

E-Bike Motor Speed Controlling System using STM32 Microcontroller and PWM Feedback

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Abstract

This paper describes the design and development of an affordable motor speed control for e-bike systems based on the STM32F103C8T6 microcontroller and PWM feedback method. An analog Hall effect throttle is utilized in this design for generating a speed control signal. The speed of a brushless DC (BLDC) motor is controlled through the PWM generated with the help of the microcontroller. Real-time speed feedback is provided with the help of the Hall-effect sensor installed on the motor. The feedback speed is shown on the SSD1306 OLED display using the I²C communication interface. The design includes the IRF540N MOSFET motor driver circuit and the 7805/AMS1117 powered regulated power supply circuits. The embedded firmware programmed in the STM32CubeIDE acquires the throttle signal, generates PWM signal, calculates speed, and displays it on the OLED screen. Testing of the developed controller was performed experimentally in the form of hardware testing, speed calibration, and waveforms analysis. The maximum speed achieved during testing is about 3000 RPM along with stable PWM operation at 10 kHz and efficiency of 83.3%.

Keywords: STM32, BLDC Motor, PWM Control, OLED Display, Motor Driver, Hall Effect Sensor.

1. Introduction

The rise in the requirement of eco-friendly and energy-efficient modes of transportation has increased the usage of electric bicycles (e-bikes) as an alternative to traditional fuel-based vehicles. E-bikes have many benefits such as emission reduction, cost-effectiveness, and better mobility within the cities. One of the main parts of an e-bike is its motor control unit that manages the speed and performance of the electric motor and maintains the efficient use of energy and safety of the rider.

Brushless DC motors are mostly used in the e-bike because of their efficiency, small size, less maintenance, and good speed-to-torque ratio. The control of speed of brushless DC motors is very important to provide better acceleration and riding experience and increase the life of the battery. The existing motor control units are not flexible and customizable and hence cannot be used for research purposes.

Advances in embedded systems technology have led to the creation of affordable and efficient motor control systems that make use of microcontrollers. Of the many types of microcontrollers available, the STM32 microcontroller series has powerful computing power, peripheral support, and flexible PWM generation features. This makes it ideal for implementing real-time motor control applications that take advantage of PWM speed control and Hall effect sensors. This project proposes a novel system architecture for implementing speed control of a BLDC motor with the help of the STM32 microcontroller series.

The proposed system is capable of taking in inputs from the throttle of an e-bike, generating PWM signals for motor control, reading the speed of the motor using sensor input, and displaying the motor speed in real time on an OLED screen. The developed prototype provides a low-cost, reliable, and scalable platform for future enhancements such as IoT connectivity, sensorless control, and regenerative braking.

2. Literature Survey

BLDC and Permanent Magnet Synchronous Motors (PMSM) have found application in numerous electric vehicle designs because of their high efficiency and speed–torque characteristics. Principles, mathematics, and analysis of such drives, including the simulation part, were extensively explored [1], [2]. PMSM and BLDC motors are reliable and efficient

motors that can be utilized in any traction drive system as an effective solution for e-bikes propulsion systems.

Embedded microcontrollers made the development of flexible and cost-effective solutions possible. Such a microcontroller as STM32F103C8T6 has numerous capabilities related to PWM generation, ADC channels, and communication interface required for the control of the motor in real time [3]. Effective application of the BLDC motor controller designed on the basis of STM32 was shown by Zhang et al., demonstrating its efficiency in speed regulation and closed loop and feedback control [4]. Reliability of PWM control of DC motors for speed and direction control by using STM32 platforms was proved by Jangid et al. [9].

Regarding e-bikes, research has addressed several areas that include energy efficiency, distance range improvement, and adaptive speed control. Ridwan et al. designed a motor controller that optimizes the operation of e-bike motor drive systems and improves its distance range [5]. Additionally, Adeoti et al. designed an adaptive speed control system for pedal-assisted e-bike systems, which adapts to the changes in motor torque and speed as per user input to improve the energy utilization [6]. There have also been efforts to incorporate smart IoT solutions; for example, Mohamed et al. designed a system for energy optimization and localization monitoring in e-bikes [7].

Safety and reliability in embedded motor control systems is of prime importance. Over-voltage protection methods, thermal management, and EMI mitigation measures ensure safety and prevent damage to power electronics modules [8]. Furthermore, there have been innovations in sensorless control approaches to eliminate the hardware requirements while ensuring accurate motor behavior. For instance, Saha and Singh have proposed a back-EMF observer-based sensorless BLDC drive with SEPIC converter for electric vehicles [10].

Overall, from the examined literature, it is clear that controllers based on the use of STM32 microcontroller, together with the use of PWM control, sensor feedback, and protection techniques, make an efficient and reliable solution to implement speed control of BLDC motors in e-bikes. This research constitutes the theoretical basis of the proposed system for this project.

3. Methodology

The suggested design of the e-bike motor speed control system includes a throttle, a STM32F103C8T6 microcontroller, a PWM generator, a motor driver, a speed feedback unit, and a display unit. The structure of the proposed system is shown in Fig. 1. The throttle is a Hall effect sensor providing an analog signal with values from 0.8V to 4.2V depending on the acceleration request from the rider. The signal is captured by the 12-bit Analog to Digital Converter of the STM32 microcontroller and is converted to digital.

The captured throttle signal is mapped to the PWM duty cycle from 0% to 100% that allows controlling motor speed proportionally to the rider's acceleration request. On the basis of the input, the controller creates a Pulse Width Modulated (PWM) signal utilizing the TIM2 and TIM3 timers' modules of the STM32 microcontroller. The created PWM signal is used as an input of a three-phase driver circuit based on IRF540N MOSFET. The system works from the 12V battery source. There are 7805 and AMS1117 regulators providing 5V and 3.3V supply voltage for the logic circuit and STM32 controller respectively.

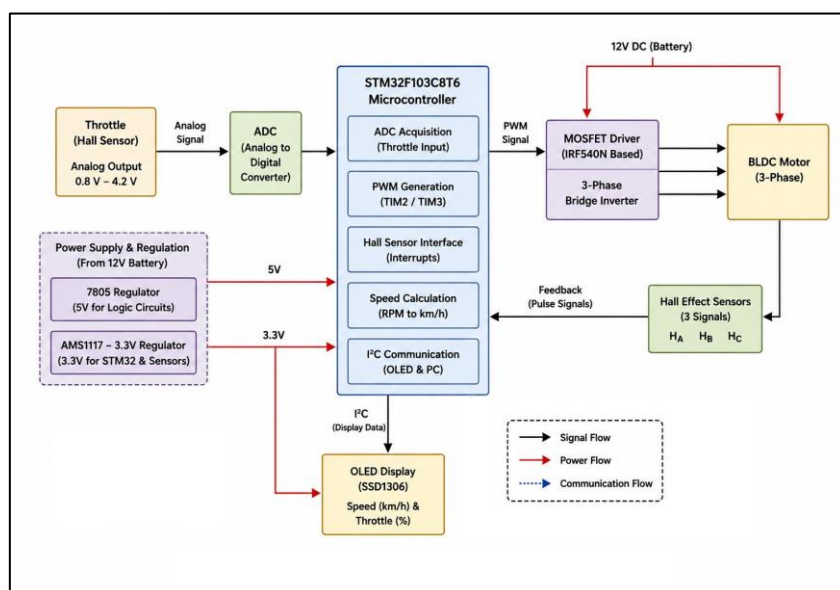


Figure 1. Architecture of the STM32 based e-bike motor speed control system

To measure speed in real time, Hall effect sensors that are attached to the motor will give output signals based on the rotation of the rotor and speed of the motor. This signal will be processed with external interrupts of the STM32 microcontroller. Motor speed will be calculated using

$$RPM = (60 \times f) / P$$

where f is the measured pulse frequency in hertz and P is the number of pulses generated per revolution.

The vehicle speed is then calculated using the wheel circumference and expressed in kilometres per hour as

$$\text{Speed (km/h)} = (\text{RPM} \times C \times 60) / 1000$$

where, C is the wheel circumference in metres.

The obtained speed will be displayed on an SSD1306 OLED screen via the I²C communication interface. This will provide real-time information of vehicle speed and throttle input.

The firmware of this project was written using STM32CubeIDE. The program continuously reads throttle input, generates PWM signals, processes Hall-sensor interrupt, calculates motor speed, and displays data on OLED screen in real time.

4. Results and Discussion

The performance of the proposed STM32-based electric bike motor speed control system was tested via extensive hardware implementation and experimentation under both no-load and loaded conditions. The details of hardware implementation and components involved in this are provided in Table 1.

Table 1. Components used in the hardware model

Component	Specification / Model	Function
Microcontroller	STM32F103C8T6	Core control unit for PWM generation, ADC reading, and speed computation
Motor	Brushless DC (BLDC) Motor	Acts as the driving unit for the e-bike propulsion
Motor Driver	IRF540N MOSFET-based 3-phase inverter	Provides switching and power amplification for BLDC motor
Throttle Sensor	Hall-effect throttle (0.8V–4.2V output)	Generates analog acceleration control signal
Speed Sensor	Hall-effect sensors (3-phase)	Provides rotor position and speed feedback

Display Unit	SSD1306 OLED Display	Displays real-time speed and system status
Voltage Regulator (5V)	7805 Regulator	Supplies regulated 5V for logic circuits
Voltage Regulator (3.3V)	AMS1117 Regulator	Supplies 3.3V for STM32 and sensors
Power Source	12V DC Battery	Main power supply for the system
Communication Interface	I ² C Bus	Used for OLED display communication
Switching Device	IRF540N MOSFET	High-speed switching for motor control
Measurement Tool	CRO (Oscilloscope)	Used for PWM waveform verification

Hardware implementation of the designed controller is illustrated in Fig. 2. The prototype consists of the STM32F103C8T6 microcontroller, IRF540N MOSFET-based three phase driver, hall effect throttle, brushless direct current (BLDC) motor, hall effect speed sensor, and SSD1306 OLED display. The system runs on a 12V DC power supply with 5V and 3.3V rails. The components enable the communication and real-time control of the motor. In order to increase system reliability, switching effects, thermal effects, and EMI issues were considered. 10 kHz switching rate of the MOSFET reduces switching losses and voltage stress. Thermal effect is minimized by employing proper heat sink design for the MOSFET driver and motor. EMI effect can be reduced by minimizing the signal lengths, decoupling, and grounding of the signal paths for reducing noise that impacts ADC inputs and PWM generation.



Figure 2. E-bike speed control system using STM32 microcontroller and PWM feedback

The Hall effect throttle provided an analog voltage output between 0.8 V and 4.2 V, and conversion is carried out through the STM32 12-bit ADC. The mapping from throttle voltage to PWM duty cycle is performed as follows:

$$D = \frac{V_{in} - V_{min}}{V_{max} - V_{min}} \times 100$$

where,

- D = PWM duty cycle (%)
- V_{in} = throttle voltage
- V_{min} = 0.8 V,
- V_{max} = 4.2 V

The PWM wave generation by the STM32 controller is tested using cathode-ray oscilloscope (CRO) and it was found that a switching frequency of approximately 10 kHz was stable over the whole range. Thus, steady motor speed without fluctuations can be obtained.

The motor speed was measured when the motor was loaded and unloaded. For no load condition, the maximum motor speed attained is around 3000 RPM. With the load of a rider weight of around 80 kg, the motor attained speed of 2650 RPM.

Table 2. Motor response and torque characteristics

Parameter	Value
Rise Time (0–100% RPM)	0.42 s
Settling Time	0.65 s
Overshoot	6%
Maximum Torque	2.3 Nm

The motor response and torque characteristics of the STM32-based e-bike controller are summarized in Table 2. Rise time and settling time are noted during the step change in the input of the throttle position, whereas the overshoot is calculated based on peak transient speed. The maximum torque is calculated from the motor current and motor constant at a rider weight of about 80 kg. These results support the rapid acceleration and minimum overshoot, which proves that closed loop control with PWM is an effective approach.

The linear dependency between PWM duty cycle and motor speed is summarized in Table 3. These results demonstrate the correctness of throttle-to-speed map:

$$RPM = k \cdot D$$

where, k = experimentally derived proportional constant

Table 3. Relationship between throttle input and motor speed

Throttle Voltage (V)	PWM Duty Cycle (%)	Motor Speed (RPM)
0.8	0	0
1.5	25	750
2.5	50	1500
3.5	75	2250
4.2	100	3000

The interface of the display based on OLED technology demonstrated in Fig. 3 was successfully implemented. The display refresh time was estimated as less than 100 milliseconds, which provides fast response and allows to use this interface in practice. Throttle changes are immediately reflected not only in motor speed but also in display output, which leads to smooth response of the system.

The circuit for protection against over-voltage was tested at voltage higher than 14.5V, and PWM signal was disabled, thus protecting the stage with motor driver. In addition, testing for 12 hours did not show any thermal shutdown or other unusual behavior of the system.



Figure 3. Speed display on OLED screen

Performance of the suggested STM32-based motor controller was analyzed under different operating conditions to confirm the speed regulation, feedback accuracy, and the overall reliability of the designed system. Measured performance parameters are presented in Table 4.

Table 4. Experimental observations of the STM32-based e-bike motor control system

S. No	Parameter	Value
1	Input Voltage	12V DC
2	No-load Speed	~3000 RPM
3	Throttle–Speed Mapping	Linear
4	OLED Display Lag	< 100 ms
5	PWM Frequency	10 kHz (Stable)
6	System Efficiency	~83.3% (estimated)
7	Safety Trigger	Over-voltage trip at >14.5V
8	PCB Footprint	90mm x 60mm
9	Testing Duration	12 hours continuous – no thermal shutdown

As can be seen from Table 4, the controller demonstrated the maximum no-load speed close to 3000 RPM in case of being supplied by a 12V DC source. The connection between the speed of the motor and the throttle input signal was revealed to be nearly linear, confirming the successful PWM-based speed regulation. Maximum system efficiency was found to be about 83.3%, meaning the appropriate energy consumption by the designed system in terms of its application to the e-bike purposes. Thus, the performed experiments have shown that the designed STM32-based motor controller ensures reliable speed regulation and feedback monitoring.

5. Conclusion and Future Scope

The paper discussed the design and implementation of BLDC motor speed control using STM32 for application in electric bicycles. The designed control algorithm uses a Hall effect throttle for speed command input, PWM for motor speed control, and Hall sensors for the measurement of motor speed. A SSD1306 OLED screen is used for displaying user feedback on the speed of the operation of the control system. Experimental results revealed a reliable PWM signal generation at 10 kHz, accurate mapping of speed commands from the throttle

input to speed and a maximum speed of 3000 RPM without loading on the motor. The control system operates efficiently at 83.3% efficiency, over-voltage protection and extensive testing proves that the designed control system is safe and robust. The design serves as a low-cost solution for control of motors in e-bikes. Further work on control algorithm implementation for sensorless BLDC motor control will make the design more effective and reliable, IoT based wireless monitoring will allow for better system diagnosis and use of regenerative braking will optimize the use of batteries.

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