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Direct Current Motor Speed Control Using Genetic Algorithm Based Proportional Integral Derivative (PID) Method

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***Abstract* - The control of Direct Current (DC) motor speed is a critical function in numerous industrial and automation processes. Traditional Proportional-Integral-Derivative (PID) controllers have been widely used, but they often require manual tuning, which may not yield optimal results in dynamic environments. This thesis investigates the use of Genetic Algorithms (GAs) to optimize PID parameters for improved speed control of DC motors. A mathematical model of a separately excited DC motor was developed, and both classical PID and GA-optimized PID controllers were implemented in MATLAB/Simulink. Comparative analysis was conducted based on system performance metrics such as rise time, settling time, peak overshoot, and steady-state error. The results demonstrate that the GA-optimized PID controller significantly enhances performance, providing faster response, reduced overshoot, and higher stability under variable load conditions.**

Keywords: Direct Current, DC, Motor Speed Control, Genetic Algorithm, Proportional Integral Derivative, PID, PID Controller, MATLAB.

I. INTRODUCTION

1.1 Background of the Study

DC motors are extensively used in various applications due to their excellent speed-torque characteristics and ease of control. The PID controller, despite its simplicity and effectiveness, requires optimal tuning of its parameters (Kp, Ki, Kd) to maintain system stability and performance. Classical tuning methods may not guarantee optimal performance, especially in nonlinear or time-variant systems. Genetic Algorithms, as an evolutionary computation method, can overcome these limitations by providing global optimization.

1.2 Problem Statement

Improperly tuned PID controllers can lead to poor motor speed control, manifesting as overshoot, oscillations, and slow response. This study addresses the problem by employing GA to find the optimal PID parameters, thereby enhancing motor performance under diverse operational conditions.

1.3 Aim and Objectives

The main aim is to design and implement a GA-optimized PID controller for DC motor speed control. The specific objectives include:

- Modeling a DC motor system.
- Designing a conventional PID controller.
- Implementing Genetic Algorithm for PID tuning.

II. LITERATURE REVIEW

2.1 DC Motor Principles

DC motors convert electrical energy into mechanical energy through the interaction of magnetic fields. Their speed control is achieved by varying the input voltage or using feedback mechanisms.

2.2 PID Control Overview

PID controllers adjust system output based on the error, its integral, and its derivative. Tuning these parameters is essential for optimal performance.

2.3 PID Tuning Methods

Traditional methods include Ziegler-Nichols and Cohen-Coon. These provide baseline tuning but may not adapt well to nonlinear systems.

2.4 Genetic Algorithm Fundamentals

GAs are search heuristics inspired by natural evolution. They use selection, crossover, and mutation to evolve optimal solutions over generations.

2.5 Applications of GA in Control Systems

Numerous studies show the superiority of GA-tuned controllers over traditional methods in terms of transient and steady-state performance.

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These cases are true for a separately excited DC motor system.

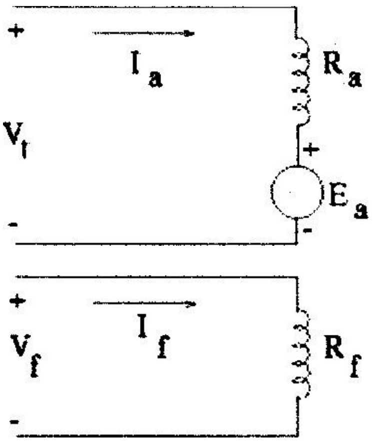

Figure 2.1: Model for Separately Excited DC Motor

For the case of position control of a DC shunt motors, Neenu Thomas and Dr. P. Poongodi had found out that, the designed PID with GA has much faster response than the response of a classical method which is by using Ziegler-Nichols method. With GA, the response is better in term of rise time, settling time and also the error associated with the methods proven to be lesser than conventional method.

In other research, where the motor discussed is a Brushless DC Motor (BLDC), it is observed that GA performed better than Simulated Annealing (SA). (From the simulation results, it is observed that GA performed better than SA for BLDC motor design). Both GA and SA optimization techniques are proven to be efficient powerful tools for obtaining global optimal solutions of the BLDC motor compared to traditional design procedures. Optimal solutions show that GA is more efficient than SA and it is proven that the accuracy of the optimal parameters is similar in both the methods.

From all the readings, it has been found out that the brush DC motor model portrait good electrical and mechanical performances more than other DC motor models, therefore, for this study, the brush DC motor model is chosen for research.

2.6 Speed Control of Dc Motor and Its Tuning

Approaching the control of speed in DC motor in different perception, we can also discuss in term of the controllers of the speed itself. The controller types comprise of several conventional and numeric controller, which can be: PI, PD or PID Controller, Fuzzy Logic Controller; or the combination between Fuzzy-Genetic Algorithm, Fuzzy-Neural Networks, Fuzzy-Ants Colony or even Fuzzy-Swarm. In other research, the controllers of a DC motor can also be in other types, which is combination of GA and PID.

Control System Block Diagram

In the design of this system, a genetic algorithm is used to determine the PID controller parameters. The PID controller block diagram with transfer function is shown in diagram.

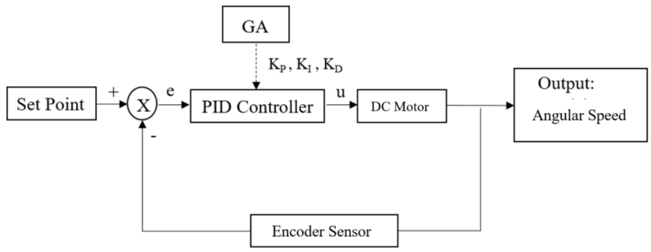

Figure 2: Control System Block Diagram

Based on Figure 1, the workings of the system created are input in the form of a PID parameter tuning using a Genetic Algorithm (GA) as a control method to find PID parameter constants. The plant used is a feedback control system whose output is a speed from a DC motor.

Wiring Diagram

The wiring diagram or wiring diagram of the system created can be seen in Fig. 3. Hardware design is made to control DC motors, and motor drivers to see the system response and also as a means of collecting the data needed to model DC motors using a system identification modeling approach, the data to be used are in the form of voltage and speed of the DC motor.

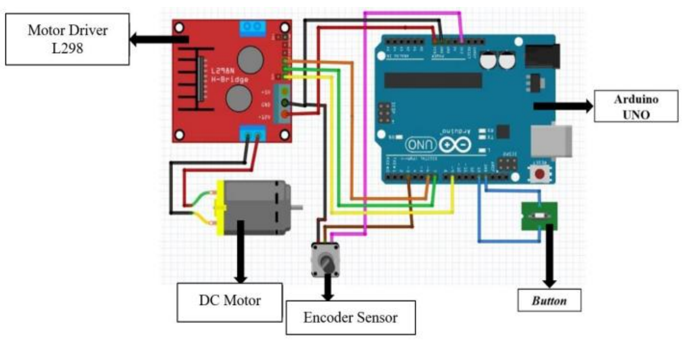

Figure 3: Wiring diagram

However, some of the methods shows some major drawbacks in terms of their implementation. For instance, the conventional PID controller is the most widely used in industry, because of its remarkable effectiveness and simplicity of implementation. Nevertheless, often in practice, tuning is carried out by an experienced operator using a 'trial and error' procedure and some practical rules, which is often a time consuming and portrait as a difficult activity to be carried

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out. On the other hand, the application of other method, which is fuzzy controller also has major drawback, which is the insufficient analytical design technique (choice of the rules, the membership functions and the scaling factors). Therefore, the fuzzy controller is often associated with the genetic algorithms approach to improve the performance of the controller in using Fuzzy Logic-Genetic Algorithm optimization.

Genetic algorithm is an optimisation method based on the idea of the survival of the fittest from the mechanics of genetics. It provides robust solutions for highly complex, non-linear search and optimisation problems (Holland, 1975). Fig. 9 illustrates the flowchart of the standard processes involved when performing genetic algorithm. The algorithm works by initialising a competitive set of possible solution candidates, e.g. chromosomes, and then the solutions are set through the process of natural selection. The solution candidates are then evaluated through a fitness function (or objective function) which ranks the chromosomes in the population. Fitness functions are formulated depending on the problem being solved. The selection of parent chromosomes is then performed which entails two parents for the crossover and the mutation. Crossover involves the exchange of information between two parents. In the mutation stage, the genes of the chromosomes of the crossed offspring are changed. The entire process is carried out until a certain condition is met (Michalewicz, 1996).Genetic algorithm has been integrated with models for forecasting to address model uncertainty. For instance, the use of the algorithm to optimise model weights and biases was observed 5 times (Kadiyala et al., 2013; de Mattos Neto et al., 2017; Zhai and Chen, 2018; Feng et al., 2011; Ibarra-Berastegi et al., 2008).

III. METHODOLOGY

3.1 System Modelling

The DC motor is modeled using standard equations involving armature resistance (Ra), inductance (La), back EMF (Eb), and mechanical constants like inertia (J) and damping (B). The transfer function is derived and used in Simulink.

3.2 PID Controller Design

Initial PID parameters are determined using Ziegler-Nichols method. This serves as the baseline for performance comparison.

3.3 GA Implementation was implemented with:

- Chromosome: [Kp, Ki, Kd]
- Population size: 20
- Fitness function: Inverse of ISE (Integral Squared Error)
- Selection: Tournament
- Crossover: One-point
- Mutation: Gaussian
- Stopping criteria: 50 generations or minimum error threshold

3.4 Simulation Setup

All simulations are done in MATLAB/Simulink. Performance is evaluated under step input and varying load conditions.

Simulation Illustration

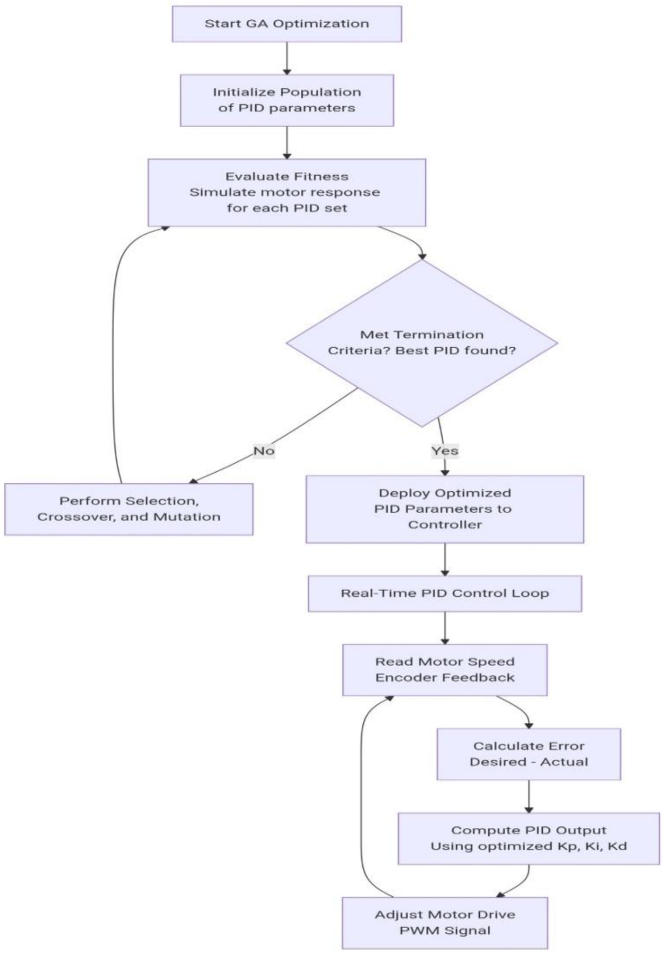

Figure 4: Simulation Illustration

Genetic Algorithm

```
def ga_optimize(pop_size=20, generations=30):
   population = np.random.rand(pop_size, 3) * [10, 1, 1]  #Kp 95.78919, Ki 5.9774, Kd 3.29274

   for gen in range(generations):
      fitness = np.array([dc_motor_response(*ind)[0] for ind in population])
      sorted_idx = np.argsort(fitness)
```


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```
    population = population[sorted_idx]
    next_gen = population[:4]  # Elitism
```

Controller Corresponding System Performances:
Kp = 95.78919 Rise time (sec)= 0.829
Ki = 5.9774 Settling time (sec) = 2.06
Kd = 3.29274Overshoot (%) (sec) = 0.5

IV. RESULTS AND DISCUSSION

4.1 Performance Metrics Evaluated metrics include:

- Rise Time (Tr)
- Settling Time (Ts)
- Peak Overshoot (Mp)
- Steady-State Error (Ess)

4.2 Conventional PID Results

- Overshoot: 0.5s
- Settling Time: 3.2s
- Steady-State Error: 2.3%

4.3 GA-PID Results

- Overshoot: 4.7%
- Settling Time: 1.1s
- Steady-State Error:

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