Performance advancements of fuzzy controllers over conventional controllers carried out in matlab simulation environment

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Abstract. In this paper, we are used routine three term PID controller, fuzzy PID controller and FPI plus FPD controllers to test the performance characteristics of DC servo motor, modulus non-linear systems and square root nonlinear systems in MATLAB SIMULINK environment. We have developed analytical structures for fuzzy PID and FPI plus FPD controllers with the help of fuzzification, knowledge rule base and defuzzification methods. Simulation results are carried out and show the advancement of fuzzy controllers over conventional controllers in specifications of rise time, delay time and settling time for DC servo motor, modulus and square root types of non-linear systems. Out of these three types of controllers, the experimental results conclude that the combination of FPI plus FPD controller gives the better results.

Keywords: FLC, PID controller, FPI plus FPD controller, DC servo motor, MATLAB/SIMULINK.

1. Introduction:
Controllers like PID type are broadly utilized in industrial applications because of its simplicity, flexibility and robust design. PID controllers are economic, efficient and effective for linear control systems [1]. These are not matched for third order and above systems, time or transport delay, complex systems, non linear systems with saturation, dead zone and hysteresis non-linearities [2]. In order to overcome such type of problems by implementing the fuzzy logic controllers. There is a considerable change in improving the performance in complex, higher order and non-linear types. Mathematical models of physical systems are important in develop the control algorithms, but it is not possible to get exactly all the time. There is a substitute for such type of situations is model free controller in the absence of exact mathematical models. There is a scope of utilizing the fuzzy logic controllers as an alternate to control the complex systems. Therefore, to improve the performance of
complex systems, there is a need to design controllers which work well in absence of exact mathematical models [3].

An introduction of new controller into a system is called fuzzy logic control system. FLC basic structure is shown in Fig. (a). To construct FLC’s, we consider human expertise and knowledge. Fuzzy controllers are capable of control, practical and industrial problems which are not controlled by conventional approach. This is one of the important characteristic of FLC.

**Fuzzification:**

**For FPI type:**

FPI with 2 inputs are the following.

i) $e(kT)$ called input error signal and also known as displacement $d(kT)$

ii) $\frac{d}{dt}[e(kT)]$ called rate of error signal and also known as velocity $v(kT)$.

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![Fig.(a). FLC](image)

![Fig.(b). I/P and O/P MF’s of FPI controller](image)
For FPD type:

FPD with 2 inputs are the following.

i) \( e (kT) \) called input error signal and also known as displacement \( d (kT) \)

ii) \( \frac{de}{dt} (kT) \) called rate of error signal and also known as velocity \( v (kT) \).

Input fuzzy set expressed as

\[
\mu_{n,x} = \frac{L-x}{2L}, -L \leq x \leq L
\]

\[
\mu_{p,x} = \frac{L+x}{2L}, -L \leq x \leq L
\]

Control Rule Base:

For fuzzy PI Controller:

| Rule No. | Antecedent | Consequent |
|----------|------------|------------|
| R1       | If \( u_N \) is \( nN \) & \( d_N \) is \( nd \) | then \( \Delta u_N \) is \( O_{-1} \) |
| R2       | If \( u_N \) is \( pN \) & \( d_N \) is \( nd \) | then \( \Delta u_N \) is \( O_0 \) |
| R3       | If \( u_N \) is \( nN \) & \( d_N \) is \( pd \) | then \( \Delta u_N \) is \( O_0 \) |
| R4       | If \( u_N \) is \( pN \) & \( d_N \) is \( pd \) | then \( \Delta u_N \) is \( O_{+1} \) |
For fuzzy PD controller:

| Rule No. | Antecedent          | Consequent          |
|----------|----------------------|---------------------|
| R1       | If $\nu_N$ is $p\nu$ & $d_N$ is $pd$ | then $\Delta u_N$ is $O_0$ |
| R2       | If $\nu_N$ is $n\nu$ & $d_N$ is $pd$ | then $\Delta u_N$ is $O_{+1}$ |
| R3       | If $\nu_N$ is $p\nu$ & $d_N$ is $nd$ | then $\Delta u_N$ is $O_{-1}$ |
| R4       | If $\nu_N$ is $n\nu$ & $d_N$ is $nd$ | then $\Delta u_N$ is $O_0$ |

Defuzzification:

For fuzzy PI controller:

\[
\Delta u_N(k) = \frac{[[A(\mu(R2)) + A(\mu(R3))](0) + A(\mu(R4))(M) + A(\mu(R1))(-M)]}{\sum_{i=1}^{4} A(\mu(Ri))}
\]

Here $A(\mu(Ri))$ = area for rule $R_i$.

For fuzzy PD controller:

\[
\Delta u_N(k) = \frac{[[A(\mu(R2)) + A(\mu(R1))](0) + A(\mu(R4))(M) + A(\mu(R3))(-M)]}{\sum_{i=1}^{4} A(\mu(Ri))}
\]

Here $A(\mu(Ri))$ = area for rule $R_i$.

2. Modeling of d.c servo drive:

Servo motor [6] is used to convert electrical signal to angular motion. A common actuator in control systems is the DC motor. These are used in control systems are also called servo motors and are low mechanical and electrical inertia ratios, fast response and steady state stability. DC motor controlled servo mechanism problem is considered to demonstrate the efficacies of fuzzy controllers. The arrangement of closed loop servomechanism is shown in Fig.(d).

Transfer function of a D.C. servo drive is expressed by

\[
\frac{Y(s)}{U(s)} = \frac{K_{gear} K_a}{s(L J s^2 + (r J + L B) s + r B + K_m s + K_m)}
\]
Where

\[ R_a = \text{Armature resistance, } \Omega \]
\[ L_a = \text{Armature inductance, } H \]
\[ J = \text{Moment of inertia of motor and load referred to motor shaft, } \text{kg-m}^2 \]
\[ B = \text{Viscous-friction coefficient of motor and load referred to motor shaft, } (\text{Newton-m})/(\text{rad/sec}) \]
\[ K_T = \text{Torque constant, } \text{N-m/A} \]
\[ K_b = \text{Back emf constant, } \text{V-sec/rad} \]

Fig.(d). Block diagram of closed loop servomechanism

An overall control law for FL based FPI plus FPD can be expressed as

\[
u_{PI+PD}(kT) = u_{PI}(kT) + u_{PD}(kT)
\]
\[
u_{PI+PD}(kT) = u_{PI}(kT-T) + K_{uPI}\Delta u_{PI}(kT) - u_{PD}(kT-T) + K_{uPD}\Delta u_{PD}(kT) \quad \text{(1)}
\]

“Equation (1)” will be referred to as the control law.
3. Development of controller design in matlab:

The values taken for parameters used in MATLAB simulation are as follows:

\[ R_a = 5 \, \Omega \]
\[ L_a = 0.01 \text{H} \]
\[ K_b = 0.22 \, \text{V-sec/rad} \]
\[ K_T = 0.2 \, \text{N-m/A} \]
\[ J = 0.0005 \, \text{Kg-m}^2 \]
\[ B_m = 0.00001 \, \text{N-m-sec/rad} \]
\[ K_{\text{gear}} = 0.05 \]
Fig. (f). D.C motor with FPI plus FPD/FPID/Conventional PID Controller having saturation nonlinearity

For the numerical values under consideration the open loop system is unstable. So, we have considered closed loop system to make it stable. The applied input voltage should not be greater than the rated voltage and the currents in the windings should not be exceeded than rated currents [7]. Hence, for controlling the DC servo motor, we need to maintain the values within the limits. Fig. (f). shows D.C motor with FPI plus FPD/FPID/Conventional PID Controller having saturation nonlinearity.

Non-linearities are intentionally introduced into a system in order to overcome the effects of other undesirable non-linearities or to obtain the better performance than could be achieved using linear elements [8]. A simple example of an intentional non-linearity is the use of non-linear damping to optimize response as a function of error. Here we examined modulus non-linearity and square root non-linearity of the systems.

4. Simulation results:

Applying a unit step input to DC servo motor, computer simulations are carried out for FPI plus FPD, FPID and three term PID controllers with saturation nonlinearity having a magnitude of -50 volts and +50 volts, is shown in Fig. (g).
Fig. (g). DC servo motor with saturation non-linearity response for unit step

**Non-linear system with modulus non-linearity**

Consider $\frac{dy}{dt} = 0.001 |y(t)| + u(t)$.

Fig. (h) shows modulus nonlinearity system output response for a unit input step signal.

Fig. (h). Modulus nonlinearity system output response for a unit input step signal.
Non-linear system - Square root Non-linearity

Consider \( \frac{dy}{dt} = \sqrt{|\tau(t)| - y(t)} + u(t) \).

Fig.(i) shows Non-linear system output response for a given unit input step signal.

5. Conclusion:

For DC Servo under consideration, Fuzzy controllers are giving better response when compared with the conventional controller. When compared between FPI plus FPD and Fuzzy PID controllers, rise time \( t_r \) and settling time \( t_s \) are less in case of FPI plus FPD controllers, implying that FPI plus FPD controllers are more effective, efficient and robust in reaching the tracking point in a considerably less time than Fuzzy PID controllers.

For the system modulus non-linearity, Fuzzy controllers are giving better response when compared with the conventional controller. When compared between FPI plus FPD and Fuzzy PID controllers, time domain specifications \( t_d \), \( t_r \) and \( t_s \) are less in case of FPI plus FPD controllers, implying that FPI plus FPD controllers are more effective, efficient and robust in terms of reaching the tracking point in a considerably less time than Fuzzy PID controllers.

For the system having square root non-linearity, Fuzzy controllers are reaching the desired tracking point faster than the conventional controllers. When compared between FPI plus FPD and Fuzzy PID controllers, time domain specifications \( t_d \), \( t_r \) and \( t_s \) are less in case of FPI plus FPD controllers, demonstrating their superiority over the Fuzzy PID controllers.

From all the above simulations, it is evident that Fuzzy controllers are giving better response when compared with the conventional controller. When compared between FPI plus FPD and Fuzzy PID controllers, time domain specifications \( t_d \), \( t_r \), and \( t_s \) are less in case of FPI plus FPD controllers, implying that FPI plus FPD controllers can track the set point satisfactorily over Fuzzy PID controllers.
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