Smart Electric Bicycle with Infotainment System

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Abstract – *The rapid advancement of electric mobility has accelerated the development of intelligent and sustainable transportation systems. This project presents the design and implementation of a Smart Electric Bicycle with an Infotainment System, aimed at enhancing ride efficiency, user experience, and eco-friendly commuting, Promoting green transportation. The proposed system converts a conventional bicycle into an electric-powered vehicle using a Brushless DC (BLDC) motor, battery pack, and a custom-built motor controller for efficient speed and torque control. A joystick-based throttle regulates motor speed, while Hall sensors provide real-time feedback for precise motor commutation. The bicycle is integrated with a 7-inch infotainment unit developed using the Raspberry Pi 5 platform, featuring real-time ride statistics such as speed, battery status, distance covered, and navigation support. The system also offers smart functionalities like Bluetooth connectivity, multimedia control, and safety alerts, thereby enhancing usability and rider experience. Experimental analysis demonstrates smooth acceleration, reduced power losses, and improved comfort. The developed prototype achieves a range of approximately 46 km per charge, validating its potential as a low-cost, intelligent, and sustainable personal transportation solution.*

Key Words: Electric Bicycle, BLDC Motor Controller, Raspberry Pi 5, Infotainment System, IoT, Smart Mobility

1.INTRODUCTION

The continuous evolution of electric mobility has paved the way for sustainable and intelligent transportation systems, with electric bicycles (e-bikes) emerging as a practical and eco-friendly solution for modern commuting. E-bikes offer energy efficiency, low maintenance, and zero emissions, making them ideal for urban and short-distance travel. However, traditional e-bikes often lack advanced data monitoring, smart control, and user interface capabilities that enhance rider experience and operational efficiency.

This project proposes the development of a Smart Electric Bicycle integrated with a Multi-Screen Infotainment System, designed to combine electric propulsion, real-time monitoring, and interactive user experience. The system transforms a conventional bicycle into an intelligent e-bike using a Brushless DC (BLDC) motor powered by a battery pack and controlled via a custom-built driver circuit. The ESP32 microcontroller serves as a triggering and data acquisition unit, generating PWM signals to control the driver circuit and reading inputs from Hall sensors, throttle, and battery sensors. The collected data is transmitted wirelessly to the Raspberry Pi 5, which acts as the central infotainment and processing unit.

A 7-inch touchscreen display hosts these five screens, offering an intuitive and visually appealing interface. The infotainment system is further enhanced with Bluetooth connectivity, media playback, and safety notifications, providing both functional and entertainment features.

By integrating the real-time control capability of the ESP32 with the computational performance of the Raspberry Pi 5, the proposed system achieves efficient motor control, seamless data exchange, and a rich multimedia experience. This project demonstrates a cost-effective, scalable, and intelligent mobility solution that bridges the gap between electric propulsion and smart infotainment technology, contributing to the advancement of next-generation sustainable transportation systems.

2. LITERATURE SURVEY

2.1 BLDC motor drives and controller strategies

Efficient and reliable BLDC motor control is fundamental to electric bicycle design. Several practical guides and papers emphasize three-phase BLDC topology, commutation strategies, and protection features (overcurrent, undervoltage), which are essential for safe e-bike operation. Industry application notes provide recommended hardware design considerations for battery interface, gate driving, and sensor integration for BLDC systems used in micro-mobility. These references inform the selection of switching devices, PWM schemes, and sensing required for a robust driver circuit in a retrofit e-bike. Texas Instruments+1

2.2 Microcontroller-based triggering and local sensing (ESP32)

Low-cost microcontrollers such as the ESP32 are commonly used as local control and data-acquisition nodes in e-bike projects. The ESP32 is frequently chosen for generating PWM triggers for driver circuits, reading Hall sensors and battery voltage, and implementing safety interlocks. Several recent prototype and journal articles document ESP32-based e-bike monitoring systems where the ESP32 handles real-time sampling (speed/Hall state), local decision making (cutoff, throttle mapping), and wireless uplink of telemetry to higher-level units or cloud servers. This aligns with your architecture of using the ESP32 exclusively for driver triggering and sensor telemetry. Scribd+1

2.3 Edge/infotainment platforms — Raspberry Pi in vehicle systems

Raspberry Pi family boards (including recent Pi models) are widely adopted for vehicle infotainment and edge-compute applications because of their rich I/O, multimedia support, and Linux ecosystem. Community and industry write-ups demonstrate building touchscreen car-puter units and in-vehicle infotainment prototypes with Raspberry Pi: these systems host multi-screen GUIs, navigation stacks, Bluetooth/media services, and act as aggregation points for telemetry from distributed microcontrollers. For an e-bike, the Raspberry Pi is an appropriate supervisory unit for visualization (home, lock, main menu, control panel, navigation screens), route guidance, and higher-level analytics. Raspberry Pi

2.4 IoT monitoring, fleet management and communications

Recent research on smart e-bikes and shared e-bike systems explores remote monitoring, energy optimization, and connectivity protocols (Wi-Fi, BLE, GPS). Studies demonstrate methods for transmitting telemetry (battery SOC, location, motor status) to local servers or cloud dashboards for diagnostics and fleet management. These works inform choices for communication stacks (e.g., using Wi-Fi/Bluetooth for local ESP32→Raspberry Pi links, or GPS for long-range telemetry if required). Implementations also report energy-aware strategies that extend range and improve battery life — useful when evaluating the prototype's 30 km range and potential future enhancements. PMC+1

2.5 Human–machine interfaces for e-mobility

User interaction and safety-oriented UI design are crucial in micro-mobility. Existing projects implementing multi-screen infotainment on small touch displays emphasize clear hierarchy (lock/authentication, realtime summary, configuration menus, direct control panels, and navigation) and safety considerations such as glanceable metrics and minimal distraction. The recommended five-screen layout (Lock, Home, Main Menu, Control Panel, Navigation) follows these practical guidelines and is consistent with Raspberry Pi-based infotainment implementations in the literature. Raspberry Pi

3.Proposed Methodology

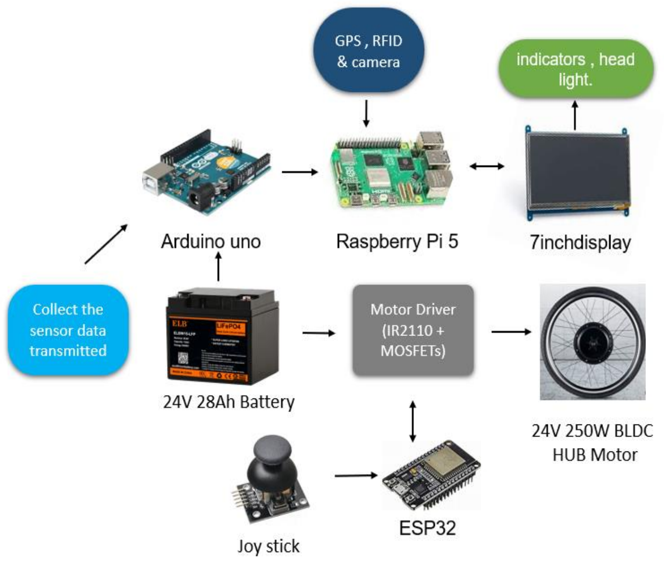

Fig 1 Flow diagram

3.1Motor Controller Design:

The motor control unit is developed using the ESP32 microcontroller, which is responsible for sensing the Hall sensor signals from the BLDC hub motor and triggering the gate driver circuit. The gate driver section consists of IR2110, TLP250 optocoupler, and IRF3205 MOSFETs, providing efficient switching and isolation between the control and power circuits. Two independent programs are deployed on the ESP32 — one for BLDC motor triggering and another for electromagnetic braking. The motor triggering program operates only when the navigation mode is active, and the motor speed is controlled using the joystick module input. In idle or non-navigation conditions, the electromagnetic braking system is activated to ensure vehicle safety and energy recovery. The ESP32 communicates with the Raspberry Pi 5 via a USB serial interface, enabling data synchronization and coordinated system control.

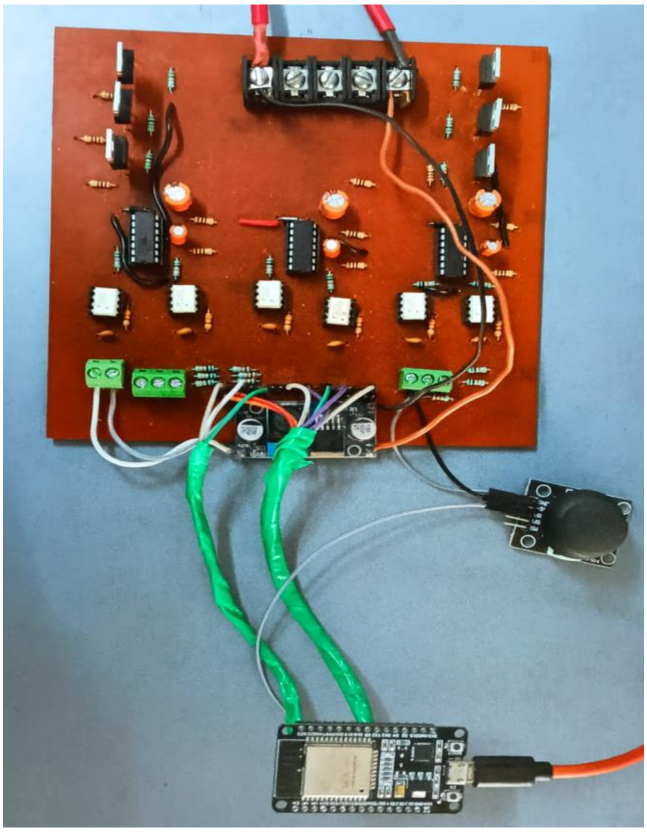

Fig 2 BLDC Motor Controller

Custom-Made Motor Controller Components

Component Name	Purpose / Function
ESP32 Microcontroller	Reads joystick input and generates PWM signals to control motor speed.
Joystick Module	Provides speed control input to the ESP32.
IR2110 IC	Drives high-side and low-side MOSFETs.
IRF3205 MOSFET	Switches motor current for speed control.
TLP250 Optocoupler	Provides isolation between ESP32 and MOSFETs.
Bootstrap Capacitor	Supplies voltage to high-side MOSFET gate.
Decoupling Capacitor	Stabilizes IC supply and reduces noise.
Bootstrap Diode	Charges bootstrap capacitor for high-side MOSFETs.
Resistors	Limits current and sets gate timing.

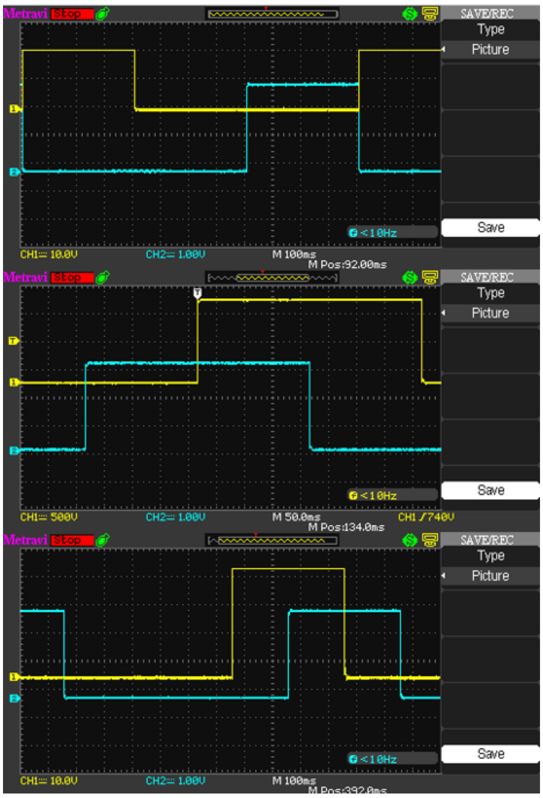

Fig 3 BLDC Motor Controller Waveform

2. Sensor Data Acquisition:

The sensor data acquisition system is implemented using an Arduino microcontroller, which interfaces with various analog and digital sensors such as temperature, speed, proximity, and battery voltage sensors. The Arduino collects and processes these sensor readings in real time and transmits them to the Raspberry Pi 5 through a USB connection for further analysis and display. The sensor interface and communication protocols are programmed in Embedded C using the Arduino IDE. This module ensures continuous data monitoring, which supports safety alerts, performance tracking, and intelligent decision-making for the electric bicycle system.

3. Infotainment System:

- The Raspberry Pi 5 serves as the central infotainment controller and human–machine interface (HMI) of the Smart Electric Bicycle. It integrates multiple subsystems, including motor monitoring, sensor data visualization, navigation, multimedia, and user interaction. The infotainment dashboard is developed in Python using the PyQt5 framework, which provides a modern, interactive, and highly responsive graphical interface. Various PyQt5 modules such as QtWidgets, QtGui, and QtCore are utilized for dynamic layout management, styling, image rendering, event handling, and real-time system updates. Additionally, PyQt5.QtWebEngineWidgets enables integration of live navigation maps, online data, and web-based resources directly on the GUI, while Pygame handles audio output, including music playback, notifications, and user alert sounds, enhancing the overall riding experience.

- The software imports essential libraries including: QApplication, QWidget, QLabel, QPushButton, QVBoxLayout, QHBoxLayout, QMainWindow, QFrame, QSlider, QGraphicsDropShadowEffect, QIcon, QPixmap, QFont, QTimer, QDateTime, QUrl, and QWebEngineView. System-level modules such as os, sys, and subprocess are employed for executing background tasks, running system commands, and facilitating hardware communication.

- Two joystick modules are integrated for precise control and enhanced usability:

- Motor and Light/Indicator Joystick: This joystick, mounted on the handlebar, controls both the speed of the BLDC motor and the light/indicator system. The motor is designed for forward motion only, and pushing the joystick down gradually increases motor speed, reaching full speed after approximately 10 seconds, allowing smooth acceleration and safe ride dynamics. The joystick also controls the lighting system: moving it left activates the left indicator, right activates the right indicator, while pushing it up toggles the headlight ON/OFF. Holding the joystick continuously upward makes the headlight blink rapidly, functioning as a pass light for signaling other vehicles. This dual-function joystick simplifies rider control, reduces hand movements, and ensures operational safety while riding.

- Infotainment Mouse Joystick: This second joystick is dedicated to controlling the PyQt5-based infotainment GUI on the Raspberry Pi. It functions as a virtual mouse, allowing the rider to interact with system menus, launch applications such as Chrome, play games, listen to music, and control multimedia functions. This design minimizes the need for a physical touchscreen, reduces distractions, and ensures the rider can operate the infotainment system safely while on the move.

- The Raspberry Pi 5 communicates with both the ESP32 and Arduino through USB serial connections, receiving real-time data such as motor speed, battery status, sensor readings, and system alerts. The received data is processed and displayed dynamically on the GUI, providing the rider with immediate feedback on system status. Additionally, the Pi manages Bluetooth connectivity, user authentication via PIN, and data logging for security and monitoring purposes.

- This integrated infotainment and control system ensures smooth interaction between motor control, lighting, sensor monitoring, and multimedia operations, creating a highly intelligent, user-friendly, and safe riding experience. By combining motor speed control, indicator/light management, and infotainment operations in a centralized, GUI-driven platform, the system promotes eco-friendly commuting, enhanced ride efficiency, and seamless operational convenience for the rider. The dual-joystick design allows intuitive handling and multitasking capabilities, making the Smart Electric Bicycle both technologically advanced and practical for everyday urban and semi-urban commuting.

- **Home Screen:** the current time, date, month and a stylish background image of the e-bike, It includes a power button for system control

- **Lock Screen:** The Ensures system security through a PIN-protected numeric keypad, allowing only authorized users to access the Smart Electric Bicycle

- **Main Menu:** The right and left arrows activate the right and left turn indicators, respectively, while the gear icon opens the control menu. The up arrow opens the navigation menu, and the lightning bolt displays the charging status. The headlight can be toggled between high and low beam modes for visibility, and the center of the screen displays the 360° view model

- **Control Panel:** Offers access to different features like ride analytics, Bluetooth & Wifi connectivity, and system settings.

- **Navigation Menu:** Provides route guidance, map visualization, and GPS-based ride tracking.

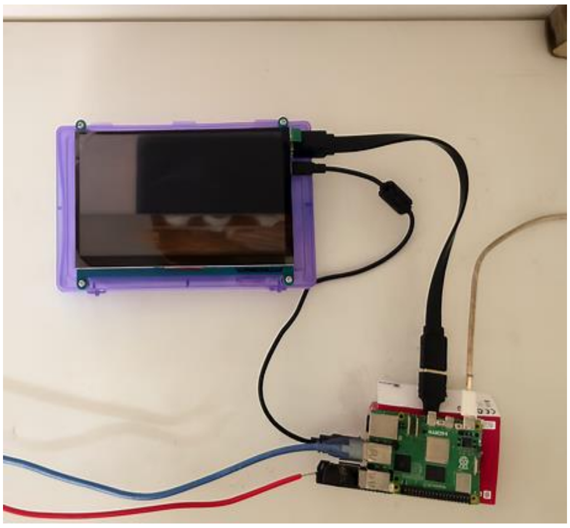

Fig 4 Infotainment system

Fig 5 Cycle overview

Remaining Project Components

Component Name	Purpose / Function
BLDC Hub Motor	Provides main propulsion for the bicycle.
Battery Pack (24V, 28Ah Lead acid)	Supplies power to motor and electronics.
DC-DC Converter (24V → 5V/12V)	Powers low-voltage electronics like ESP32 and Raspberry Pi.
Raspberry Pi 5 with memory card	Handles infotainment, multimedia, web, and game functions.
7-Inch Touchscreen Display	Displays speed, battery status, navigation, and infotainment interface.
Indicators and Front light	Shows left/right turn signals and headlight status.
Charging Port	Allows battery charging from external power source.
Frame and Mounting Assembly	Provides mechanical support for all components.
Infotainment Software Interface	Runs multimedia, web browsing, and game applications.
Speakers	Provides music and audio alerts for infotainment and navigation.

5. RESULTS AND DISCUSSION

The **Smart Electric Bicycle with Infotainment System** was designed, fabricated, and tested under various load and terrain conditions to evaluate its performance and functionality. The results demonstrate that the system operates efficiently with stable control and real-time data feedback between the **ESP32 controller** and **Raspberry Pi 5** infotainment platform.

5.1 Performance Evaluation

- **Motor Performance :**
  The 250 W BLDC hub motor delivered smooth torque with negligible vibration. The average top speed achieved was **25 km/h** under a total load of **80 kg.**

- **Battery Range:**
  The 24 V, 28 Ah battery pack provided a continuous range of approximately **46 km per charge**, validating the energy efficiency of the system.

- **Energy Efficiency:**
  The regenerative braking mechanism improved energy recovery by about **8–10 %**, contributing to extended range and reduced energy loss.

- **Communication and Data Logging:**
  The ESP32 successfully triggered the gate driver circuit and transmitted real-time data (speed, voltage, and Hall feedback) to the Raspberry Pi 5 via UART/Wi-Fi without latency issues.

- **Infotainment Interface :**
  The five-screen GUI (Lock, Home, Main Menu, Control Panel, and Navigation) responded smoothly with a transition delay of less than one second between screens. Bluetooth pairing and navigation services operated reliably during test runs.

6. CONCLUSION

The Smart Electric Bicycle with Infotainment System is an innovative project that merges technology, sustainability, and user convenience to redefine modern personal mobility. Designed to enhance ride efficiency, safety, and entertainment, this system integrates advanced electronic control with an eco-friendly electric drive. Powered by a 24V, 250W BLDC hub motor, the bicycle ensures smooth acceleration, reliable torque, and efficient energy use, even under varied road conditions. The ESP32 microcontroller serves as the intelligent core of the system, managing motor control through hall sensors and gate drivers while supporting regenerative braking to recover energy during deceleration. In addition to this, an **electromagnetic braking system** has been incorporated to enhance rider safety by providing additional stopping power and precise braking control, ensuring smooth and secure deceleration under all conditions.The infotainment system is designed to act as the brain and entertainment hub of the vehicle. It features a touchscreen interface that provides real-time data such as speed, battery level, navigation guidance, and system health monitoring. For user convenience and security, it includes a PIN-based access system to prevent unauthorized usage. Beyond utility, the system offers multiple smart features, including **music playback, web browsing, and casual game playing**, allowing the rider to enjoy entertainment during rest stops or charging intervals. The interface is designed to function **like a smartphone**, giving users access to multimedia, internet connectivity, and application control directly from the bicycle's display unit.With IoT integration, riders can monitor performance statistics, optimize energy usage, and receive system updates remotely. The inclusion of regenerative and electromagnetic braking significantly enhances control and safety, while the infotainment features elevate the overall riding experience. Compact design, efficient battery management, and intelligent control make the system reliable for daily urban commutes. Overall, the Smart Electric Bicycle with Infotainment System demonstrates a successful combination of electrical, mechanical, and digital technologies—delivering a smart, safe, and enjoyable mobility solution that aligns with the vision of sustainable and connected urban transportation.

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BIOGRAPHIES

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