested in two modes: autonomous and remote manual. Furthermore, the SPARB System uses a solar panel as its power supply, harnessing solar energy to charge a 12V rechargeable battery. This sustainable approach reduces reliance on conventional power sources and ensures extended operation time without manual recharging, making the system more autonomous and efficient in the field.

4.1 Voltage Generated by Solar Panel During a Day

To determine the voltage generated by a solar panel, use a multimeter to measure output voltage at regular intervals. Connect the multimeter terminals to the panel and check for DC voltage. Collect readings every hour from 8:00 AM to 6:00 PM. Compute the average voltage, add readings, and divide by total measures to determine the greatest voltage achieved as shown in Figure 8.

Figure 8: Measure the output voltage from solar panel.

Keep in mind that the voltage required to charge a 12V rechargeable battery may be more than 12V owing to variables such as voltage loss during charging and battery characteristics. As a result, confirm that the voltage readings from the solar panel are sufficient to charge the 12V battery successfully. Figure 9 presented the data collection graph outcome.

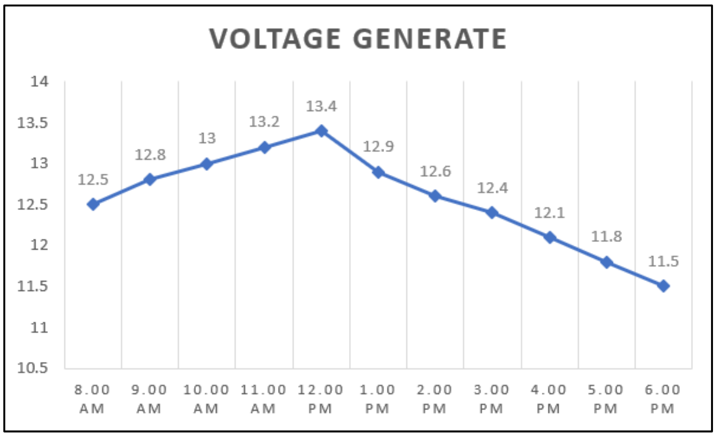

Figure 9: Graph results for voltage generate.

The graph shows the highest solar panel voltage of 13.4V at 12.00 PM, influenced by factors like solar panel model, environmental conditions, and sunlight intensity. Data collection involves measuring rechargeable battery voltage, connecting the solar panel, solar charge controller, and battery, and recording voltage and charging current at regular intervals as shown in Figure 10.

Figure 10: The Connections of Solar Charge Control

Figure 11 shows the graph result of charge performance after using solar charge controller. A solar charge controller improves charging performance and offers control and protection features. Analyzing data helps identify consistent increases in battery voltage, maintain current values, and evaluate supplementary data like temperature, charging status, or fault indications. This data assesses charging effectiveness, extends battery lifespan, and protects against potential issues.

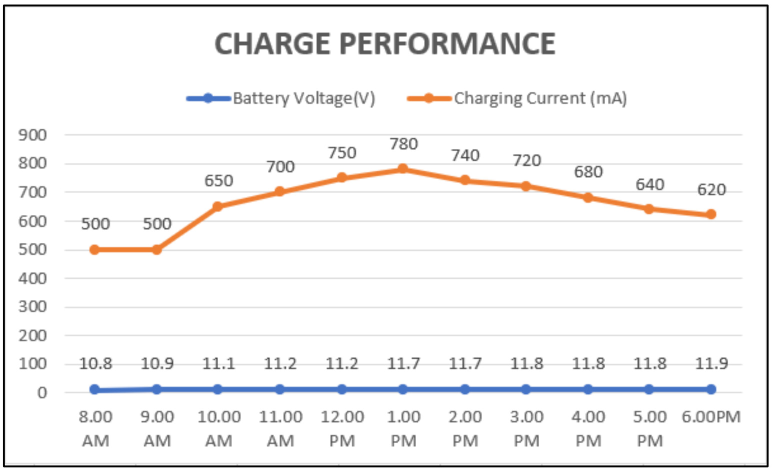

Figure 11: The graph result for charge performance

Data collection and analysis are crucial for assessing the autonomy and sustainability of a solar-powered system. Measurement, monitoring, and analysis of relevant parameters provide insights into energy efficiency, battery health, and overall system autonomy as shown in Figure 12.

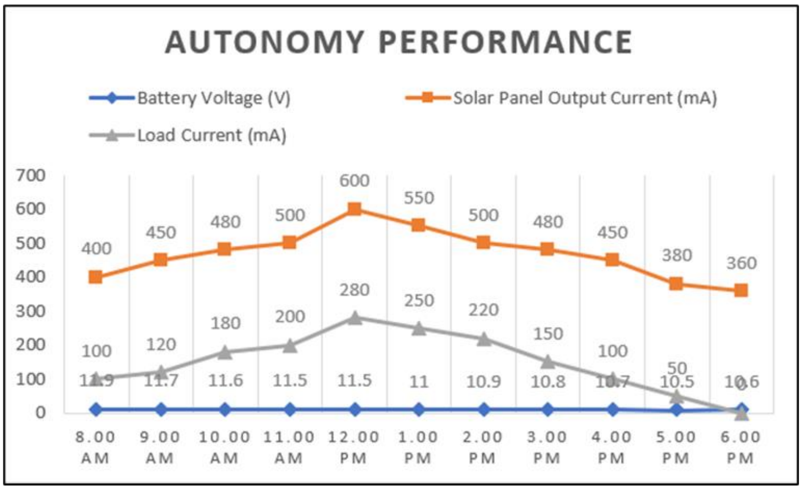

Figure 12: The graph result for autonomy performance

The average voltage is 11.15V, and solar panel output current ranges from 300mA to 600mA. Optimization, load adjustments, and energy storage components are needed for improved autonomy and sustainability.

4.2 Durability in Carrying Weight

To assess the endurance of a SPARB system in carrying weight, data on the system's performance and carrying capacity must be collected over time. Figure 13 shows the durability of the SPARB system.

Figure 13: Durability of the SPARB system

Perform tests on different weights and parameters to analyze a system's performance under different loads. Record weight, battery voltage, and motor performance. Repeat multiple times for thorough evaluation. Table 3 shows the data collected of the SPARB system's durability. Figure 14 demonstrates the graph analysis of the motor performance.

Table 3: Data collected on durability.

Test	Weight Carried	Battery Voltage (V)	Motor Performance
1	2kg	11.9	Smooth movement, no issues observed
2	5kg	11.4	Reduced speed, system effectively handles weight
3	10kg	10.8	System reduces speed and power, manages weight

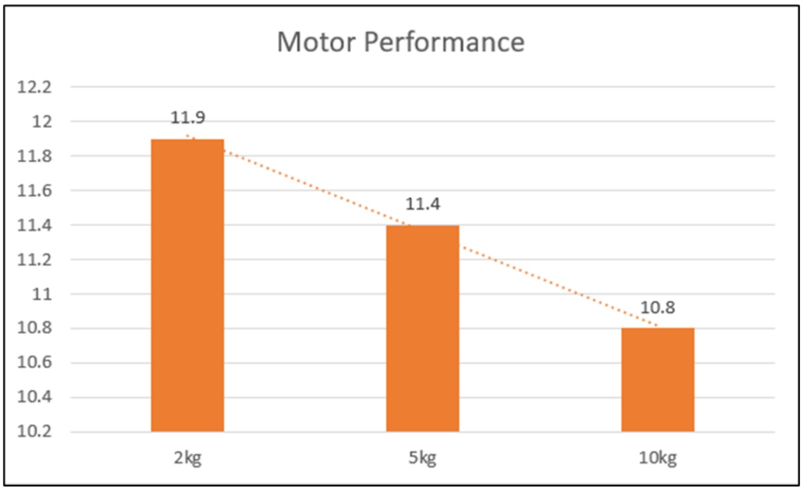

Figure 14: The graph result for Table 6

Analyzes weight carrying tests, showing the system's ability to carry different weights with smooth motor movement. It remains effective with a 2 kg weight but decreases motor performance with a 5 kg weight. The analysis evaluates durability and potential improvement areas.

4.3 Runtime for Weight Transport

The test evaluates the runtime performance of a 10kg solar-powered robot using solar panels and a solar charge controller. The test aims to assess energy efficiency and solar power utilization effectiveness. The real-world test provides insights into the robot's performance in a durian farm as shown in Figure 15.

Figure 15: Runtime testing for SPARB System

The test uses a 12V battery with a 2.6Ah capacity, allowing the robot to work for 0.31 hours or 18 minutes. The Raspberry PI 4B uses a PV module for extra runtime if the current reaches the appropriate value. The battery's limited runtime for power consumption highlights the need for a higher capacity battery or more efficient power management to extend the robot's runtime for transporting a 10kg weight.

5. Conclusion

The prototype system developed a highly efficient agricultural robot for transporting harvested products in agriculture fields. The robot can travel automatically without human intervention and can be easily navigated and controlled in remote manual mode. Blynk controls the robot's movement, while a solar panel generates voltage, and a solar charge controller ensures safety. The robot's durability was tested for three different load weights, demonstrating its functionality in transporting durian. As weight increases, motor performance slows down, and work durations become longer. This intelligent vehicle assists farmers in transporting harvested products without encountering them directly, reducing the difficulty of the task and enabling more individuals to take up agriculture.

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