IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.066 ⁘ Peer-reviewed & Refereed journal ⁘ Vol. 10, Issue 11, November 2023

DOI: 10.17148/IARJSET.2023.101123

Design & Development of Micro-Mobility E-Bike

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Abstract: The rapid increase in urbanization and environmental concerns has led to a growing demand for sustainable transportation solutions. Electric vehicles (EVs) have emerged as a promising alternative, with their zero-emission nature and efficient energy utilization. This project aims to design and develop an electric bike (MINI R) with the futuristic features to address the challenges of urban mobility while promoting eco-friendly transportation. The E-Bike project involves the integration of advanced technologies like ultrasonic mapping and it also includes electric propulsion systems, lightweight materials, and internet of things (IOT)features. The primary objective is to create a compact, energy-efficient, affordable EBike and add more features in the bike other than bikes present in the market that offers convenience and comfort to the user. The research focuses on optimizing the E-Bike performance in terms of range, speed, and charging time, while ensuring safety and reliability. The project follows a systematic approach, beginning with a comprehensive review of existing electric bikes designs and related technologies. This analysis serves as the basis for selecting the most suitable components and subsystems for the E-Bike. Prototyping phase is also conducted to evaluate the design's functionality, durability, and user experience. Furthermore, about the technology, human-computer interaction plays a significant role in the E-Bike design. The project explores the development of a user-friendly interface that provides real-time information about battery status, speed, distance travelled, and navigation assistance. And one more feature is about the automatic head light intensity. This integration enhances the overall user experience and encourages the adoption of E-Bikes among diverse user groups. The successful implementation of the EVB project will contribute to a cleaner and greener urban transport ecosystem, reducing dependence on fossil fuels and minimizing air pollution.

Keywords: Electric bike, ultrasonic mapping, sustainable transportation, urban mobility, electric propulsion, lightweight materials, intelligent control, energy efficiency, user experience, human-computer interaction.

I. INTRODUCTION

The increasing urbanization and growing concerns about climate change have underscored the urgent need for sustainable transportation solutions. The modern world requires the development of eco-friendly technologies that can address current and future challenges. The scarcity of fossil fuels has become a critical issue, with projections suggesting that their lifespan may only last for the next three to four decades at the current consumption rate. The rapid climate change serves as a clear warning sign that the use of fossil fuels should be curtailed.

In this context, electric vehicles (EVs) have emerged as a viable and sustainable solution. Among EVs, electric bikes, or e-bikes, have gained popularity due to their versatility and numerous advantages. E-bikes offer a visionary solution for a better world, catering to the needs of upcoming generations and promoting a healthier environment. They provide an efficient and eco-friendly means of transportation, particularly in congested urban areas. By reducing air pollution and promoting energy efficiency, e-bikes contribute to a sustainable and cleaner future. With the escalating urbanization worldwide, cities are facing significant challenges in terms of traffic congestion, increased fuel consumption, and rising air pollution.

The reliance on conventional vehicles powered by fossil fuels has exacerbated these issues, contributing to greenhouse gas emissions and detrimental effects on public health. Thus, there is an urgent need for sustainable transportation options that can alleviate these challenges. The widespread use of conventional vehicles powered by fossil fuels has led to numerous environmental challenges also. These vehicles contribute to air pollution through the emission of greenhouse gases, particulate matter, and harmful pollutants. The negative impacts on air quality and public health are significant, with increased rates of respiratory diseases and the degradation of urban ecosystems.

The rise of electric vehicles has emerged as a promising solution to address the environmental concerns associated with conventional transportation. The advancements in battery technology, motor efficiency, and charging infrastructure have propelled the growth of electric vehicles, but there remains a significant opportunity to leverage these technologies in the design and development of electric bikes. The significance of electric vehicles gives the one of the most important benefits to the human being that is health benefit.

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Electric bikes have the potential to bring about numerous socio-economic benefits. They offer an affordable mode of transportation, reducing the costs associated with fuel consumption and vehicle maintenance. Moreover, electric bikes can provide employment opportunities in areas such as manufacturing, maintenance, and charging infrastructure development. So, to promote the electric vehicles governments around the world are implementing the policies and initiatives to promote the adoption of electric vehicles, including electric bikes. These measures often include subsidies, tax incentives, and many more.

The application studied and experimented in the project is about E-bike advancement and its features. The work flow is from the product idea to the final product it contains the design of the E-Bike from the designing software and development in its design stage and manufacturing stage. After manufacturing the E-Bike chassis add battery pack, motor and electronics to add more features to the bike. The use of E-bike will overcome environmental and urbanization challenges and provide many socio-economic benefits.

II. PROSPECT OF E-BIKE

Environmental Benefits: E-bikes contribute to reducing air and noise pollution, promoting cleaner and greener transportation options.

Cost Savings: E-bikes offer a cost-effective mode of transportation, with lower operational and maintenance expenses compared to traditional vehicles.

Commuting Efficiency: E-bikes enable faster and more efficient commuting, especially in congested urban areas, reducing travel time and increasing productivity.

Accessibility: E-bikes provide accessible transportation options for individuals of different fitness levels and abilities, making cycling more inclusive.

Flexibility: E-bikes offer the flexibility to switch between pedal-assist and full-electric modes, allowing riders to adjust their level of exertion and adapt to different terrains.

Reduced Traffic Congestion: E-bikes contribute to reducing traffic congestion, as they occupy less space on the road and can navigate through narrow streets more easily.

Parking Convenience: E-bikes require minimal parking space, allowing riders to park conveniently and bypass the challenges of finding parking in crowded areas.

Fun and Enjoyment: E-bikes provide an enjoyable and thrilling riding experience, combining the benefits of cycling with the added assistance of electric power.

Sustainable Mobility: E-bikes promote sustainable mobility by reducing reliance on fossil fuels and promoting a shift towards eco-friendly transportation options.

III. METHODOLOGY

- Conduct a comprehensive literature review to gather information and insights from academic papers, research articles, industry reports, and other relevant sources. Identify key themes, challenges, and existing solutions related to E-Bikes.

- Conduct interviews with key stakeholders, including E-Bike operators, municipal authorities, riders, and advocacy groups. Gather their perspectives, experiences, and recommendations on various aspects of E-Bike operations.

- Project Idea to Project Design: Utilize CATIA and Fusion 360 design software to create detailed 3D models, analyse functionality, and refine the design, resulting in a comprehensive and feasible project blueprint.

- Various design analysis, such as structural analysis and thermal analysis, will be performed to evaluate different material options and select the most suitable material for the project based on factors like strength, durability, and thermal properties.

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- The development of the bike foundation, including the chassis and suspension system, involves designing and engineering components that provide structural integrity, stability, and optimal handling characteristics for the bike's overall performance and rider comfort.

- The installation process involves integrating the battery pack and motor into the bike's design, ensuring proper alignment, electrical connections, and secure mounting for efficient and reliable power delivery.

- The user interface development incorporates attractive features such as embedded GPS, GSM, Wi-Fi, Bluetooth, and more to enable real-time data logging and enhance the user experience with seamless connectivity and advanced functionalities.

- Dismantling the project for final finishing, followed by the assembly process and comprehensive testing, culminating in the finalization of the project with a refined and validated design.

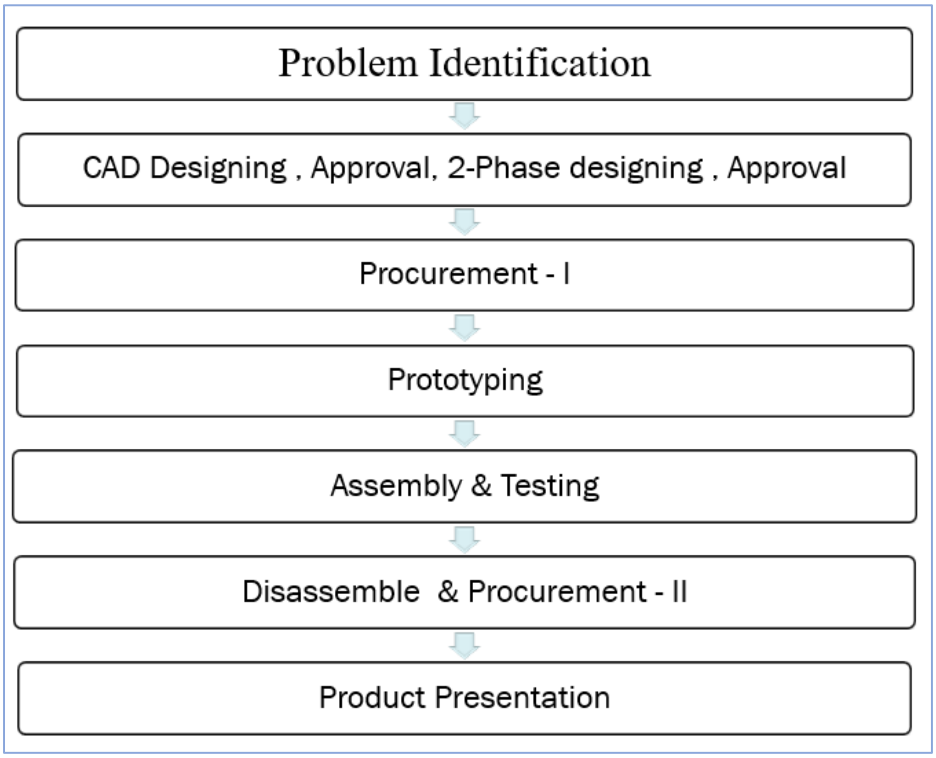

Fig. 1 Work Methodology

IV. DESIGN

4.1 Frame Design and Material Selection

While designing the E-Bike it is very important and crucial part of the design to aspect the overall performance and strength of the vehicle.

Considerations in frame selection design Following factors should be considered in designing the frame

Strength and stiffness: The frame should be structurally strong and rigid enough to withstand the forces generated during riding, including the additional weight of the motor and battery.

Weight Optimization: It should be lightweight as it increases the efficiency of the vehicle.

Geometry: Geometry plays a crucial role in determining the bike's handling characteristics, stability and riding comfort.

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Frame durability and fatigue resistance: E-bikes may experience increased stresses due to higher speeds, heavier loads, and more frequent use. The frame should be designed with the consideration of durability and fatigue resistance.

Integration of components: The frame should be designed to seamlessly integrate components such as the motor, battery, wiring, and control system. Consideration should be given to proper positioning, secure mounting, and easy access for maintenance or replacement.

Frame material selection: The selection of frame material is a critical decision when designing an e-bike, as it directly impacts various aspects of the bike's performance, weight, durability, and cost.

Weight capacity: Consider the weight capacity requirements of the e-bike, including the maximum load it needs to support. The frame material should be selected to handle the anticipated weight without compromising safety or performance.

Flexibility and compliance: Frame materials, such as steel or titanium, can provide a degree of flexibility or compliance that improves rider comfort by absorbing road vibrations. To achieve the desired level of comfort and compliance flexibility of material should be considered.

Longevity and aging: While designing the frame the structure of the frame should designed like that it will face all the stresses occurred by the surrounding conditions and frame material must be excellent in the long-term stability. Some materials may be more prone to degradation but some are excellent.

Testing: Ensure that the chosen frame material complies with relevant industry standards, safety regulations, and certification requirements for e-bikes.

Maintenance and repair: Selected material for frame and its design must not be so complicated to repair. It should be easily repaired and maintenance cost should be low.

Generally, material selection and frame structure play very important role in E-Bike i.e why above parameters must be considered while designing the frame and selection of material.

Fig. 2 CAD Model of Frame

4.2 Body Design

4.2.1 Battery Pack Enclosure

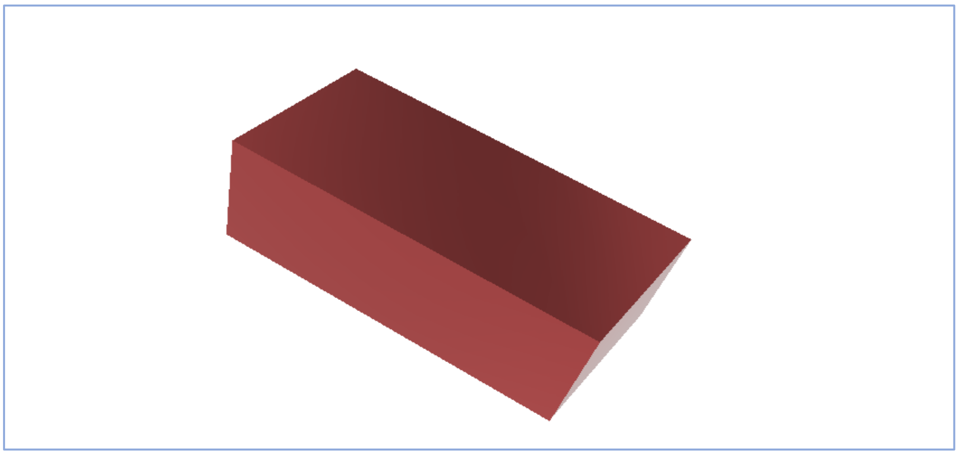

Fig. 3 CAD Model of Battery Enclosure

The battery pack container, also known as the battery enclosure or housing, is the protective casing that houses the battery cells and associated components in an e-bike. The battery pack enclosure is designed to fit securely within the e-bike frame or mounting location. It should be integrated seamlessly to ensure stability, proper weight distribution, and protection of the battery pack. It may include safety features such as impact-resistant design, built-in shock absorption, or additional reinforcement to protect the battery cells from external impacts or vibrations. The battery pack container should allow for easy access during maintenance or replacement of battery cells, wiring, or electronic components.

4.2.2 Motor Mounting

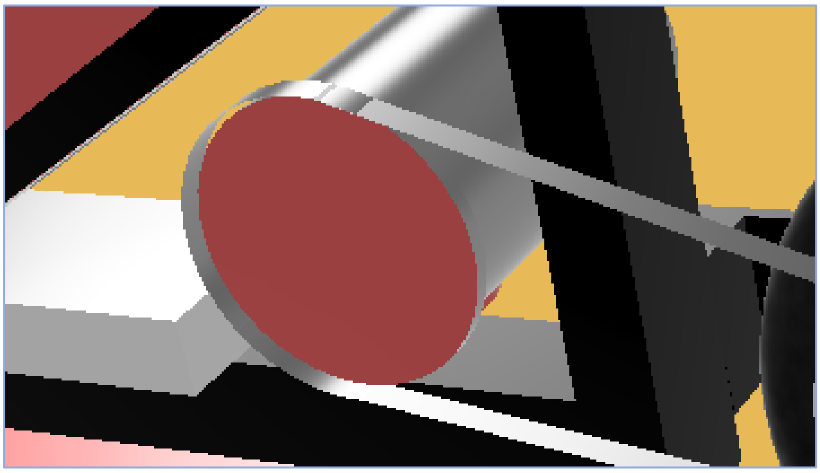

Fig. 4 CAD Model of Motor Mounting

By determining the optimal position for mounting the motor based on factors like weight distribution, centre of gravity, and overall bike performance. Ensure proper alignment of the motor with the drivetrain components, such as the chainring or sprockets.

Misalignment can lead to poor shifting performance, increased wear, or chain derailment. Must provide sufficient clearance around the motor to prevent interference with other components, such as the chain, derailleur, or frame structure. Motor compatibility, position, motor alignment, belt clearance motor protection, serviceability and regulatory compliances also should be considered while mounting the motor.

IARJSET

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4.2.3 Assembly

Fig. 5 CAD Model of Mini-R

In the context of an e-bike, assembly refers to the process of integrating various components such as the frame, wheels, drivetrain, brakes, motor, battery, and control systems to create a fully operational electric bicycle. This includes properly mounting and connecting components, adjusting and fine-tuning mechanisms, ensuring proper alignment and fit, and conducting tests to ensure functionality and safety. The assembly process is crucial in ensuring that the e-bike functions properly, meets safety standards, and provides an enjoyable riding experience.

The assembly of e-bike components involves the process of putting together various parts to create a functional E-Bike. Here is a general overview of the assembly process: After designing individual parts in CAD software, the next step is to assemble the parts to form a complete e-bike using the same software. The assembly includes the frame, wheels, drivetrain components, battery pack, motor, and control systems. The parts are assembled using appropriate fasteners such as screws, nuts, and bolts.

Firstly, the frame components, such as the main frame tubes, seat tube, and rear triangle, are joined together using screws or welding operations to form the main structure of the e-bike. The frame serves as the backbone of the e-bike, providing support and rigidity. Next, the front and rear wheels are attached to the frame using axle systems, such as quick release or thru-axles. The wheels are aligned and centered within the frame to ensure proper functionality and balance.

The drivetrain components, including the chainring, crankset, cassette, and derailleur, are installed on the frame. The chain is threaded through the front and rear sprockets, and the derailleur is adjusted for smooth and precise shifting. The motor and battery pack are mounted onto designated locations on the frame. The motor is securely attached to the bottom bracket area or rear dropout, depending on the type of motor system used. The battery pack is mounted on the frame, ensuring a secure and stable connection.

The control systems, such as the motor controller, display unit, and wiring harness, are integrated into the assembly. The controller is connected to the motor and battery pack, and the wiring is routed and secured properly to avoid interference or damage. Additional components, such as the handlebar, stem, seat, and pedals, are installed on the frame.

The handlebar is attached to the stem, which is securely clamped onto the fork steerer tube. The seat post is inserted into the seat tube. Finally, a series of safety checks and adjustments are performed. This includes verifying the tightness of all bolts and fasteners, checking the alignment of wheels and brakes, adjusting the brakes for proper lever feel, and ensuring that all electrical connections are secure and functioning correctly. Overall, the assembly of an e-bike involves carefully joining and integrating various components to create a functional and safe electric bike.

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4.3 Working

4.3.1 Parts working

Motor: The motor is the heart of the e-bike, providing the power to assist the rider. In this case, the motor has a power rating of 1000 watts, indicating its capability to deliver a higher level of assistance compared to lower-rated motors. It is typically mounted near the pedals or within the wheel hub, depending on the e-bike design.

Battery: The battery supplies electrical energy to the motor. The 48V 22Ah battery has a voltage rating of 48 volts and a capacity of 22 ampere-hours. The higher voltage allows for more power output, while the capacity determines the energy storage capacity of the battery. The battery is rechargeable and usually mounted on the e-bike frame or integrated into the design.

Controller: The controller acts as the intermediary between the motor and the battery. It regulates the flow of electrical energy from the battery to the motor, controlling the speed and power output. The controller receives input signals from the rider and adjusts the motor assistance accordingly.

BMS System: The BMS system, or Battery Management System, monitors and protects the battery. It ensures optimal performance, prevents overcharging, over-discharging, and overheating of the battery, and balances the charge across individual cells within the battery pack. The BMS system helps prolong the battery's lifespan and ensures safe operation. the battery arrangement is such that 2 parallel and 4 series combinations.

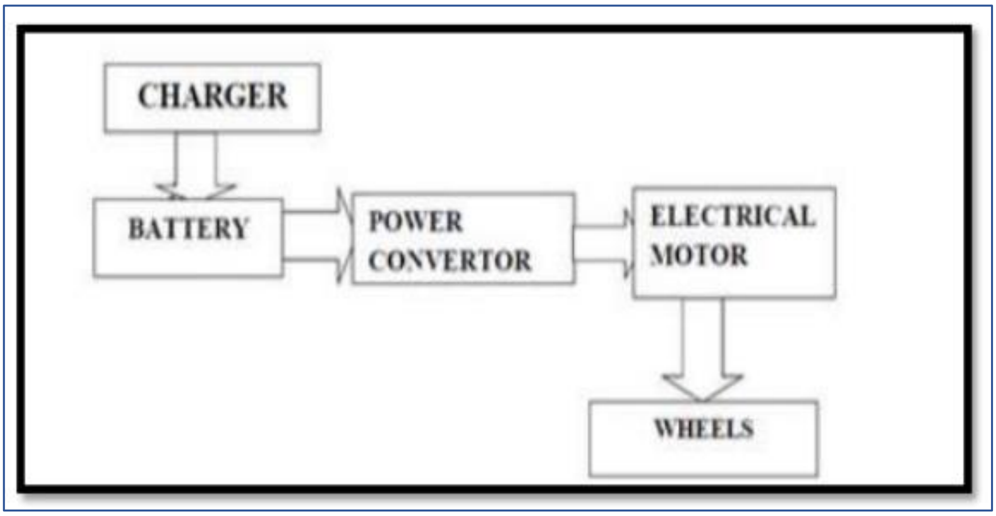

Fig. 6 Working Flowchart

Battery Range Estimation: E-bikes often incorporate algorithms or software that estimate the remaining battery range based on various factors. These factors may include the current battery charge level, assist level, riding speed, terrain, and historical data. By analysing these variables, the e-bike's system can provide the rider with an estimated range, helping them plan their rides and manage battery usage more effectively.

Chain and Sprockets: In a chain drive system, a chain is looped around the front sprocket (attached to the motor) and the rear sprocket (connected to the rear wheel). The chain consists of links that engage with teeth on the sprockets, creating a mechanical connection.

Power Transmission: When the rider pedals or activates the motor, the power is transferred from the motor's sprocket to the chain. As the rider pedals, the chain rotates, and the engaged teeth on the front and rear sprockets drive the rear wheel. This propels the e-bike forward, with the chain acting as the intermediary between the motor and the rear wheel.

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4.3.2 Raspberry Pi 4

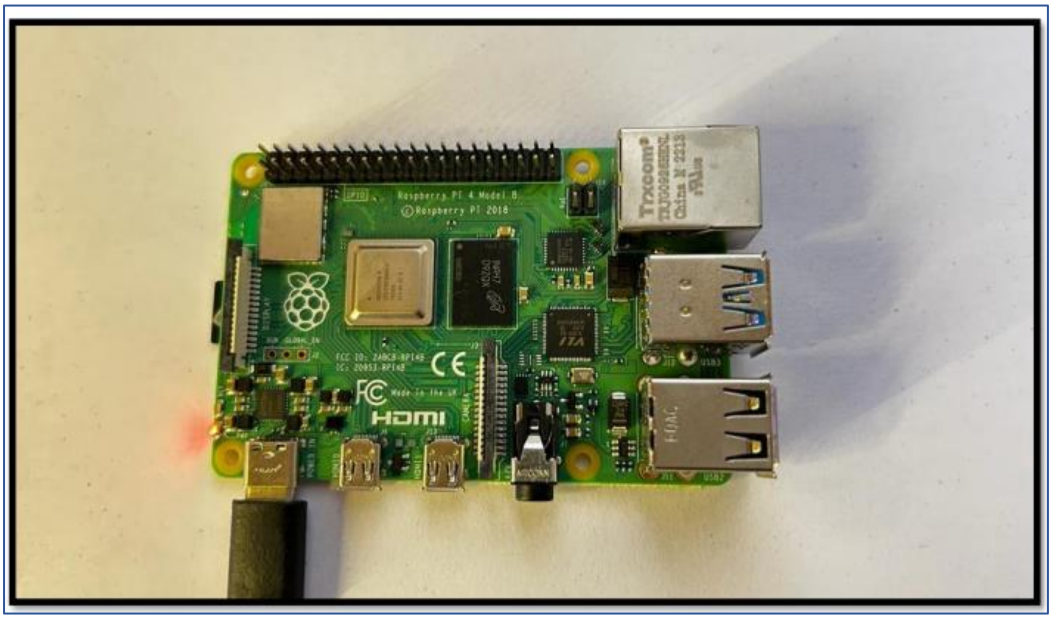

Fig. 7 Raspberry Pi 4

The Raspberry Pi 4GB module can be utilized in an electric bike project to enhance its functionality and control. Here's an overview of how the Raspberry Pi 4GB module can work in an electric bike setup: Motor Control: The Raspberry Pi can be used to control the electric motor of the bike. It can interface with motor controllers or motor driver circuits to regulate the speed and torque of the motor based on user input or predefined algorithms. The GPIO pins of the Raspberry Pi can be used to connect with the motor control circuitry.

Data Logging and Analysis: The Raspberry Pi can log data from various sensors and store it for further analysis. This data can include ride statistics, battery usage, motor performance, and more. By analysing this data, it becomes possible to optimize the electric bike's performance, and energy efficiency, and diagnose any issues that may arise.

Connectivity and IoT Integration: The Raspberry Pi can connect to the internet or other devices using its built-in Wi-Fi or Ethernet connectivity. This allows for integration with IoT platforms and cloud services, enabling features like remote monitoring, firmware updates, and even smart functionalities such as GPS tracking or anti-theft systems.

Power Management: The Raspberry Pi can be programmed to monitor and manage the power system of the electric bike. It can interface with the battery management system (BMS) and control charging, discharging, and battery protection mechanisms. This ensures the safe and efficient operation of the battery and extends its lifespan

Sensor Integration: The Raspberry Pi can integrate with various sensors to gather data about the electric bike's speed, acceleration, battery voltage, and other parameters. Sensors like speed sensors, torque sensors, and battery voltage sensors can provide real-time data that can be processed and utilized for motor control, power management, and display purposes.

User Interface: The Raspberry Pi can serve as the user interface for the electric bike, providing a graphical display and input capabilities. It can connect to a touchscreen display, allowing the rider to interact with the system, view information like speed, battery level, and assist mode, and adjust settings as needed.

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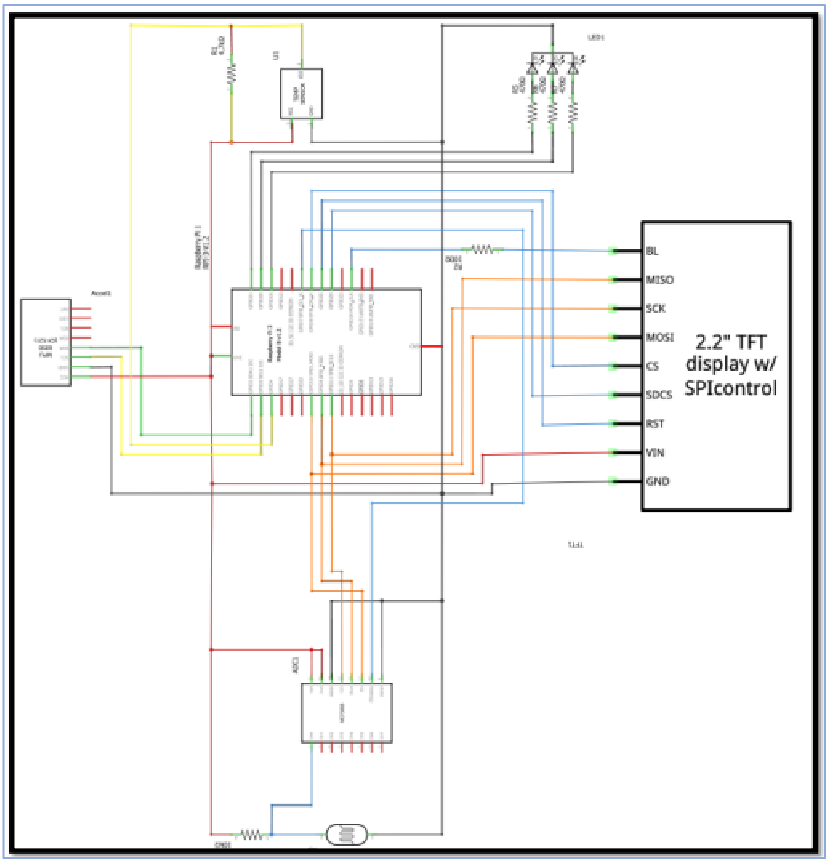

Fig. 8 Raspberry Pi Dashboard Connection

The dashboard of an e-bike typically serves as the central control panel, providing information such as speed, battery level, trip distance, and other relevant data to the rider. Connecting a Raspberry Pi to the e-bike's dashboard opens up opportunities to enhance the functionality and capabilities of the dashboard

4.4 Control System

4.4.1 Battery Management System

Fig. 9 Battery Management System

The BMS for a 48V 28Ah battery performs crucial functions to ensure safe and efficient operation. It monitors the voltage of individual battery cells to detect imbalances. The BMS measures the temperature of the battery pack to prevent overheating. It tracks charging and discharging currents to prevent overcharging and over-discharging. The BMS protects against overvoltage and undervoltage conditions.

DOI: 10.17148/IARJSET.2023.101123

Communication interfaces allow real-time monitoring, diagnostics, and firmware updates. Cell balancing functionality optimizes battery performance by maintaining uniform voltage levels. The BMS detects and responds to faults such as short circuits or overcurrent. Safety measures are activated, and warnings are displayed in case of faults or abnormalities.

4.4.2 Controller

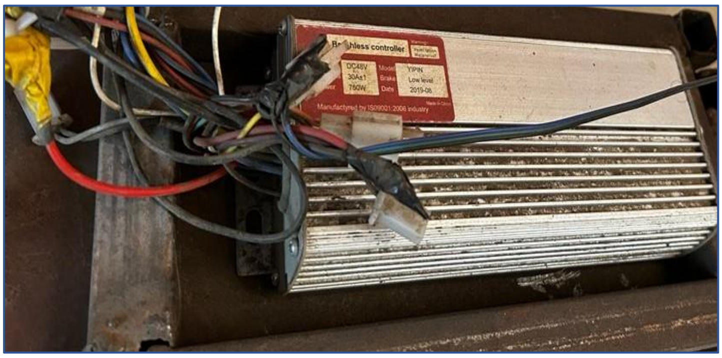

Fig. 10 Controller

The controller is the central component that manages the operation of the electric bicycle system. It controls the motor's speed, torque, and power output based on user input and system parameters. It converts the DC battery voltage to the appropriate AC or DC signals required by the motor. The controller often includes a user interface for power level selection, battery monitoring, and settings adjustment. Sensors provide feedback to the controller, allowing it to optimize motor performance based on factors like speed or torque. Safety features like overcurrent protection, overtemperature protection, and shortcircuit protection are incorporated into the controller. The controller plays a role in optimizing energy efficiency through power management and regenerative braking. Programmable controllers offer customization of control algorithms and power settings to meet specific requirements or preferences.

4.4.3 Motor

Fig. 11 Motor

Specifications of Motor –

- Power Rating: 1000 watts, indicating its high-power output capability.
- Voltage and Current: Operates within a specific voltage and current range.
- Brushless Design: Utilizes brushless DC (BLDC) technology for improved efficiency and durability.
- Torque and Speed: Generates sufficient torque for propulsion and offers a range of speeds.
- Controller Compatibility: Requires a compatible controller for proper operation and control.
- Cooling and Heat Dissipation: Incorporates cooling mechanisms to manage heat generated during operation.
- Efficiency and Energy Consumption: Provides efficient power delivery for improved energy consumption and range.
- Regulatory Compliance: Meets applicable regulations and standards for noise emissions and power limitations.
- Maintenance and Serviceability: Considerations for maintenance, repair, and availability of spare parts.

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V. RESULT AND ANALYSIS

5.1 Accidental Analysis

Accidental analysis of an e-bike frame involves assessing the structural integrity and performance of the frame in the event of an accident or impact. Accidental analysis aims to understand how the frame responds to external forces and to identify potential weaknesses or failure points. During the analysis, the frame is subjected to various simulated accident scenarios, such as collisions, impacts, or falls. Finite Element Analysis (FEA) or physical testing methods may be used to evaluate the frame's response to these forces. The analysis focuses on factors such as stress distribution, deformation, and potential failure modes within the frame structure. By conducting an accidental analysis, we can enhance the design and construction of e-bike frames, making them more robust and capable of withstanding accidental impacts.

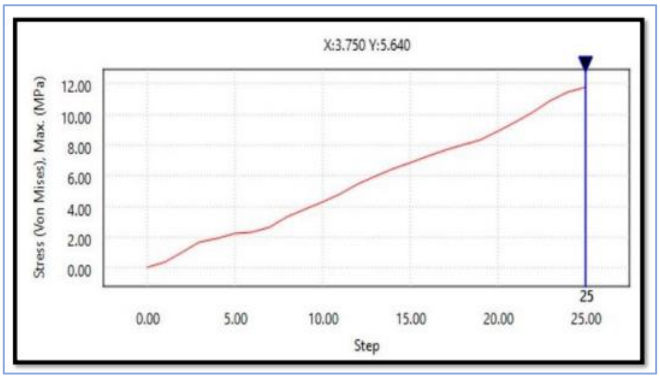

Fig. 12 Accidental Graph

Result Summary

Name	Minimum	Maximum
Stress		
Von Mises	0 MPa	11.79 MPa
Normal XX	-6.516 MPa	8.294 MPa
Normal YY	-5.884 MPa	5.944 MPa
Normal ZZ	-12.34 MPa	10.96 MPa
Shear XY	-4.838 MPa	4.402 MPa
Shear YZ	-3.787 MPa	3.896 MPa
Shear ZX	-5.032 MPa	4.064 MPa
1st Principal	-1.321 MPa	11.08 MPa
3rd Principal	-12.38 MPa	1.498 MPa
Displacement		
Total	0 mm	11.95 mm
X	-11.95 mm	0 mm
Y	-0.007425 mm	0.007205 mm
Z	-0.07179 mm	0.003458 mm
Reaction Force		
Total	0 N	0 N
X	0 N	0 N
Y	0 N	0 N
Z	0 N	0 N

Strain		
Equivalent	0	5.152E-05
Normal XX	-2.958E-05	3.697E-05
Normal YY	-3.089E-05	2.89E-05
Normal ZZ	-5.972E-05	5.084E-05
Shear XY	-3.048E-05	2.773E-05
Shear YZ	-2.386E-05	2.454E-05
Shear ZX	-3.17E-05	2.56E-05
1st Principal	-2.912E-07	5.161E-05
3rd Principal	-5.999E-05	2.31E-07
Plastic Strain	0	0
Acceleration		
Total	0 m / s^2	7465 m / s^2
X	-1405 m / s^2	1355 m / s^2
Y	-937.5 m / s^2	1172 m / s^2
Z	-7465 m / s^2	1015 m / s^2
Velocity		
Total	11.92 m / s	11.96 m / s
X	-11.96 m / s	-11.92 m / s
Y	-0.01892 m / s	0.01891 m / s
Z	-0.1123 m / s	0.01703 m / s

Fig. 13 Accidental Graph Study Report Result

5.2 Static Analysis

Static analysis of an e-bike frame involves assessing its structural integrity, material properties, and design through various methods. The analysis aims to ensure that the frame can withstand the loads and forces it encounters during regular use. The analysis begins by examining the material composition of the e-bike frame, evaluating properties such as tensile strength, yield strength, modulus of elasticity, and fatigue resistance. This information helps determine the frame's durability and performance.

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Next, the structural design of the frame is analyzed, considering factors such as geometry, tube shapes, joint configurations, and reinforcement techniques. The frame's stiffness, weight distribution, and ability to withstand forces are assessed to ensure structural integrity. Finite Element Analysis (FEA) is often employed to simulate the behavior of the frame under different loading conditions. This allows for stress distribution, deformation, and potential failure points to be identified within the structure. Results from the analysis are compared to material stress limits to evaluate the frame's strength and durability. The static analysis also considers safety standards and regulations specific to e-bike frames, ensuring compliance with requirements related to strength, fatigue resistance, and structural stability. Manufacturing processes and quality control measures are evaluated to ensure consistent and reliable frame production. This includes examining welding techniques, frame alignment, and adherence to industry standards.

Overall, the static analysis of an e-bike frame provides insights into its structural integrity and identifies areas for improvement. By analyzing the frame's material properties, structural design, and manufacturing processes, manufacturers can enhance safety, durability, and performance, providing riders with a reliable and robust e-bike frame.

⊟ **Results**

⊟ **Result Summary**

Name	Minimum	Maximum
Safety Factor		
Safety Factor (Per Body)	6.614	15
Stress		
Von Mises	6.337E-09 MPa	31.3 MPa
1st Principal	-4.12 MPa	29.49 MPa
3rd Principal	-33 MPa	4.767 MPa
Normal XX	-12.81 MPa	13.63 MPa
Normal YY	-10.5 MPa	12.37 MPa
Normal ZZ	-32.9 MPa	29.32 MPa
Shear XY	-7.215 MPa	7.692 MPa
Shear YZ	-6.129 MPa	6.208 MPa
Shear ZX	-9.181 MPa	6.258 MPa
Displacement		
Total	0 mm	0.1337 mm
X	-0.0731 mm	0.01838 mm
Y	-0.01208 mm	0.008796 mm
Z	-0.1327 mm	0.02362 mm
Reaction Force		
Total	0 N	152.1 N
X	-91.76 N	24.82 N
Y	-34.6 N	36.94 N
Z	-16.82 N	143.1 N
Strain		
Equivalent	4.211E-14	1.423E-04
1st Principal	-6.769E-13	1.32E-04
3rd Principal	-1.527E-04	3.771E-12
Normal XX	-5.15E-05	5.806E-05
Normal YY	-4.877E-05	5.488E-05
Normal ZZ	-1.504E-04	1.262E-04
Shear XY	-8.933E-05	9.524E-05
Shear YZ	-7.589E-05	7.686E-05
Shear ZX	-1.137E-04	7.749E-05
Contact Force		
Total	0 N	0 N
X	0 N	0 N
Y	0 N	0 N
Z	0 N	0 N

⊟ **Safety Factor**

⊟ **Safety Factor (Per Body)**

0 8

Fig. 14 Static Analysis Study Report Result

VI. CONCLUSION

In conclusion, the adoption and evaluation of electric bikes (e-bikes) present both obstacles and prospects. The rising demand for eco-friendly transportation solutions is evident in the rapid expansion and acceptance of street e-bikes. Nonetheless, it is crucial to tackle safety issues related to e-bike integration, including promoting rider education and enforcing compliance with traffic laws. By addressing these concerns, we can prioritize the safety of ebike riders and other individuals sharing the road.

To ensure the reliability of e-bikes, it is crucial to address issues related to battery performance, electrical system malfunctions, and mechanical failures. Ongoing maintenance and regular inspections are necessary to keep e-bikes in optimal condition and ensure their longevity. While e-bikes are considered a greener alternative to conventional vehicles, it is important to acknowledge their environmental impact. Challenges such as battery disposal, energy consumption, and manufacturing impacts need to be addressed through sustainable practices, including the use of recyclable materials, efficient battery technologies, and proper waste management. Equity and accessibility barriers also need to be overcome to ensure that e-bikes are accessible to a wide range of individuals. Affordability, availability of infrastructure, and technological literacy are factors that influence equitable access to e-bikes. Efforts should be made to address these barriers through subsidies, infrastructure development, and educational programs.

In addition to addressing challenges, there are opportunities for improvement in e-bike technology and services. Enhancements in battery design can help eliminate heating issues and improve overall performance. The provision of fast charging services can contribute to a seamless user experience and encourage wider e-bike adoption.

DOI: 10.17148/IARJSET.2023.101123

Furthermore, e-bikes have the potential to revolutionize campus and micro-mobility systems, offering eco-friendly transportation options within confined areas. Their integration within university campuses, corporate spaces, and residential communities can promote sustainability and reduce carbon emissions. Overall, the implementation and testing of e-bikes require addressing safety concerns, improving reliability, mitigating environmental impacts, ensuring equity and accessibility, and exploring opportunities for technological advancements. By tackling these challenges and capitalizing on opportunities, e-bikes can play a significant role in creating a greener, more efficient, and inclusive transportation future.

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