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Performance Analysis of Electric Bicycles with Planetary BLDC Motors under Different Rider Weights

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Abstract

Electric bicycles are increasingly used as eco-friendly personal transportation due to their efficiency and low emissions. This study analyzes the effect of rider weight on the energy consumption of a 48V 14Ah lithium-ion battery in an electric bicycle equipped with a 500W planetary BLDC motor. Tests were carried out on three rider weight categories: 60–65 kg, 70–75 kg, and 80–85 kg, to evaluate their impact on current consumption, travel distance, and operating duration. Measurements were taken using a PZEM-015 sensor to monitor voltage, current, and battery capacity in real-time, while speed and distance data were recorded through the Strava application. The results show that as the rider's weight increases, the average current consumption also rises, decreasing both distance and travel time in a nearly linear pattern. At 60 kg, the bicycle traveled 24.32 km with an average current of 9.52 A, while at 80 kg, the distance decreased to 19.76 km with an average current of 23.15 A. The findings indicate that rider weight significantly affects electric bicycles' performance and energy efficiency. Heavier riders require greater battery power, shorter travel range, and reduced operational efficiency.

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1. Introduction

The government's consistent push for electric vehicle adoption is increasingly evident through a series of supportive regulations that facilitate the adoption of environmentally friendly technology and create a conducive ecosystem for developing the electric vehicle industry in Indonesia. The government's efforts to support electric vehicles are evident in regulations such as Presidential Regulation Number 55 of 2019 concerning the Acceleration of the Battery-Based Electric Motor Vehicle Program for Road Transportation. This measure is expected to support Indonesia's clean energy transition and reduce dependence on fossil fuels [1].

Electric bicycles are a recent innovation because they can reduce air pollution and greenhouse gas emissions often associated with fossil-fueled vehicles. With a smaller and lighter design, electric bicycles allow users to maneuver more easily on narrow roads, making them more flexible than other electric vehicles. Electric vehicles, including e-bikes, rely on batteries as their primary energy source, often called Battery Electric Vehicles (BEVs) [2]. Batteries play a crucial role in converting chemical energy into electrical energy. The most commonly used battery in electric bicycles is the lithium-ion (Li-ion) battery, which offers advantages such as high energy storage capacity, long life, and light weight [3]. In addition to relying on batteries, electric bicycles are equipped with BLDC motors for propulsion [4]. It can be observed in research conducted by Samant and Shubham in 2021, which discussed the design of a propulsion and energy storage system for the IIRED E-BIKE electric bicycle using a 1000W BLDC motor and a 48V 50Ah lithium-ion battery.

Calculations showed that a BLDC motor with 85% efficiency at a speed range of 2900–3100 rpm had sufficient capacity to power the electric bicycle, while a 50Ah lithium-ion battery provided sufficient energy to cover the required distance. Calculations of the power required to overcome obstacles in various track conditions showed a power requirement of 0.66 kW at 50 km/h on a concrete track and 0.7 kW on an asphalt track. Selecting the right motor and battery capacity, based on calculated power and energy requirements, is crucial to ensuring optimal electric bicycle performance [5].

The performance of a motorcycle can be affected by the user's weight. According to a study conducted by Mashudi (2022), entitled "Analysis of the Effect of Load on Lithium Battery Consumption Efficiency in Electric Bicycles," the study examined the effect of varying weights on the efficiency of lithium batteries in electric bicycles. The test method involved testing various weights (50, 70, 90, and 110 kg) over a distance of 2 km. Data were analyzed using standard deviation and error. This study concluded that the design and construction of an electric bicycle were conducted, as well as an analysis of the effect of weight variations on the efficiency of lithium batteries in electric bicycles. The results showed that increasing rider weight causes a linear decrease in battery efficiency [6]. Meanwhile, research by Muhamad Iksan (2022) entitled "The Effect of Loading and Speed Control of a 1 kW BLDC Motor on an Electric Motorcycle" using various weights (60, 90, and 125 kg) showed that the greater the and speed, the greater the battery power and capacity used, resulting in higher battery consumption and shorter battery life [3]. Meanwhile, research by Mufid Muhammad Ariq (2024) entitled "Lithium-Ion Battery Efficiency in Restricting Current on a 2000 Watt BLDC Motor on an Electric Motorcycle" found that current limiting on a BLDC motor significantly improves lithium-ion battery efficiency, reducing power consumption, extending range, and preserving battery life by reducing energy loss due to heat [7]. Another study on the power consumption of lithium-ion batteries in electric motorcycles with varying slopes showed that power consumption increased on uphill terrain. At a speed of 15 km/h and a 13° incline, the power consumption reached 904.87 watts for a distance of 60 meters. Conversely, on a flat road at a speed of 30 km/h for a distance of 150 meters, the power consumption was only 455.50 watts. This test showed that uphill terrain requires a higher current and power, which causes the battery to drain faster than on flat terrain [8]. Contrasts with research conducted by Banjari in 2025, which added solar panels to charge the battery. His research focused primarily on the effect of the number of gear teeth on the front and rear tires on the speed and distance traveled by the bicycle. The observed results showed that the smaller the rear gear, the higher the speed and distance traveled by the bicycle [9].

Several previous studies have focused more on high-power electric motors for electric two-wheeled vehicles than on lightweight electric bicycles that use planetary gear systems. This study differs because it uses a 500-Watt planetary BLDC motor that offers high efficiency, high torque at low speeds, and smoother, quieter performance. In addition, the battery capacity used is 48V 14Ah lithium-ion, which is smaller than in previous studies, making it more suitable for lightweight electric bicycles. Testing was conducted on riders weighing 60–85 kg, which represents the conditions of typical users in Indonesia, with real-time monitoring of current consumption and distance traveled using the PZEM-015 sensor and the Strava application to record speed and distance. With this design, this study not only measures battery efficiency but also empirically evaluates the performance of electric bicycles in terms of current consumption, distance, and travel time, and presents a linear relationship between rider weight and energy consumption.. This study analyzes the effect of weight on lithium-ion battery consumption in electric bicycles with planetary BLDC motors. Brushless DC (BLDC) motors offer several advantages that make them a superior choice for a wide range of applications, including electric bicycles. One advantage is their high energy efficiency, which can reduce power consumption and extend battery life. Furthermore, BLDC motors offer smoother performance and quieter operation than conventional motors, as they do not use brushes, which are susceptible to wear and tear over time. Higher reliability and minimal maintenance are also factors in favor of choosing these motors, making them more durable and easier to maintain in the long term [10]. The tests involved varying rider weights: 60 to 65 kilograms, 70 to 75 kilograms, and 80 to 85 kilograms. These weights were taken from samples of Electrical Engineering students at Teknokrat Indonesia University. Each test was conducted on the roads around the Teknokrat Indonesia University campus during a single battery charge. The test results will be analyzed graphically to demonstrate the effect of weight on battery energy consumption. It is hoped that this research can make a significant contribution to the development of more advanced and effective electric bicycle technology.

2. Research Methodology

The study, which analyzes the effect of weight on lithium-ion battery consumption in electric bicycles with planetary BLDC motors, involves several stages, as discussed in Figure 1. Based on the flowchart, the research stages begin with a literature study to study relevant materials to obtain the necessary knowledge to serve as a basis for the research. The next stage is defining and identifying the research problem, which is how to design an electric bicycle using a planetary BLDC motor. The electric bicycle is tested after the design is complete to ensure design suitability. If discrepancies are found during the testing process, the electric bicycle design will be repeated until satisfactory results are obtained. Conversely, if the testing is successful, the research proceeds to the data collection stage. After all data has been collected, the next step is to systematically analyze the data, which will be discussed and compiled into a final research report. The block diagram of how this research tool works can be seen in Figure 2.

In Figure 2 (a), illustrates The block diagram of the device used in this research shows the process starting with the battery, which serves as a power source to supply energy to the controller and PZEM 015 sensor. Next, the controller distributes voltage to the throttle, which then drives the BLDC motor. Once the BLDC motor is running, the output, in the form of motor speed, is displayed on the speedometer. Meanwhile, to monitor the current, voltage, and remaining battery capacity, this data can be viewed using the PZEM 015 sensor connected to the system. The schematic design used in this study and the 3D design of the electric bicycle can be seen in Figures 2 (b) and Figure 3.

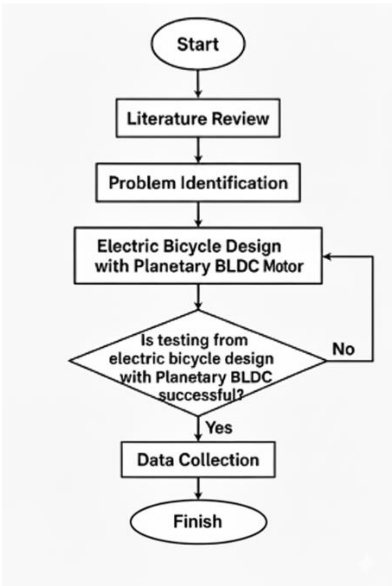
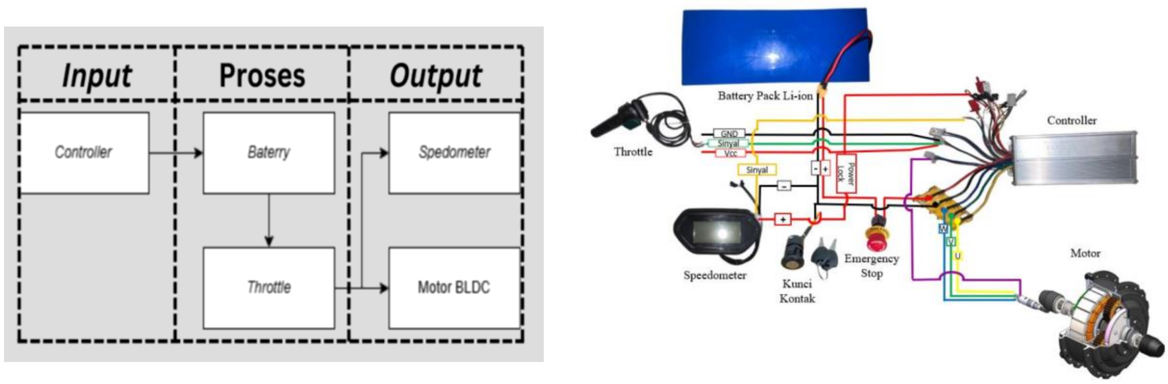


Figure 1. The flowchart of research



(a) (b)

Figure 2. The system's (a) workflow (b) wiring diagram

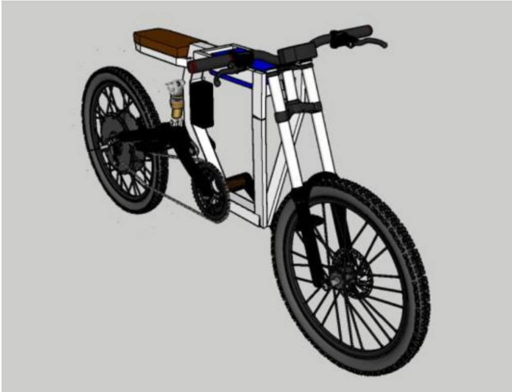


Figure 3. 3D design of electric bicycle

Figure 2 (b) shows the circuit schematic used in this study, where the author used a 48V 14Ah lithium-ion battery as the input source for the components [11]. The electric current from the battery is then channeled to the controller, which serves as the control center for all components, Although the initial cost of lithium-ion batteries tends to be higher, this technology is able to provide a balance between performance, practicality, and sustainability, especially if equipped with a battery management system (BMS) to maintain the safety and stability of its performance [12]. From the controller, the electric current is transmitted to the throttle to drive the 500-Watt planetary BLDC motor, which is then connected to the speedometer to monitor the bicycle's speed [13]. The data flow is then forwarded to the PZEM-015 sensor, which monitors battery capacity, current, and voltage in real time. While in Figure 3, the 3D design of electric bicycle were made in solidwork application which depicts the final form of the design and layout of the components used [14]. In designing an electric vehicle, it is necessary to calculate the thrust or traction force to find out the torque and rpm values of the motor, which are a consideration in choosing which motor to choose as the wheel drive. This is influenced by Newton's second law, the total force acting on the system (bicycle + driver) is proportional to the acceleration (a) and total mass (m), which can be expressed in equation (1).

$$F = m \times a \tag{1}$$

Which,
F : total force (N)
m : total mass(kg)
a : acceleration (m/s^2)

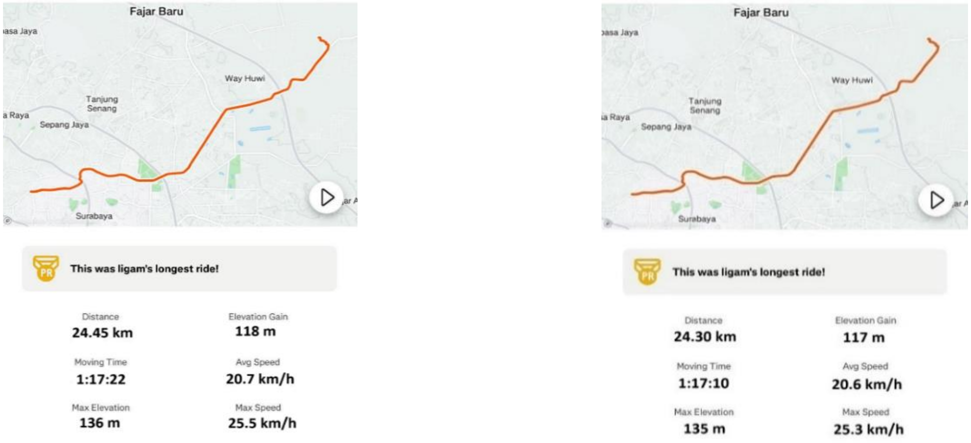
The greater the driver's mass, the greater the thrust required to produce the same acceleration. If the thrust (pedaling power or electric motor power) remains constant, acceleration decreases [15],[16].

3. Results and Discussions

In this study, tests will be conducted to analyze the effect of varying rider weights (60 to 65 kg, 70 to 75 kg, and 80 to 85 kg) on the energy consumption of lithium-ion batteries in electric bicycles. These weight variations are taken from the average weight of Electrical Engineering students at Teknokrat Indonesia University. The goal is to identify how much energy lithium-ion batteries consume when electric bicycles are operated with different weights. Data collected will include battery capacity, battery voltage, and battery current. Furthermore, the author will collect motor speed data to analyze the effect of weight on the speed of the BLDC Planetary motor. The collected data will then be analyzed and presented graphically.

3.1. Performance testing of electric bicycles on Body Weight 60 kg to 65 kg

The test was carried out using riders weighing 61 kg and 63 kg, then several performance parameters were measured such as speed, distance, time, and current. Performance parameters can be observed in Figures 4 (a) and (b) taken from the Strava application.



(a) (b)

Figure 4. Performance display on the Strava app (a) for a body weight of 61 kg (b) for a body weight of 63 kg

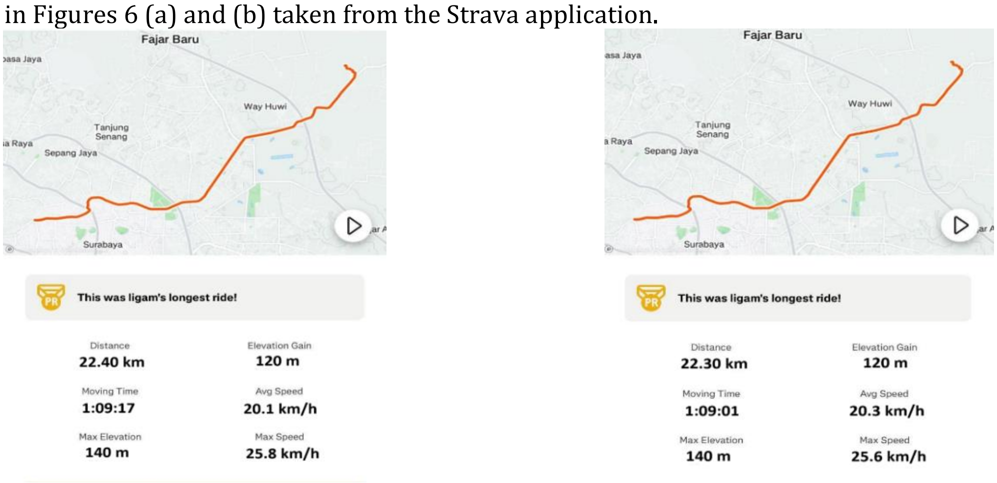
(a) (b)

Figure 5. The result of current (a) for a body weight of 61 kg (b) for a body weight of 63 kg

In addition to testing using the Strava application, an average electric current test was carried out using an ammeter that shown in Figures 5. Data collection using an ammeter aims to measure the average current on an electric bicycle, carried out by measuring the current flowing through the battery phase cable and obtaining an average current of 9.52 A and 9.83 A starting from a fully charged battery condition until it is empty.

3.2. Performance testing of electric bicycles on Body Weight 70 kg to 75 kg

The test was carried out using riders weighing 72 kg and 75 kg, then several performance parameters were measured such as speed, distance, time, and current. Performance parameters can be observed in Figures 6 (a) and (b) taken from the Strava application.



(a) (b)

Figure 6. Performance display on the Strava app (a) for a body weight of 72 kg (b) for a body weight of 75 kg

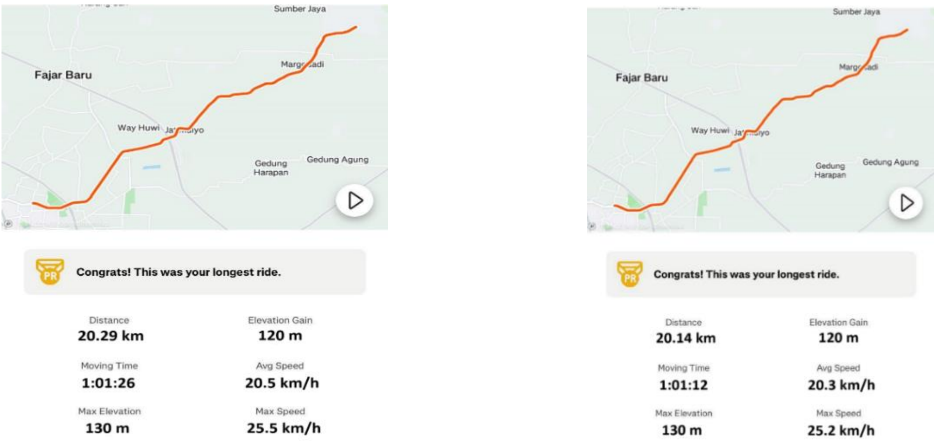
(a) (b)

Figure 7. The result of current (a) for a body weight of 72 kg (b) for a body weight of 75 kg

In addition to testing using the Strava application, an average electric current test was carried out using an ammeter that shown in Figures 7. Data collection using an ammeter aims to measure the average current on an electric bicycle, carried out by measuring the current flowing through the battery phase cable and obtaining an average current of 16.76 A and 16.78 A starting from a fully charged battery condition until it is empty.

3.3. Performance testing of electric bicycles on Body Weight 80 kg to 85 kg

The test was carried out using riders weighing 82 kg and 85 kg, then several performance parameters were measured such as speed, distance, time, and current. Performance parameters can be observed in Figures 8 (a) and (b) taken from the Strava application. Figure 9. Performance display on the Strava app (a) for a body weight of 82 kg (b) for a body weight of 85 kg. In addition to testing using the Strava application, an average electric current test was carried out using an ammeter that shown in Figures 9.



(a) (b)

Figure 8. Performance display on the Strava app (a) for a body weight of 82 kg (b) for a body weight of 85 kg

(a) (b)

Figure 9. The result of current (a) for a body weight of 82 kg (b) for a body weight of 85 kg

Data collection using an ammeter aims to measure the average current on an electric bicycle, carried out by measuring the current flowing through the battery phase cable and obtaining an average current of 26.52 A and 26.86 A starting from the condition of the battery being fully charged until it is empty.

3.3. Discussion

Based on the test results shown in the Figures for each test for different body weights, all the results can be observed in Table 1. In addition to the data presented in tabular form, the data has been analyzed in a graph. The following is a graph of the results of the weight test against travel time which can be seen in Figure 11. In Figure 10, it can be seen that the blue line shows the travel time of a bicycle with a body weight of 61 and 63 kg is 1 hour 17 minutes, which is the longest travel time in this study, while those with a body weight of 72 and 75 kg managed to travel 1 hour 9 minutes and those with a body weight of 82 and 85 kg managed to travel 1 hour 1 minute. The results of this test show a decrease in the use time of an electric bicycle against the user's body weight. Next, the analysis of the rider's weight graph against the distance traveled by the electric bicycle is shown in Figure 12, so that you can find out how far the distance that can be covered by the electric bicycle.

Table 1. Performance test data for all rider weights

Body Weight (kg)	Speed (km/h)	Distance (km)	Time (minutes)	Current (A)
61	20,7	24,45	77.37	9,42
63	20,6	24,30	77.17	9,83
72	20,1	22,40	69.28	16,76
75	20,3	22,30	69.02	16,78
82	20,3	20,29	61.43	26,52
85	20,5	20,14	61.20	26,86

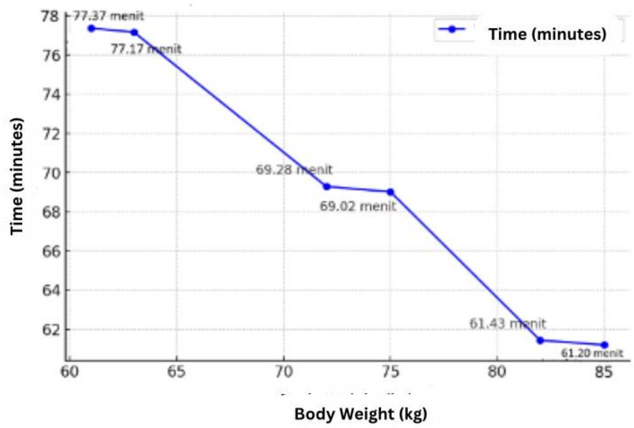


Figure 10. The Graph of body weight against travel time

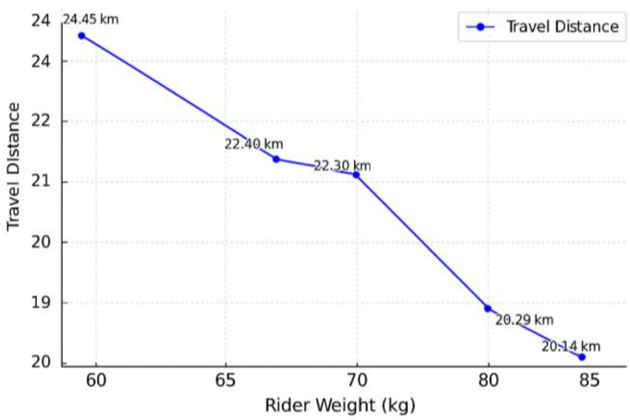


Figure 11. The graph of body weight against travel distance

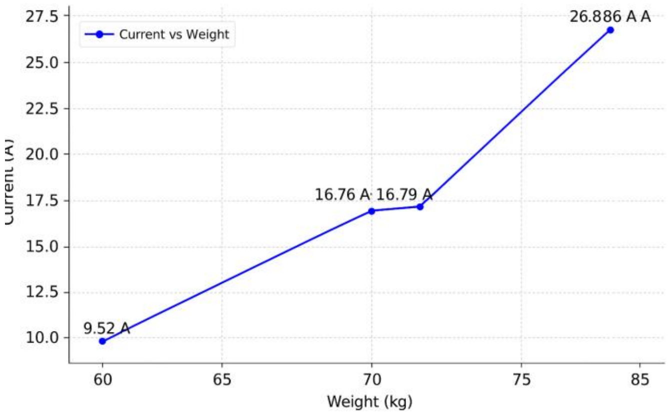


Figure 12. The graph of rider weight against battery's current

In Figure 11, the blue line shows that those weighing 61 and 63 kg managed to cover a distance of 24 km and became the furthest distance successfully covered in this study, while those weighing 72 and 75 kg managed to cover a distance of 22 km and those weighing 82 and 85 kg managed to cover a distance of 20 km. From this data, there is a decrease in distance covered with each increase in the weight of the electric bicycle rider. The next data analyzed in graphical form in this study is body weight versus electric bike battery current, to determine how much body weight affects battery current on an electric bike. This can be seen in Figure 12.

In Figure 12, the blue line shows that the weight of 61 and 63 kg has an average current output of 9 A, which is the weight that consumes the most amperes on the electric bicycle battery, while the weight of 72 and 75 kg has an average current output of 16 A, and the weight of 82 and 85 kg has an average current output of 26 A, which is the weight that consumes the most amperes on the electric bicycle battery.

4. Conclusion

Based on the research entitled "Analysis of the Effect of Load on Lithium-Ion Battery Consumption in Electric Bicycles with Planetary BLDC Motors," several important conclusions were drawn. The study successfully analyzed the effect of load variation on energy consumption in electric bicycles. From the collected and analyzed data, it was found that the greater the rider's weight, the higher the energy consumption drawn from the battery. Furthermore, the study evaluated the impact of rider load on both travel distance and travel time. The findings indicate that as the rider's weight increases, the achievable distance and travel duration decrease; conversely, lighter riders enable the electric bicycle to travel farther and for longer.

Based on these findings, several suggestions for future research are proposed. It is recommended that further analysis include different types of tracks, such as uphill roads and uneven terrain, to understand performance under varied conditions better. Additionally, integrating a load cell sensor under the bicycle seat is suggested to accurately measure the rider's weight in real time, thereby simplifying data collection and improving the accuracy of subsequent experiments.

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