**Performance Enhancement of Speed and Position Control for DC Servo Motor Using Artificial Intelligence Technique**

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**Abstract**: Servo motors were often used in many industrial position control applications, it features a feedback control system to modify the performance of a mechanism. Also with the high accuracy in its angle movement, so it has important in industrial life. It has numerous advantages, such as easy controllability, high efficiency, and control of the position applications.

In this paper, different control strategies such as PID controller, fuzzy logic controller (FLC), and fuzzy with PID controller were used to control the position and speed of servo motors. The tuning methodology improved the response of characteristics by reducing the rise time, settling time, and maximum overshoot in position control of DC servo motors. A comparison between all types of controllers was achieved. The simulation is verified by using the MATLAB program, also a process of practical experience using (Analogue Servo Fundamentals Trainer 33-002) for decreasing the steady-state error.

**Keywords**: DC Servo Motor, Fuzzy Logic Controller (FLC), Proportional Integral Derivative (PID)

**1. Introduction**

The servo engine operates within a closed system, in which information and data are used on the image of the signals coming from the machine to be moved to control or speed of their movement [1-5]. The strength of the control system depends on the number of relevant signals, the more given the reliability system. Servo motors between DC and AC motors are different from the electrical source. The impact servo motors are distinguished by their simplicity of installation and cheapness due to the absence of brushes, uniform members, or slip rings, thus they almost do not need maintenance, which increases their life, and are also characterized by small electrical components, which improve their efficiency. Large efforts have been made to improve DC servo motors control systems, the primary goal is to raise their efficiency and increase flexibility in their control systems [5-10].

Precise control of the servo motor was an important subject in the industry the error rate was reduced in production processes requiring high precision. Therefore, PWM was used for the control signal to determine the rotation angles of the servo motor. Through this system, motors operating at full torque and high speeds were obtained. Servo motors contain the actual position sensors of the motor shaft that were connected to the control unit [11-16].

Most industrial projects use linear controllers; it was suitable in simple cases. In complex cases, intelligent control systems were required, the comparison process was made between systems (PID & fuzzy PID), and the mathematical model was created by using MATLAB. The process of studying was found that the system reached stability in a faster time than PI & PID, so it was shown their importance to results [17].

Due to their high-power rating and motor speed, DC servo motors were favored. A real-time closed-loop control strategy was presented, with position control received by a position sensor and coupled to the motor shaft to generate a position feedback signal. When compared to a
traditional PI controller motor, the FLC provides higher dynamic performance and is more robust for industrial site control drive applications [18-22].

In [23], most of the current methods used PID controllers, because it was the cheapest, but it was disappointing that it was not effective and needed delay time, so the treatment was done with FLC. In this way, the time and control of the DC servo motor were set, and a simulation was also carried out using the MATLAB program when the controller created using fuzzy logic was compared to PID control, which was a standard control approach and extensively used in industrial applications, the fuzzy logic controller showed better results in position control.

In [24], The Firefly Algorithm was applied to self-adjust the PID parameters, and the PID controller was employed to operate the DC servo motor. PID control ability has been improved. Most main problems occur in a very slow and inaccurate method. To create an optimal FA, an inertial weight and tuning factor were included. The inertia weight increases the influence of the firefly's current position on its next position. The adjustment factor increases the accuracy of the later optimization by speeding up convergence in the early iterations.

A servo motor is controlled to give the best performance by using many methods to reach the target position [24-30], the first method is using a conventional PID controller, second method fuzzy logic controller in this method is reduce rising time compared to the previous method, The third technique is regulated by combining a PID controller and a fuzzy logic controller to reduce system overshoot. In this method, the system gives the best performance.

In this paper comparisons of the different controllers for position and speed with different loads. Different strategies for controlling DC servo motors, such as parallel PID controllers, have been used to track DC servo motors. Ideal PID and comparison between two types for know best controller, the second type of controller using Fuzzy logic controller, the third type of controller using PID controller and fuzzy logic together use in the same time. Apply simulation on MATLAB for all previous methodology for the investigation of dc servo-motor performance with different loads.

2. Methodology

Figure 1 shows the speed [1-23] and position [24-30] control of the DC servo motor by using a different methodology. Comparison between PID, fuzzy PI, and fuzzy PID concerning rising time, settling time, and overshoot sit is seen that the fuzzy controller safeguards the fancied reaction, even within the sight of burden unsettling influence and changing control situations.

![Figure 1. Methodology of the controller of DC servo motor.](image)

Figure 2 shows a block diagram of a parallel PID controller controlling the speed and position of a DC servo motor. Ideal PID and comparison between two types for know best controller, the second type of controller using fuzzy logic controller, the third type of controller using PID controller and fuzzy logic together use in the same time [10-24].
**Figure 2. Block diagram of DC servo motor speed and position control**

Form [31], \( e(t) \) is the system error, \( \theta_{\text{ref}}(t) \) is the reference position, and \( \theta(t) \) is the actual location (1)

Traditional PID type controller's time-domain representation:

\[
e(t) = \theta_{\text{ref}}(t) - \theta(t) \tag{1}
\]

\[
m = k_p e + \frac{1}{T_i} \int e \, dt + \frac{1}{T_d} \frac{de}{dt} + b \tag{2}
\]

Laplace transforms of (1) and (2) are DC servo system equivalent circuit diagrams as following

\[
V_a(s) = R_a I_a(s) + L_a I_a(s) - K_b \cdot w(s) \tag{3}
\]

\[
K_m \cdot I_a(s) = J_m \cdot w(s) - (R_a B_m + K_b K_m) \tag{4}
\]

If the current is obtained from (4) and substituted in (3) we have.

\[
V_a = w(s) \frac{1}{K_b} \left[ L_a J_m S^2 + (R_a J_m + L_a B_m) + (R_a B_m + K_b K_m) \right] \tag{5}
\]

Then there's the Transfer function, which represents the relationship between rotor shift speed and applied armature voltage

\[
\frac{W(s)}{V_a(s)} = \frac{K_m}{[L_a J_m S^2 + (R_a J_m + L_a B_m) + (R_a B_m + K_b K_m)]} \tag{6}
\]

Thus, the relationship between position and speed can be found

\[
\theta(s) = \frac{w(s)}{S} \tag{7}
\]

When there is no load, the transfer function between shaft position and armature voltage is:

\[
\frac{\theta(s)}{V_a(s)} = \frac{K_m}{[L_a J_m S^2 + (R_a J_m + L_a B_m) + (R_a B_m + K_b K_m)]} \tag{8}
\]

Where are \( V_a \) = armature voltage (V), \( R_a \) = armature resistance (\( \Omega \)), \( L_a \) = armature inductance (H), \( I_a \) = armature current (A), \( E_b \) = back emf (V), \( \omega \) = angular speed (rad/s), \( T_m \) = motor torque (N-m), \( \Theta \) = angular position of rotor shaft (rad), \( J_m \) = rotor inertia (kg-m\(^2\)), \( B_m \) = Motor viscous damping coefficient, \( T_d \) = disturbance load, \( b \) = constant, \( S \) = Displacement, \( m \) = output of PID controller, \( K_b \) = Back emf coefficient, \( K_m \) = torque coefficient, \( e(t) \) = error of system, \( \theta_{\text{ref}}(t) \) = reference position, \( \theta(t) \) = feedback position, \( k_p \) = Proportional gain, \( T_i \) = Integral action time and \( T_d \) = derivative action time.

**3. Proposed Controller Methods**

**A. PID Controller of DC servo motor**

The proportional (kp), integral (ki), and derivative (kd) control methods are employed in most applications because they are simple to create and provide the best performance within stable systems. PID is responsible for correcting errors the result of the difference between the desired value and measured value [32-36].

The closed-loop operation allows you to speed up transient processes, limit the impact of disturbances on the system, and fine-tune steady-state behavior.

The PID controller generates an error signal by comparing the system output to a user-defined set point and then seeks to lower the error signal by altering its output, which drives the system. This driving signal is obtained by adding three terms calculated separately from the error signal:
the teams are referred to as proportional (P), integral (I), and derivative (D). There are many
types of PID controllers.

B. Parallel PID controller

Because every procedure (P, I, D) happens in separate parts of the equation, the overall effect
is a simple sum, the equation used to describe PID control in earlier articles is the simplest and
is frequently termed the parallel equation.

\[ m = k_p e + \frac{1}{t_i} \int e \, dt + t_d \frac{de}{dt} + b \]  (9)

Each action parameter (kp,ti, td) in the parallel equation is independent of the others. This
may appear to be a benefit at first because it means that any disk of the control unit must only
affect one component of its work, as shown in Figure 3.

It is showing the mathematical independence of the three activities by dividing the equation
into three parts, each of them was found to participate in the directing operations (Δm) [29].

\[ \Delta m = k_p \Delta e \]  Proportional action  (10)
\[ \Delta m = \frac{1}{T_I} \int e \, dt \]  Integral action  (11)
\[ \Delta m = t_d \frac{de}{dt} \]  Derivative action  (12)

C. Ideal PID Controller.

The ideal or ISA equation is an alternate form of the PID equation in which the gain (kp)
affects all three actions. In this case, constant profit (kp) was distributed among all items within
parenthesis, affecting all three control measures [29]. In this mode of PID controller, increasing
kp makes actions P, I, and D equally aggressive.

\[ m = k_p (e + \frac{1}{T_I} \int e \, dt + t_d \frac{de}{dt}) + b \]  (13)

This is demonstrated mathematically by separating the "ideal" equation into three pieces,
each of which describes its contribution to the result. (Δm).
\[ \Delta m = k_p \Delta e \quad \text{Integral action} \quad (14) \]
\[ \Delta m = \frac{k_p}{T_i} \int e \, dt \quad \text{Proportional action} \quad (15) \]
\[ \Delta m = k_p T_d \frac{de}{dt} \quad \text{Derivative action} \quad (16) \]

Because of the algebraic distribution, the gain \((k_p)\) affects all three components of the PID equation, except the integral and derived tuning parameters \( (t_i, t_d) \).

**D. Fuzzy logic control of DC servo motor**

Fuzzy logic control (FLC) has been proved to be an effective solution for complicated and non-linear systems, as well as systems that are difficult to detect. Moreover, because of its improved performance, it is currently used in a wide range of industrial applications[37-38]. In fuzzy logic, the obvious values are employed instead of the truth values, and the data is configured using language variables such as large, medium, small, etc. In opacity, the data can be simply translated to multiple file formats, such as the degree of membership in a function with a real value.

All of the system's inputs are evaluated using conditional rules to determine the truth and value in the fuzzy thinking mechanism. All non-obvious values are now gathered in a file with a specific value. After processing the bases, the suggested fuzzy value is translated to a real value in the last stage. The phase is a condition for directing the physical system, and it's beautiful. As shown in Fig.5. As seen in Fig 6, members ship for the fuzzy logic controller (FLC).

![Figure 5. Basic structure of FLC](image)

![Figure 6. output membership functions](image)

**4. Simulation results**

**A. Speed control**

Speed control of the dc servo motor by using different strategy controllers at different torque. The effect of changing the torque on the motor was studied, then a comparison was made to know the effect of changing the torque on the servo motor. Table 1 shows the motor parameters.

- **Using PID controller method**
  Figure.7 shows the relationship between speed and time, using different torque values such as \((0, 3, 7, \text{ and } 11)\) N.m.
When the motor has a torque at no load. The speed of the motor reaches 1 p.u at the time 0.4 sec, but overshoot was increased to 1.2 p.u and settling time 1.5 sec at speed 1 p.u.

The torque was increased to 3 N.m, the motor speed reaches 1 p.u at the time of 0.6 sec, overshoot will be decreased to 1.15 p.u, and settling time is the same previous case.

The higher the torque value on the motor the rising time was increased to arrival speed of the motor to 1 p.u. The maximum torque of the rising time was increased and overshoots were decreased.

<table>
<thead>
<tr>
<th>Expression</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Armature voltage $V_a$</td>
<td>100 Volt</td>
</tr>
<tr>
<td>Armature resistance $R_a$</td>
<td>0.4 Ohm</td>
</tr>
<tr>
<td>Armature inductance $L_a$</td>
<td>0.1 H</td>
</tr>
<tr>
<td>Motor inertia $J_m$</td>
<td>7 kg m²</td>
</tr>
<tr>
<td>Motor viscous damping Coefficient $B_m$</td>
<td>0.02</td>
</tr>
<tr>
<td>Back emf coefficient $K_b$</td>
<td>1.4 Vs/rad</td>
</tr>
</tbody>
</table>

Figure 7. Speed-time graph of simulation System with different torque (PID).

- **Using Fuzzy PID controller method**

Figure 8, the present relationship between speed and time, and applies the test by using more values from torques. The motor running with no load the speed of the motor speed reaches 1 p.u at the rising time 1.8 sec. The increased torque on the motor, the motor speed arrival to max speed within 2 sec, overshoots was an element with different torque and settling time arrival to steady-state within 6 sec at speed 1 p.u also the settling time was same with different torques.

Figure 8. Speed-time curve with different torque (Fuzzy PID).

- **Using Fuzzy PI method**

This shown in Figure 9, explain the relationship between speed and time, using different torques. The motor worked at maximum torque, and the speed of the motor reaches 0.5 p.u at the rising time of 1 sec. The motor speed arrival to 1 p.u at steady– state within 3 sec when motor working...
with no load, the rising time increased to 1.7 sec, but no found overshoots in the system, and settling time is same with different torque.

Figure 9. Speed-time curve with different torque (Fuzzy PI).

• Compression between PID, Fuzzy PID, and Fuzzy PI methodology.
Compression between controllers such as PID, fuzzy PID, and fuzzy PI controllers are all types of PID controllers. The fuzzy PID curve was the best one, because of element overshoot from the system, slow rising time, and the settling time was slow. In the PID controller, the rising time and settling time is very fast, but there is an overshoot, as shown in Figure 10, Table 1. shows the comparison of speed control methods without load.

Figure 10. Speed-time curve with different methodology with torque (0 N.m).

Table 1. Comparison of speed control methods without load

<table>
<thead>
<tr>
<th>Performance Index</th>
<th>PID</th>
<th>Fuzzy_PID</th>
<th>Fuzzy_PI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rise time</td>
<td>0.26</td>
<td>2.67</td>
<td>2.67</td>
</tr>
<tr>
<td>Settling time</td>
<td>1.6</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Overshoot</td>
<td>34.8%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Table 2. Comparison of speed control methods with load

<table>
<thead>
<tr>
<th>Performance Index</th>
<th>PID</th>
<th>Fuzzy_PID</th>
<th>Fuzzy_PI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rise time</td>
<td>0.24</td>
<td>2.88</td>
<td>2.85</td>
</tr>
<tr>
<td>Settling time</td>
<td>1.4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Overshoot</td>
<td>5.57%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

In Figure 11, the Simulation is verified with load and shows the response of the system with a different controller. The curve fuzzy PID was the best one because element overshoot from the system, slow rising time, and Settling time is fast. The fuzzy PI was the best one because element overshoot from the system, slow rising time, and settling time is fast. The fuzzy PI curve was down when increasing load, this was affected because of the moment of inertia of load of the
motor, this action of the motor was not affected on rising time and settling time,

as shown in Figure 11, Table 2 shows the comparison of speed control methods with load

![Speed-time curve with different methodology with torque (7 N.m).](image)

**Figure 11. Speed-time curve with different methodology with torque (7 N.m).**

**B. Position control**

Control in Speed of the dc servo motor by using different strategy controllers at different torque. The effect of changing the torque on the motor was studied, then a comparison was made to know the effect of changing the torque on the servo motor

- **Using the PID controller method**

  Figure 12, the present relationship between position and time, using different torque values such as (0, 1, 3, and 5) N.m. The higher the torque the overshoot was reduced, but rising time is fast even to arrival the motor speed to 1 p.u within 1.5 sec. The motor worked at no load, and the motor speed arrived at steady-state within 2 sec. When increased torque, settling time is slowed down to arrive at a steady state with increased torque value.

![Position-time curve with different torque (PID).](image)

**Figure 12. Position-time curve with different torque (PID).**

- **Using the Fuzzy PID controller method**

  Figure 13, the present relationship between position and time, using different torque. When worked motor without loaded, the rising time toked 2.3 sec to arrival motor speed to 1 p.u. The motor worked at torque 1 N.m, the motor worked without overshoot, and the curve arrival at a steady-state within 2 sec. The increased torque overshoot is decreased, but rising time is slowed down when increased torque, and settling time is fast when increased torque value.
• **Using the Fuzzy PI controller method**

Figure 14 shows the relationship between speed and time. When worked motor without loaded, the rising time took 2.3 sec to arrival motor speed to 1 p.u. The motor worked at torque 3 N.m, and the motor curve arrived at steady-state within 6 sec.

The rising time slows down when increased torque and the settling time is fast when increased torque value. In this method the curve is going down with increasing load, this is affected because of the moment of inertia of a load of the motor, but this action of the motor is not affected by rising time and settling time.

Figure 14. Position- time curve with different torque (Fuzzy PI).

• **Compression between PID, Fuzzy PID, and Fuzzy PI methodology.**

Figure 15 shows Compression between controllers such as PID controller, fuzzy PI controller, and fuzzy PID controller. The fuzzy PI curve is the best one, because element overshoot from the system, the overshoot was affected some industrial applications such as robots. Table 3 shows the comparison of position control methods without load.

Figure 15. Position-time curve with different methodology with torque (0 N.m)
Table 3. Comparison of position control methods without load.

<table>
<thead>
<tr>
<th>Performance Index</th>
<th>PID</th>
<th>Fuzzy_PID</th>
<th>Fuzzy_PI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rise time</td>
<td>0.414</td>
<td>2.26</td>
<td>2.15</td>
</tr>
<tr>
<td>Settling time</td>
<td>4</td>
<td>6</td>
<td>5.88</td>
</tr>
<tr>
<td>Overshoot time</td>
<td>30%</td>
<td>5.75%</td>
<td>5.60%</td>
</tr>
</tbody>
</table>

Figure 15 presents a simulation verified with load and shows the response of the system with a different controller. The fuzzy PI is the best one because the settling time is fast and removed overshoot from the system. In the PID controller, the settling time does not arrive at a steady state when increasing load. Table 4 shows the comparison of position control methods with the load.

![Position-time curve with different methodology with torque (3 N.m).](image)

Table 4. Comparison of position control methods with load.

<table>
<thead>
<tr>
<th>Performance Index</th>
<th>PID</th>
<th>Fuzzy_PID</th>
<th>Fuzzy_PI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rise time</td>
<td>0.47</td>
<td>2.23</td>
<td>2.42</td>
</tr>
<tr>
<td>Settling time</td>
<td>Inf</td>
<td>5.59</td>
<td>5.54</td>
</tr>
<tr>
<td>Overshoot</td>
<td>21.92%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

5. Experimental Work

Figure 17 shows overall experimental work consisting of a system frame, a power supply, mechanical Unit, USB Interface Unit, Unit, Connecting cables, and Analogue Unit. The control system is based on closed loop speed control. The speed control process was carried out by linking the mechanical load to Servo, through an analog unit to control speed and angle as shown in Fig.17. The link between the mechanical unit and the analog unit was used by using a 34-way ribbon. The closed control process used a tachometer, it is a generator that is installed on the motor shaft, converting the output speed into an electric voltage. It represents the main feature of many various industrial applications, especially heavy industrial, the load adjustment process was done using a magnetic brake.

![The experimental work with servo motor circuits](image)
A. Experimental result of DC servo motor without controller

Figure 18 presents the system without control, as shown the yellow curve presents the output of the motor, and another curve presents the reference input signal. The two curves are symmetrical because of overshoot.

Figure 18. The experimental work with servo motor circuits

B. Experimental result of DC servo motor with PID controller

After adjusting the parameters of PID the output curve is symmetrical with the reference signal, decreasing overshoot, and the stable system as shown in Figure 19.

Figure 19. The experimental result with PID controller

6. Conclusion

In this paper, a practical experiment was conducted to control the speed and the movement angle of the servo motor. The results were derived using (Analogue Servo Fundamentals Trainer 33-002), it is a laboratory unit that gives the results of the various systems in the process of controlling the servo motor. The simulation process of the servo motor was accomplished in this study with various loads. For PID controllers, fuzzy logic was applied to many types of controllers. The performance of fuzzy logic and traditional PID was compared. Evaluations results were carried out on a steady-state error, settling time, and international performance requirements. Problems have been overcome in traditional control systems. Fuzzy Logic represents a real boom in the modern control process to avoid practical problems, this will be reflected in sensitive applications such as robotic applications and CNC machines.

7. References


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