Design and Implementation of a Closed-Loop PWM-Based DC Motor Speed Control System Using Advanced Microcontrollers

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***Abstract*—Motor speed control systems are essential in various applications such as industrial automation, robotics, electric vehicles, conveyor systems, and smart manufacturing. Conventional Pulse Width Modulation (PWM)-based motor control techniques commonly operate in an open-loop configuration, where the motor speed is controlled without considering actual output feedback. Although these systems are simple and cost-effective, they suffer from several limitations including poor speed regulation, slow dynamic response, sensitivity to load disturbances, and inability to maintain constant speed under varying operating conditions. Furthermore, implementations using basic microcontrollers often lack sufficient real-time processing capability and efficient control tuning mechanisms. To address these issues, this paper presents the design and implementation of a closed-loop PWM-based DC motor speed control system using an advanced microcontroller integrated with a PID (Proportional–Integral–Derivative) control algorithm. In the proposed system, the desired reference speed is continuously compared with the actual motor speed obtained through a feedback sensor such as an encoder or Hall-effect sensor. The PID controller processes the error signal and dynamically adjusts the PWM duty cycle to regulate motor speed accurately and efficiently. The advanced microcontroller enables high-speed PWM generation, real-time feedback processing, and improved control performance. The proposed closed-loop control system significantly enhances motor performance by reducing steady-state error, improving transient response, increasing stability, and effectively compensating for sudden load variations. Experimental analysis demonstrates that the system maintains stable motor operation and precise speed regulation under different loading conditions when compared with traditional open-loop PWM control methods. The developed system offers a reliable, efficient, and low-cost solution for modern embedded motor control applications and can be further extended for intelligent automation and IoT-enabled industrial systems.**

***Index Terms*—Closed-loop motor control, PWM speed control, DC motor, PID controller, advanced microcontroller, embedded systems, feedback control, speed regulation, real-time control, industrial automation.**

I. INTRODUCTION

Motor control systems play an important role in modern industrial and embedded applications such as robotics, conveyor systems, electric vehicles, CNC machines, home automation, and manufacturing industries. Among various motor control techniques, Pulse Width Modulation (PWM) is widely used due to its simplicity, low power loss, and efficient speed regulation capability. In conventional PWM-based motor control systems, the motor speed is generally controlled using an open-loop configuration where the control signal is generated without considering the actual motor output. Although open-loop systems are simple and inexpensive, they suffer from several drawbacks including poor speed accuracy, slow response, instability under varying load conditions, and inability to automatically correct speed deviations. In practical applications, motor loads continuously vary depending on operating conditions. Open-loop systems cannot compensate for these disturbances effectively, resulting in fluctuations in motor speed and reduced overall performance. Additionally, traditional implementations using basic microcontrollers provide limited processing capability and lack advanced real-time control features required for precise motor operation. Therefore, there is a growing need for intelligent and efficient motor control systems capable of maintaining stable performance under dynamic conditions.

Closed-loop control techniques overcome these limitations by continuously monitoring the actual motor speed using feedback sensors such as encoders or Hall-effect sensors. The measured speed is compared with the desired reference speed, and the error generated is processed using a control algorithm to automatically adjust the PWM duty cycle. Among various control techniques, the Proportional–Integral–Derivative (PID) controller is widely preferred because of its simple structure, fast response, reduced steady-state error, and improved system stability.

Recent advancements in embedded systems and advanced microcontrollers such as STM32, ESP32, ARM Cortex, and PIC controllers have enabled the implementation of high-speed real-time motor control systems with improved computational efficiency. These controllers support advanced PWM generation, multiple communication interfaces, sensor integration, and efficient feedback processing, making them highly suitable for modern motor control applications.

This paper presents the design and implementation of a closed-loop PWM-based DC motor speed control system using an advanced microcontroller and PID control algorithm. The proposed system continuously monitors motor speed and dynamically adjusts the PWM signal to maintain accurate and stable operation under varying load conditions. The developed system aims to improve speed regulation, transient response, robustness, and overall efficiency compared to conventional open-loop motor control methods.

II. LITERATURE SURVEY

Paper 1

Microcontroller Based Closed-Loop Automatic Speed Control of DC Motor Using PWM

- Used ATmega microcontroller and PWM technique.
- Improved speed regulation using feedback control.
- Limitation: slower processing capability and limited adaptability.

Paper 2

PWM DC Motor Speed Regulation Using STM32 with Fuzzy PID

- Used STM32 advanced controller.
- Implemented fuzzy PID algorithm for improved response.
- Achieved better load disturbance rejection.

Paper 3

Embedded PI Controller for DC Motor Speed Control

- Implemented PI controller for speed regulation.
- Reduced steady-state error.
- Limitation: less effective under rapid load changes.

2.1 Research Gap

Existing systems mainly focus on basic controllers and conventional tuning methods. There is a need for advanced microcontroller-based closed-loop systems with fast response, accurate speed regulation, and robustness under varying loads.

III. METHODOLOGY

Step 1: Speed Reference Input

The user sets the desired motor speed using a controller or interface.

Step 2: PWM Signal Generation

The microcontroller generates PWM signals based on the required motor speed.

$$Duty\ Cycle = \frac{T_{ON}}{T_{TOTAL}} \times 100$$

Step 3: Motor Driving

The PWM signal is applied to the motor driver circuit to control motor voltage and speed.

Step 4: Feedback Sensing

An encoder or Hall sensor continuously measures actual motor speed.

Step 5: Error Calculation

The controller compares reference speed and actual speed.

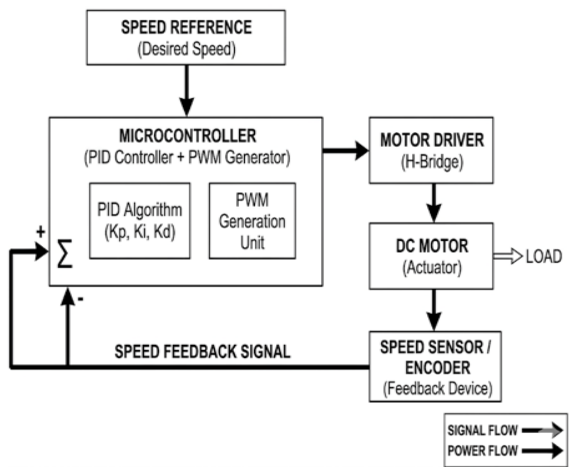
$$\mathrm{e(t)} = \mathrm{Speed}_{\mathrm{reference}} - \mathrm{Speed}_{\mathrm{actual}}$$

Step 6: PID Control Action

The PID controller processes the error and updates PWM duty cycle.

Step 7: Continuous Monitoring
The process repeats continuously for accurate and stable motor operation.

Block Diagram



Closed-Loop PWM Motor Control System Architecture

IV. RESULTS

The proposed closed-loop PWM motor control system produced the following improvements:

- Accurate speed regulation
- Faster transient response
- Reduced steady-state error
- Improved stability
- Better load disturbance compensation

Parameter	Open Loop	Closed Loop
Speed Accuracy	Low	High
Response Speed	Slow	Fast
Load Compensation	Poor	Excellent
Stability	Moderate	High
Error Correction	Not Available	Automatic

The system maintained constant speed even when motor load conditions changed

V. CONCLUSION

This paper presented a closed-loop PWM-based motor control system using an advanced microcontroller and PID controller. The proposed system effectively improves speed accuracy, response time, and stability compared to traditional open-loop systems. Real-time feedback and automatic PWM adjustment enable robust performance under varying load conditions. The system can be widely used in automation, robotics, and electric vehicle applications.

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