Scilab case study project on

PID Control of DC Motor

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Abstract:

This case study project focuses on the development and simulation of a DC motor control system using a Proportional-Integrated-Derivative (PID) controller in Scilab. The primary objective is to design a system that efficiently regulates the speed and position of a DC motor by implementing a PID control algorithm. The system's performance is evaluated under various operating conditions, such as step input and disturbance, to assess the effectiveness of the PID controller in maintaining stable motor performance.

In this study, a mathematical model of the DC motor is first derived, considering factors such as electrical and mechanical dynamics. The PID controller is then designed and tuned to achieve desired performance metrics, including minimizing steady-state error, reducing overshoot, and improving response time. Scilab, a powerful open-source software tool, s used for system simulation and controller tuning. The simulation results demonstrate the potential of the PID controller in optimizing motor performance, as well as highlight challenges like parameter tuning and system stability.

This case study provides valuable insights into the application of PID control in motor systems and serves as a foundation for future research in industrial automation and control systems.

Introduction:

In modern engineering systems, controlling the speed and position of motors is a fundamental task, especially in applications involving automation, robotics and electric vehicles. The DC motor (Direct Current motor) is one of the most commonly used types due to its simplicity, reliability and ease of control. However, to achieve precise control of the motor's speed or position, it is essential to use a control technique that ensures stability and accuracy under varying conditions.

Among various control techniques, PID control (Proportional-Integrated-Derivative control) is widely regarded as one of the most effective and versatile methods for motor control. PID controllers are used in many industrial applications because they provide an easy way to control dynamic systems, ensuring the system's output closely follows a desired setpoint with minimal error.

Purpose of the Project:

This project focuses on the design, simulation, and implementation of a PID controller for the speed control of a DC motor using Scilab, a powerful open-source software for numerical computation. Scilab provides a flexible environment for modeling, simulating, and analyzing systems, and is especially useful in control system design.

The objective of the project is to:

- ❖ Model a DC motor using Xcos toolbox in Scilab.
- ❖ Design and implement a PID controller to regulate the motor speed.
- ❖ Simulate the motor's response under different conditions such as load variations and reference speed changes.
- ❖ Tune the PID parameters to achieve optimal performance.

DC motor Basics:

A DC motor is an electromechanical device that converts electrical energy into mechanical energy. It operates on the principle that a current-carrying conductor placed in a magnetic field experiences a force. The torque generated by the motor is proportional to the current in the armature winding and the magnetic field.

The key components of a DC motor include:

- Armature: The rotating part of the motor that contains the coil windings.
- Stator: The stationary part that generates the magnetic field.
- Commutator: A device that reverses the current direction in the armature to maintain the motor's rotation.
- Brushes: Conductors that allow current to flow into the armature.

The motor speed depends on the applied voltage and the load torque, and the speed is influenced by various parameters such as the armature resistance, inductance, and back EMF (electromotive force). A key challenge in DC motor control is maintaining a stable speed under varying load conditions.

PID Controller:

The PID controller is a feedback control system that adjusts the output based on the error between the desired and actual system output. The controller operates by combining three components:

- **Proportional (P):** The proportional term adjusts the output in proportion to the current error. It helps reduce the steady-state error.
- **Integral (I):** The integral term accounts for the accumulation of past errors, correcting any residual steady-state error.
- **Derivative (D):** The derivative term predicts the future error based on the rate of change of the error, helping to dampen oscillations and improve system stability.

The general form of the PID control algorithm is:

$$u(t)=K_p e(t)+K_i \int e(t)dt+K_d de(t)/dt \quad (1)$$

where,

- e(t) is the error (difference between the desired and actual speed).
- K_p, K_i, and K_d are the proportional, integral, and derivative gains, respectively.

By adjusting these parameters, the PID controller can be fine-tuned to achieve optimal performance for the DC motor.

Overview of Scilab:

Scilab is an open-source software that provides a robust environment for numerical computation, data analysis, and simulation. It is widely used in academic and industrial applications for system modelling, control system design, and simulation. Scilab offers several tools, including Xcos, a graphical modelling tool for dynamic system simulation, and a scripting environment for numerical analysis.

Scilab's ability to handle differential equations and run simulations makes it an ideal platform for developing and testing control systems like PID controllers. In this project, Scilab will be used to model the DC motor, implement the PID controller, and simulate its performance under different operating conditions.

Significance of the Study:

The study of PID control for DC motors is essential for many practical applications, where precise control over motor speed is critical. These applications range from small robotics systems to large-scale industrial automation, where speed regulation is crucial for maintaining performance and safety. By simulating the PID controller in Scilab, this project provides a cost-effective and flexible approach to understanding and implementing motor control systems.

In conclusion, this project will not only enhance the understanding of PID control theory but also demonstrate the practical use of Scilab for system simulation and analysis. The successful implementation of the PID controller for DC motor speed control will serve as a foundation for more advanced control strategies and applications in the future.

Description of the work:

DC motors are widely used in various applications requiring precise speed and position control. To achieve accurate control of motor speed, PID control (Proportional-Integral-Derivative control) is a widely implemented and effective technique. In this context, Scilab, an open-source numerical computation software, provides a flexible environment to model, simulate, and control DC motors. Scilab's Xcos simulation tool allows the user to model the dynamic behaviour of DC motors and implement PID controllers for real-time control applications.

This section outlines the PID control strategy for DC motors, its mathematical formulation, and how it can be implemented using Scilab.

Overview of PID Control:

The PID controller combines three fundamental control actions to regulate the system output based on the error between the desired and actual values:

- **Proportional (P):** The proportional term generates an output that is proportional to the current error. This term drives the system toward the setpoint, but by itself, it can result in steady-state error.
- **Integral (I):** The integral term accounts for the accumulated error over time. It helps to eliminate steady-state error by continuously adjusting the control output.
- **Derivative (D):** The derivative term predicts the future error based on the rate of change of the error. It helps to reduce overshoot and damping by counteracting rapid changes in the error.

The general form of the PID control equation is:

$$u(t)=K_p e(t)+K_i\int e(t)dt+K_d de(t)/dt \qquad (2)$$

Where:

- u(t) is the control signal (e.g., motor voltage),
- e(t) is the error (difference between desired speed and actual speed),

- K_p, K_i, and K_d are the proportional, integral, and derivative gains, respectively.

Mathematical Model of the DC Motor

To implement PID control for DC motors, it is necessary to first develop a mathematical model of the DC motor that can describe its behaviour. A typical DC motor can be modelled by the following equations:

- Electrical Equation:

$$V(t)=LdI/dt+RI+Eb$$

Where:

  - V(t) is the applied voltage,
  - L is the armature inductance,
  - R is the armature resistance,
  - I is the armature current,
  - E_b is the back EMF (electromotive force), $E_b = k_e \cdot \omega$, where ω is the angular velocity and k_e is the back EMF constant.

- Mechanical Equation:

$$\mathbf{J d\omega/dt = T_m - T_L} \quad \textbf{(4)}$$

Where,

  - J is the moment of inertia of the rotor,
  - T_m is the motor torque, $T_m = k_t \cdot I$ (where k_t is the motor torque constant),
  - T_L is the load torque.

The motor's speed, ω, is controlled by the applied voltage V(t). The interaction between the electrical and mechanical parts of the system defines the motor's dynamics.

PID Control of DC Motor:

To control the speed of a DC motor using a PID controller, the objective is to adjust the motor's input voltage V(t) based on the error between the desired speed $\omega_{desired}$ and the actual speed $\omega(t)$.

- Speed Error Calculation: The speed error e(t)e(t)e(t) is the difference between the desired speed and the actual motor speed:

$$\mathbf{e(t) = \omega_{desired} - \omega(t)} \quad \textbf{(5)}$$

- PID Control Algorithm: The PID controller calculates the control signal (motor voltage) as:

$$V(t)=K_pe(t)+K_i\int e(t)\,dt+K_dde(t)/dt \quad (6)$$

Where,

- Proportional Term $K_pe(t)$ reduces the error by applying a correction proportional to the current error.
- Integral Term $K_i\int e(t)$ eliminates steady-state error by accumulating past errors.
- Derivative Term $K_dde(t)/dt$ anticipates the future error by considering the rate of change of the error, helping to reduce overshoot and oscillations.

The resulting control signal V(t) is then applied to the motor to adjust its speed. The effectiveness of the PID controller depends heavily on the correct tuning of the three gains K_p, K_i, and K_d.

Implementation of PID Control in Scilab:

Scilab is an excellent tool for designing and simulating control systems, and it includes the graphical simulation tool Xcos for modeling dynamic systems. The implementation of PID control for a DC motor using Scilab involves the following steps:

- **Modelling the DC Motor:** The first step is to model the DC motor's dynamics in Scilab using the electrical and mechanical equations discussed earlier. This can be done using Xcos blocks like Integrator, Gain, and Sum to represent the motor's dynamics and behavior.
  - The integrator block is used to simulate the integration in the motor's equations (e.g., for the current and speed).
  - The gain block represents parameters such as armature resistance, inductance, and motor constants (back EMF constant and torque constant).
  - The sum block is used to compute the error between the desired and actual speed.
- **PID Controller Implementation:** To implement the PID controller, a block diagram can be created in Xcos:
  - Use the sum block to compute the error e(t).
  - Use gain blocks to apply the proportional, integral, and derivative terms.
  - The integrator block is used for the integral term.
  - The derivative block calculates the rate of change of the error for the derivative term.

- **Simulation:** After designing the model, the system can be simulated to observe the motor's response. The simulation allows the user to visualize how the motor speed changes with different values of K_p, K_i, and K_d.
- **Tuning the PID Parameters:** The PID controller's performance is highly dependent on the tuning of the PID gains. These parameters can be manually adjusted in Scilab to achieve the desired motor performance. For example, increasing K_p can reduce the rise time, but too high a value can cause overshoot. Increasing K_i eliminates steady-state error but may introduce instability. The derivative gain K_d can be tuned to improve the system's transient response.

Advantages of PID Control for DC Motors:

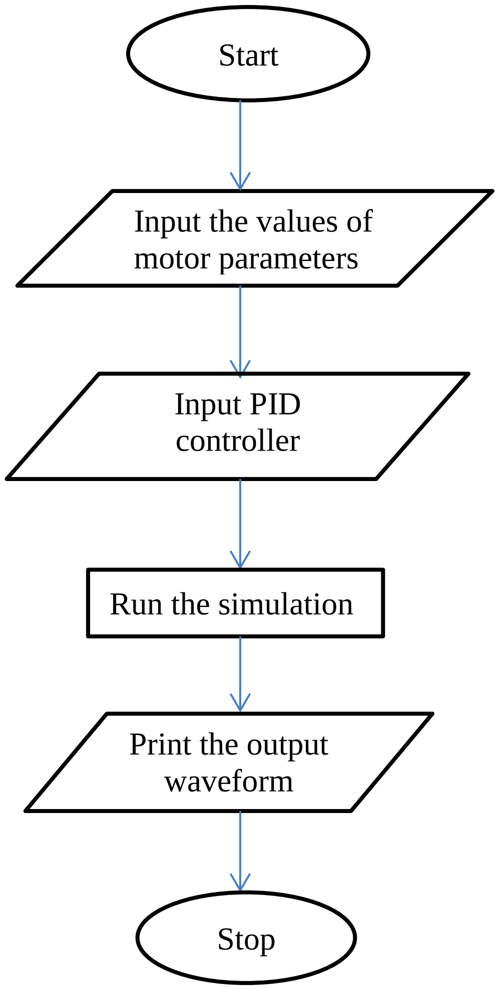
- **Versatility:** PID control is widely applicable for controlling the speed of DC motors in various scenarios, such as robotics, conveyor systems, and automation.
- **Accuracy:** With the proper tuning, PID controllers can achieve very precise control, minimizing steady-state errors and improving the transient response.
- **Simplicity:** The PID control algorithm is straightforward and easy to implement, making it a practical choice for many motor control applications.

Challenges in PID Control:

While PID control is effective, some challenges need to be considered:

- **Tuning Complexity:** Proper tuning of, K_p, K_i, and K_d is crucial. Poorly tuned controllers can lead to overshoot, oscillations, or slow response.
- **Derivative Action Noise:** The derivative term can amplify noise in the system, leading to instability, especially in systems with measurement noise. In such cases, a low-pass filter is often used to smooth the derivative signal.
- **Nonlinearities:** DC motors can exhibit nonlinear behavior under varying load conditions, which can affect the performance of the PID controller.

Flow chart:



Steps to execute the simulation:

1) Open Xcos in scilab.
2) Open DCMotorPID.zcos file.
3) In the simulation set up, enter simulation time.
4) Enter all control block parameters.
5) Run the simulation.

Simulation results:

The simulation block diagram of speed control of DC motor using PID controller is shown in Figure 1. The system is simulated with the following parameters as shown in Table 1.

Table 1 System Parameters

Symbol	**Name**	**Parameter value**
J	Inertia	0.01kg-m^2
L	Inductance	0.5H
R	Resistance	1 ohm
B	Damping coefficient	0.1 N-m-sec/rad
K_m	Motor constant	0.01 N-m/A
K_B	Back-EMF constant	0.01V-sec/rad

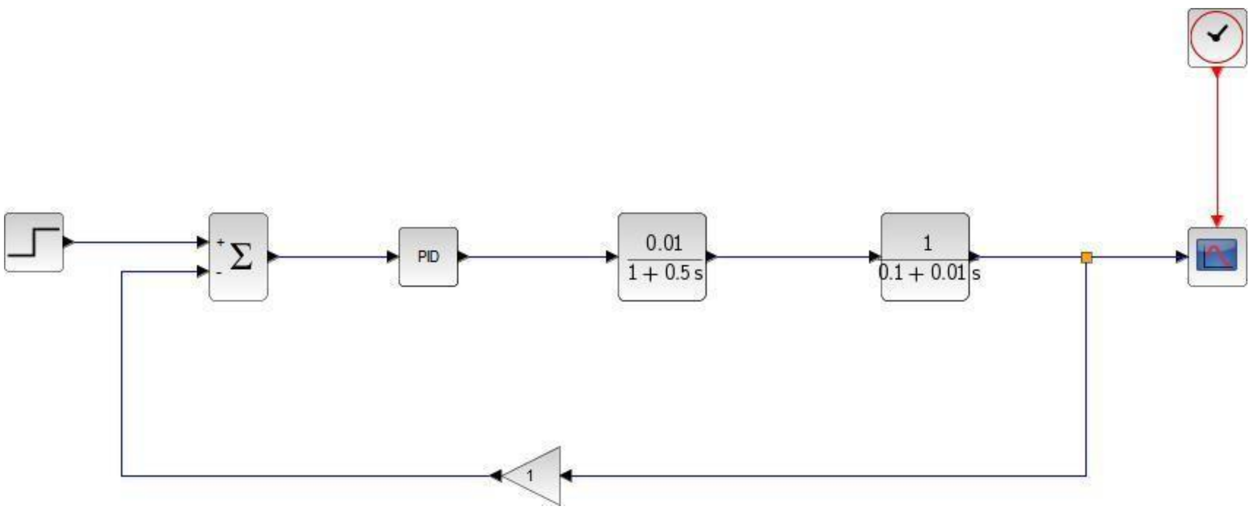


Figure 1 Simulation block diagram of DC motor speed control based on PID controller

The system is tested for three different set speeds of 1000 rpm, 1500 rpm and 2000 rpm respectively and the corresponding speed waveforms are presented in Figures 2, 3 & 4 respectively. The PID controller controls the error between actual and reference speed. The proportional, integral and derivative gain values are chosen as 0.01, 10 and 1 respectively.

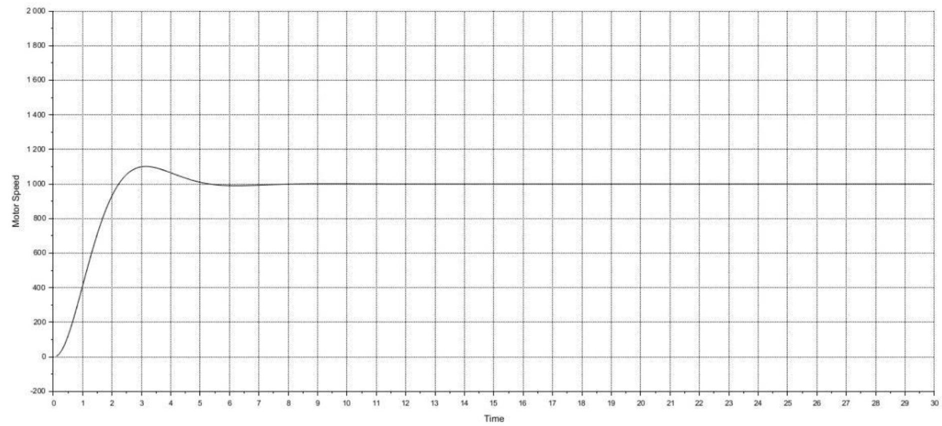


Figure 2 Speed output for reference speed of 1000 rpm

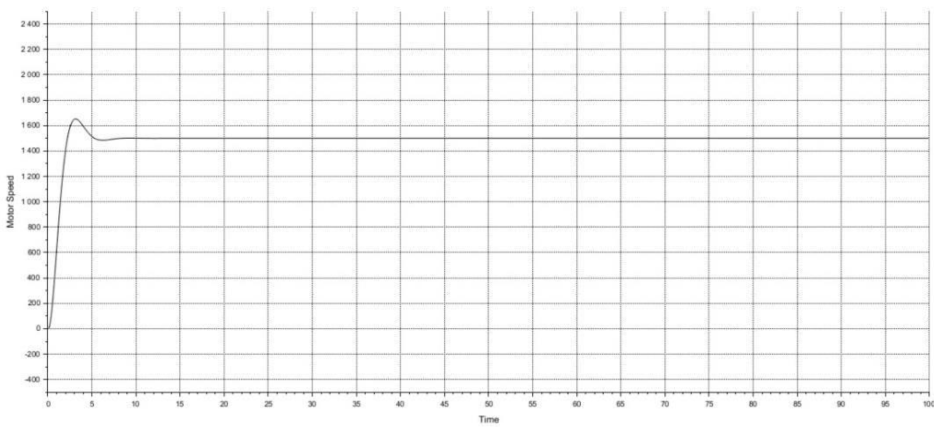


Figure 3 Speed output for reference speed of 1500 rpm

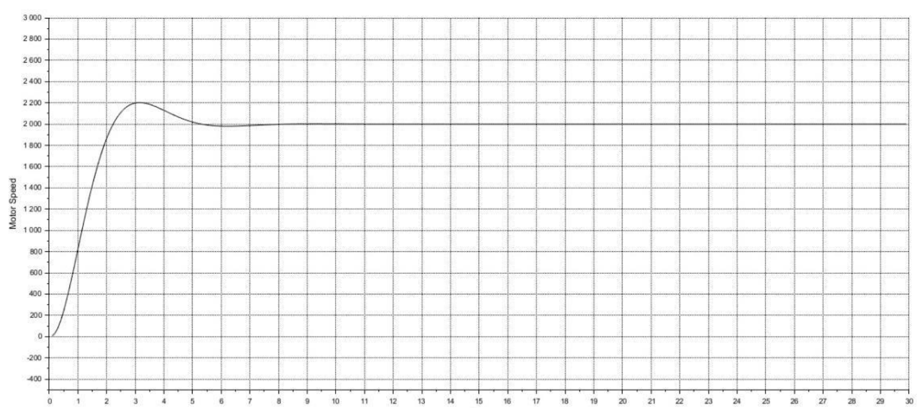


Figure 4 Speed output for reference speed of 2000 rpm

CONCLUSION:

In conclusion, the Scilab simulation of a PID-controlled DC motor showcases the practical implementation and performance of PID controllers in regulating motor speed. The results emphasize the importance of tuning the PID parameters to achieve desired performance, minimizing steady-state errors, overshoot, and oscillations, and ensuring a smooth and stable response. Through such simulations, engineers and control system designers can gain valuable insights into motor dynamics and control strategies before implementing them in real-world applications.

The deviation in waveforms compared with reference paper is due to the different values of gain parameters of the PID controller. Also the speed is given in per unit in the reference paper.

References:

- **Aung Ye Tun. (2018).** "DC Motor Control System with PID Controller." *International Journal of Science and Engineering Applications*, Volume 7–Issue 08,250-253.