iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 Issue: IV Month of publication: April 2026

DOI: https://doi.org/10.22214/ijraset.2026.79866

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue IV Apr 2026- Available at www.ijraset.com

An Analog Centric Smart Motor Drive for Sustainable Electric Mobility

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Abstract: This paper presents the design and development of an analog-centric motor controller for electric mobility applications. The proposed system eliminates dependency on complex firmware by utilizing a fully hardware based control architecture. The PWM control stage drives a MOSFET based power stage through an efficient gate driver, ensuring stable and reliable operation. The design focuses on affordability, ease of repair, and reliability using domestically available components. Experimental validation confirms smooth motor operation, stable dutycycle control, and effective protection, making the system suitable for low cost and sustainable electric vehicle applications.
Keywords: Analog Motor Controller, Electric Vehicle, PWM, MOSFET Driver,Sustainable Mobility

I. INTRODUCTION

The rapid transition toward sustainable transportation has significantly increased the demand for efficient and reliable electric mobility solutions. Electric bicycles and small electric vehicles are emerging as practical alternatives for both rural and urban transportation due to their affordability, energy efficiency, and reduced environmental impact. As the adoption of such systems grows, the need for robust and efficient motor control mechanisms becomes increasingly important.The motor controller plays a critical role in determining the performance, efficiency, and safety of an electric vehicle. Conventional motor controllers are predominantly based on microcontroller driven architectures that rely on embedded firmware for operation. Although these systems offer flexibility and advanced control features, they introduce several challenges, including increased system complexity, higher cost, and reduced ease of maintenance. Furthermore, these controllers often depend on imported components, making them less accessible and more difficult to repair in resource constrained environments.In many real world scenarios, especially in rural and semi urban regions, there is a strong requirement for systems that are simple, reliable, and easy to service. Complex firmware-based solutions are not always practical in such conditions due to limited technical support and higher maintenance costs. These limitations highlight the need for an alternative approach that prioritizes simplicity without compromising performance. This work presents the design and development of an analog centric motor controller aimed at addressing these challenges. The proposed system adopts a hardware-based control strategy that eliminates the dependency on software and embedded programming. By utilizing analog control techniques, the system achieves stable motor operation, smooth speed control, and improved reliability. The design emphasizes the use of locally available components to ensure cost-effectiveness and ease of repair.The primary objective of this work is to develop an indigenous motor control solution that is suitable for sustainable electric mobility applications. The proposed approach focuses on delivering a balance between performance, affordability, and serviceability, making it particularly suitable for low-cost electric vehicles and practical deployment in diverse operating environments

II. EXISTING SYSTEM

In conventional electric bicycle systems, the architecture is simple and consists of a battery, controller, throttle, and motor. The throttle provides an input to the controller, which regulates power from the battery to drive the motor. This setup primarily focuses on speed control and lacks advanced features. Most existing controllers use PWM based control, making fault detection and performance evaluation difficult.Most existing controllers are embedded centric, relying on microcontroller based systems for control functions. However, such systems increase complexity and cost, and often lack simple, low cost user interface or display solutions for monitoring and navigation, which limits usability in practical applications.Additionally, these systems are not designed for easy maintenance, as fault identification is difficult and component level repair is rarely feasible, leading to higher replacement costs.

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III. PROPOSED SYSTEM

The proposed EV controller illustrates the overall architecture of the system, integrating hardware control modules. The system is designed to regulate the speed of a PMDC motor using an analog PWM control mechanism.The operation begins with the rider input module (throttle), which generates an analog voltage signal corresponding to the rider's acceleration demand.

A. Hardware Design Overview

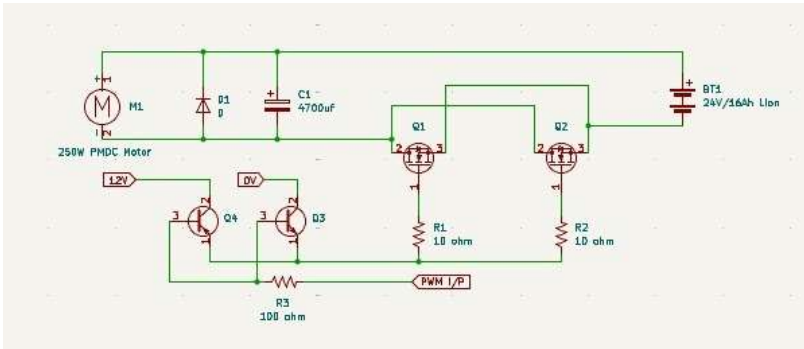

Fig. 1 Circuit Diagram of Proposed Method

The proposed system is developed based on an analogcentric control architecture aimed at achieving reliable and efficient motor operation without relying on embedded firmware. The methodology focuses on implementing hardware based control techniques to ensure smooth speed regulation, stable performance, and effective protection under varying operating conditions. The overall system is structured into functional stages that handle signal generation, power driving, energy conversion, and protection, working together to deliver controlled power to the motor. Overall Block diagram shown in Fig.1.

B. PWM Generator Design

The control process begins with the generation of a pulsewidth modulated signal derived from the throttle input. This PWM signal plays a crucial role in determining the effective voltage applied to the motor, thereby controlling its speed and torque. The analog implementation enables continuous and smooth variation of the duty cycle, which results in gradual acceleration and improved operational stability. Since the system does not rely on software-based control, it eliminates computational delays and enhances responsiveness as Shown in Fig 2.

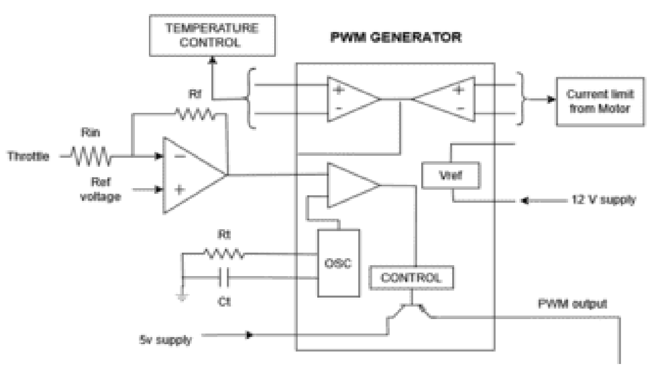

Fig. 2 PWM Generator

C. Driver Stage

The driver stage acts as an interface between the lowpower control circuitry and the high power switching devices. In the proposed system, a totem-pole configuration is employed to drive the MOSFET switches efficiently. This arrangement provides both sourcing and sinking capability for the gate, enabling rapid charging and discharging of the gate capacitance. The use of the totem pole driver ensures fast switching transitions, reduces switching losses, and improves overall system efficiency. It also enhances signal strength and maintains the integrity of the PWM signal during operation. By providing sufficient drive capability, the driver stage enables reliable and stable switching of the power devices under varying load conditions, shown in Fig.3.

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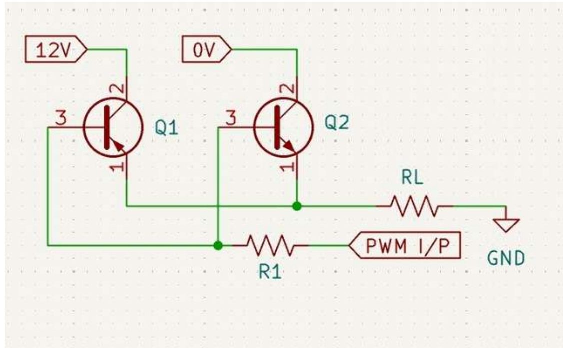

Fig. 3 Driver Stage

D. Display and monitoring unit

The display and monitoring unit provides real-time visualization and user interaction for the proposed system by integrating a TFT display and a web-based dashboard interface. The TFT display presents essential information such as route path, position, and distance directly from the ESP32 microcontroller. The system receives navigation data through WiFi and processes it to update the display dynamically. In addition, a web-based interface allows users to input destination data and monitor system parameters remotely. Communication between the ESP32 and the dashboard is performed efficiently to ensure continuous data exchange. The dashboard utilizes mapping services such as OpenStreetMap to generate route and distance information. The ESP32 processes this data and synchronizes it with the TFT display for real-time updates, ensuring effective monitoring and control., shown in Fig.7.

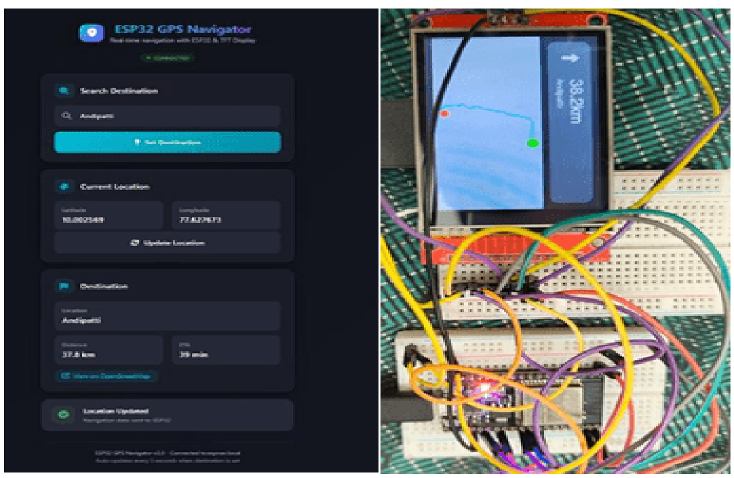

Fig 4 Prototype Implementation and Real-Time Monitoring Interface

IV. WAVEFORM ANALYSIS

The waveform analysis provides insight into the modulation characteristics of the controller under varying throttle inputs. The PWM output of the PWM generator was observed at three representative duty cycles 10%, 50%, and 90% corresponding to low, medium, and high throttle positions. At 10% duty cycle, narrow pulses indicate minimal conduction time, suitable for low speedoperation,shownin Fig.5.

Fig. 510% duty cycle

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At 50% duty cycle, the pulse width increases proportionally, delivering moderate torque while maintaining efficiency, shown in Fig.6.

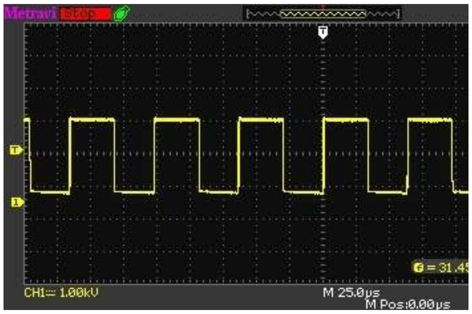

Fig. 6 50% duty cycle

At 90% duty cycle, wide pulses demonstrate near continuous conduction, representing maximum motor drive conditions, shown in Fig.7.

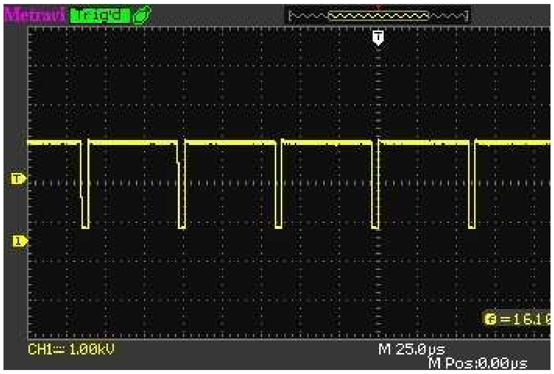

Fig. 7 90% duty cycle

The measured waveforms confirm the linearity and stability of duty cycle control across the throttle range. No distortion or jitter was observed, indicating reliable switching and effective feedback regulation. This analysis validates the performance of the modulation stage and confirms proper functioning of the protection and sensing circuits within the designed control framework.

V. HARDWARE IMPLEMENTATION

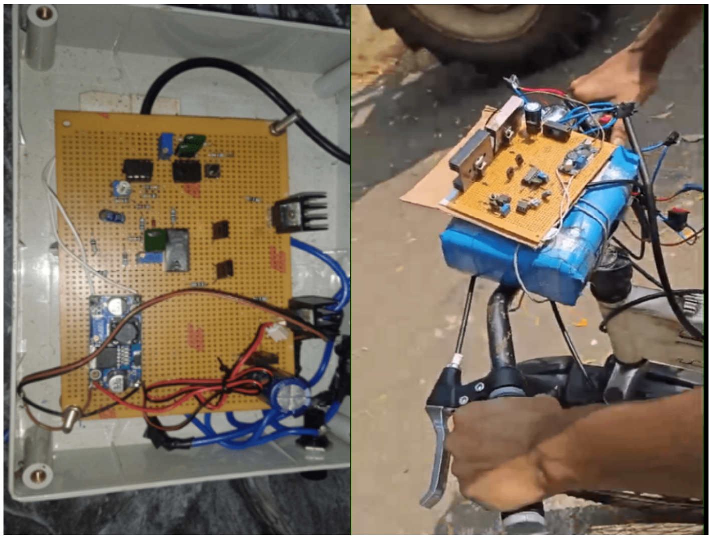

Fig. 6 Dot Board Implementation of PWM Controller

The proposed motor controller was implemented using a dot board prototype comprising the controller, battery pack, and permanent-magnet DC motor under variable throttle and load conditions. Oscilloscope measurements verified the stability of the pulse-width-modulated (PWM) signal, with linear duty-cycle variation in response to throttle input.The motor exhibited smooth acceleration and consistent speed control across the operating range, indicating reliable system performance. The controller maintained stable operation under varying load conditions, demonstrating robustness and suitability for practical electric mobility applications.

VI. CONCLUSION

The experimental results validate the implemented design of an energy-efficient E-cycle controller developed for reliable propulsion. Hardware testing confirmed stable PWM generation and smooth torque response under varying load conditions, ensuring efficient operation. The results demonstrate the practicality and robustness of the proposed system, making it a suitable solution for low cost electric mobility applications.

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