# Analysis of Battery Energy Consumption in the Barelang V Base Robot with 4 Brushed DC Motors

Alief Rivaldo Rey[1] and Rifqi Amalya Fatekha*[2]

[12] Department of Electrical Engineering, Politeknik Negeri Batam, Indonesia
rifqi@polibatam.ac.id

**Abstract.** This research discusses the power consumption analysis of the Barelang V base robot, which uses four brushed DC motors. The main objective of this research is to determine the capacity of the battery to store and supply the energy needed for the base robot. This research includes motor frequency testing, power consumption testing with three load variations and four PWM (Pulse Width Modulation) variations, electrical power calculation, battery capacity, and usage time. The measured variables include voltage, current, and power sourced from lithium polymer batteries using ESP8266, RS485, PZEM - 017, and Blynk, which will display and store real-time readings. Tests show that the optimal motor frequency for power efficiency is 285.000 Hz. Analysis of different load and PWM values significantly impacted power consumption, battery capacity, and operational duration. The average power consumption required for the basic ro-bot to move for 4 minutes ranged from 142.67 Watts to 178.39 Watts. The battery capacity required for these conditions ranged from 0.476 Ah (476 mAh) to 0.598 Ah (598 mAh). If using a 4500 mAh Lithium Polymer (LiPo) 6S battery, the basic robot can move from 0.485 hours (29.10 minutes) to 0.607 hours (36.42 minutes). These findings help optimize the selection and use of batteries in basic robots to improve the operational functions of the robot.

**Keywords:** Power Consumption, Battery Capacity, PWM (Pulse Width Modulation).

## 1 Introduction

Robotics technology, particularly in wealthy nations like Japan, China, Korea, and the US, rapidly evolves as a significant sector in the technological revolution. Robots, a division of Artificial Intelligence, are computer-controlled machines that imitate human physical abilities. As these nations continue to advance, the significance of robotics in industrial and everyday settings is growing, making it one of the most dynamic and rapidly progressing industries [1–3]. It is crucial to have a strong and dependable base robot to create a reliable robot. The base robot is the fundamental support structure for all other components, including the sensor system, actuators, and control devices. In addition, the base robot contributes to the robot's stability and maneuverability. When designing a base robot, it is essential to consider its weight, dimensions, and surface


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characteristics to be traversed. An optimized design will significantly influence the robot's energy efficiency and task performance [4, 5].

One component often used in making base robots is a brushed DC motor. The brushed DC motor is a popular and reliable electric motor due to its simplicity and ease of use. It uses brushes and a commutator to transmit electric current to the rotor coil, producing rotational motion for the robot's movement. The interaction between the magnetic field and the electric current in the rotor coil generates the torque that propels the motor's shaft [6, 7].

Electrical energy is obtained from the battery to drive the brushed DC motor in the base robot. A battery is an apparatus that accumulates energy in the form of chemicals and transforms it into electrical energy when necessary [8]. There are many types of batteries, including Lithium Polymer (LiPo) batteries. Lithium Polymer (LiPo) batteries are attractive because of their capacity to store energy in high density and deliver high currents quickly [9]. The electrical power consumption of the battery needs to be measured and analyzed to determine its ability to store and provide the energy needed by the base robot. By knowing the electrical power consumption used in the base robot, the user can determine how much battery capacity the base robot will use according to the time of use and how long the battery used in the base robot will run out.

# 2 Method

The object of this research is a 6-cell Lithium Polymer (LiPo) battery used in the Barelang V base robot. The measured variables include voltage, current, and power sourced from Lithium Polymer (LiPo) batteries. This research includes motor frequency testing, power consumption testing with load variation and PWM (Pulse Width Modulation) value variation, electric power calculation, battery capacity calculation, and battery usage time calculation.

## 2.1 System Design

The system design describes how the system will run. Figure 1 illustrates the system design used in this study.


**Fig. 1.** System Design

A Lithium Polymer (LiPo) battery is used as the power supply for the base robot. The process starts with moving the base robot. Next, the PZEM-017 module will read the voltage, current, and power as the base robot moves. The data read by PZEM-017 is then forwarded via RS485 to ESP8266. The ESP8266 will process and send the data to

Blynk, where the results of the voltage, current, and power readings will be displayed. The data displayed on Blynk will be stored and used to calculate the battery energy consumption the base robot uses while moving.

The base serves as the foundation that allows the robot to move. The Base Robot is good at linear and rotational movements because it uses brushed DC motors and omnidirectional wheels. The omnidirectional wheel design allows the base robot to move quickly in multiple directions without requiring rotation, which benefits navigation and maneuverability in tight spaces [10, 11]. A brushed DC motor uses brushes to transfer electric current to the rotor, generating rotational movement. It consists of brushes, rotors, and stators. Performance is influenced by brush quality. Brushed DC motors offer more straightforward speed and direction regulation but a limited lifespan due to brush commutator friction [12, 13]. PZEM-017 is a monitoring system instrument that measures electrical properties, including direct current (DC) power and overcurrent, with a shunt installation from 50A to 300A. It can measure voltage, current, power, and energy. Although it does not have a display, it has an RS485 connection with the Modbus RTU protocol. Measured values can be viewed on a PC/Laptop using a UART to RS485 converter and the included software[14, 15].

RS485 is a serial communication standard widely used in industrial and building automation applications. It utilizes differential transmission for superior receiver sensitivity and noise resistance. It offers enhanced security and reliability for remote data transfer, making it advantageous in industrial applications and integrated access control systems [16]. ESP8266 is a WiFi-enabled microcontroller module used in base robot voltage, current, and power monitoring systems. The device is compatible with 802.11 b/g/n wireless technology, multiple TCP/IP connections, UART/GPIO communication, and supports analog to digital converter channels. It can receive firmware upgrades over the air [17]. Blynk is a web-based tool for developing IoT projects, offering a real-time visual interface for users to manage the system through online and mobile applications. This tool works to display data collected from sensors[18, 19]. The components used are assembled to be ready for data collection; the overall system circuit can be seen in Figure 2.

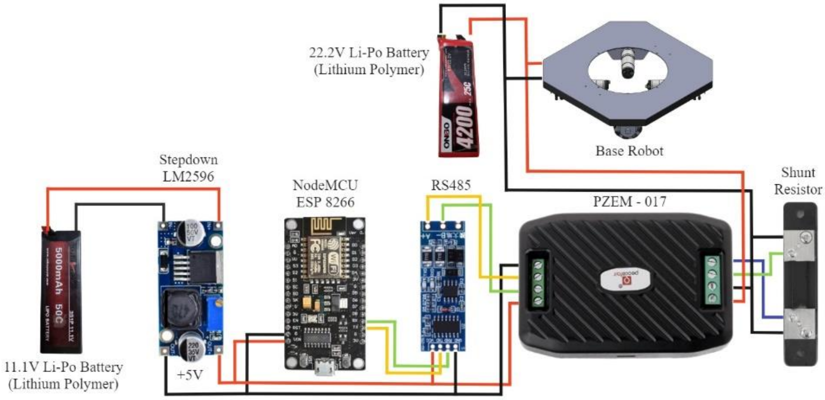


**Fig. 2.** Electrical Design

This circuit uses a 11.1V battery as the primary power source, which is then reduced to a 5 voltage. This 5V voltage powers the ESP8266, RS485, and PZEM-017. To receive data from the PZEM-017, the RX and TX pins on the ESP8266 are connected to the RS485 with the configuration RX to RX and TX to TX. Meanwhile, pins A and B on the RS485 are connected to pins A and B on the PZEM-017, configuring A to A and B to B. The terminal block connected to the shunt resistor and base robot battery measures the base robot's voltage, current, and power. The ESP8266, RS485, and PZEM-017 components are put together in one place to form a monitoring tool. Figure 3 illustrates this monitoring tool, while Figure 4 illustrates the PCB design used.

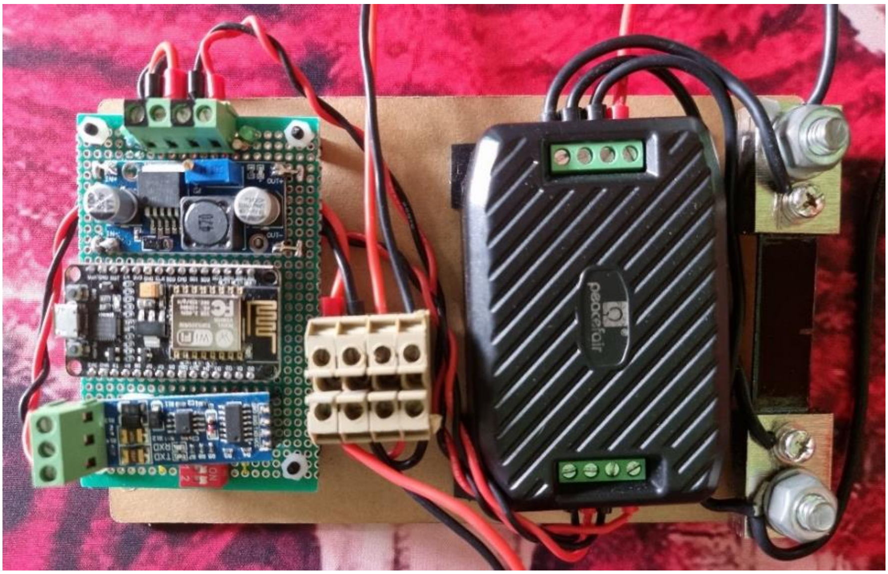

**Fig. 3.** Monitoring Tool

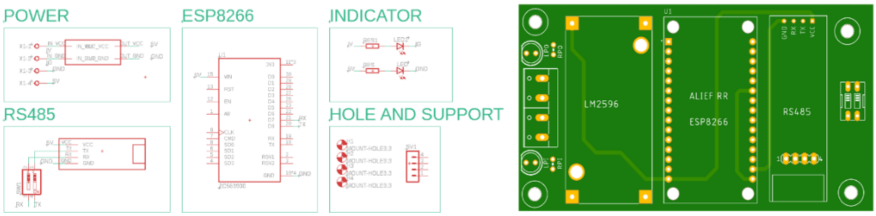


**Fig. 4.** PCB Design

## 2.2 Algorithm

After the hardware design is complete, the next step is to design the software. This software design uses the Arduino IDE and will be uploaded to the ESP8266. Before creating a program, the initial task is to create a program design flowchart, which serves as a guide and is divided into two parts.

**Testing Program Design.** This test program is used to determine the most suitable frequency value for the brushed DC motor on the base robot. Figure 5 shows the flowchart for the testing program.

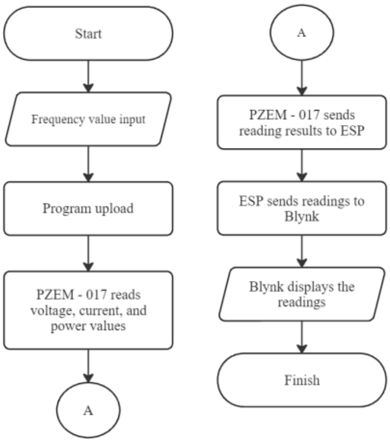


**Fig. 5.** Testing Program Flowchart

The initial stage of designing the test program begins by entering the frequency value to be tested into the program. After the program is uploaded to the microcontroller, the PZEM-017 sensor will read the voltage, current, and power values on the base robot while moving. Furthermore, the values read by the PZEM-017 sensor will be sent to the ESP8266 via the RS485 module. After that, the reading results received by the ESP8266 will be sent to Blynk so that the results of the PZEM-017 sensor reading when the base robot moves can be displayed on Blynk. When the results of the sensor readings have appeared on Blynk, the test program design is considered complete.

**Data Retrieval Program Design.** This data retrieval program is used to obtain voltage, current, and power measurement values when the base robot moves. Figure 6 displays the flowchart of the data retrieval program.

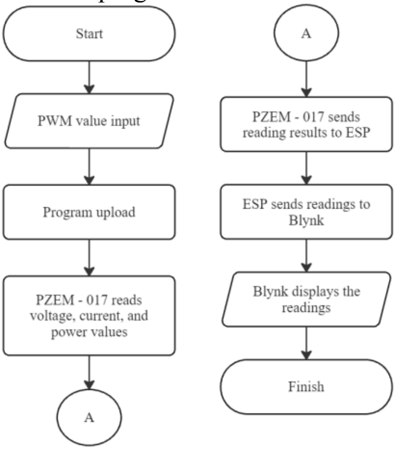


**Fig. 6.** Data Retrieval Program Flowchart

In the initial stage of designing the data retrieval program, the process begins by entering the PWM value for use. After the program is uploaded to the microcontroller, the PZEM-017 sensor will read the voltage, current, and power values on the base robot while moving. Furthermore, the value read by the PZEM-017 sensor will be sent to the ESP8266 via the RS485 module. After that, the results of the PZEM-017 sensor reading received by the ESP8266 will be sent to Blynk to display the sensor reading results when the base robot moves. When the results of the sensor readings have appeared on Blynk, the data retrieval program design is considered complete.

## 2.3 Electric Power Formula

Electrical power is the energy consumed or generated within an electrical circuit, requiring synergy between energy sources like voltage and current. The load uses this power to illuminate lights, operate motors, or replenish batteries [20]. The fundamental equation for computing electrical power in a circuit is:

$$P = V \, x \, I \quad (1)$$

P = Power (Watt)
V = Voltage (Volt)
I = Current (Ampere)

### 2.4 Battery Usage Power Formula

The electrical storage capacity of a battery, measured in ampere-hours (Ah), a battery has a time limit before its energy runs out if it is used to supply power to a load continuously. This capacity directly impacts the duration for which the battery can provide power to the electric motor. The correlation between battery capacity, electric motor working current, and power supply duration can be mathematically represented using the fundamental equation:

$$\text{Battery usage time} = \text{Battery capacity } x \text{ Motor working current} \quad (2)$$

Considering the battery's deficiency, the discharge time will be decreased[20].

## 3 Results

### 3.1 Motor Frequency Testing Results

In this test, researcher conducted trials to determine the most appropriate frequency to use for the motor. The main objective is to find the frequency that can produce the lowest power consumption when the base robot moves. This test was conducted for 4 minutes while the base robot was moving. The average values of voltage, current, and power of the base robot after being used for 4 minutes are presented in Table 1. Based on the TEENSY 4.1 microcontroller datasheet with a 600 MHz clock, the ideal frequency is 585937.5 Hz. Therefore, the test starts from a frequency of 85.000 Hz with an increase of 100.000 Hz at each stage until it reaches a frequency value of 585.000 Hz. Testing was also conducted at a frequency of 685.000 Hz to evaluate whether the motor can still move if the frequency exceeds the microcontroller's ideal frequency value.

**Table 1.** Load of 25 kg, a PWM value of 255, and varying frequency values

| Frequency Value | Voltage (V) | Current (A) | Power (W) |
|---|---|---|---|
| 85.000 | 23.62 | 7.57 | 178.80 |
| 185.000 | 23.62 | 7.59 | 179.28 |
| 285.000 | 24.01 | 7.43 | 178.39 |
| 385.000 | 23.79 | 7.54 | 179.38 |
| 485.000 | 23.91 | 7.5 | 179.33 |
| 585.000 | 23.93 | 7.5 | 179.48 |
| 685.000 | 23.97 | 7.49 | 179.54 |

### 3.2 Power Consumption Testing

In this test, researchers measured the voltage, current, and power while the base robot was moving, and the average usage values of the three parameters are presented in Table 2 to Table 4 after being used for 4 minutes. Tests were conducted with 127, 169, 212, and 255 PWM values. The test started from a PWM value of 127 because the robot did not move below that value, with a frequency range of 85.000 to 685.000. PWM value 127 is the minimum value to start the movement of the motor with a load of 15 – 25 kg, while PWM values 169 and 212 represent a gradual increase in motor speed with each stage increasing by 42.67; the value is obtained from the subtraction between PWM values 255 and 127, which results in 128, then divided into 3 to get three stages of increasing PWM values. The PWM value of 255 was chosen because it is the maximum speed that can be achieved. Testing was also carried out with load variations with a weight of 15 kg, which is the essential weight of the base robot, 20 kg is the weight of the base robot with additional paddy rice gripper and ball gripper mechanisms, and 25 kg is the maximum weight of the robot according to ABU Robocon 2023 rules.

**Table 2.** Frequency Value of 285.000, a Load of 15 kg, and Varying PWM Values

| PWM Value | Voltage (V) | Current (A) | Power (W) |
|---|---|---|---|
| 127 | 24.06 | 5.93 | 142.67 |
| 169 | 24.19 | 6.17 | 149.25 |
| 212 | 24.03 | 6.51 | 156.44 |
| 255 | 23.91 | 6.89 | 164.74 |

**Table 3.** Frequency Value of 285.000, a Load of 20 kg, and Varying PWM Values

| PWM Value | Voltage (V) | Current (A) | Power (W) |
|---|---|---|---|
| 127 | 24.29 | 6.18 | 150.11 |
| 169 | 24.43 | 6.44 | 157.33 |
| 212 | 24.39 | 6.77 | 165.12 |
| 255 | 24.36 | 7.08 | 172.47 |

**Table 4.** Frequency Value of 285.000, a Load of 25 kg, and Varying PWM Values

| PWM Value | Voltage (V) | Current (A) | Power (W) |
|---|---|---|---|
| 127 | 23.1 | 6.81 | 157.31 |
| 169 | 23.57 | 6.94 | 163.58 |
| 212 | 23.58 | 7.29 | 171.90 |
| 255 | 24.01 | 7.43 | 178.39 |

Based on the tests conducted using three load variations and four different PWM value variations, it is evident that both the load and PWM value significantly affect the power consumption of the base robot while moving. In tests with a PWM value of 127 and load variations of 15 kg, 20 kg, and 25 kg, the average voltage, current, and power values during the robot moving for 4 minutes showed different results. This shows that even though the PWM value is fixed, the different loads on the robot cause variations in power consumption. Similarly, in the test with a fixed load of 15 kg and varying PWM values of 127, 169, 212, and 255, the average voltage, current, and power values also showed significant differences. This confirms that even though the load is constant, the variation of PWM values affects the power consumption of the base robot. To drive the base robot for 4 minutes with varying PWM values and loads, as in Table 2 to Table 4, the average power consumption required is 142.67 Watts to 178.39 Watts.

## 3.3 Electrical Power Calculation

Based on the measurement results in Tables 2 through 4, the calculation of the battery's power can be seen as follows. The calculation uses the equation below:

$$P = V \, x \, I \quad (3)$$

**Table 5.** Frequency Value of 285.000, a Load of 15 kg, and Varying PWM Values

| PWM Value | V | I | $P = V$ x $I$ |
|---|---|---|---|
| 127 | 24.06 | 5.93 | 142.67 |
| 169 | 24.19 | 6.17 | 149.25 |
| 212 | 24.03 | 6.51 | 156.44 |
| 255 | 23.91 | 6.89 | 164.74 |

**Table 6.** Frequency Value of 285.000, a Load of 20 kg, and Varying PWM Values

| PWM Value | V | I | $P = V$ x $I$ |
|---|---|---|---|
| 127 | 24.29 | 6.18 | 150.11 |
| 169 | 24.43 | 6.44 | 157.33 |
| 212 | 24.39 | 6.77 | 165.12 |
| 255 | 24.36 | 7.08 | 172.47 |

**Table 7.** Frequency Value of 285.000, a Load of 25 kg, and Varying PWM Values

| PWM Value | V | I | $P = V$ x $I$ |
|---|---|---|---|
| 127 | 23.1 | 6.81 | 157.31 |
| 169 | 23.57 | 6.94 | 163.58 |
| 212 | 23.58 | 7.29 | 171.90 |
| 255 | 24.01 | 7.43 | 178.39 |

Table 5 to 7 show the power calculation results obtained when the base robot moves. The power value is obtained from the product of voltage and current.

## 3.4 Battery Capacity Calculation

Calculations are made based on the collected data to determine the battery capacity required for the base robot to operate for 4 minutes. The calculation uses the equation below:

$$\text{Battery usage time} = \text{Battery capacity } x \text{ Motor working current} \tag{4}$$

$$\text{Battery deficiency} = \text{Battery capacity } x \text{ } 20\% \tag{5}$$

$$\text{Required battery capacity} = \text{Battery capacity} + \text{Battery deficiency} \tag{6}$$

**Table 8.** Frequency Value of 285.000, a Load of 15 kg, and a PWM Value of 127

| | |
|---|---|
| 1. Battery capacity = 0.067 hr x 5.93 Ah<br>Battery capacity = 0.397 Ah<br>2. Battery deficiency = 0.397 Ah x 20%<br>Battery deficiency = 0.079 Ah | 3. Required battery capacity = 0.397 Ah + 0.079 Ah<br>Required battery capacity = 0.476 Ah or 476 mAh |

**Table 9.** Frequency Value of 285.000, a Load of 15 kg, and a PWM Value of 169

| | |
|---|---|
| 1. Battery capacity = 0.067 hr x 6.17 Ah<br>Battery capacity = 0.413 Ah<br>2. Battery deficiency = 0.413 Ah x 20%<br>Battery deficiency = 0.083 Ah | 3. Required battery capacity = 0.413 Ah + 0.083 Ah<br>Required battery capacity = 0.496 Ah or 496 mAh |

**Table 10.** Frequency Value of 285.000, a Load of 15 kg, and a PWM Value of 212

| | |
|---|---|
| 1. Battery capacity = 0.067 hr x 6.51 Ah<br>Battery capacity = 0.436 Ah<br>2. Battery deficiency = 0.436 Ah x 20%<br>Battery deficiency = 0.087 Ah | 3. Required battery capacity = 0.436 Ah + 0.087 Ah<br>Required battery capacity = 0.523 Ah or 523 mAh |

**Table 11.** Frequency Value of 285.000, a Load of 15 kg, and a PWM Value of 255

| | |
|---|---|
| 1. Battery capacity = 0.067 hr x 6.89 Ah<br>Battery capacity = 0.462 Ah<br>2. Battery deficiency = 0.462 Ah x 20%<br>Battery deficiency = 0.092 Ah | 3. Required battery capacity = 0.462 Ah + 0.092 Ah<br>Required battery capacity = 0.554 Ah or 554 mAh |

**Table 12.** Frequency Value of 285.000, a Load of 20 kg, and a PWM Value of 127

| | |
|---|---|
| 1. Battery capacity = 0.067 hr x 6.18 Ah<br>Battery capacity = 0.414 Ah<br>2. Battery deficiency = 0.414 Ah x 20%<br>Battery deficiency = 0.083 Ah | 3. Required battery capacity = 0.414 Ah + 0.083 Ah<br>Required battery capacity = 0.497 Ah or 497 mAh |

**Table 13.** Frequency Value of 285.000, a Load of 20 kg, and a PWM Value of 169

| | |
|---|---|
| 1. Battery capacity = 0.067 hr x 6.44 Ah<br>Battery capacity = 0.431 Ah<br>2. Battery deficiency = 0.431 Ah x 20%<br>Battery deficiency = 0.086 Ah | 3. Required battery capacity<br>= 0.431 Ah + 0.086 Ah<br>Required battery capacity<br>= 0.517 Ah or 517 mAh |

**Table 14.** Frequency Value of 285.000, a Load of 20 kg, and a PWM Value of 212

| | |
|---|---|
| 1. Battery capacity = 0.067 hr x 6.77 Ah<br>Battery capacity = 0.454 Ah<br>2. Battery deficiency = 0.454 Ah x 20%<br>Battery deficiency = 0.091 Ah | 3. Required battery capacity<br>= 0.454 Ah + 0.091 Ah<br>Required battery capacity<br>= 0.545 Ah or 545 mAh |

**Table 15.** Frequency Value of 285.000, a Load of 20 kg, and a PWM Value of 255

| | |
|---|---|
| 1. Battery capacity = 0.067 hr x 7.08 Ah<br>Battery capacity = 0.474 Ah<br>2. Battery deficiency = 0.474 Ah x 20%<br>Battery deficiency = 0.095 Ah | 3. Required battery capacity<br>= 0.474 Ah + 0.095 Ah<br>Required battery capacity<br>= 0.569 Ah or 569 mAh |

**Table 16.** Frequency Value of 285.000, a Load of 25 kg, and a PWM Value of 127

| | |
|---|---|
| 1. Battery capacity = 0.067 hr x 6.81 Ah<br>Battery capacity = 0.456 Ah<br>2. Battery deficiency = 0.456 Ah x 20%<br>Battery deficiency = 0.091 Ah | 3. Required battery capacity<br>= 0.456 Ah + 0.091 Ah<br>Required battery capacity<br>= 0.547 Ah or 547 mAh |

**Table 17.** Frequency Value of 285.000, a Load of 25 kg, and a PWM Value of 169

| | |
|---|---|
| 1. Battery capacity = 0.067 hr x 6.94 Ah<br>Battery capacity = 0.465 Ah<br>2. Battery deficiency = 0.465 Ah x 20%<br>Battery deficiency = 0.093 Ah | 3. Required battery capacity<br>= 0.465 Ah + 0.093 Ah<br>Required battery capacity<br>= 0.558 Ah or 558 mAh |

**Table 18.** Frequency Value of 285.000, a Load of 25 kg, and a PWM Value of 212

| | |
|---|---|
| 1. Battery capacity = 0.067 hr x 7.29 Ah<br>Battery capacity = 0.488 Ah<br>2. Battery deficiency = 0.488 Ah x 20%<br>Battery deficiency = 0.098 Ah | 3. Required battery capacity<br>= 0.488 Ah + 0.098 Ah<br>Required battery capacity<br>= 0.586 Ah or 586 mAh |

**Table 19.** Frequency Value of 285.000, a Load of 25 kg, and a PWM Value of 255

| | |
|---|---|
| 1. Battery capacity = 0.067 hr x 7.43 Ah<br>Battery capacity = 0.498 Ah<br>2. Battery deficiency = 0.498 Ah x 20% | 3. Required battery capacity<br>= 0.498 Ah + 0.1 Ah<br>Required battery capacity<br>= 0.598 Ah or 598 mAh |

| |
|---|
| Battery deficiency = 0.1 Ah |

Based on the calculations in Table 8 to Table 19, both the load and the PWM value affect the battery capacity required by the base robot. Different results are obtained when calculating battery capacity with load variations of 15 kg, 20 kg, and 25 kg with a PWM value of 169. This shows that eventhough the PWM value is the same, the different loads on the robot cause variations in determining the battery capacity used. In addition, calculating battery capacity with variations in PWM values 127, 169, 212, and 255 at a load of 20 kg also produces different calculations. This confirms that even though the load on the base robot is the same, variations in PWM values affect the battery capacity requirements. To move the base robot for 4 minutes with three load variations and four PWM value variations, the required battery capacity ranges from 0.476 Ah or 476 mAh to 0.598 Ah or 598 mAh.

### 3.5 Battery Usage Time Calculation

Calculations based on the collected data to determine how long the 6S 4500 mAh Lithium Polymer (LiPo) battery can provide electrical energy for the base robot. The calculation uses the equation below:

$$\text{Battery usage time} = \text{Battery capacity}\ x\ \text{Motor working current} \quad (7)$$

$$\text{Battery deficiency} = \text{Battery usage time}\ x\ 20\% \quad (8)$$

$$\text{Battery usage time with deficiency} = \text{Battery usage time} - \text{Battery deficiency} \quad (9)$$

**Table 20.** Frequency Value 285.000, a Load of 15 kg, and PWM Value 127

| | |
|---|---|
| 1. Battery usage time = 4.5 Ah / 5.93 A<br>Battery usage time = 0.759 hr<br>2. Battery deficiency = 0.759 x 20%<br>Battery deficiency = 0.152 hr | 3. Battery usage time with deficiency<br>= 0.759 hr – 0.152 hr<br>Battery usage time with deficiency<br>= 0.607 hr or 36.42 min |

**Table 21.** Frequency Value 285.000, a Load of 15 kg, and PWM Value 169

| | |
|---|---|
| 1. Battery usage time = 4.5 Ah / 6.17 A<br>Battery usage time = 0.729 hr<br>2. Battery deficiency = 0.729 x 20%<br>Battery deficiency = 0.146 hr | 3. Battery usage time with deficiency<br>= 0.729 hr – 0.146 hr<br>Battery usage time with deficiency<br>= 0.583 hr or 34.98 min |

**Table 22.** Frequency Value 285.000, a Load of 15 kg, and PWM Value 212

| | |
|---|---|
| 1. Battery usage time = 4.5 Ah / 6.51 A<br>Battery usage time = 0.691 hr<br>2. Battery deficiency = 0.691 x 20%<br>Battery deficiency = 0.138 hr | 3. Battery usage time with deficiency<br>= 0.691 hr – 0.138 hr<br>Battery usage time with deficiency<br>= 0.553 hr or 33.18 min |

**Table 23.** Frequency Value 285.000, a Load of 15 kg, and PWM Value 255

| | |
|---|---|
| 1. Battery usage time = 4.5 Ah / 6.89 A<br>Battery usage time = 0.653 hr<br>2. Battery deficiency = 0.653 x 20%<br>Battery deficiency = 0.131 hr | 3. Battery usage time with deficiency<br>= 0.653 hr – 0.131 hr<br>Battery usage time with deficiency<br>= 0.522 hr or 31.32 min |

**Table 24.** Frequency Value 285.000, a Load of 20 kg, and PWM Value 127

| | |
|---|---|
| 1. Battery usage time = 4.5 Ah / 6.18 A<br>Battery usage time = 0.728 hr<br>2. Battery deficiency = 0.728 x 20%<br>Battery deficiency = 0.146 hr | 3. Battery usage time with deficiency<br>= 0.728 hr – 0.146 hr<br>Battery usage time with deficiency<br>= 0.582 hr or 34.92 min |

**Table 25.** Frequency Value 285.000, a Load of 20 kg, and PWM Value 169

| | |
|---|---|
| 1. Battery usage time = 4.5 Ah / 6.44 A<br>Battery usage time = 0.699 hr<br>2. Battery deficiency = 0.699 x 20%<br>Battery deficiency = 0.14 hr | 3. Battery usage time with deficiency<br>= 0.699 hr – 0.14 hr<br>Battery usage time with deficiency<br>= 0.559 hr or 33.54 min |

**Table 26.** Frequency Value 285.000, a Load of 20 kg, and PWM Value 212

| | |
|---|---|
| 1. Battery usage time = 4.5 Ah / 6.77 A<br>Battery usage time = 0.665 hr<br>2. Battery deficiency = 0.665 x 20%<br>Battery deficiency = 0.133 hr | 3. Battery usage time with deficiency<br>= 0.665 hr – 0.133 hr<br>Battery usage time with deficiency<br>= 0.532 hr or 31.92 min |

**Table 27.** Frequency Value 285.000, a Load of 20 kg, and PWM Value 255

| | |
|---|---|
| 1. Battery usage time = 4.5 Ah / 7.08 A<br>Battery usage time = 0.636 hr<br>2. Battery deficiency = 0.636 x 20%<br>Battery deficiency = 0.127 hr | 3. Battery usage time with deficiency<br>= 0.636 hr – 0.127 hr<br>Battery usage time with deficiency<br>= 0.509 hr or 30.54 min |

**Table 28.** Frequency Value 285.000, a Load of 25 kg, and PWM Value 127

| | |
|---|---|
| 1. Battery usage time = 4.5 Ah / 6.81 A<br>Battery usage time = 0.661 hr<br>2. Battery deficiency = 0.661 x 20%<br>Battery deficiency = 0.132 hr | 3. Battery usage time with deficiency<br>= 0.661 hr – 0.132 hr<br>Battery usage time with deficiency<br>= 0.529 hr or 31.74 min |

**Table 29.** Frequency Value 285.000, a Load of 25 kg, and PWM Value 169

| | |
|---|---|
| 1. Battery usage time = 4.5 Ah / 6.94 A<br>Battery usage time = 0.648 hr<br>2. Battery deficiency = 0.648 x 20%<br>Battery deficiency = 0.13 hr | 3. Battery usage time with deficiency<br>= 0.648 hr – 0.13 hr<br>Battery usage time with deficiency<br>= 0.518 Hr or 31.08 min |

**Table 30.** Frequency Value 285.000, a Load of 25 kg, and PWM Value 212

| | |
|---|---|
| 1. Battery usage time = 4.5 Ah / 7.29 A<br>Battery usage time = 0.617 hr<br>2. Battery deficiency = 0.617 x 20%<br>Battery deficiency = 0.123 hr | 3. Battery usage time with deficiency<br>= 0.617 hr – 0.123 hr<br>Battery usage time with deficiency<br>= 0.494 hr or 29.64 min |

**Table 31.** Frequency Value 285.000, a Load of 25 kg, and PWM Value 255

| | |
|---|---|
| 1. Battery usage time = 4.5 Ah / 7.43 A<br>Battery usage time = 0.606 hr<br>2. Battery deficiency = 0.606 x 20%<br>Battery deficiency = 0.121 hr | 3. Battery usage time with deficiency<br>= 0.606 hr – 0.121 hr<br>Battery usage time with deficiency<br>= 0.485 hr or 29.10 min |

Based on the calculations in Table 20 to Table 31, the PWM value and the load on the base robot affect the battery usage time. At load variations of 15 kg, 20 kg, and 25 kg with a PWM value of 212, the calculation results show different results, which confirms that even though the PWM value is the same, changes in load affect the length of time the battery will run out. In addition, variations in PWM values of 127, 169, 212, and 255 at a load of 25 kg also show differences in calculation results, confirming that even though the load is constant, variations in PWM values affect the time the battery will run out. Using a 6S 4500 mAh Lithium Polymer (LiPo) battery, the base robot can last between 0.485 hours (29.10 minutes) to 0.607 hours (36.42 minutes) under varying loads and PWM values as calculated in Table 20 to Table 31.

## 4 Conclusion

The experimental results show that an increase in motor frequency is not always directly proportional to power consumption. In frequency testing, the average power generated at 285.000 Hz is lower than other frequencies. The average power consumption required by the basic robot for 4 minutes, with three load variations and four PWM value variations, ranged from 142.67 Watts to 178.39 Watts. The battery capacity required for these conditions ranged from 0.476 Ah (476 mAh) to 0.598 Ah (598 mAh). If a 4500 mAh Lithium Polymer (LiPo) 6S battery is used, the base robot can move from 0.485 hours (29.10 minutes) to 0.607 hours (36.42 minutes). Load and PWM variations significantly affect pow-er consumption, battery capacity, and operational duration. A heavier load and higher PWM increased power consumption and shortened battery duration, while a lower load and PWM reduced power consumption and extended battery duration. These tests successfully optimized battery usage, reducing battery size and weight, thus freeing up space and weight for other components. In addition, by understanding the battery usage duration, battery replacement time can be estimated more efficiently, reducing robot downtime and improving operational efficiency. These results provide a solid foundation for future research by exploring other variables that affect power consumption or using alternative methods for more accurate calculations.

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