Design and Experimental Evaluation of a Mid-Drive Electric Bicycle with BLDC Motor Bracket and Gearbox Integration

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ABSTRACT

Electric bicycles with mid-drive systems provide better weight balance and performance, particularly on uphill terrain. However, their production cost is generally higher than hub-drive systems, limiting accessibility for wider users. This study aims to develop a cost-effective mid-drive conversion system by modifying a hub-drive e-bike using a custom steel bracket and an integrated gearbox, and to evaluate its power performance and energy efficiency. The prototype was powered by a 60V 15Ah LiFePO$_4$ battery and tested under laboratory and road conditions, including no-load, flat-road, and uphill tracks (5°–15° slopes). Data were collected using a tachometer, GPS, and PZEM-015 module to record speed, voltage, current, and power consumption. The motor required 659 W during acceleration from 0–10 km/h, decreased to 183 W at 19 km/h, and increased to 867 W at 39 km/h. Under a 15° incline, the e-bike maintained 15 km/h with 1120 W of power. Distance-based tests (2.08–4.07 km) showed stable energy consumption between 21–26 Wh/km, increasing proportionally with rider weight. The gearbox-assisted mid-drive conversion improved torque distribution, transmission efficiency, and energy performance, providing a practical and affordable alternative for developing efficient electric bicycles.

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INTRODUCTION

The development of electric vehicle technology is progressing rapidly in line with increasing public awareness of the need for environmentally friendly transportation and energy efficiency [1]. One of the alternative vehicles that has become increasingly popular is the electric bicycle (E-Bike). E-Bikes are widely favored because they offer various advantages, including energy savings, low operational costs, and significantly lower environmental impact compared to fossil fuel-based vehicles [2][3]. Currently, electric bicycles have been widely used in various countries, particularly in urban areas, as a practical as well as sustainable transportation solution.

The main component of the electric bicycle drive system is the electric motor, which functions to convert electrical energy into mechanical energy to propel the bicycle [4]. Based on their type, E-Bikes are divided into two categories: pure electric bicycles and power-assisted bicycles. Meanwhile, in terms of motor placement, there are two main systems, namely Hub-Drive and Mid-Drive [5][6][7].

In the Hub-Drive system, the motor is placed inside the front or rear wheel, while in the Mid-Drive system, the motor is mounted at the center of the bicycle and transmits power through the gearbox, chainring, and rear sprocket. The Mid-Drive system is generally considered superior to the Hub-Drive because it provides better power efficiency, balanced weight distribution, and optimal performance when riding uphill [7]. This makes the Mid-Drive increasingly popular in the development of modern electric bicycles.

However, the use of the Mid-Drive system still presents several challenges, one of which is its relatively high cost compared to the Hub-Drive system. To address this issue, the researchers designed a bracket for the Mid-Drive system that allows the use of a high-speed BLDC motor combined with a gearbox [8]. This approach is expected to produce a more efficient and affordable Mid-Drive drivetrain system without compromising the E-Bike's performance. The gearbox plays a crucial role in optimizing power transmission, enabling the motor to operate more efficiently under various riding conditions.

Many studies on electric bicycle (E-Bike) systems have been conducted with diverse focuses and approaches. One study investigated efforts to extend the range of mid-drive electric bicycles by mapping system efficiency and optimizing riding strategies. That study analyzed the motor's energy consumption patterns and rider behavior under different route conditions. The simulation results indicated that applying appropriate riding strategies such as adjusting motor load can reduce battery energy consumption by up to 19% [4]. This finding emphasizes that power management and transmission systems have a significant influence on the overall efficiency of an E-Bike.

Another study examined the use of a small Brushless DC (BLDC) motor controlled by an Electronic Speed Controller (ESC), in which the motor was directly mounted on the wheel during operation [9]. This configuration aimed to provide simple motion without additional transmission mechanisms. However, this approach has limitations, such as low torque when climbing and reduced efficiency under heavy loads, due to the absence of torque multiplication or reduction through a gearbox.

Meanwhile, another research analyzed the relationship between power and revolutions per minute (RPM) in a mid-drive type BLDC motor. The test results showed that higher RPM values required greater current and power to maintain rotational speed. The voltage remained relatively stable at around 78–80 V, while the current increased along with RPM. This demonstrates a direct relationship between power consumption and motor speed, indicating that a mid-drive system can operate more effectively if it can regulate rotational distribution through an appropriate transmission ratio [10].

In addition, a previous study by the authors discussed the design of a bracket for integrating a Ninebot ES hub-drive motor into a mid-drive system for an electric bicycle. Although the prototype was mechanically functional, the testing revealed a weakness in the form of excessively high electrical power consumption during initial acceleration. This occurred because the motor's starting torque was not reduced or managed through a gearbox. Therefore, the current study continues this research by incorporating a gearbox into the transmission system to improve power efficiency, enhance torque at low speeds, and reduce current load during acceleration [11].

The development of a bracket with a gearbox in this study aims to provide a more affordable mid-drive system solution without sacrificing the mechanical quality or performance of the electric bicycle. Commercial mid-drive systems available on the market are typically expensive due to high manufacturing costs and brand value. By designing and manufacturing the bracket independently, the researchers can select suitable materials and utilize a hub-drive type BLDC motor that is more economical yet capable of delivering sufficient torque and power efficiency. This approach makes it possible to create a mid-drive

system with competitive performance compared to commercial products but at a lower production cost. Consequently, this design has the potential to serve as a practical alternative for users who wish to upgrade their electric bicycles without significant financial investment, thereby promoting wider adoption of mid-drive technology among cost-conscious users seeking efficiency and performance.

METHOD

The types of research conducted are included in the applied research category with an experimental approach. The main focus of this research is to design, create, as well as test the BLDC motorcycle bracket along with the Mid-Drive transmission system on the prototype of electric bicycles. This study aims to produce a functional mechanical design and be able to improve the performance of electric bicycles, especially in terms of power distribution, transmission efficiency, and battery energy consumption. The research method used is the design, manufacturing, and experimental testing. At the design stage, a BLDC bracket design was made by calculating the dimensions of the motor, gearbox, bottom bracket, as well as the suitability of the chainring position to be parallel to prevent misalignment. The next step is the process of making a prototype bracket and the assembly of the transmission system that connects the BLDC motorbike, gearbox, crankset, and rear sprocket using a chain. After the system is installed, laboratory tests and road tests are carried out. Laboratory testing is focused on evaluating the strength of the bracket, the stability of the transmission system, as well as the comparison of torque and rotation between components according to the gear ratio [5]. Meanwhile, the road test is carried out to analyze battery energy consumption, average speed, stability, vibration, and the effect of variations in the rider's weight on energy needs [12]. Test data obtained through measurement instruments such as GPS, Speedometer, Strava application, and PZEM-015 module for monitoring electrical energy consumption.

The electric bicycle prototype is powered by a 60V 15Ah LiFePO$_4$ battery, chosen for its high energy density, long cycle life, and stable voltage output, making it suitable for continuous testing under various load conditions [13]. This battery specification provides a total energy capacity of 900 Wh, allowing for extended test durations while ensuring consistent performance throughout all trials.

This study was conducted to evaluate the battery energy consumption and performance of a converted mid-drive electric bicycle system. The independent variables were travel distance (2.08 km, 3.05 km, and 4.07 km) and rider weight (50 kg, 55 kg, 65 kg, and 72 kg), while the dependent variables included energy consumption (Wh) and average speed (km/h) [14]. All tests were carried out under controlled conditions with constant tire pressure, identical battery type, and similar track surfaces. The tests were performed in throttle-only mode to ensure that all measured power originated from the motor, eliminating the effect of pedaling assistance. Data were collected using GPS and a speedometer for speed and distance measurement, the Strava application for route tracking, and a PZEM-015 module to monitor voltage, current, and total electrical energy consumed. Each condition was repeated three times, and the results were expressed as energy consumption per kilometer (Wh/km) to compare system efficiency [15].

The experimental procedure involved three track conditions: flat terrain, an uphill track with a slope of 5°–10° [16], and a no-load condition where the rear wheel rotated freely. Two rear sprocket configurations (14T and 32T) were tested to evaluate the effect of gear ratio on power transmission and efficiency. The tests on flat terrain included measurements of energy consumption per distance, speed stability, and transmission performance, as well as the influence of varying rider weights. This experimental design enables comprehensive

evaluation of how travel distance, gear ratio, and load variation affect the energy efficiency and mechanical stability of the mid-drive system.

BLDC Bracket Design

The design of this BLDC bracket aims to provide strong and stable barrier for BLDC motorcycles, gearboxes, chainring so that the system can be installed and can be used. The position of the motor determines that the chainring on the BLDC motor is parallel to the chainring of the gearbox. Bolt hole design needs to be adjusted to the pattern of installation of BLDC and gearbox motorcycles, with the distance between the precision holes and the diameter that matches the size of the bolt used. The designed bracket must have adequate resistance to withstand the force and torque that arises during the motor operating [17]. The bracket design design is shown in Figure 1.
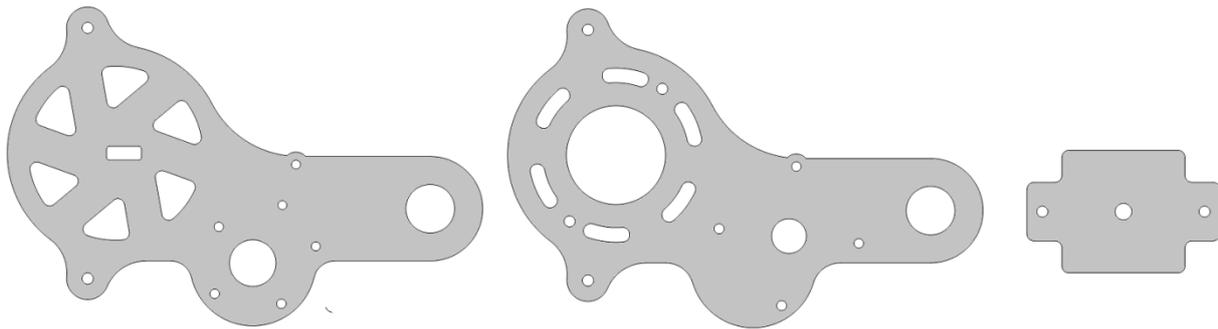

Figure 1. BLDC Bracket Design

The part that becomes a unit with the bracket itself is the bracket holder. This bracket holder is used to make the bracket not change position when the motor rotates and there is a allowance when driving [18]. In this design there are 2 holders, namely the holder in the Bracket Botton (BB), can be seen in Figure 1 and the iron retaining which is associated on the down tube of the bicycle. Pictures of the holder associated on the Down tube can be seen in Figure 1. Bracket Botton is modified by giving a ring of 5 mm on both sides of the right and left. While the iron holder associated on the down tube of the bicycle frame is bent, as shown in Figure 2.

Figure 2. Design of the BLDC Bracket Holder

Transmission System Design

Transmission on this system is designed using a chain as the main media [19]. This chain is used to connect each component efficiently so that it can transfer power optimally. The power transmission process starts from the BLDC motorbike equipped with a chainring of 15 teeth (15 Teeth). This BLDC motorbike transmits the initial round to the gear box connected to the 16T chainring. Furthermore, the gear box functions as a multiplier of torque with a tooth ratio ratio of 1: 5. BLDC motorcycles and gear boxes can be seen in Figure 3.
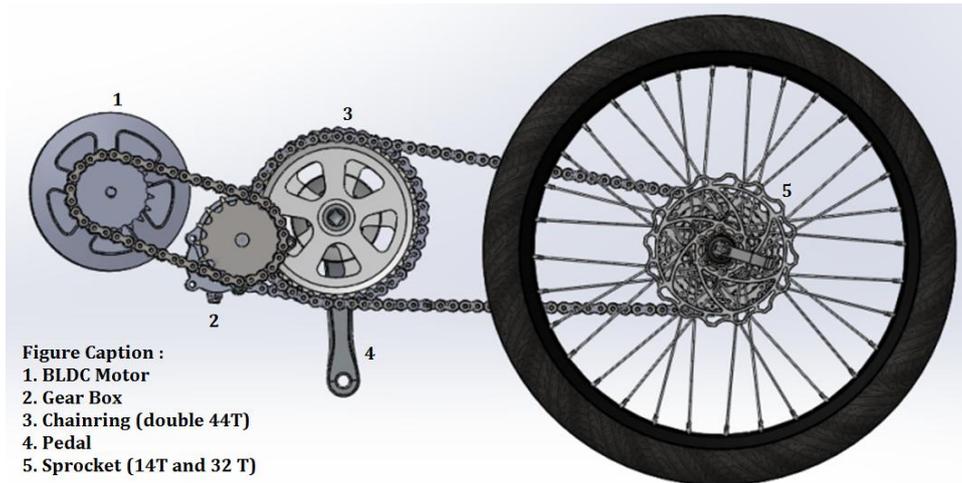
Figure 3. Left-Side View of the Transmission System

From the gearbox, power is transmitted through a 12T chainring, which then drives the crankset equipped with a 44T chainring, as shown in Figure 4. The 44T crankset shares the same shaft with another 44T chainring, which subsequently drives the rear sprocket via a secondary chain. The gears on the rear sprocket can be shifted during operation [20]; however, for this test, the researcher utilized 32T (low gear) and 14T (high gear) configurations. Finally, the rear sprocket transfers the mechanical power to the 20-inch rear wheel, generating wheel rotation and propelling the bicycle as a whole.
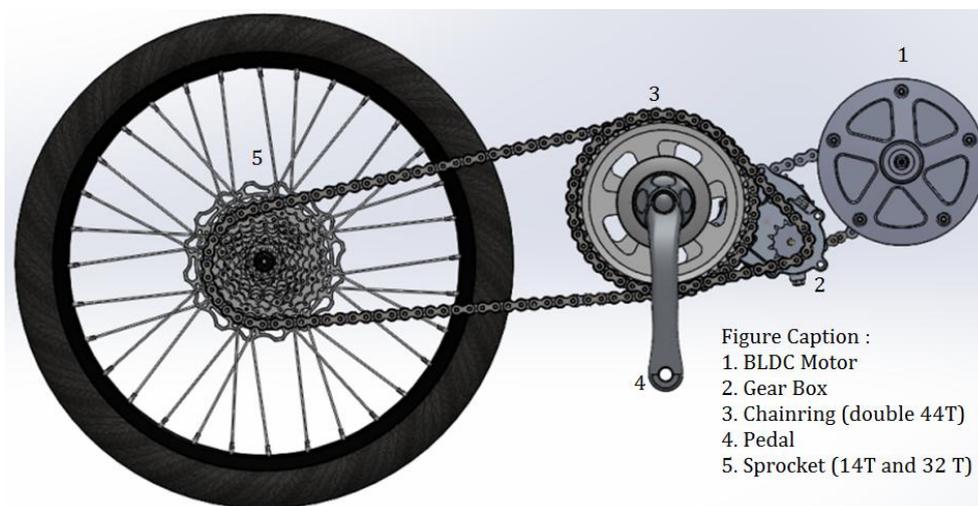

Figure 4. Right-side view of the transmission system

The explanation above can be presented in Table 1.

Table 1. Gear ratio stages from motor to sprocket

No	Stage	Value	Ratio	Comparison of total rpm
1	Motor → Gearbox input	15 → 16	0,9375	
2	Gearbox (1:5)	Internal	0,2	
3	Gearbox output → Crankset	12 → 44	0,272727	

| No	Stage	Value	Ratio	Comparison of total rpm
4a	Crank (44) → rear Sprocket (low)	44 → 32	1,375	0,07031
4b	Crank (44) → rear Sprocket (high)	44 → 14	3,142857	0,16071

From Table 1 and calculations for low gear (44:32), obtained rpm wheel = 7.03% rpm motor and wheel torque = 14.2 × motor torque. As for high gear (44:14), wheel rpm = 16.1% rpm motor, wheel torque = 6.22 × motor torque.

The selection of gear ratios in this study was carried out to achieve a balance between torque and wheel rotational speed that matches the load characteristics and testing conditions. The low gear ratio (44:32) produces higher torque at lower rotational speeds, allowing the motor to operate more easily during initial acceleration or when handling heavier loads, such as a rider with higher body weight. Conversely, the high gear ratio (44:14) is used to achieve higher speeds with lower torque, which is suitable for flat road conditions and constant-speed operation.

Gear ratio has a direct impact on energy consumption. At low gear ratios, the motor operates more efficiently during the initial acceleration phase because the torque load is transmitted more proportionally, thereby reducing current draw. At high gear ratios, energy consumption tends to increase, especially during acceleration or speed gain, as the motor must deliver higher torque at elevated rotational speeds to maintain velocity. Therefore, selecting the appropriate gear ratio can enhance energy efficiency using low gears for initial acceleration and high gears for achieving higher speeds while simultaneously minimizing power surges during startup and under heavy-load conditions.

BLDC bracket design

The BLDC motor and gearbox are positioned beneath the down tube. The alignment between the BLDC motor chainring and the left-side gearbox chainring must be precise to prevent the chain from slipping. Furthermore, the right-side gearbox chainring is aligned with the crankset. Several factors considered in this design include dimensional constraints, the weight of the BLDC motor, the width of the Bottom Bracket (BB) tube, and the length of the BLDC motor gear shaft. The BLDC motor dimensions are 200 mm in diameter, 50 mm in width, and 90 mm in shaft length, while the gearbox dimensions are 131 × 47.5 mm. Figure 5 illustrates the overall bracket plan and presents the right-side design.
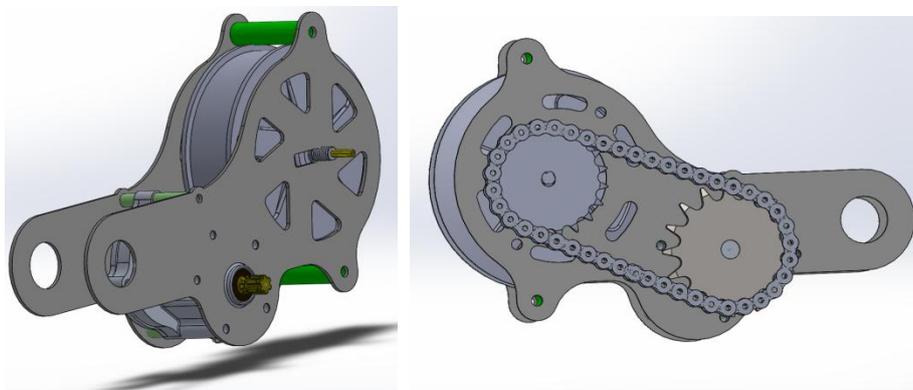
Figure 5. Image of the overall BLDC bracket

RESULT AND DISCUSSION

Electric Bicycle Specifications

The technical specifications of the electric bicycle prototype to be tested are presented in Table 2.

Table 2. Specifications of the Electric Bicycle Designed and Developed

No	Parameter	Value
1	Motor Type	BLDC 300W, Controller Hand Throttle
2	Battery	Lipefo4, 60 V, 15 Ah
3	Maximum Speed	±42 km/h (Flat road)
4	Front Wheel Profile	20" x 3.00
5	Rear Wheel Profile	20" x 3.00
6	Front Brake Type	Disk brake 25 cm
7	Rear Brake Type	Disk brake 18 cm
8	Frame	Alloy
9	Dimensions	P x L x T = 180 cm x 70 cm x 100 cm

The criteria for component selection are determined based on dimensional compatibility parameters, particularly regarding the integration between the motor shaft and the supporting bracket [20]. The shaft width must be compatible with the bracket width to prevent misalignment or residual stresses that could affect the reliability of the transmission system. The planned BLDC motor has an outer diameter of 200 mm, a body width of 50 mm, and a shaft width of 90 mm.

Electric Bicycle Prototype Testing

The testing of the electric bicycle prototype focused on the performance of the BLDC motor transmission system, which was mounted using a special bracket at the bottom bracket (BB). The testing was carried out to ensure the strength and stability of the bracket in supporting the motor, as well as to verify that the motor's rotation could be effectively transferred to the freewheel crankset and the drive chain [21]. The testing process involved observing the alignment between the motor gear rotation and the main chainring, as well as the stability of the chain both during pedaling and when the motor provided power assistance. The form of the freewheel crank is shown in Figure 6.

Figure 6. Illustration of the Freewheel Crank and BLDC Motor Bracket

In addition, the vibrations and noise generated by the transmission system were also observed to assess the mechanical quality and rider comfort. Transmission efficiency was tested by comparing the input power from the BLDC motor to the output power delivered to the rear wheel. From a structural perspective, the durability of the bracket material was examined under dynamic loads, including potential deformation or bolt loosening caused by vibrations. The results of this testing serve as an important reference in determining the

reliability of the drivetrain system and provide input for design improvements, particularly in terms of joint strength, gear alignment precision, and enhanced power transfer efficiency in the electric bicycle prototype.

No-Load Testing

Rotational speed measurements were conducted using a digital tachometer, while current consumption was measured using a PZEM-015, which also records real-time power data. The test results showed that under no-load conditions, the BLDC motor achieved a maximum rotational speed of approximately 1300 rpm, whereas under moderate load conditions, the speed decreased to around 600 rpm. After passing through the gearbox, the rear wheel rotation was reduced to approximately 464 rpm for the high gear sprocket (14T) and 205 rpm for the low gear sprocket (32T). The results also indicated that the current supplied to the motor increased proportionally with the mechanical load applied to the transmission system. Under no-load conditions, the motor required only about 988 mA (approximately 1 A) to reach its maximum free rotation speed of 1300 rpm, indicating that the transmission operated with minimal friction and negligible mechanical resistance. However, during the startup phase, the motor required a higher current of approximately 3.69 A for one second before returning to around 1 A. Figure 7 (left) illustrates the initial condition when the motor begins to rotate, while Figure 7 (right) shows the steady-state condition at the maximum speed of approximately 1300 rpm.

Figure 7. PZEM-015 readings during no-load testing.

Flat-Road Testing

The flat-road test was conducted to determine the relationship between the electric bicycle's speed and the corresponding current, voltage, and output power of the BLDC motor system. During testing, the electric bicycle was ridden along a straight path of approximately 1 km. Measurements were taken using two instruments: a digital PZEM meter to monitor voltage, current, and electrical power, and a GPS-based Android application to record speed and travel time. The experiment was divided into two parts: testing with the rear sprocket in high gear (14T) and low gear (32T).

In Figure 8, the test was carried out using the high gear (14T) configuration. Initially, the rider started with the larger rear sprocket (32T) to facilitate easier acceleration, then shifted to the smaller 14T sprocket as the speed increased. The speed rose from zero to a maximum of 39 km/h. At this maximum speed, the measurement instruments recorded a voltage of 62.0 V, a current of 13.9 A, and a power output of 867 W. These results indicate that the motor system operated efficiently with relatively low power consumption at high speed. This occurs because, under constant velocity, the torque required to maintain motion is smaller than that needed during initial acceleration, leading to a reduction in current drawn from the battery.

Figure 8. Flat road test with 14T rear sprocket

Figure 9. Flat road test with 32T rear sprocket.

Figure 9 illustrates the flat-road test using the low gear configuration (32T rear sprocket). Under this condition, the maximum speed achieved was 19 km/h, with a recorded voltage of 64.8 V, current of 2.82 A, and power output of 183 W.

When the bicycle began moving from 0–10 km/h, the recorded voltage was 64.8 V, the current increased to 10.2 A, and the power reached 659 W. The higher power observed at lower speeds indicates that during initial acceleration or startup, the motor system requires greater torque to overcome the bicycle's inertia and the initial friction between the tires and the road surface. This results in a higher current draw from the battery even though the speed has not yet reached its maximum, as shown in Figure 10.

Figure 10. Flat road test during initial acceleration using 32T rear sprocket.

Table 3. Electrical Performance of the Mid-Drive Electric Bicycle under Different Gear Conditions

No	Test Condition	Rear Sprocket	Speed (km/h)	Voltage (V)	Current (A)	Power (W)	Remarks
1	High Gear	14T	39	62.0	13.9	867	High-speed condition, stable operation
2	Low Gear	32T	19	64.8	2.82	183	Low-speed condition, high initial torque, higher current during acceleration
3	Initial Start	32T	10	64.8	10.2	659	Initial acceleration phase, peak current and torque observed

As shown in Table 3, during operation with the 14T sprocket (high gear), the e-bike reached a maximum speed of 39 km/h. At this point, the recorded voltage was 62.0 V, current

13.9 A, and power 867 W. These values indicate efficient motor performance with relatively low power consumption at higher speeds. This occurs because, under constant speed, the torque required to maintain motion is smaller than that required during acceleration, resulting in reduced current draw from the battery.

In contrast, the low-gear condition (32T) produced a lower maximum speed of 19 km/h, with a recorded voltage of 64.8 V, current of 2.82 A, and power of 183 W. This setup provides higher torque at lower rotational speeds, which is beneficial for acceleration and climbing. However, although the average current is lower during steady motion, the system draws significantly higher current during startup due to the increased torque requirement.

During the initial acceleration phase (0–10 km/h) using the 32T sprocket, the current reached a peak of 10.2 A, and power increased to 659 W, even though the speed remained low. This indicates that the motor exerted maximum torque to overcome the bicycle's inertia and road friction. The spike in current and power during this phase is typical of BLDC motor behavior under transient load conditions.

From these results, it can be concluded that on flat terrain, the mid-drive system equipped with a gearbox delivers efficient performance, maintaining high speed with low power consumption. Furthermore, the system provides sufficient torque at low rotational speeds, enabling quick acceleration without excessive strain on the battery. These findings confirm that the gearbox effectively aligns motor rotation with wheel load, achieving an optimal balance between energy efficiency and riding performance

On-Road Testing

On-road testing of the mid-drive electric bicycle is an essential step to evaluate its performance under real-world conditions. The mid-drive motor, mounted at the center of the bicycle frame, provides advantages such as balanced weight distribution and the ability to utilize the bicycle's gear system [6]. However, field testing is required to ensure that the entire system operates optimally in accordance with rider needs.

The first stage of on-road testing was conducted on flat roads. This test is one of the standard methods for evaluating vehicle performance, particularly for electric bicycles, and was carried out on a level surface without slope. The purpose of this test was to evaluate the vehicle's performance under ideal and controlled conditions. Measurement tools such as GPS or a speedometer were used to record speed, travel distance, and power consumption data.

During testing, the electric bicycle demonstrated good stability while moving in a straight line. This stability was maintained even when the bicycle reached maximum speeds ranging between 39–41 km/h.

As shown in Figure 11, to cover a distance of 3.05 km, the bicycle required 7 minutes and 52 seconds, with an average speed of 23.3 km/h, while consuming 81 Wh of energy. The Strava application was used to measure distance and time, while the PZEM-015 module was employed to measure the energy consumed.

Figure 11. First Cycling Test over a Distance of 3 km

Figure 11 illustrates the travel data of the electric bicycle (e-bike), which includes the travel route, performance statistics, and electrical parameters. The map on the left shows the route taken, with the red line representing the path. The route was located around Jalan Candi Trowulan, following a circular pattern. The travel statistics indicate that the total distance covered was 3.05 km, with a travel time of 7 minutes and 52 seconds. The average speed recorded was 23.3 km/h, while the maximum speed reached 40.5 km/h. The maximum altitude during the trip was 490 meters above sea level, with an elevation change of 15 meters. The voltage measured was 65.9 V, representing the operational battery voltage, and the total energy consumption was 81 Wh.

These results demonstrate the e-bike's performance in a short trip with high energy efficiency. The average speed of 23.3 km/h indicates stable performance, making it suitable for daily use. The electrical parameters confirm that the battery was in good condition, with sufficient remaining capacity for longer trips. This figure provides comprehensive information on the e-bike's performance and can serve as a reference for further evaluation. In the second test, the cycling distance was 2.08 km, requiring 5 minutes and 57 seconds with an average speed of 21.0 km/h, while consuming 44 Wh of energy. The results of this second test are presented in Figure 12.

Figure 12. Second Cycling Test over a Distance of 2.08 km

In the third test, the cycling distance was 4.07 km, requiring 9 minutes and 39 seconds with an average speed of 25.3 km/h, while the energy consumed was 108 Wh. The results of this test are presented in Figure 13.

Figure 13. Third Cycling Test over a Distance of 4.07 km

Table 4. Energy Consumption across Different Distances

No	Distance (Km)	Average Speed (km/h)	Time (menutes)	Energy (Wh)	Energy / km (Wh/km)
1	3,05	23,3	7:52	81	26,5
2	2,08	21,0	5:57	44	21,1
3	4,07	25.3	9:39	108	26,5

From the results in the Table 4, it can be concluded that the energy consumption per kilometer ranges between 21.1 and 26.5 Wh/km. The second segment (2.08 km) demonstrated the best energy efficiency (21.1 Wh/km), likely due to speed stability or optimal motor settings during riding. A higher average speed tends to result in better energy efficiency. The average energy consumption per kilometer is 24.7 Wh/km. All the previous tests were conducted with a rider weight of 72 kg
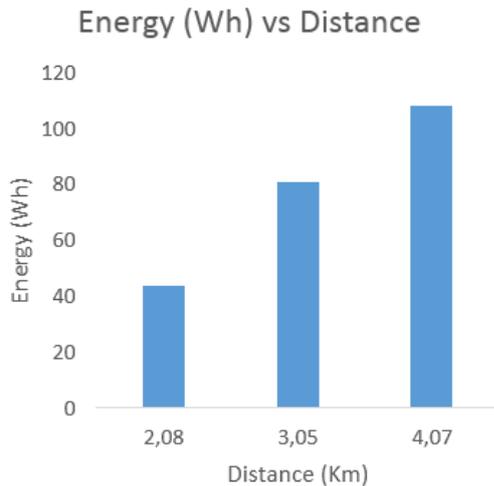

Figure 14. Graph of the Relationship between Travel Distance and Energy Consumption
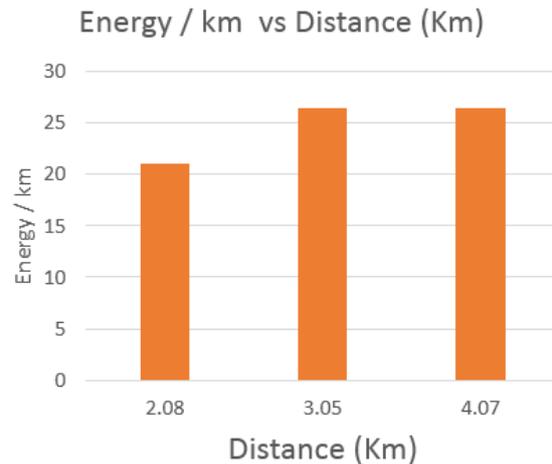
Figure 15. Graph of Energy Efficiency Comparison (Wh/km)

Figure 14 shows the relationship between travel distance and electrical energy consumption. It can be observed that as the travel distance increases, energy consumption rises proportionally. However, the efficiency (Wh/km) remains relatively stable between 21–26 Wh/km, indicating that the transmission system operates consistently across different test distances.

Figure 15 illustrates a comparison of energy efficiency (Wh/km) across the three test tracks. The highest efficiency was achieved on the 2.08 km track with 21.1 Wh/km, while the highest consumption occurred on the 4.07 km track with 26.5 Wh/km. These results suggest a minor influence of average speed on overall energy efficiency.

Electric Bicycle Testing with Different Rider Weights

This test was conducted to determine the energy consumption of the electric bicycle under varying load conditions. The load variation was based on the rider's body weight, with an average riding duration of 8 minutes. The test of the rider's weight influence on travel time was carried out on a straight and flat road. In this test, riders with body weights of 50 kg, 55 kg, 65 kg, and 72 kg rode the electric bicycle for a distance of 3 km.

Table 5. Energy Data Comparison under Varying Rider Weights

No	Weight Kg	Energy (Wh)
1	50	61,67
2	55	65,83
3	65	74,17
4	72	81

The analysis results in Table 5 are as follows: Energy consumption increases in proportion to the rider's weight. This means that the lighter the rider, the less energy is

consumed. The constant energy consumption per kilogram indicates that the motor efficiency remains stable despite variations in rider weight. In conclusion, the heavier the rider, the more energy is required to maintain speed.
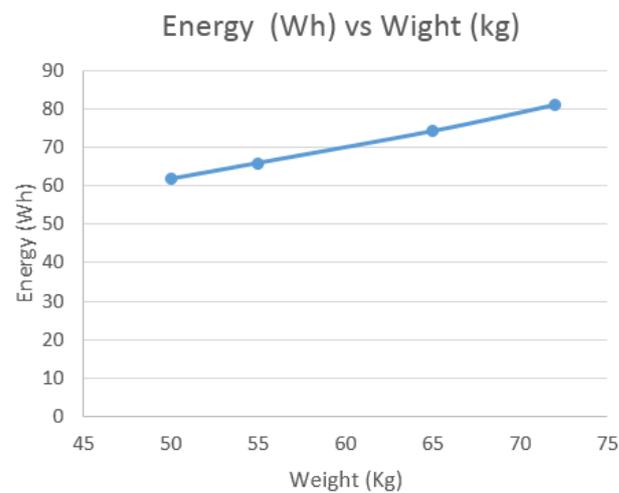

Figure 16. Graph of the Effect of Rider Weight on Energy Consumption

Figure 16 illustrates the relationship between rider weight and electrical energy consumption. A linear trend can be observed, where an increase in rider weight corresponds directly to an increase in energy consumption. At a weight of 50 kg, the energy consumption was 61.67 Wh, while at 72 kg it increased to 81 Wh. This finding confirms that the total load has a significant effect on the motor's power demand.

CONCLUSION AND FUTURE WORK

The results of this study show that the converted mid-drive system with an additional gearbox is able to improve the power efficiency and mechanical performance of the electric bicycle compared to a conventional hub-drive system. The tests revealed that when the bicycle accelerates from 0 to 10 km/h, the motor requires 659 W of power to generate sufficient initial torque. As the speed reaches 19 km/h, the power demand decreases to 183 W due to reduced torque load and higher motor efficiency. When the speed increases to 39 km/h, the power rises again to 867 W to maintain high-speed operation. Under a 15° uphill condition, the bicycle maintains a stable speed of 15 km/h, requiring a higher power of 1120 W.

Distance-based testing showed relatively stable energy consumption across various travel distances (21–26 Wh/km) and a proportional increase in energy use with heavier rider weight. These findings also support previous studies emphasizing the importance of power and transmission management strategies in optimizing e-bike energy efficiency. With the use of a gearbox, torque distribution can be adjusted according to load and road conditions, allowing a significant reduction in current consumption during the initial acceleration phase. This concept aligns with transmission mechanics theory, which states that a lower gear ratio provides higher torque at low speeds, while a higher ratio enhances efficiency at constant speeds.

Furthermore, the bracket design developed in this study demonstrates that mechanical components can be produced economically without compromising stability or durability. These results provide practical contributions to the knowledge and development of mid-drive technology, particularly in the context of energy-efficient electric vehicle engineering in Indonesia. By integrating a gearbox with a more affordable BLDC motor, the system

successfully achieves a balance between performance and cost, offering broader application opportunities for users with limited budgets.

Further testing of the bracket material under more extreme dynamic load simulations is required to ensure long-term durability, along with consideration of lighter yet strong materials, such as high-carbon steel or heat-treated aluminum alloys. Gear ratios may be further optimized to achieve a better balance between torque efficiency and speed, particularly for varied terrains (steep inclines or downhill roads).

The motor control system can be enhanced with power management algorithms to improve energy efficiency, especially under varying rider loads. Testing on more diverse routes (inclines, rough terrain, and long-distance travel) is needed to provide a more comprehensive overview of the e-bike's performance. For long-term implementation, the prototype may be integrated with an IoT-based energy monitoring system, enabling users to track power consumption, travel distance, and battery condition in real-time.

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