Analogous Research of Classical PI Controller and Fuzzy Logic Controller to Control the Speed of D.C. Servo Motor

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Abstract. Servo motors are widely used in several fields such as industrial, electronics and robotics etc. The precise positioning & speed control of servo motor is compulsory for desired result and output. In this study, the speed control of dc servo motor is compared utilizing two different controllers. First is a classical PI controller while the second one is a fuzzy logic controller (FLC). PI controller and FLC both can be utilized for controlling the speed of servo motor. Both techniques provide good results but the fast response for the proposed calculation is achieved by the fuzzy logic controller. MATLAB/SIMULINK provide the conventional tool to analyze the model precisely so that the performance of servo motor is satisfactory. The performance of both controllers is compared and analyzed on different parameters such as speed, current for DC Servo Motor.

Keywords: Proportional-Integral (P-I) controller, FLC, Speed control, System modelling, D.C. Servo Motor (Separately Excited), MATLAB / SIMULINK

1. INTRODUCTION

Some servo motors are utilized in the field of electronics engineering and robotics due to their exceptional performance and their ability to control the position of shaft [1]. The key features of servo motors are high performance and efficiency, high torque, minimum noise [2], high response and precise control of position, velocity, or acceleration. A number of controlling strategies have been already proposed to control the servo system precisely [3].

A servo motor is considered as closed-loop control system that utilizes the position feedback system to control the motion [4]. As this motor is capable of controlling the angle of rotation and also its speed, so it is widely used in many types of equipment. Some Applications areas are given as:

- High power & compact electrical panels
- For variable speed (wide range)
- Standard Geared Type
- Planetary Geared Type
- Electromagnetic Braking System
While controlling the nonlinear systems, it has been experienced that undesired overshoots are obtained generally which affects the quality of the control of the system or equipment. In this article, a comparative study is presented which compares the performance of a conventional (PI) controller and fuzzy logic controller to control the speed of servo motor.

The PI controllers are utilized in Switched DC Servo Motor for precise speed control and better speed holding capacity. The advantages of the combination of proportional and integral are that as the increase in time of the response and reduction in the steady-state error. While we can use FLC to reduce harmonics and accurate speed regulation at rated speed in closed loop control system.

2. LITERATURE REVIEW

2.1 Servo Motor:

Generally servo motor is used to rotate or push any object with high accuracy. It can rotate the object at a specific angle using servo-mechanism. The applications of servo motor are in robotics, RC helicopters and toys car etc. Servo motors are coupled DC motors having closed-loop system. It mainly consists of a controlled device, output sensor and feedback system. The closed-loop control system with positive feedback is typically used to control the shaft's motion and position. The motor is controlled by the produced feedback signal which compares the output signal with the reference input signal [5].

A variable resistor and gear mechanism is used for the controlling of DC servo motor. The working of servo motor depends on PWM (pulse width modulation) that controls the rotation angle by utilizing the time limit of applied signal to its control pin.

2.2 Conventional Controller:

Proportional control is a linear control system for feedback that is widely used in first-order system to stabilize the unstable system. It is generally used to reduce the steady-state error. The need of a Proportional Integral controller is for the non-integrating process which means that any process eventually returns to the same output given the same set of inputs and disturbances. Integral action enables PI controllers to remove offset which is the major drawback of the Proportional controller. PI controllers thus provide a combination of complexity and capability that makes them the most extensively used algorithm in applications for process control arguably. PI controller utilizes a feedback control system that calculates error signal by considering the difference between the output signal, eventually returns to the same output given the same set of inputs and disturbances. PI controller provides zero control error and is insensitive to the interference of the measurement channel. The most common variant is the PI controller, much more so than complete PID controllers. The PI control has the disadvantage of slow reaction to disturbances.

2.3 Fuzzy Logic Controller (FLC):

Fuzzy Logic is the specific field of concentration to study Artificial Intelligence. It functions on the analysis of data that may be true or may not be true. A flexible set based on if-then rules is used by fuzzy logic controllers whose output is applied to suitable membership functions.

Fuzzy Logic endeavors to evaluate the human reaction and apply the best result fit to the information. Boolean logic is mostly used in conventional computing which is represented either one or zero. This prompts refutation and inadequate findings in some cases. Through expansion, Fuzzy logic controllers aim to manage uncertainty by making algorithms that relate closely to the real impression of problems. Fuzzy logic deals with non-linearity and imprecision in complex control circumstances.

Another advantage of Fuzzy logic control might not bother with an exact numerical model, can deal with nonlinearity; can work with fuzzy sources of knowledge. Fuzzy logic controllers depend on fuzzy sets, which are the classes of data in which the change from enrolment to non-membership is smooth instead of unexpected. The fuzzy logic controller is highly dependent on the ability of the fuzzy rules to comply with the properties of completeness, consistency and continuity [6].

The behaviour of FLC depends on some parameters which have to be adjusted during the design of the controller. These parameters are membership functions, inference rules and defuzzification [7-9].
In general, FLC has three stages:

1. **Fuzzification**
2. **Inference Unit**
3. **Defuzzification**

1. **Fuzzification**: Fuzzifier is used for fuzzification. In this process, the input data set is changed into fuzzy input set.

2. **Inference Unit**: It is the decision-making unit in which the human decision is simulated using some techniques and calculations.

3. **Defuzzification**: In this process, the result of the inference unit (fuzzy output set) is converted into output.

Block Diagram of fuzzy logic controller has been provided here:

![Block Diagram of Fuzzy Logic Controller](image1.png)

**Figure 1.** Block Diagram of Fuzzy logic Controller

### 3. SYSTEM MODELING

3.1 **Mathematical Modeling of D. C. Servo Motor System [10]**

A model of servo-motor is represented in **Figure 2**.

![Separately Excited DC Motor](image2.png)

**Figure 2.** Separately Excited DC Motor

Let:
- \( E_a(t) \) = Supply voltage (input)
- \( i_a(t) \) = Armature winding current
- \( R_a \) = Armature winding resistance
- \( L_a \) = Inductance of the armature
- \( E_b(t) \) = Backe.m.f
- \( T_m \) = Developed Torque
- \( \omega_m \) = Angular velocity
\( J \) = Moment of inertia
\( B \) = Viscous friction coefficient
\( K_b \) = Back emf constant
\( K_T \) = Torque constant

The equation (differential) of the armature circuit is given as –
\[
E_a(t) = R_a i_a(t) + L_a \frac{di_a(t)}{dt} + E_b(t)
\]
(1)

The Torque equation is given as -
\[
T_m(t) = J \frac{d\omega_m(t)}{dt} + B \omega_m(t)
\]
(2)

As, the torque of the dc motor is directly proportional to the multiplication of the armature current and field winding current:
\[
T_m(t) = K_I i_a
\]
(3)

Where \( K_I \) is constant.

As the field current \( i_f \) is considered as constant for armature controlled D.C. motor, so
\[
\frac{1}{s^2} = \frac{1}{s} \int_0^s \omega_m(s)
\]
(4)

Where, \( K_I = K_f i_f \) is torque constant.

As the back emf. of the motor is proportional to the speed i.e.
\[
E_b(t) = K_b \omega_m
\]
(5)

Where \( K_b \) is constant.

Initial conditions are zero, applying Laplace transformation. i.e.
\[
E_a(s) = R_a I_a(s) + s L_a I_a(s) + E_b(s)
\]
\[
I_a(s) = \frac{E_a(s) - E_b(s)}{R_a + s L_a}
\]
(6)

\[
T_m(s) = s \omega_m(s) + B \omega_m(s)
\]
\[
\omega_m(s) = \frac{T_m(s)}{s} + \frac{B}{s}
\]
(7)

\[
T_m(s) = K_T I_a(s)
\]
(8)

\[
E_b(s) = K_b \omega_m(s)
\]
(9)

3.2 Block Diagram:

![Block Diagram of Separately Excited DC Motor](image)

Figure 3 Block Diagram of Separately Excited DC Motor

4. DESIGN OF CONTROLLER

4.1 Parameters of D.C. Servo Motor

There is a 100V D.C. motor used in this experiment.

The speed of motor at no-load speed is 2575 rpm.

Parameter Values are:
\( R \) – resistance 1 \( \Omega \)
\( L \) – inductance 29.79 mH
\( J \) - moment of inertia0.01 kg.m
\( K_T \) - constant of torque0.052 Nm/Amp
\( K_b \) - back emf constant0.1 V/radian/s

B – co-efficient of viscous friction which is neglected
4.2 Simulink Model

4.2.1 Block diagram for the classical PI Controller Simulink model.

![Simulink Model for Classical PI Controller](image1)

Figure 3. Classical PI controller Simulink Model for D.C. Servo Motor

4.2.2 Block diagram for the Fuzzy Logic controller Simulink model.

![Simulink Model for Fuzzy Logic Controller](image2)

Figure 4. Fuzzy Logic controller Simulink Model for D.C. Servo Motor

4.3 PI controller Design

The control equation of a PI controller is given by the following equation:

\[ u(t) = K_p e(t) + K_i \int_0^t e(t) \, dt \tag{10} \]

Where:
- \( u(t) \) actuating signal,
- \( e(t) \) error signal,
- \( K_p \) Proportional gain constant & \( K_i \) Integral gain constant

The Laplace transform of \( u(t) \)

\[ u(s) = K_p E(s) + K_i \frac{E(s)}{s} \tag{11} \]

Figure 6. represents the block diagram of a closed-loop control system with PI control of the D.C. Servo Motor System. The error signal \( E(s) \) is given to the two controllers, i.e. proportional and integral controllers. The output of PI controller \( U(s) \), is provided to D.C. Servo Motor System. The overall output of D.C. drive may be speed or position, \( C(s) \) is feedback to reference input \( R(s) \). The error signal can be removed by increasing the value of \( K_p \), \( K_i \). However, the feedback of the control system is unity. To increase the gain of feedback, the stability of the system is reduced.

![Block diagram of PI Controller with D.C. Servo Motor System](image3)

Figure 5. Block diagram of PI Controller with D.C. Servo Motor System
4.4 Fuzzy Controller Design

The important features for designing the fuzzy logic controller are design of membership functions for inputs, outputs, and fuzzy process rule base [11]. For the D.C. drive, the speed error ($E$) and change in the speed error ($CE$) are considered as the two inputs for the fuzzy controller and one output is control input ($CI$). For this, a three-member is designed, as well as a seven-member rule base. The rule base for seven membership functions is shown in Table-I.

| E   | NH | NM | NL | ZO | PL | PM | PH |
|-----|----|----|----|----|----|----|----|
| NH  | NH | NH | NH | NH | NM | NL | ZO |
| NM  | NH | NH | NH | NM | NL | ZO | PL |
| NL  | NH | NH | NM | NL | ZO | PL | PM |
| ZO  | NH | NM | NL | ZO | PL | PM | PH |
| PL  | NM | NL | ZO | PL | PM | PH | PH |
| PM  | NL | ZO | PL | PM | PH | PH | PH |
| PH  | ZO | PL | PM | PH | PH | PH | PH |

Figure 6. The membership functions of $E$, $CE$, and $CI$ in normalized scale

In the above Figure 7 (a) represents the membership functions of speed error ($E$), (b) shows change in speed error ($CE$) and (c) shows control input ($CI$) in normalized scale.
4.5 Rule Viewer

Figure 7. Rule Viewer representation for $E$, $CE$ and $CI$.

4.6 Surface View

Figure 8. Surface view

5. EXPERIMENTAL RESULTS

The simulation studied for the classical PI controller and the fuzzy logic controller-based control system to validate the design and evaluate the performance as well as comparison of their responses. Simulation result processed by a PI controller and FLC both provide precise performance in case of a constant load that is shown in figure. 10.1 (a), (b) and figure. 10.3 (a), (b). It is seen that FLC as compare to PI controller provides faster response and lesser overshoot figure. 10.1 (a), (b) & figure. 10.3 (a), (b). The response current of the D.C. servo motor of PI controller as well as the fuzzy logic controller is shown in Figure. 10.2 and Figure. 10.4 respectively.
Figure. 10.1 (a) Speed Response with the classical PI controller
Curser1: Rise time - 0.052s & Curser2: Peak Time - 0.095s

Figure. 10.1(b) Speed Response with the classical PI controller
Curser1: Settling Time - 0.504s

Figure. 10.2 Current Response with the classical PI controller
The steady-state error is reduced by PI-controller while the fuzzy logic controller provides transient state for fast response and minimum overshoot. Simulation result in Figure 10.1 (a), (b) and Figure 10.4.
10.3 (a), (b) represent the speed responses of D.C. servo motor which are constant. The comparative chart is shown in Table 2.

| Responses          | Rise Time (response reach 0 to 100%) (sec.) | Peak Time (sec.) | Settling Time (sec.) |
|--------------------|---------------------------------------------|------------------|----------------------|
| PI Controller      | 0.052                                       | 0.095            | 0.505                |
| Fuzzy Logic Controller | 0.364                                      | 0.364            | 0.364                |

**Figure 10.4** Comparison of time of responses for FLC and PI controller

From Figure 10.4 the rise time and peak time of response of PI controller is better than Fuzzy logic controller but the settling time of fuzzy logic controller is better than PI controller. Using FLC instead of PI controller maximum overshoot is minimized up to 8.92%.

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