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IMPLEMENTATION OF HYBRID PID CONTROLLER BASED ON GENETIC ALGORITHMS FOR MODULAR SYSTEM POSITION CONTROL

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Abstract— An examination of the nonlinear characteristics of DC servomotors, along with the design challenges and mechanical variations associated with different operating conditions reveals that a conventional Proportional – Integral – Derivative (PID) controller alone cannot achieve precise control. This study introduces an enhanced approach to optimize DC motor control in position mode by minimizing transient response characteristics including overshoot, rising time (t_r), and settling time (t_S). A genetic algorithm (GA) was employed to determine the optimal self-tuning parameters for K_P, K_I, and K_D. The study was conducted in three phases; first, the system was configured using the standard controller; second, the standard controller was replaced with the GA algorithm, with the integral time absolute error (ITAE) selected for the performance criterion for the DC servomotor control system; finally, a hybrid controller was developed by integrating the GA controller with the standard controller. Simulation results indicate that this dual controller achieves remarkable accuracy in control response, with a minimal overshoot increase of 1.667%, a 19.83% reduction in rise time (t_r), a 29.18% decrease in settling time (t_S) and a steady state error of 9.373% for the DC servomotor in position mode.

I. Introduction

A DC servo motor is an electromechanical actuator that converts electrical power into mechanical power [1]. It is the application of Lorentz law, which states that electricity is present in a conductive wire in a magnetic field [2]. Servo motors are considered one of the main technologies of automatic control systems and have been developed in several ways while serving vital tasks [3]. It has been widely accepted in industrial motion control due to its substantial qualities, such as energy savings, rapid response, low noise level, low production cost, high control precision, and torque-to-inertia ratio [4]. Servo motor systems are simple low-order systems without designing or implementation problems [5-6]. However, load influences have an obstructing effect on the system's response.

The controller design aims to increase the model's performance and permit dependable operation. The servo motor's response can be affected not only by external disturbance input but also by mechanical properties such as inertia and friction [7-8]. The current research involves the modular servo 33-927 (MS-927) manufactured by Feedback. The PID controller has good control performance but is not sturdy enough to withstand disturbances, as shown in Figure 1.

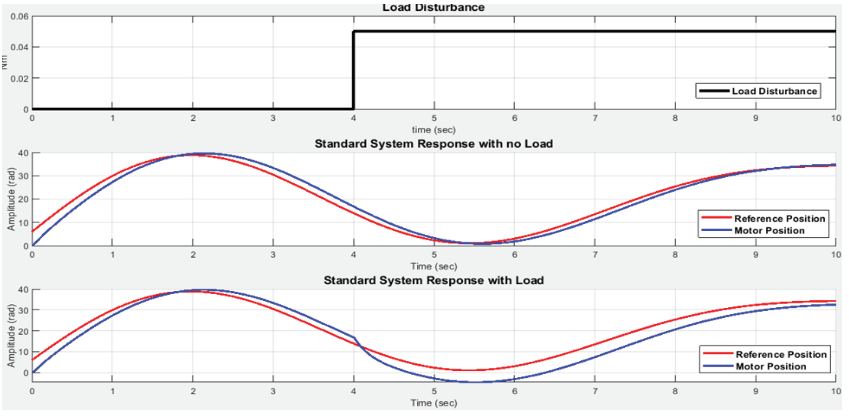

Figure 1: Simulation of a modular servo system with the standard PID controller operating with and without Load

An earlier study [9] introduced a Fuzzy logic controller (FLC) to optimize the modular servo performance. The researchers compared the outcomes of both controllers, which approved the reliability of FLC for the system response. Moreover, the control model blends PID conventional controllers with intelligent approaches as a Fuzzy-PID controller [10]. Results demonstrated that the fuzzy-PID controller has outperformed both the individual fuzzy controller and the PID controller.

In this research, the genetic algorithm (GA) technique is suggested to be combined with a standard PID controller provided by Feedback company with the modular servo to enhance the system performance. The GA is a search and optimization approach based on natural selection and genetics processes; it is suitable for handling nonlinear dynamics such as servomechanisms.

II. The Servomotor Model

The servo motor is an electrical engine used in servo frameworks. A servo control structure is a closed-loop system in which the motor is controlled through a feedback signal of actual position or speed. This indicator acts as an error; an accurate position and speed is achieved depending on the compensator.

The mathematical equations derived from the Kirchhoff voltage law are as Equation (1) and (2).

$$v(t) = R\, i(t) + L\frac{di(t)}{dt} + Vemf(t) \quad (1)$$

$$T_e(t) = K_f\omega(t) + J\frac{d\omega(t)}{dt} \quad (2)$$

When the motor is rotating, back emf, $e(t)$, is generated and is proportional to the angular speed, $\omega(t)$, by a back emf constant $K_b(t)$, that is in Equation (3).

$$Vemf(t) = K_b\omega(t) \quad (3)$$

Also, the motor torque, $T_e(t)$, is proportional to the armature current, $i(t)$, by a motor torque constant K_t as shown in Equation (4).

$$T_e(t) = K_t\, i(t) \quad (4)$$

The transfer function of servomotor speed mode as shown in Equation (5).

$$G_1(s) = \frac{\omega(s)}{u(s)} = \frac{K_t}{JLs^2+(JR+K_fL)s+K_fR+K_tK_b} \quad (5)$$

To convert the system to position mode:

$$\omega = \dot{\theta}$$

$$G_1(s) = \frac{\omega(s)}{u(s)} = \frac{s\theta(s)}{u(s)}$$

Thus, the transfer function will be as Equation (6).

$$G_2(s) = \frac{\theta(s)}{u(s)} = \frac{G_1(s)}{s} = \frac{K_t}{JLs^3+(JR+K_fL)s^2+(K_f+K_tK_b)s} \quad (6)$$

III. Methodology

The control algorithm ensures the system works as intended, sustains stability, and responds properly to environmental change [11]. Control algorithms are classified into numerous types, such as PID Control, Adaptive Control, Optimal Control, Fuzzy Logic Control, etc.[12]. The current study has been interested in three types of controllers, the conventional PID controller, genetic algorithm-based controller, and combining both as cascade controllers to design a hybrid

GA-PID controller as proposed in Figure 2 to reach the optimum value of the P, I, and D gains, in addition to the existing standard PID controller, to enhance the overall system performance.

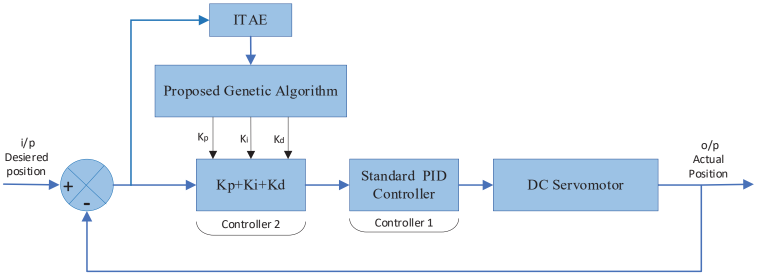

Figure 2: The Hybrid Genetic Algorithm (GA-PID+ Standard PID) scheme

A PID controller is utilized to control the system and minimize error. In the closed-loop system, the feedback signal is compared with the reference point signal, which is defined initially. The PID controller uses the difference error signal to control the required plant. In the present research, the PID controller has already been designed and provided by Feedback. The system's transfer function, including the PID controller, is presented in Figure 4.

A genetic algorithm (GA) is an optimization method that takes inspiration from the concepts of selection and evolution. It aims to produce solutions for search and optimization tasks [13]. The core concept behind algorithms is to mimic the process of evolution to generate a population of potential problem solutions (when the system works under various conditions) over multiple generations [14].

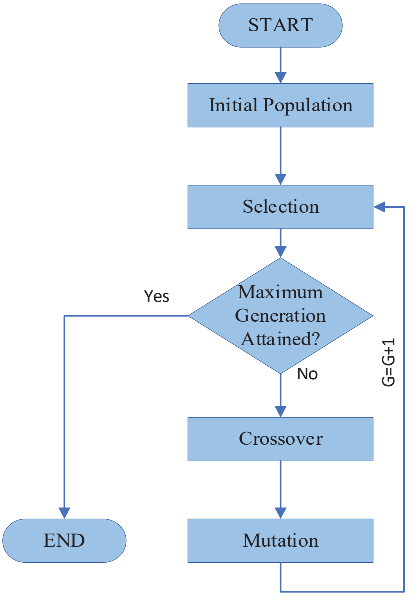

Figure 3: The working sequence of the GA

A hybrid controller integrates elements or techniques from many controllers to improve process or system performance, efficiency, or versatility [15]. The term hybrid denotes combining or integrating various control systems [16]. The PID, fuzzy logic, genetics, adaptive control, module predictive control, and other control algorithms can be used in hybrid controllers to leverage the characteristics of each method and increase overall system performance [17-18].

Obtaining the optimal parameters K_P, K_I, and K_D in the GA using the optimization toolbox in MATLAB. In the coding file, the fitness function must be defined before being established into the *optimtool* box in the command window. The ITAE is chosen as the fitness function. The parameters are listed in Table 1. Figure 6 illustrates the GA working sequence.

Table 1: Genetic Optimization Toolbox Parameters

Number of Variables	3
Lower bound	[0 0 0]
Upper bound	[5 5 5]
Population type	Double vector
Population size	30
Selection function	Stochastic uniform
Elite count	2
Crossover function	0.8
Mutation function	Constraint dependent
Crossover function	Scattered

The sequence of the GA flowchart in Figure 3 execution is as follows:

a. The output variables are defined as K_p, K_i, and K_d. The ITAE is the fitness function.
b. The initial population of 30 has been established. For the present system, three outputs and a small number of populations are sufficient to improve accuracy. A bigger number of populations will

increase simulation time. From the individuals in the generation, MATLAB will generate a new population.

c. The initial population of 30 has been established. For the present system, three outputs and a small number of populations are sufficient to improve accuracy. A bigger number of populations will increase simulation time. From the individuals in the generation, MATLAB will generate a new population.
d. As shown in Table 1, the lower bound [0 0 0] and upper bound [5 5 5]. The value of the upper bound has been selected by trial and error, which is crucial to reducing the iteration time.
e. Each individual's fitness is evaluated based on the function value. A low value indicates high fitness, while a high value suggests lower fitness.
f. Only the best-fit individuals are selected as parents.
g. Creating a new population by picking the best-fit parent to breed through crossover and mutation. In this research, the elite count is 2, meaning that only a small number of low-fitness individuals are chosen to be inherited by the new population in the next generation.
h. The parents in Crossover and mutation are used to create new children for the next generation.

The sequence is repeated until the output satisfies the stopping criteria. For each generation, the iteration tries to reach the fitness function's zero value.

IV. Results and Discussions

This study investigates three control models. Firstly, the control system that uses the standard PID controller, which the manufacturer provided with the MS-927. Then, swap the current PID controller with the GA-PID. In the last step, Configure the dual controller GA-PID with the standard PID. This study investigates three control models. Firstly, the control system that uses the standard PID controller, which the manufacturer provided with the MS-927. Then, swap the current PID controller with the

GA-PID. In the last step, Configure the dual controller GA-PID with the standard PID.

The standard PID controller is the first performance test for modular servo; the work will be conducted on the system, as shown in Figure 7. The manufacturing company already designed the PID controller; the parameters were K_P=0.0357, K_I=0.00714, and K_D=0. In the position mode, the rising time is 0.3106, the overshoot is 2.8866%, the settling time is 2.9602, and the error steady state is 0.0160, as shown in Figure 1 Step Response of System with Standard PID Controller in Position Mode in Section I. The manufacturer's predefined PID controller has a limited precession level in the no-load scenario and decreases slightly with the actual load; as illustrated in Figure 1, the system takes five seconds to return to stable states in position modes.

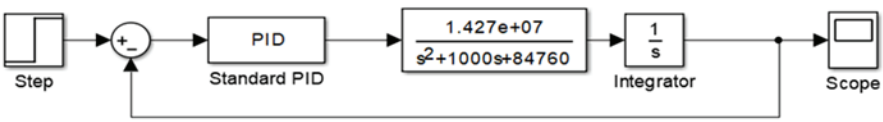

Figure 4: The control close loop of the standard system

The second strategy is replacing the standard PID with the GA-PID algorithm controller, as shown in Figure 5. The system's response was evaluated using GA. The integral time absolute error (ITAE) control specification for the DC servo motor control system was adopted. The data system's response was obtained according to MATLAB. The optimal output results were K_P=1.225, K_I=4.896, K_D=002. As shown in Figure 6, the system's response is very fast. The rising time is very small (0.0070); the overshoot is high (46.4457%). The settling time is (0.0933 sec) with (0.0065) steady-state error, close to zero. The high value of overshoot results in vibrations and noise that can potentially damage some of the system components and reduce their lifespan.

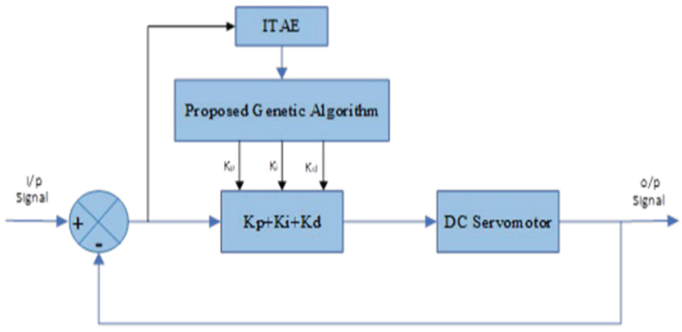

Figure 5: The closed loop system with GA-PID algorithm

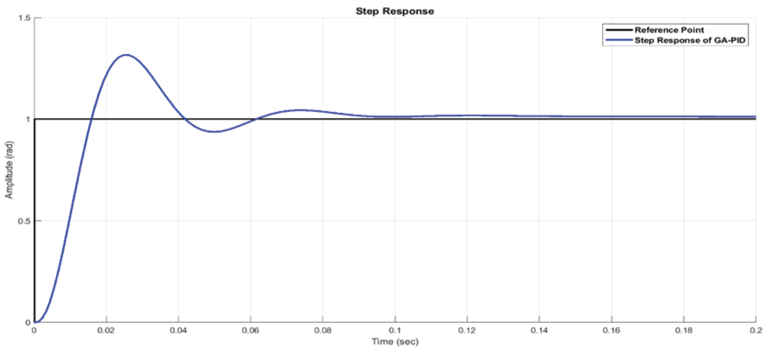

Figure 6: System response of GA-PID controller

Figure 7 shows the modular servo system's response, comparing it to the standard system's response and the system with the GA-PID added. The GA algorithm's optimizing values of P, I, and D fully eliminated the inaccuracy of a stable state. There was an unstable system signal from 0 until 0.2 seconds, then the input and output signals matched, and the system's response error under load dropped to zero.

The last stage is implementing a hybrid controller combining the GA-PID with the standard PID as a cascade dual controller, as shown in Figure 5. The GA seeks to determine the optimal value of the PID parameters to support the standard PID controller and enhance the whole system's performance. The output parameters were K_P=4.992, K_I=5, K_D=0.02. The rising time is (0.0616 sec), with low overshoot (4.4954 %), settling time (0.8638 sec), and

(0.0015) steady-state error, which is close to zero, as illustrated in Figure 8. The system's behavior is improved, as shown in Figure 9; the system simulation shows that the error between both signals, the reference and motor positions, is reduced, and the system response time under load decreases from 6 to 0.9 sec to reach the stable state again.

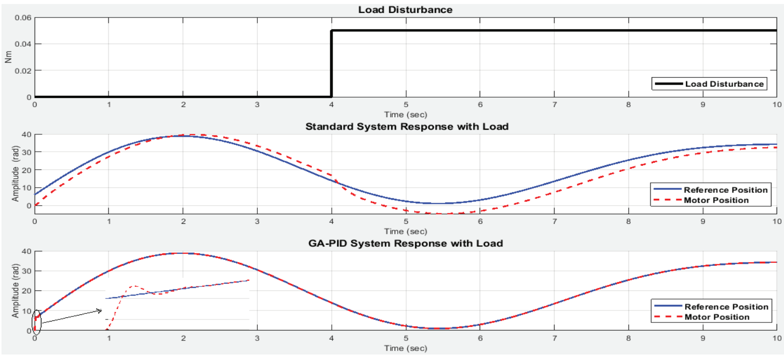

Figure 7: The modular servo system response with the GA-PID controller

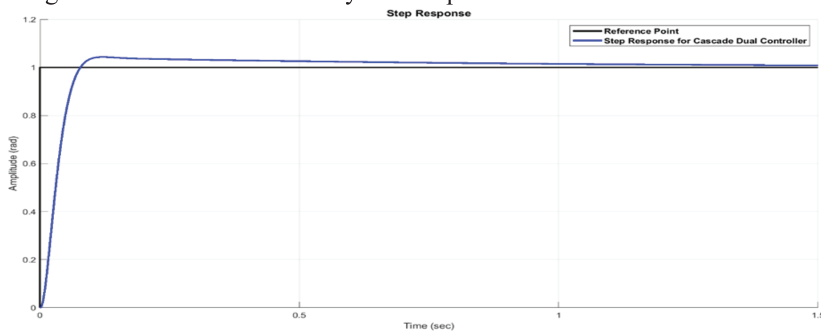

Figure 8: Step response of the cascade controller

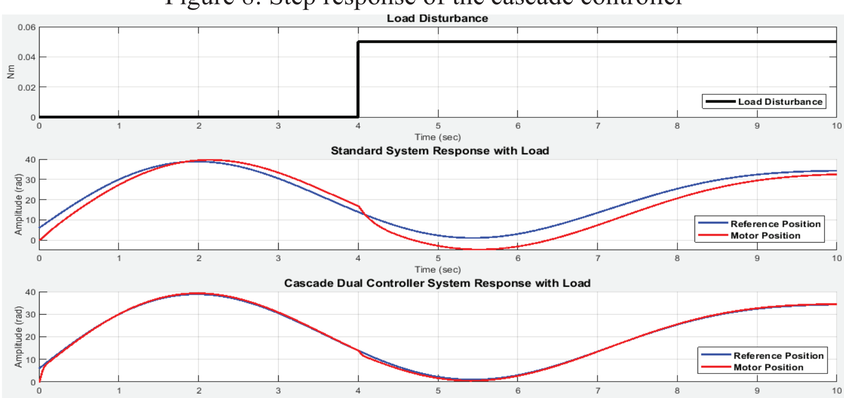

Figure 9: The modular servo simulation with the Hybrid (cascade) controller

As presented in Figure 10, the GA-PID controller has a fast response with a high overshoot of 46.445%; this high value causes vibration and noise in the system. Otherwise, the system response of dual controller, with a slightly higher overshoot of 1.667% more than the standard PID controller, a shorter percentage response time with the tr 19.83%, t_S 29.18%, and the error steady state 9.373%, and a smaller overshoot compared to the conventional PID controller. Table 2 illustrates the system step response results; it is determined that, compared with the conventional PID controller, GA-PID controller, cascade dual controller (GA-PID + Standard PID), and the FLC from an earlier study. The Cascade dual controller approved a better dynamic response curve under the disturbing load. The controller displays excellent efficiency and distinctive performance in tracking the motor position mode compared to other recommended and earlier explored controllers.

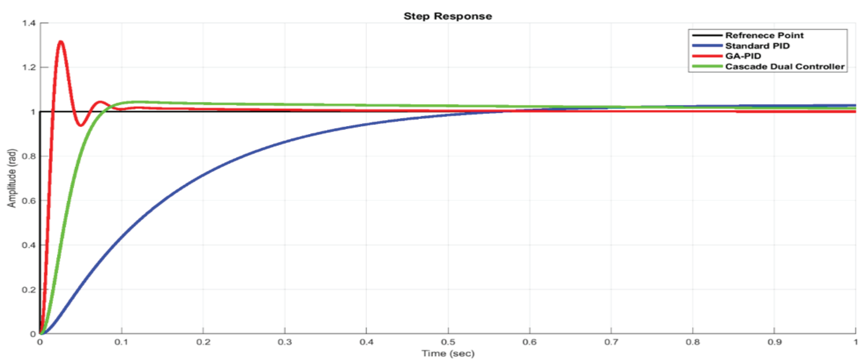

Figure 10: System step responses comparison for each controller

Table 2: Step response comparison of characteristics of each controller

Controller \ Parameters	t_r (sec)	Overshoot %	t_S (sec)	E.s.s.
Standard PID	0.3106	2.8286	2.9602	0.0160
GA-PID	0.0070	46.4457	0.0933	0.0065
GA-PID+ Standard PID	0.0616	4.4954	0.8638	0.0015
FLC	0.400	16	0.100	0.0197

V. Conclusion

This study focuses on utilizing a Hybrid Genetic Algorithm (GA) to optimize the parameters of a PID controller. The system's performance was compared against traditional PID, Genetic-PID controllers, and Fuzzy Logic Controllers (FLC) from previous research. The Integral of Time-weighted Absolute Error (ITAE) was chosen as the fitness function for this evaluation. Performance metrics included rise time, settling time, percentage overshoot, and steady-state error. The results indicate that the hybrid (cascade) controller outperforms both GA-PID and standard PID controllers. Simulation results demonstrated that the hybrid controller achieved moderate values in comparison the other proposed controllers. The cascade controller exhibited effective automatic control by reducing steady-state error and successfully tracking reference signals even when load variations occurred due to external disturbances. Overall, the findings are consistent, reliable, and satisfactory. The application of hybrid controller in control systems and industrial processes shows significant potential for improvement.

VI. Acknowledgement

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