

Flexible Electric Bicycle with Embedded Fall-Detection and Safety Alert System

Lipin Paul¹, Sharan Sivan², Gokul Suresh³, Alfiya Haneefa⁴

¹Assistant Professor, Department of EEE & ICET, Mulavoor

²Student, Department of EEE & ICET, Mulavoor

³Student, Department of EEE & ICET, Mulavoor

⁴Student, Department of EEE & ICET, Mulavoor

Abstract – A foldable, portable electric bicycle equipped with an automated fall-detection and alerting system is presented to deliver a compact, energy-efficient, and low-cost urban transport solution. The design centres on a hinge-based folding mechanism that minimizes storage footprint and eases handling and portability, enabling convenient carriage and stowage in constrained environments. Propulsion is provided by a brushless DC (BLDC) hub motor powered by a Lithium Iron Phosphate (LiFePO₄) battery, selected for its favourable safety profile, extended cycle life, and reliable energy delivery; the drive train includes a motor controller, throttle, pedal-assist sensor, brake cut-off switch, headlight, horn, and a 26-inch wheel bicycle frame. A pedal-assist feature permits human-powered operation when electric energy is unavailable, enhancing operational flexibility and overall energy efficiency. The BLDC hub motor offers high efficiency, smooth torque delivery, and reduced maintenance compared with conventional brushed or chain-driven alternatives, while the LiFePO₄ chemistry reduces thermal and fire risks relative to other lithium-ion variants. Rider safety is augmented by an embedded fall-detection system comprising an MPU6050 inertial measurement unit (IMU), an Arduino Nano microcontroller, and a SIM800L GSM modem. The IMU continuously measures angular velocity and acceleration to monitor vehicle orientation and detect abnormal tilt or impact signatures; the microcontroller executes a real-time algorithm to differentiate normal dynamic maneuvers from fall events and triggers the alert sequence if a fall is confirmed. On detection, the GSM modem transmits emergency text notifications to predefined contacts, and an audible buzzer provides an immediate local warning. The fall-detection electronics are battery powered and regulated via an LM2596 DC–DC buck converter to ensure stable supply voltages for the sensors, microcontroller, and communication module. System-level advantages include eco-friendly operation through

zero tailpipe emissions during electric driving, improved travel efficiency from power-assisted pedaling, a relatively low initial cost enabled by off-the-shelf components and a simple folding mechanism, and enhanced portability afforded by the lightweight frame. The integrated safety subsystem is intended to reduce response time following accidents by enabling rapid remote notification, while the mechanical and electrical choices—BLDC hub drive, LiFePO₄ energy storage, and a compact folding architecture—support reliability, reduced maintenance, and daily-commute suitability. Design trade-offs considered include balancing folding-stability and frame stiffness, optimizing controller parameters for smooth pedal-assist transitions, and tuning the fall-detection sensitivity to minimize false positives during normal riding. The overall architecture demonstrates a practical approach to combining compact form factor, efficient propulsion, and rider-protective sensing and communication, making the concept appropriate for short-distance urban mobility where storage constraints, safety, and lifecycle costs are primary concerns.

Key Words: Foldable-bike, fall detection,

1.INTRODUCTION

Urbanization and rising travel demand have intensified the need for sustainable, space-efficient mobility solutions that mitigate congestion and environmental impacts associated with conventional internal-combustion vehicles. Electric propulsion has emerged as a viable alternative due to markedly lower local emissions, enhanced energy efficiency, and reduced lifecycle operating costs; within this domain, electrically assisted bicycles (e-bikes) present a particularly attractive option for short-distance travel by combining pedal power with electric assistance to reduce rider effort and improve trip efficiency. Modern e-bike architectures

integrate an electric motor, battery energy storage, and control electronics to manage torque assist, regenerative opportunities, and user inputs such as throttle or pedal-assist sensors. Brushless DC (BLDC) hub motors have gained prominence in these applications because of their high power-to-weight ratio, efficient torque delivery, compact packaging, and minimal maintenance demands relative to brushed or geared drive systems; their electronic commutation enables smoother operation, superior torque characteristics at low speeds, and improved overall energy utilization, which together enhance ride quality and extend operational range. Concurrently, urban constraints on storage space and multimodal transport compatibility have elevated portability as a key design requirement, motivating deployment of hinge-based folding mechanisms that reduce the effective footprint of the bicycle for carriage, stowage in apartments or offices, and integration with public transit. Foldable e-bike designs must reconcile conflicting requirements: achieving a compact folded envelope while maintaining frame stiffness, ride stability, and reliable mechanical locking under dynamic loads. Energy storage selection plays a pivotal role in safety, lifecycle cost, and performance; lithium iron phosphate (LiFePO₄) chemistries are often favored for their thermal stability, long cycle life, and lower thermal runaway risk compared with other lithium-ion variants, supporting safer daily use in dense urban environments. System-level considerations extend to control strategies and human factors: the motor controller must seamlessly blend human pedal input with electric assist to preserve natural ride feel and prevent stalling or abrupt torque spikes, while user interfaces should offer intuitive modes (eco, normal, boost) and clear feedback on battery state-of-charge and system health. Mechanical and electrical subsystems must be optimized jointly—frame geometry, wheel size, and suspension choices influence power demand and handling, while motor sizing and battery capacity determine range, recharge time, and cost. Practical deployment also requires attention to manufacturability, cost-effectiveness, and regulatory compliance for roadworthiness and battery transport. Finally, adoption is influenced by infrastructure and user behavior: availability of charging options, safe cycling lanes, and cultural acceptance of micromobility shape the utility of e-bikes for last-mile and commuter use. By integrating efficient BLDC hub drives, safe energy storage, and folding architectures, designers can produce compact, low-maintenance, and user-friendly e-bikes that address the twin urban challenges of emissions and space scarcity, provided that careful attention is paid to

mechanical robustness, control smoothness, and system-level trade-offs between portability and ride performance.

2. FLEXI E-BIKE

The proposed foldable electric bicycle system represents an advanced and integrated approach to modern urban mobility by combining compact structural design, efficient hybrid propulsion, and intelligent safety monitoring into a unified framework that addresses the growing demand for sustainable, space-efficient, and user-safe transportation solutions in densely populated environments, where conventional vehicles often face limitations related to congestion, parking availability, and environmental impact; the system architecture is centered around a lightweight yet structurally robust frame engineered using high-strength materials such as aluminum alloys or carbon-fiber composites, which not only ensure durability and mechanical stability under varying load conditions but also enable the incorporation of a foldable hinge mechanism that allows the bicycle to be collapsed into a compact form factor, thereby significantly enhancing portability and facilitating convenient storage in constrained spaces including residential apartments, office environments, and public or private transport vehicles, while also reducing the logistical challenges associated with first-mile and last-mile connectivity; the propulsion subsystem of the electric bicycle is designed as a hybrid configuration that seamlessly integrates manual pedaling with an electrically driven assist mechanism powered by a 24V, 250W brushless direct current hub motor, selected for its high efficiency, low maintenance requirements, and ability to deliver consistent torque suitable for urban commuting scenarios, including moderate inclines and stop-and-go traffic conditions, while minimizing mechanical losses and acoustic noise, thus contributing to an improved riding experience and optimized energy utilization; the electrical energy required for motor operation is supplied by a 24V, 10Ah lithium iron phosphate battery, which is specifically chosen over other lithium-ion chemistries due to its superior thermal stability, enhanced safety characteristics, longer cycle life, and resistance to degradation under repeated charge-discharge cycles, thereby ensuring reliable long-term performance and reducing the total cost of ownership, while also supporting flexible charging options through both portable charging units and stationary charging infrastructure, enabling users to adapt to diverse usage patterns and accessibility constraints; the system further incorporates a comprehensive set of auxiliary

components including a motor controller for regulating power delivery and speed, a throttle interface for user-controlled acceleration, a pedal assist sensor that dynamically adjusts motor output based on pedaling input to improve energy efficiency and extend battery range, a brake cut-off mechanism that immediately interrupts motor power during braking to enhance safety, and essential signaling devices such as a headlight and horn to ensure visibility and communication in traffic conditions, all of which are integrated into a standard 26-inch wheel bicycle platform that balances maneuverability with ride comfort; in addition to propulsion and structural innovations, the system places significant emphasis on rider safety through the integration of an intelligent fall detection module that operates continuously during vehicle motion, leveraging a combination of sensing, processing, and communication technologies to detect abapial events and initiate timely emergency responses, wherein the sensing component is based on an MPU6050 gyroscope and accelerometer module capable of capturing real-time orientation, angular velocity, and tilt angle data across multiple axes, which is subsequently processed by an Arduino Nano microcontroller that executes predefined algorithms to identify abnormal motion patterns or sudden deviations indicative of a fall or collision, thereby enabling rapid and reliable detection of potentially hazardous situations; upon confirmation of a fall event, the system activates a GSM communication module, specifically the SIM800L, which is programmed to transmit automated emergency alert messages to a set of predefined contacts, such as family members or emergency services, thereby ensuring that assistance can be dispatched promptly even in scenarios where the rider is incapacitated or unable to communicate, while simultaneously triggering an onboard buzzer to generate an audible alert signal that can attract attention from nearby individuals and facilitate immediate local intervention; the electronic subsystem supporting the fall detection mechanism is powered by a dedicated rechargeable lithium battery to ensure operational independence from the main propulsion battery, thereby maintaining functionality even in the event of primary power failure, and incorporates a DC-DC buck converter, such as the LM2596, to regulate voltage levels and provide stable power supply to sensitive electronic components, thus enhancing system reliability and preventing malfunctions due to voltage fluctuations; collectively, the integration of these subsystems results in a cohesive and multifunctional platform that not only addresses the fundamental requirements of efficient and

eco-friendly transportation but also extends its capabilities to include proactive safety features, thereby aligning with contemporary trends in smart mobility and intelligent transportation systems, where the convergence of mechanical design, electrical engineering, and embedded systems plays a critical role in delivering user-centric solutions; moreover, the foldable electric bicycle contributes to environmental sustainability by reducing dependence on fossil fuel-based transportation, lowering greenhouse gas emissions, and promoting the use of renewable energy sources when paired with green charging infrastructure, while also supporting public health initiatives by encouraging physical activity through pedal-assisted riding modes, which allow users to engage in moderate exercise without excessive fatigue; from an engineering perspective, the system demonstrates an effective balance between performance, cost, and complexity, making it a viable candidate for large-scale adoption in urban areas, particularly in developing regions where affordability and practicality are key considerations, and where infrastructure constraints necessitate compact and adaptable mobility solutions; furthermore, the modular nature of the design allows for potential future enhancements, such as integration with Internet of Things platforms for real-time tracking and diagnostics, incorporation of advanced battery management systems for improved energy optimization, and the addition of navigation and connectivity features to further enhance user convenience and system intelligence; in conclusion, the foldable electric bicycle with integrated fall detection represents a comprehensive and forward-looking approach to urban transportation, combining mechanical innovation, electrical efficiency, and embedded intelligence to deliver a solution that is not only practical and user-friendly but also aligned with the broader goals of sustainability, safety, and smart city development, thereby offering significant potential for improving the quality of urban mobility and addressing the challenges associated with modern transportation systems [1][2].

2.1 Working Principle of FLEXI E-BIKE

The electric bike operates using a BLDC hub motor powered by a Lithium Iron Phosphate (LiFePO) battery, which supplies electrical energy for propulsion. The motor controller regulates the power delivered to the motor based on the rider's input through the throttle or pedal assist sensor. The pedal assist system detects the rider's pedaling action and provides additional motor support, improving energy efficiency and reducing rider effort. If electrical power is unavailable, the bike can still

function as a normal bicycle through manual pedaling. The foldable hinge mechanism in the frame allows the bike to be easily folded for convenient storage and transportation. The LiFePO battery provides stable power output, longer life cycle, and improved safety compared to conventional batteries. Additional components such as the headlight and horn enhance visibility and rider safety during travel. The lightweight frame structure further improves maneuverability, making the electric bike suitable for daily urban commuting [2] [5].

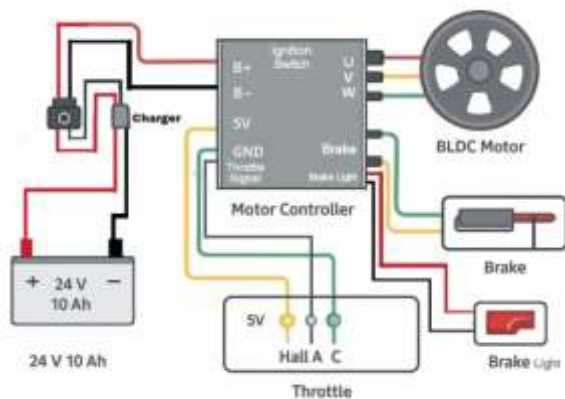


Figure 1: Circuit Diagram of Flexi E-Bike system

2.1.1 Working of Fall Detection system

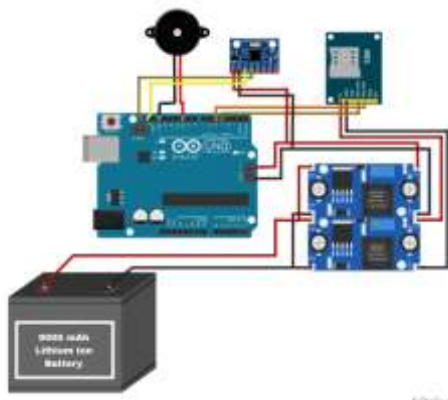


Figure 2: Circuit Diagram of Fall Detection

The fall detection system uses an MPU6050 gyroscope sensor, Arduino Nano microcontroller, and SIM800L GSM module to monitor rider safety. The MPU6050 sensor continuously measures the tilt and orientation of the bike and sends the data to the Arduino Nano for processing. When the system detects abnormal tilt conditions indicating a fall, the microcontroller activates

the GSM module to automatically send an emergency alert message to predefined contacts. At the same time, a buzzer is triggered to provide an immediate warning signal. The fall detection circuit is powered by a rechargeable lithium battery and regulated using an LM2596 DC-DC buck converter to maintain a stable power supply [11][13].

3. Simulation Diagram and Result

The simulation circuit diagram represents the modeling and analysis of a Brush- less DC (BLDC) motor drive system developed using simulation software such as MATLAB/Simulink. This system is designed to study the performance, speed control, and switching operation of a BLDC motor used in electric vehicle applications such as electric bikes.

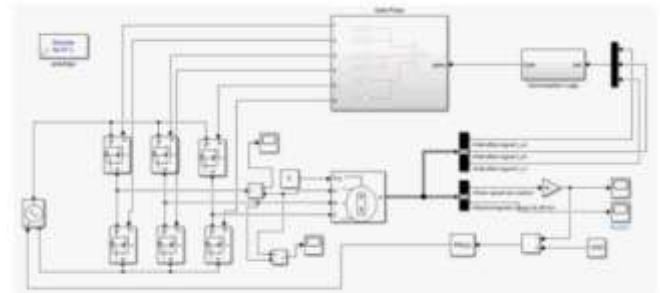


Figure 3: Simulation Diagram of Flexi E-Bike system

The system begins with a DC voltage source, which acts as the primary power supply. This DC supply represents the battery used in electric bikes or electric vehicles. The DC voltage is fed into a three-phase inverter circuit that consists of six power electronic switches arranged in a bridge configuration. These switches may represent MOSFETs or IGBTs, which are responsible for converting the DC supply into controlled three-phase AC signals required to drive the BLDC motor. The switching of the inverter is controlled by a Gate Pulse Generator block. This block generates pulse signals that determine when each inverter switch should turn ON or OFF. The switching pulses are created based on signals received from the Commutation Logic block. The commutation logic plays an important role in BLDC motor operation because it decides the correct sequence of switching according to the rotor position. Rotor position information is obtained from sensors or simulated signals similar to Hall sensors used in practical BLDC motors. These signals are

processed by the commutation logic, which then produces the proper gate signals to ensure correct energizing of the motor windings. Proper commutation is necessary for maintaining smooth rotation and efficient motor performance. The inverter output is connected to the BLDC motor model, which converts the electrical energy into mechanical energy. The motor block represents the electromagnetic behavior of the motor, including stator windings, rotor magnets, and torque generation. As the motor operates, several parameters such as motor speed, electromagnetic torque, and phase currents are produced. These parameters are measured using sensor blocks and are sent to display or scope blocks for monitoring. The diagram also includes signal processing blocks that convert the motor speed into revolutions per minute (RPM) for easier observation. A PWM control block is used to regulate the speed of the motor by adjusting the switching signals applied to the inverter. Overall, this simulation circuit helps in analyzing the working of the BLDC motor drive system, studying switching behavior, monitoring motor performance, and validating control strategies before implementing them in a real electric vehicle system, the simulation allows for testing different load conditions and control strategies without risking hardware damage, making it an efficient tool for design optimization. It also helps in identifying potential issues such as torque ripple, overshoot, or inefficient commutation, enabling improvements before real-world deployment.

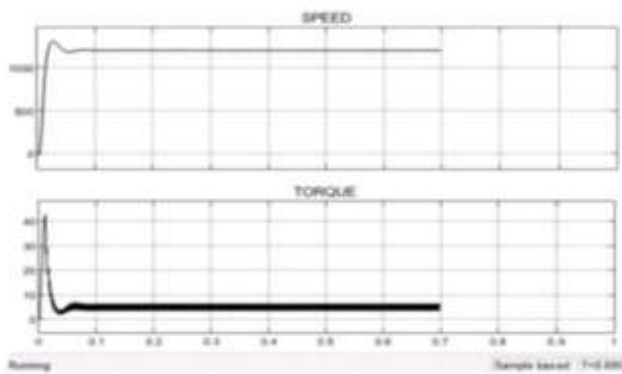


Figure 4: Simulation Result of Flexi E-Bike system

The simulation results show the speed and torque characteristics of the BLDC motor used in the proposed electric bike system. These graphs help analyze the dynamic performance and stability of the motor during operation. The first graph represents the motor speed response with respect to time. At the start of the

simulation ($t = 0$), the motor begins from rest, so the speed is initially zero. As the inverter supplies three-phase power to the motor, the speed increases rapidly due to the high starting torque produced by the BLDC motor. The graph shows a small overshoot, where the speed slightly exceeds the desired value during the starting period. This occurs because of the sudden application of voltage and switching signals from the inverter. After a short transient period, the speed gradually stabilizes and reaches a steady-state speed of approximately 1200 rpm. Once the motor reaches this steady state, the speed remains almost constant, indicating that the control system and commutation logic are working effectively. The stable speed response also confirms that the PWM control and inverter switching provide proper regulation of the motor. The second graph represents the electromagnetic torque response of the BLDC motor. At the beginning of the simulation, the torque rises sharply and reaches a high peak value. This initial high torque is known as starting torque, which is required to accelerate the rotor from rest and overcome inertia and friction. After this short starting period, the torque quickly decreases and settles to a lower constant value. This steady torque represents the load torque required to maintain the motor's constant speed during normal operation. A small fluctuation or ripple can be observed in the torque waveform. This ripple occurs due to switching operations in the inverter and commutation of the motor phases, which is common in BLDC motor drives. However, the ripple is relatively small and does not significantly affect the overall performance of the motor. Overall, the simulation results demonstrate that the BLDC motor drive system achieves fast acceleration, stable speed response, and controlled torque characteristics. The system quickly reaches the desired

speed and maintains steady operation with minimal fluctuations. These results confirm that the inverter control, commutation logic, and PWM switching strategy are effective in driving the BLDC motor efficiently. This performance is suitable for applications such as electric bikes, where smooth acceleration, stable speed, and efficient motor operation are essential, the results indicate that the motor can handle sudden changes in load without significant loss of speed, demonstrating good robustness. The small overshoot in speed is within acceptable limits, ensuring rider safety and comfort during acceleration. The minimal torque ripple also suggests reduced mechanical stress on the

drivetrain components, enhancing the longevity of the electric bike. Furthermore, these performance characteristics imply that the motor and control system are well-suited for real-world urban riding conditions, providing both efficiency and reliability

4. CONCLUSIONS

The foldable and portable electric bike with an integrated fall detection system demonstrates a practical and efficient solution for modern urban transportation, combining ecofriendly operation, energy efficiency, and enhanced rider safety. The integration of a BLDC Hub Motor powered by a Lithium Iron Phosphate (LiFePO) battery ensures reliable propulsion, reduced charging time, and consistent performance while maintaining low operational costs. The inclusion of a pedal assist sensor and throttle mechanism allows flexible riding modes, providing riders the option to conserve battery power or travel manually, further enhancing energy efficiency and extending operational range. The foldable frame, designed with a hinge mechanism, addresses space and portability concerns, allowing for convenient storage in compact urban environments or transport in vehicles. The fall detection system, utilizing an MPU6050 gyroscope sensor, Arduino Nano, and SIM800L GSM module, adds a critical safety layer by continuously monitoring the bike's orientation and tilt. Upon detection of a fall, the system triggers a buzzer alert and sends an emergency SMS notification to predefined contacts, ensuring timely assistance for the rider. The system's low-power design, regulated with an LM2596 DC-DC Buck Converter, provides reliable performance without significantly impacting battery life. Overall, the proposed electric bike achieves a balance of performance, safety, and practicality. Its eco-friendly propulsion, intelligent safety mechanisms, and foldable design make it highly suitable for urban commuters, students, and individuals seeking efficient personal mobility solutions. Future enhancements, such as rider sleep detection sensors and smart helmet integration, could further improve safety, making the system a comprehensive platform for intelligent and sustainable transportation. The combination of portability, cost-effectiveness, and intelligent features positions this design as a promising solution for next-generation urban mobility.

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