Close Loop Speed Control of DC Motor

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***Abstract*— DC motors are widely used in various industrial, commercial, and residential applications due to their simplicity, reliability, and versatility. However, to achieve precise control over the speed, direction, and torque of a DC motor, a closed-loop control system is often required. In this project, we explore the design, implementation, and evaluation of a closed-loop control system for a DC motor, using a proportional-integral-derivative (PID) controller. The project consists of several stages, including system modeling and simulation, hardware implementation, user interface design, and performance evaluation. The simulation and experimental results demonstrate that the closed-loop control system can achieve accurate and stable motor control, with fast response time and minimal overshoot. The system can also be easily customized and expanded to suit different motor specifications and control requirements. This study contributes to the advancement of DC motor control technology and opens new opportunities for practical applications in various fields.**

***Keywords*— DC motors, torque, PID, Speed control.**

I. INTRODUCTION

DC motors are widely used in different fields, such as robotics, automation, aerospace, electric vehicles, and renewable energy systems. However, controlling a DC motor accurately and reliably requires a feedback control mechanism that continuously monitors and adjusts the motor's performance [1]–[3].

In open-loop control, the motor is controlled based on a predefined input signal, without feedback from the motor itself. However, open-loop control is susceptible to various disturbances and uncertainties, such as changes in load, temperature, and voltage, which affect the motor's behavior and performance. Moreover, open-loop control cannot guarantee the desired level of accuracy, speed, and stability in the motor's operation [4]–[7]. Therefore, the motivation for the study of closed-loop DC motor control is to overcome the limitations of open-loop control and achieve more precise and robust control of DC motors. Closed-loop control, also known as feedback control, is a control technique that involves measuring the motor's output and comparing it to a desired reference signal, then adjusting the input signal accordingly to minimize the error between the two signals. By continuously monitoring and adjusting the motor's behavior, closed-loop control can compensate for disturbances uncertainties ensure accurate and stable motor control [8]–[15].

A closed-loop DC motor control system typically consists of four main components:

- Motor: A DC motor is an actuator that converts electrical energy into mechanical energy. It consists of a rotor and a stator, with the rotor rotating inside the stator in response to a current passing through the windings.
- Sensor: The sensor measures the motor's speed or position and provides feedback to the controller. Common types of sensors used in DC motor control systems include encoders, tachometers, and Hall effect sensors.
- Controller: A controller monitors the output of a sensor and compares it to a desired set-point. It then calculates an error signal based on the difference between the actual and desired values, and uses the error signal to adjust the input to the system. The controller can be implemented using a variety of algorithms, such as proportional-integral-derivative (PID) control and fuzzy logic control.
- Power supply: The power supply provides the electrical energy to drive the motor. The power supply can be adjusted by the controller to change the voltage or current delivered to the motor, which in turn affects the motor's speed or torque.
- Communication module: In a proposed closed-loop DC motor control system, there may be a communication module that allows the controller to communicate with other systems or devices. For example, the controller may communicate with a control module to allow an operator to input set-points or view system status.

- Safety features: To ensure safe and reliable operation, a closed-loop DC motor control system may include safety features such as overload protection, over-current protection, and over-temperature protection. These features help prevent damage to the motor and other system components in the event of a fault or failure.

Together, all these components form a closed-loop system that continuously monitor and adjust the motor's performance to achieve a desired output. The system can be tuned to optimize performance based on factors such as response time, stability, and steady-state error. Closed-loop DC motor control systems are commonly used in applications such as robotics, automation, and industrial control systems, where precise and stable motor control is required [16]-[18].

Our objectives are summarized as follows:

- Developing a mathematical model of a DC motor and its transfer function.
- Designing a closed-loop control system for a DC motor.
- Implementing the closed-loop control system using a microcontroller.
- Evaluating the performance of the closed-loop control system and comparing it with open-loop control.
- Analyzing the results and providing recommendations for further research and improvements.

Overall, the study of closed-loop DC motor control is significant for enhancing the efficiency, reliability, and precision of DC motor control, which has numerous practical applications in various fields.

II. METHODOLOGY

When selecting hardware components for a closed-loop DC motor control system, several factors need to be considered, including motor specifications, sensor requirements, and the capabilities of the microcontroller. Here's a step-by-step guide for selecting suitable hardware components:

- DC Motor:

Determine the required specifications of the DC motor based on the application. Consider parameters such as rated voltage, rated current, torque, speed, power rating, and physical size constraints. Select a DC motor that meets the desired specifications. Pay attention to the motor's datasheet to ensure it can handle the required load and has appropriate speed-torque characteristics. Consider factors such as brush type (brushed or brushless), efficiency, durability, and compatibility with the control algorithm [19].

- Sensors:

Determine the necessary sensors for closed-loop control. In a DC motor system, a speed sensor (e.g., encoder, tachometer) is typically used to provide feedback for the control loop. Choose a suitable speed sensor that provides accurate and reliable speed measurement. Consider factors such as resolution, output type (analog or digital), interface compatibility, and environmental considerations. Depending on the application requirements, you may also need additional sensors such as position sensors or current sensors to monitor and control specific parameters.

- Microcontroller:

Consider the computational requirements for the control algorithm and select a microcontroller with sufficient processing power and memory capacity. Determine the required peripherals/interfaces for motor control, such as PWM outputs, analog-to-digital converters (ADCs), and communication interfaces (UART, SPI, I2C). Ensure the microcontroller has suitable development tools, software libraries, and community support for motor control applications.

Consider factors such as power consumption, operating voltage range, cost, and availability.

1. Arduino Uno: is a popular microcontroller board based on the ATmega328P microcontroller. It is widely used in various electronics and robotics projects due to its simplicity and ease of use. Here are some key features and characteristics of the
2. Microcontroller: The Arduino Uno is equipped with an ATmega328P microcontroller, which is an 8-bit microcontroller with 32KB of flash memory, 2KB of SRAM, and 1KB of EEPROM. It operates at a clock speed of 16MHz.

The following are the details of Arduino Uno:

Digital I/O Pins: The Arduino Uno has a total of 14 digital input/output (I/O) pins. These pins can be used for interfacing with digital sensors, actuators, and other devices. Among these pins, 6 pins (marked as PWM) can also be used for Pulse Width Modulation (PWM) output.

Analog Input Pins: The Arduino Uno has 6 analog input pins labeled A0 to A5. These pins can be used to read analog signals from sensors or other analog devices. The Uno's ADC has a 10-bit resolution, allowing for 1024 distinct analog values.

Power Supply: The Arduino Uno can be powered using a USB connection or an external power source. It has a voltage regulator that allows it to be powered with a voltage range of 6-20V. The board also provides a 5V pin and a 3.3V pin for powering external components.

Communication: The Arduino Uno supports serial communication via USB, which allows it to be connected to a computer for programming and data transfer. It also has hardware UART (Universal Asynchronous Receiver-Transmitter) and I2C (Inter-Integrated Circuit) interfaces for communication with other devices.

Programming: The Arduino Uno is a microcontroller board that can be programmed with the Arduino language, a simplified version of C++. The Arduino IDE provides a user-friendly interface for writing, compiling, and uploading code to the board.

Shields: The Arduino Uno is compatible with various expansion boards called "shields." Shields can be easily plugged into the Uno's headers, expanding its capabilities by adding functionalities such as wireless communication, motor control, display, or sensor integration.

Open-Source: The Arduino Uno is an open-source platform, which means its schematics, board layout, and software are freely available for modification and customization, which allows the Arduino community to contribute and share their projects and libraries.

The Arduino Uno is a beginner-friendly development board that offers a straightforward way to start prototyping and building projects. Its versatility, large community support, and extensive library ecosystem make it an excellent choice for hobbyists, students, and professionals alike.

- Power Electronics:

Depending on the motor type and control strategy, you may need power electronics components such as motor drivers or H-bridge circuits to interface the microcontroller with the motor. Select motor drivers or power electronics components that are compatible with the motor's voltage and current requirements. Consider features such as overcurrent protection, thermal protection, and voltage rating.

H-bridge: is an electronic circuit that allows the control of the direction and speed of a DC motor. It consists of four switches (usually transistors or MOSFETs) arranged in a specific configuration to control the motor's movement. The H-bridge configuration enables the motor to rotate in both forward and reverse directions by controlling the voltage polarity applied to its terminals. The H-bridge circuit typically has two inputs for controlling the motor: one for the direction and another for the speed. By controlling the switching states of the four switches, the motor's rotation direction can be changed, and by varying the duty cycle of the applied voltage, the motor's speed can be adjusted. There are various types of H-bridge configurations, including the popular "full-bridge" and "half-bridge" configurations. The choice of the H-bridge configuration depends on the motor's voltage and current requirements. H-bridges are commonly used in robotics, automation, and motor control applications to precisely control the movement of DC motors. They are frequently integrated into motor driver modules or motor control boards, which provide convenient interfaces and additional features for controlling DC motors with an H-bridge circuit.

The following figure shows the design and how it should be implemented using a simulation software. The figure also illustrates the control circuit design and the needed connections between the PINs of all the used components.

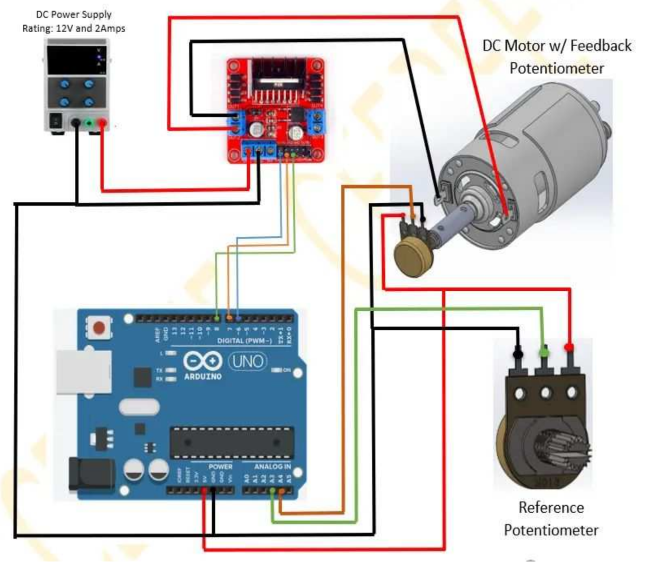

Fig. 1. A simulation circuit for the main system.

Fig. 2 shows the block diagram that illustrates the main connection between every component in the system.

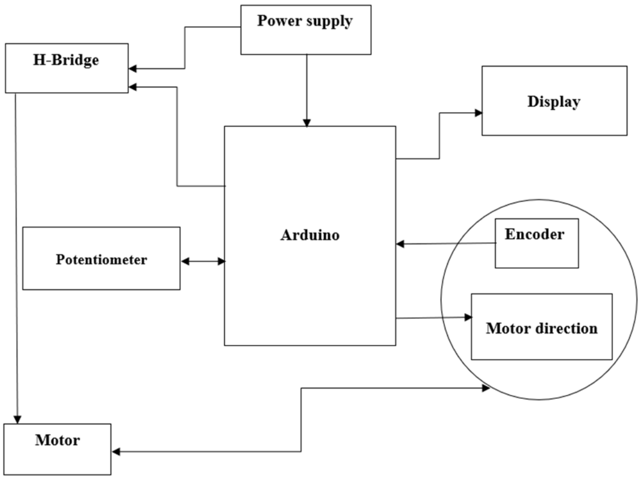

Fig. 2. Main block diagram for the system.

III. RESULTS

The Simulink of the proposed system is shown in Fig. 3. Table 1 shows a comparison between the needed value (new speed) and a previously set value (reference speed), and the steady state error is also calculated to ensure the low relative error percentage, which is illustrated in the figures 4 to 11.

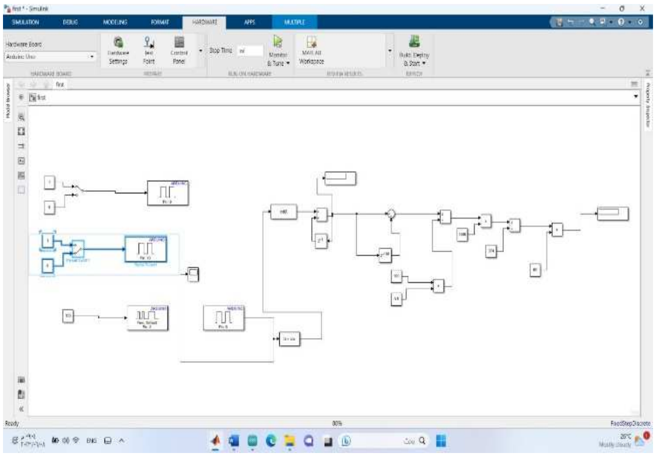

Fig. 3. Simulink in Matlab.

Reference speed	New speed	Steady state error
255	254.5	0.001964637
235	234.5	0.002132196
240	235	0.021276596
254	255	0.003921569
192	191	0.005235602
155	154	0.006493506
125	123	0.016260163
106	105	0.00952381
90	87	0.034482759
80	81	0.012345679
62	63	0.015873016
47	47.5	0.010526316
50	51	0.019607843

TABLE I. STEADY STATE ERROR CALCULATIONS.

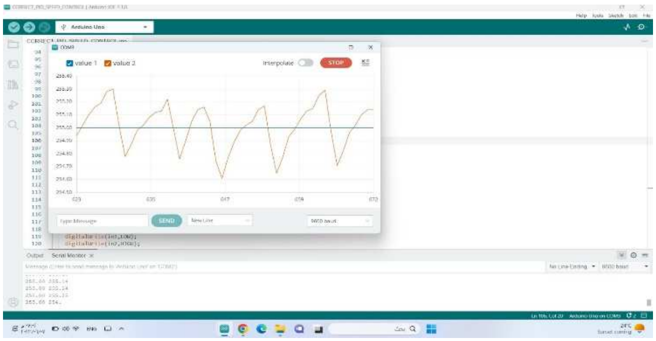

Fig. 4. Output signal 1– Speed of the motor.

Fig. 5. Output signal 2 – Armature current.

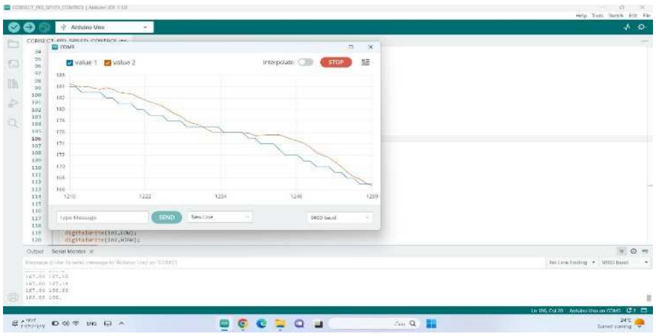

Fig. 6. Output signal 3 – Motor speed.

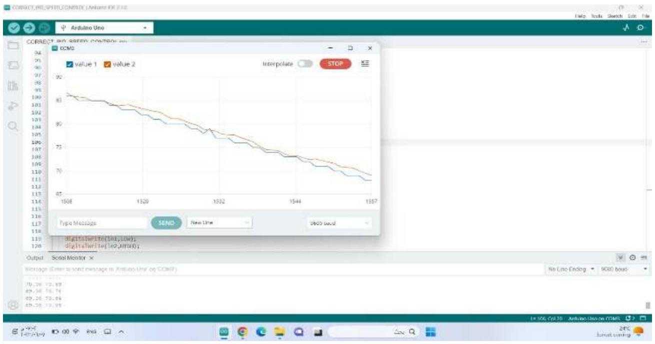

Fig. 7. Output signal 4 – Motor speed.

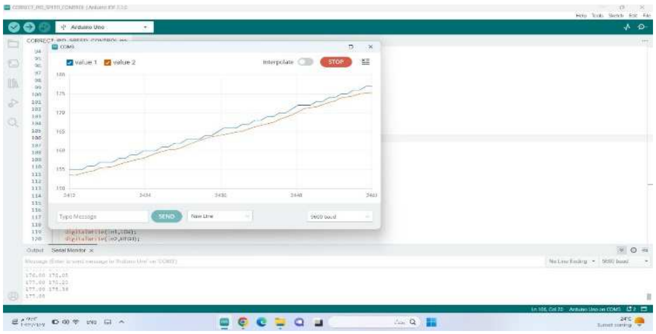

Fig. 8. Output signal 5 – Motor speed.

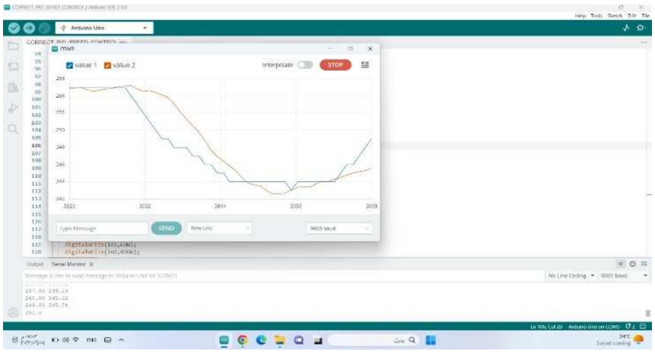

Fig. 9. Output signal 6 – Motor speed.

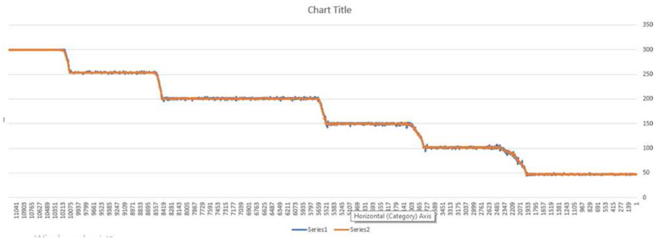

Fig. 10. Output signal 7 – Motor speed.

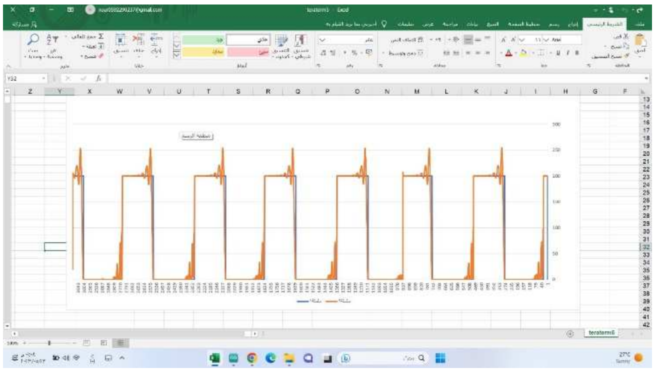

Fig. 11. Output signal 8 – Motor speed.

IV. CONCLUSIONS AND RECOMMENDATIONS

The utilization of closed-loop control systems in DC motors offers several significant advantages. Firstly, it enables the precise regulation of speed, torque, and position, ultimately leading to enhanced system performance and increased accuracy. Additionally, closed-loop control imparts stability and robustness to external factors that may otherwise disrupt motor performance, ensuring consistent and reliable operation. Moreover, the proposed approach contributes to energy efficiency by actively monitoring and adjusting control inputs as needed. The implementation of a PID controller within the closed-loop system further enhances its capabilities, where this controller continually assesses the motor's actual speed or position and compares it to the desired setpoint, making real-time adjustments based on the error between the two values. Consequently, where the results in improved stability and accuracy in maintaining the desired setpoint. By incorporating feedback from sensors such as encoders or tachometers, the closed-loop control system continuously monitors the motor's actual speed or position, fine-tuning the control signal to minimize the error between the desired setpoint and the measured value, where this meticulous process culminates in heightened accuracy and precision when achieving the desired motor performance.

Here are some possible future work recommendations:

- Employ MATLAB software accurately for control system development, avoiding sole reliance on the Arduino Uno board's programming language, where this approach enhances the system's capabilities and performance.
- Prioritize the selection of a DC motor with an accessible datasheet. Having access to comprehensive motor specifications and performance data is essential for the effective implementation of a high-precision PID controller, ensuring precise control and optimal system performance.

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