

Design and Retrofitting of a Low-cost Electric Bicycle

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Abstract

An electric bicycle, or e-bike, is essentially a traditional bicycle equipped with an electric motor and battery. The motor assists the rider while pedalling, providing an additional power source to make cycling easier and more accessible. The aim of this research is to design and retrofit a low-cost electric bicycle (e-bike) with a focus on affordability and wider market adoption. A functional e-bike was constructed, achieving a cruising speed of 25 km/hr with a 48v battery (6 Ah capacity) and a 48v, 250-watt electric motor. This combination prioritizes a balance between range, power assistance, and cost. The total cost was estimated at around N324,000. Recommendations for future iterations include incorporating regenerative braking to improve efficiency, exploring lightweight frame materials to extend range, and utilizing readily available battery formats to reduce replacement costs. Additionally, integrating a gear-shifting system and considering alternative motor placements like hub motors are suggested for potential performance enhancements. This research demonstrates the feasibility of constructing a functional e-bike with a focus on affordability, paving the way for increased eco-friendly transportation options.

Keywords: Electric bicycle, Design, Manufacturing, Retrofitting, Sustainability, Cycling.

1. Introduction

Unlike a motorcycle, the motor on an e-bike does not fully replace human power but rather complements it, reducing the effort needed to ride (AlSabah et al., 2024; Salmeron-Manzano & Manzano-Agugliaro, 2018). The fundamental functionality of an e-bike is relatively simple. The electric motor, which is typically located on the front wheel, rear wheel, or near the pedals, is powered by a rechargeable battery mounted on the frame. When the motor is activated, usually via a switch on the handlebars, it delivers extra torque to assist the rider's pedalling. This assistance can be adjusted through various power levels, allowing the rider to select the desired level of motor assistance.

There are two primary types of e-bikes: pedal-assist and throttle-based (Hung & Lim, 2020; Langford et al., 2017; Yadav et al., 2024). Pedal-assist bikes, which are the most prevalent, engage the motor only when the rider is pedalling. The more the rider pedals, the more assistance is provided. This system promotes pedalling and offers a natural riding experience. In contrast, throttle-based e-bikes operate more like a moped. They allow the rider to control the motor's power using a throttle, similar to a motorcycle, and the bike will move forward even without pedalling. However, regulations often impose limitations on the speed at which the motor can operate without pedalling (Eto, 2016; MacArthur & Kobel, 2014; Stelling et al., 2021).

Conventional bicycles, while promoting health and alleviating traffic congestion, require physical exertion, limiting their use for longer distances for those with physical limitations (Giki et al., 2024; Greyson et al., 2021). Electric bicycles offer a solution by providing electric motor assistance, but commercially available models can be expensive. Hence by undertaking this research, we aim to develop a cost-effective electric bicycle design. This will provide a greener alternative to traditional forms of transportation and expand the user base for bicycles by making them a more practical and affordable option for general commuting purposes (Ayeter et al., 2023; Hiep et al., 2023).

This research seeks to overcome the drawbacks of traditional bicycles and commercially available electric bikes. While traditional bicycles promote physical activity and contribute to reduced traffic congestion, they may pose a challenge for individuals with limited mobility or those seeking to commute longer distances due to the physical effort required (Rajper & Albrecht, 2020).

On the other hand, commercially available electric bicycles alleviate the exertion component but often come with a high price point, potentially limiting their widespread adoption (Ruan et al., 2013; Ruan et al., 2014). This research aims to bridge this gap by developing an affordable electric bicycle model that preserves the health benefits associated with cycling while providing electric motor assistance for extended range and diminished physical strain. Therefore, the aim of this study is the design and retrofitting of a low-cost electric bicycle. To achieve this aim the following objectives were implemented, namely: Creating a 3D for the electric bicycle which involves motor placement, battery compartment, and integration of electrical components; analysing and identifying the ratings of motors, batteries, controllers, and other necessary parts based on design analysis; assembling and connecting electrical components and integrating these components on a conventional bicycle; and finally carrying out a cost estimation of the retrofitted electric bicycle.

The bicycle and the electrical components were locally sourced and a detailed 3D modelling of the retrofitted assembly was done using SolidWorks. Also, the experimental testing of the bicycle to evaluate component ratings was carried out. The research holds immense importance in the renewable energy landscape. By creating an electric bicycle, we aim to revolutionize transportation and contribute to the reduction of carbon emissions. This innovative mode of transportation is designed to be accessible to a wide range of individuals due to its cost-effectiveness, paving the way for a more sustainable and eco-friendly future.

2. Methodology

The electric bicycle is equipped with an electric motor, which is positioned on the rear wheel. This motor is powered by a rechargeable battery that is integrated into the frame of the bicycle. Upon activation, through a switch located on the handlebars, the motor provides additional torque to complement the rider's efforts without the need for pedalling. The controller regulates the power flow from the battery to the motor. It receives signals from the throttle and determines how much power to deliver to the motor. A display unit on the handlebar displays the battery level. In the case of braking, the throttle is released and the bicycle brakes can be applied.

The materials selected for the fabrication of the electric bicycle in this research include the following:

- i. A brushless DC motor mounted on the rear wheel (24V 250W).
- ii. Two 12V Lithium-ion battery packs (24V 14.4Ah).
- iii. Speed controller (24V).
- iv. Handle-bar mounted throttle, key switch, and display unit.
- v. Charger (24V 12A).
- vi. Wirings.

2.1. Design Analysis of the Electric Bicycle

This section presents the various equations and methods that were utilised in designing and retrofitting the electric bicycle.

2.1.1. Speed of the Bicycle

The speed of the bicycle is given in equation 1:

$$v = w_s \times c_w \quad (1)$$

where, v is the speed of the bicycle, w_s is the wheel speed, and c_w is the circumference of the wheel.

2.1.2. Weight of Loaded Bicycle

The total weight of the loaded bicycle is given in equation 2:

$$W_T = W_R + W_B + W_C \quad (2)$$

where, W_T is the total weight of the loaded bicycle, W_R is the weight of the rider, W_B is the weight of the bicycle, and W_C is the weight of the components.

2.1.3. Normal Reaction of Each Wheel

The normal reaction on each wheel is given in equation 3 (Beer et al., 2025):

$$N_R = \frac{W_T}{2} \quad (3)$$

where, N_R is the normal reaction on each wheel, W_T is the total weight of the loaded bicycle.

2.1.4. Friction Force on Each Wheel

The friction force exerted on each wheel is given as equation 4 (Beer et al., 2006),

$$F = \mu \times N_R \quad (4)$$

where, μ is the coefficient of friction, and N_R is the normal reaction on the wheel. Friction coefficient, μ , on bituminous surface is taken as 0.012.

2.1.5. Torque on Each Wheel

The torque on each wheel is given as equation 5

$$T = F \times r \quad (5)$$

where, r is the radius of the wheel, and F is the friction exerted on each wheel.

2.1.6. Radial speed of each wheel

The radial speed of each wheel is given as equation 6

$$\omega = \frac{v}{r} \quad (6)$$

where, v is the speed of the wheel, and r is the radius of the wheel.

2.1.7. Minimum power of motor

This is the minimum power required for the bicycle to have motion taking into consideration wheel size, total weight, friction and desired speed, given in equation 7 (Theraja, 2014) as:

$$P = T \times w \quad (7)$$

where, T is the torque on each wheel, and w is the radial speed of the wheel.

2.1.8. Total power required by the motor

The total power required by the motor is given in equation 8

$$P_{Total} = P_w + P_{hill} + P_{roll} \quad (8)$$

where, P_{Total} is the total power required by the motor, P_w is the power to overcome air drag, P_{hill} is the power during hill climbing, P_{roll} is the power to overcome rolling resistance. P_w is given in equation 9 as

$$P_w = \frac{C_d \rho A}{2} (V_w)^3 \quad (9)$$

where, P_w is the power to overcome air drag, C_d is the coefficient of air drag, ρ is air density in kg/m^3 , A is the total area of the rider and the bicycle as seen from the front in m^2 , V_w is the Speed of bicycle in m/s. Coefficient of air drag is 1 for an upright cyclist. Frontal area is assumed as 0.50 m^2 . P_{hill} is given in equation 10 as

$$P_{hill} = g \times m_{total} \times V_g \times G \quad (10)$$

where, P_{hill} is the power during climbing. For uphill or downhill riding changes in potential energy are considered. G is the gravitational acceleration which is 9.81 m/s^2 , m_{total} is the total weight of the rider and the bicycle in kg, V_g is the speed relative ground in m/s, G is the road grade (%). P_{roll} is given in equation 11 as

$$P_{roll} = g \times C_r \times m_{total} \times V_g \quad (11)$$

where, P_{roll} is the power to overcome rolling resistance. The rolling resistance is due to the tyres, bearings and other moving parts in the bicycle. Hence it depends on the design of the bicycle, also the speed and total weight of the rider and bicycle. g is the gravitational acceleration, C_r is the coefficient of rolling resistance, m_{total} is the total weight of the rider and the bicycle in kg, V_g is the speed relative to ground in m/s.

2.1.9. Charging Time of Battery

The charging time of the electric bicycle battery is given by equation 12 as

$$T = \frac{\text{Battery capacity}}{\text{Charging current}} \quad (12)$$

where, Battery capacity is in ampere-hour (Ah), Charging current is the charger's output current

2.1.10. Battery Runtime

The battery runtime is given by equation 13

$$\text{Runtime} = \frac{\text{Battery capacity}}{\text{Discharge rate}} \quad (13)$$

where, Battery capacity is in ampere-hour (Ah), Discharge rate is in amp per hour (A/h). The discharge rate is given by equation 14

$$\text{Discharge rate} = \frac{\text{Motor current draw}}{\text{Battery capacity}} \quad (14)$$

where, motor current draw is in amperes (amps), battery capacity is in ampere-hour (Ah)

2.2. SolidWorks Modelling

Computer Aided Design (CAD) is a manufacturing process which helps users to create Stereolithographic (STL) files. It helps in designing, analysing and optimizing 3D models. These software helps in designing ideas and visualizing the concepts through realistic renderings. They also imitate the showing of the design in the real world.

SolidWorks is a leading computer-aided design (CAD) and computer-aided engineering (CAE) software developed by Dassault Systems, for mechanical design, engineering and product development. It enables designers to create 3D models of components and assemblies, perform simulations and analysis and generate manufacturing documentation.

The initial phase of the research involved the design and modelling of the proposed system using SolidWorks. The software was used to create a detailed 3D model of the components and assemblies relevant to the research objectives, the design process focused on achieving the functionality and manufacturability of the system.

3. Results and Discussion

3.1. Design Analysis Results

Speed of the bicycle

Number of teeth on motor sprocket, $t_1 = 9$

Number of teeth on bicycle sprocket, $t_2 = 34$

Speed on motor sprocket, $N_1 = 310$ rpm

Using speed ratio formulae,

$$N_2 t_2 = N_1 t_1$$

$$N_2 = 82 \text{ rpm}$$

$$\text{Outer diameter of wheel} = 660 \text{ mm} = 0.66 \text{ m}$$

$$\text{Circumference of wheel} = 3.14 \times 0.66 = 2.072 \text{ m}$$

Speed of vehicle, $v = ws \times cw$

$$v = 82 \times 2.072 = 169.904 \text{ m/min} = 10.2 \text{ km/hr}$$

Approximately 10.2 km/hr is the average speed of the bicycle.

Weight of the bicycle

Total weight, $W_T = \text{Bicycle weight with components} + \text{rider's weight}$

$$W_T = 19 + 65$$

$$W_T = 84 \text{ kg}$$

Normal reaction

Normal reaction acting on each wheel:

$$N = \frac{84}{2} \times 9.81$$

$$N = 412.02 \text{ N}$$

Friction force

$$F = \mu \times N$$

$$F = 0.012 \times 412.02$$

$$F = 4.94 \text{ N}$$

Torque

$$T = F \times R = 4.94 \times 0.33$$

$$T = 1.63 \text{ Nm}$$

Radial speed

$$\omega = \frac{(10,2 \times 1000 \div 3600)}{0.33}$$

$$\omega = 8.58 \text{ rad/sec}$$

Minimum power of motor

$$P = T \times \omega$$

$$P = 1.63 \times 8.58$$

$$P = 14 \text{ W}$$

This is the minimum power required for the bicycle to have motion taking into consideration wheel size, total weight, friction and desired speed

Total power required by the motor

$$P_{Total} = P_w + P_{hill} + P_{roll}$$

$$P_w = \frac{C_d \rho A}{2} (V_w)^3$$

$$P_w = \left[\frac{(1 \times 1.225 \times 0.5)}{2} \right] \times \left(\frac{10.3 \times 1000}{3600} \right)^3$$

$$P_w = 6.91 \text{ W}$$

$$P_h = g \times m_{total} \times V_g \times G$$

$$P_h = 9.81 \times \frac{2}{100} * \left(\frac{10.3 \times 1000}{3600} \right) * 84$$

$$P_h = 47.135 \text{ W}$$

$$P_{roll} = g \times C_r \times m_{total} \times V_g$$

$$P_{roll} = 9.81 \times 84 \times 0.005 \times \left(\frac{10.3 \times 1000}{3600} \right)$$

$$P_{roll} = 11.783 \text{ W}$$

$$P_{Total} = 51.28 + 114.45 + 68.67$$

$$= 65.828 \text{ Watt}$$

A 125W motor available in the market will be sufficient to achieve the bicycle's motion. A 250W motor was chosen for the project.

Charging time of battery

$$T = \frac{\text{Battery capacity (Ah)}}{\text{Charging current}} = \frac{14.4}{12} = 1.33 \text{ hours}$$

Battery Runtime

Motor current draw = 134A (typical current draw current from the datasheet)

Battery capacity = 14.4Ah

$$\text{Discharge rate} = \frac{134A}{14.4Ah} = 9.31A/h$$

Battery capacity = 14.4Ah

Discharge rate = 9.31A/h

$$\text{Runtime} = \frac{14.4Ah}{9.31A/h} = 1.55 \text{ hours}$$

The estimated runtime of the battery is 1.55 hours. This is a theoretical estimate; the actual runtime may vary due to factors that may include but not limited to riding conditions and battery temperature.

Motor, Battery and Controller selection

A 24V 250W motor is used to run the cycle. A battery with a similar 24V voltage, to match the voltage requirements of the motor, and an amperage of 14.4 Ah is used to power the motor. A 250W motor was chosen due to the inability to source a 125W motor. The controller voltage chosen needed to match the battery and motor voltage, which in this case is 24V.

3.2. Cost Estimate

From the analysis carried out and sequel to a market survey carried out, the cost of design and fabrication of an electric bicycle is calculated as shown in Table 1. The orthographic, isometric and pictorial views of the retrofitted bicycle are shown in Figure 1, Figure 2 and Figure 3, respectively.

Table 1: Cost Estimate of Assembling a Retrofitted Electric Bicycle

S/No.	Item Description	Quantity	Unit rate (₦)	Amount (₦)
1	Lithium battery pack	1	150,000	150,000
2	Controller	1	40,000	40,000
3	Throttle	1	38,000	38,000
4	Chassis (Bicycle)	1	96,000	96,000
			Total	324,000

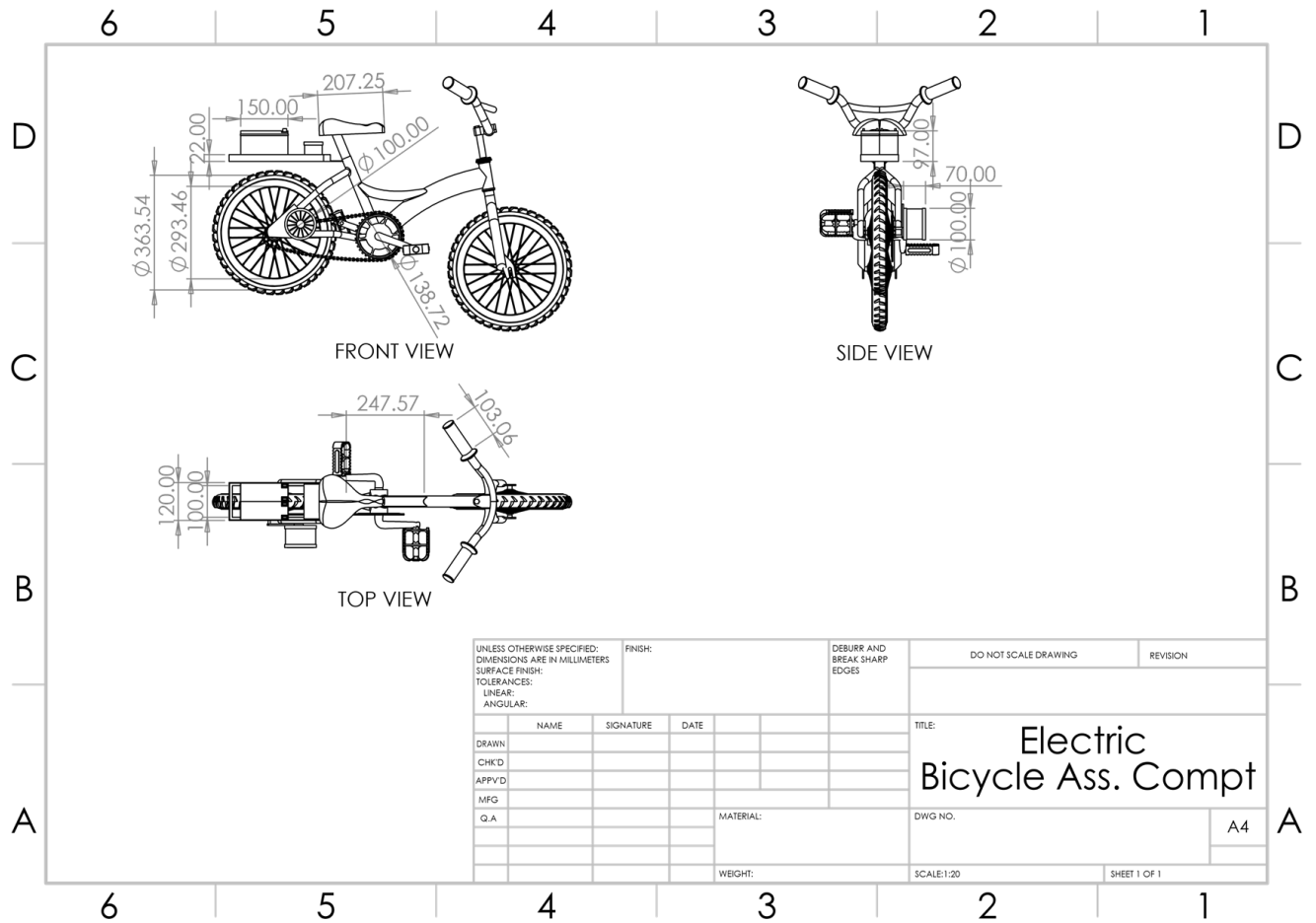


Figure 1: Orthographic view of the retrofitted electric bicycle.

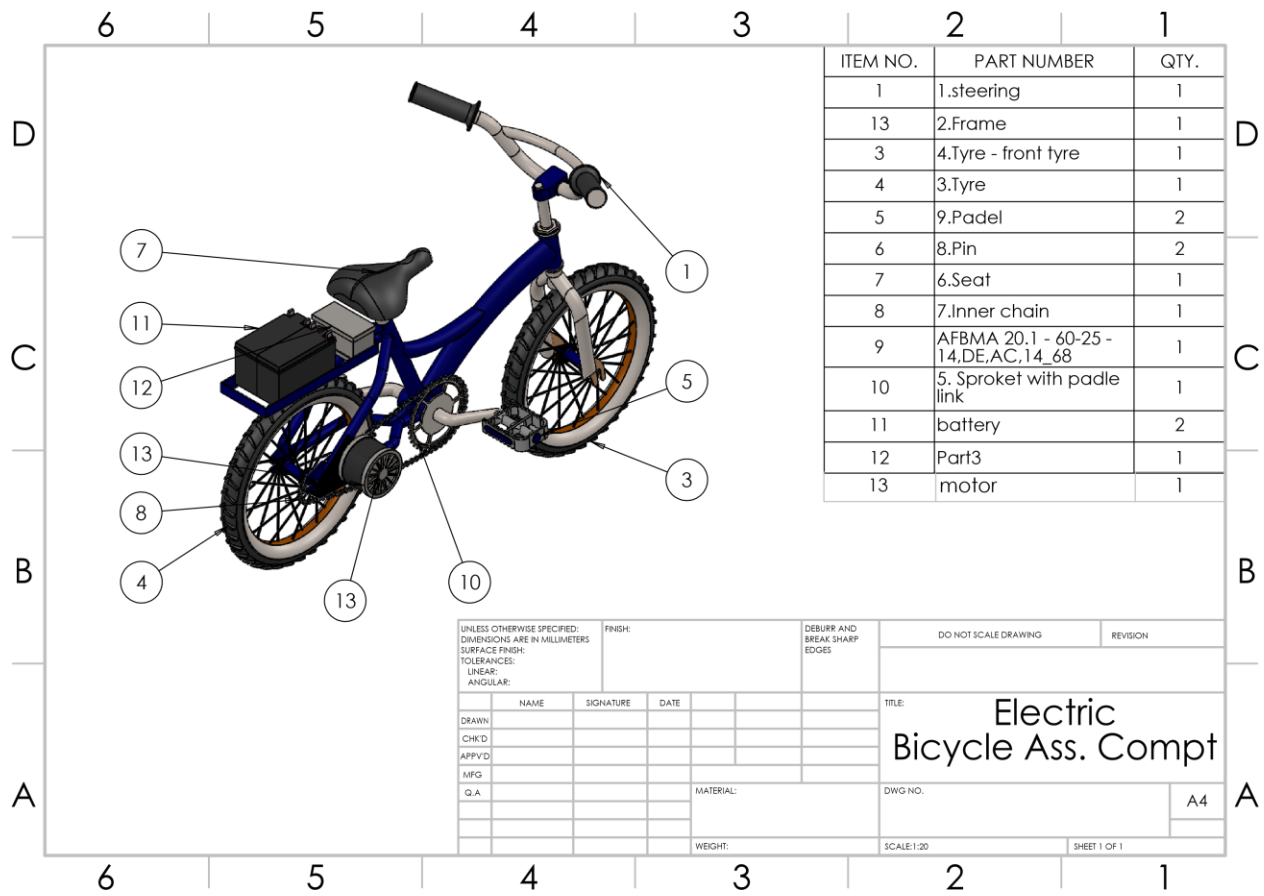


Figure 2: Isometric view of the retrofitted electric bicycle.



Figure 3: Pictorial view of the retrofitted electric bicycle.

4. Conclusion

The design and retrofitting of a low-cost electric bicycle research successfully resulted in the development of a high-performing e-bike. This electric bicycle is capable of achieving a cruising speed of 10.2 kilometres per hour (km/hr). The e-bike is powered by a 24V battery with a 14.4 amp-hour (Ah) capacity, providing an optimal balance between range and cost-effectiveness. Additionally, the bike features a 24V 250-watt motor, delivering a comfortable level of assistance for riders. These features position the e-bike at a competitive price point, opening up opportunities for a wider market and promoting eco-friendly transportation.

A comprehensive financial analysis was performed, and it was determined that the total cost of the project is N324,000. This amount encompasses the costs associated with materials, assembly, and installation necessary for the implementation of an electric bicycle. The detailed breakdown of these costs enhances transparency and facilitates effective budget planning for similar future projects. This cost estimation constitutes a crucial factor in gaining a thorough understanding of the financial requisites and the viability of integrating the electric bicycle.

The following recommendations can be made:

- i. Implement a mechanism that replenishes the battery with energy captured while braking. A regenerative controller can accomplish this, increasing the range without appreciably raising the cost.
- ii. Utilise used bicycle parts, such as wheels and frames. Reputable bike stores frequently provide high-quality used parts for a fraction of the price of new ones.
- iii. Incorporate a gear-shifting mechanism to select cycling modes. This may increase range and enhance overall performance by enabling riders to select between electric aid and manual pedalling for varying speeds and terrains.
- iv. Create the system using a battery format that is widely accessible, such as those found in power tools. This makes battery changes simpler and possibly less expensive.

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