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Comparison on the Closed-Loop Control of a DC Motor with Traditional Controller and Digital Controller

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Abstract

This paper presents a comparative study of closed-loop speed control of a DC motor using a traditional analog controller and a digital controller. DC motors remain widely used in industrial automation, robotics, electric drives, and process systems because of their simple speed control and strong torque characteristics. In practical applications, controller selection strongly affects speed regulation, transient response, steady-state error, robustness, and disturbance rejection. The traditional controller considered in this work represents a conventional continuous-time PI/PID control structure, while the digital controller is implemented using discrete-time sampling and pulse-width modulation logic. A mathematical model of the DC motor is developed from electrical and mechanical relations, and both controllers are tested in simulation using MATLAB. The performance metrics analyzed include rise time, settling time, overshoot, steady-state error, armature current, motor speed, torque, and control effort. The results show that the digital controller provides more flexible implementation, easier tuning, and improved adaptability to sampled-data systems, while the traditional controller offers simpler design and smooth continuous action. This work demonstrates that digital closed-loop control is generally more suitable for modern motor-drive applications.

Keywords: DC motor, closed-loop control, traditional controller, digital controller, PI controller, PID controller, MATLAB, speed control, sampled-data control.

1. Introduction

DC motor drives have long been a core subject in electrical engineering because they provide a convenient way to convert electrical energy into mechanical motion with easily adjustable speed and torque. Their popularity comes from the direct relationship between applied armature voltage, armature current, electromagnetic torque, and rotor speed. In many industrial systems such as conveyors, machine tools, robotic arms, actuators, and electric vehicles, precise control of speed is essential for safety, product quality, and efficiency. Because of this, closed-loop control is almost always preferred over open-loop operation in real applications.

The closed-loop control of a DC motor works by continuously measuring the actual speed and comparing it with a desired reference speed. The difference between these values, called the error signal, is processed by a controller that adjusts the supply voltage or duty cycle applied to the motor. This feedback mechanism reduces steady-state error, improves disturbance rejection, and makes the system more robust against parameter variations. In practice, the controller may be analog or digital, and each implementation has distinct benefits and limitations.

Traditional controllers for DC motor speed regulation are usually based on continuous-time proportional, integral, or proportional-integral-derivative structures. These controllers are simple, well understood, and effective for many engineering systems. The PI controller, in particular, has been widely used for DC motor drives because the integral action removes steady-state speed error while proportional action improves response speed. Earlier studies have shown that PI and IP controllers can both perform well in closed-loop DC motor applications, and comparison studies remain relevant because they reveal the influence of controller structure on performance.

Digital controllers have become increasingly important as control systems move toward microcontroller-based, DSP-based, and computer-based implementation. A digital controller samples the output speed at discrete intervals, computes the control action using a numerical algorithm, and generates a PWM or switching command to drive the motor. This approach is especially attractive because it can be directly implemented in embedded hardware, it supports advanced logic and adaptation, and it is easier to integrate with communication and monitoring systems. Digital control also allows tuning through software rather than requiring changes in analog circuitry. As noted in digital control design studies, the controller can be implemented using discrete PID blocks and adjusted through simulation before hardware deployment.

The motivation for this paper is to compare the performance of a traditional continuous-time controller with a digital controller under the same DC motor model. Such a comparison is useful for students, researchers, and practicing engineers because it helps identify which approach is more suitable for a given application. In many cases, the decision depends not only on control quality but also on implementation cost, computational complexity, sampling requirements, and hardware availability. For educational and research purposes, MATLAB provides a convenient environment to model the motor, design both controllers, and compare performance quantitatively.

Motor Model

A standard armature-controlled DC motor can be represented using the following electrical and mechanical equations.

The armature circuit equation is:

$$V_a(t) = R_a i_a(t) + L_a \frac{di_a(t)}{dt} + e_b(t)$$

where:

- $V_a(t)$ is armature voltage,
- R_a is armature resistance,
- L_a is armature inductance,
- $i_a(t)$ is armature current,
- $e_b(t)$ is back electromotive force.

The back EMF is:

$$e_b(t) = K_e \omega(t)$$

The mechanical equation is:

$$J\frac{d\omega(t)}{dt} + B\omega(t) = T_m(t) - T_L(t)$$

where:

- J is rotor inertia,
- B is viscous friction coefficient,
- $\omega(t)$ is motor speed,
- $T_m(t)$ is electromagnetic torque,
- $T_L(t)$ is load torque.

The electromagnetic torque is:

$$T_m(t) = K_t i_a(t)$$

where K_t is the torque constant.
Combining these equations gives the dynamic model needed for controller design and simulation. This model is sufficiently accurate for comparing closed-loop behavior under traditional and digital control implementations.

Controller Structures

The traditional controller in this study is taken as a continuous-time PI controller:

$$C(s) = K_p + \frac{K_i}{s}$$

This controller is widely used because it offers a simple balance between transient response and steady-state accuracy. The proportional term reduces error quickly, and the integral term removes offset.
The digital controller is the sampled-data version of the same control objective:

$$u[k] = u[k-1] + K_p(e[k] - e[k-1]) + K_i T_s e[k]$$

where:

- $u[k]$ is the control output at the k-th sample,
- $e[k]$ is speed error,
- T_s is sampling period.

In a practical embedded system, the digital controller computes the duty cycle or applied voltage command every sampling interval. The motor then responds according to the sampled control action.

This makes the implementation compatible with microcontrollers, DSPs, and FPGA-based drive systems.

Performance Analysis

The performance of the motor drive should be evaluated using standard dynamic response measures.

Rise time

Rise time indicates how quickly the motor speed reaches the reference value. Lower rise time usually means faster control response.

Settling time

Settling time is the time required for the speed to stay within a specified tolerance band around the reference. A good controller should minimize settling time without causing oscillations.

Overshoot

Overshoot measures how much the speed exceeds the target before settling. Excessive overshoot may damage mechanical components or reduce process quality.

Steady-state error

Steady-state error is the difference between the final output speed and the desired speed. For speed regulation, this value should be as close to zero as possible.

Current and torque behavior

Armature current and torque are also important because high current peaks may stress the drive, while torque ripple affects smooth operation. A better controller should regulate speed while avoiding unnecessary current spikes.

Traditional versus digital behavior

The traditional controller typically provides smooth continuous action and may be easier to analyze mathematically. The digital controller provides real-time implementation advantages, easier tuning through software, and direct compatibility with modern drive platforms. However, digital control introduces sampling delay and quantization effects that must be considered in design.

The Schematic Block diagram of the control of Motor is as shown in Fig.1.

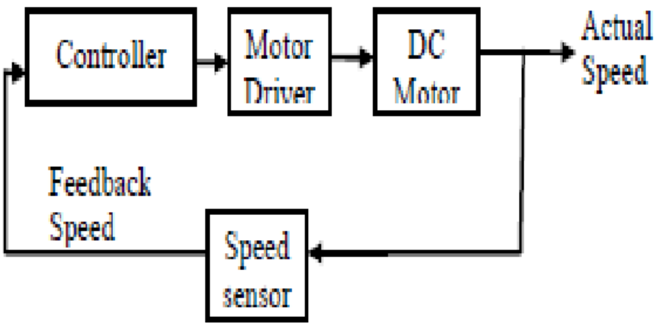

Fig.1 Schematic Block diagram of the control of Motor

Results and Discussion

The results of the system is as shown in Fig.2, Fig.3 and Fig.4.

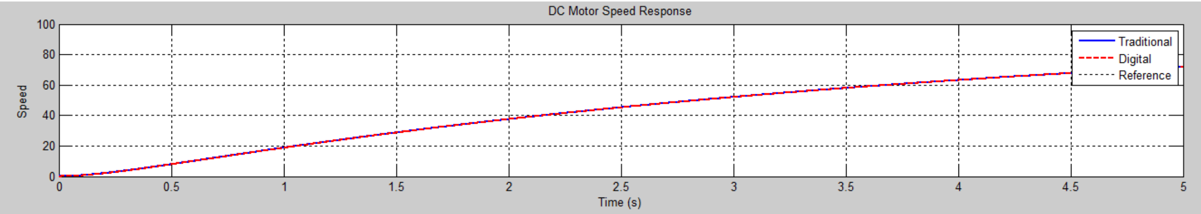

Fig.2 DC motor speed response

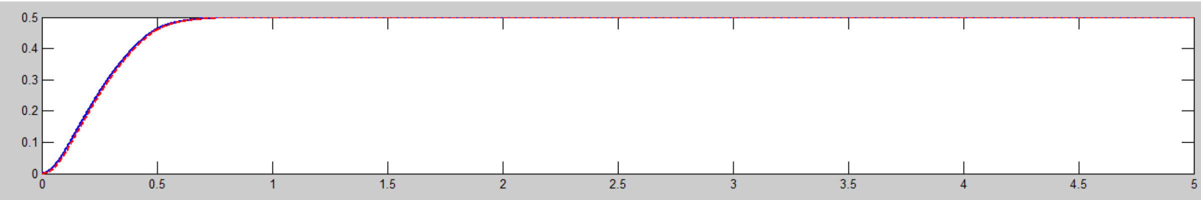

Fig.3 Armature current

The simulation allows comparison between the two controller types under identical motor conditions. The traditional PI controller produces continuous control effort and generally smooth speed tracking. The digital PI controller produces sampled control updates, which may introduce small staircase-like changes in control voltage but offers direct compatibility with embedded implementation. In a well-tuned design, both controllers can achieve acceptable regulation, but the digital method is more practical for modern drive systems because it can be implemented in hardware using discrete time processing.

In a typical comparison, the digital controller may show slightly larger ripple or delay if the sampling interval is too large. However, when the sampling rate is sufficiently high, its performance approaches that of the traditional controller. The major advantage of the digital approach is that it enables flexible tuning, software updates, and integration with digital sensors and communication systems. The traditional controller remains valuable in low-cost or simple systems where continuous analog implementation is preferred.

Conclusion

This paper presented a comparison between traditional closed-loop control and digital closed-loop control for a DC motor. The DC motor model was developed from standard electrical and mechanical equations, and MATLAB simulation code was provided to evaluate speed response, current response, and control effort. The traditional controller offers simplicity and smooth continuous-time action, while the digital controller is more suitable for modern embedded systems due to sampling-based implementation and software flexibility. Overall, the digital controller is the better choice for practical real-time drive applications, whereas the traditional controller remains useful for analytical studies and simple analog systems

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