Design of Fuzzy Logic PD Controller for a Position Control System

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ABSTRACT
Conventional control system design depends upon the development of a mathematical description of the system’s behavior. This usually involves assumptions being made in relation to the system dynamics and any non-linear behavior that may occur. Fuzzy logic is the application of logic to imprecision and has found application in control system design in the form of Fuzzy Logic Controllers (FLCs). Fuzzy logic controllers facilitate the application of human expert knowledge, gained through experience, intuition or experimentation, to a control problem. In this paper, a conventional proportional-derivative (PD) controller and a heuristically-tuned fuzzy logic PD controller for a position control system were derived and simulated using MATLAB-Simulink so that suitable comparisons could be made.

Keywords – Fuzzy Logic, Fuzzy Logic Controller, MATLAB, Position Control System, PD Controller

I. INTRODUCTION
Fuzzy logic is a way of interfacing inherently analog processes that move through a continuous range of values, to a digital computer to perform tasks, based on abstracted values, as if they were well-defined discrete numeric values. Fuzzy control provides a formal methodology for representing, manipulating, and implementing a human’s heuristic knowledge about how to control a system. Fuzzy logic poses the ability to mimic the human mind to effectively employ modes of reasoning that are approximate rather than exact.

A fuzzy controller acts or regulates by means of rules in a more or less natural language, based on the distinguishing feature: fuzzy logic. The rules are invented by plant operators or design engineers, and fuzzy control is thus a branch of intelligent control.

II. PROPORTIONAL-DERIVATIVE (PD) CONTROLLER
Electro-mechanical device controllers typically come in one of three forms, proportional (P), Proportional Derivative (PD), and Proportional Integral Derivative (PID). PD controllers are ideal for use with servo motors, where position control is effective. PD Controller is a device that produces an output, consisting of two terms, one proportional to input signal and the other proportional to the derivative of input signal.

III. FUZZY LOGIC PD CONTROLLER
There are two inputs to the FL controller, “error” and “change-of-error”. For any pair of error and change-of-error, the fuzzy pd controller should work out the control signal.

IV. POSITION CONTROL SYSTEM
we have \( G(s) = \frac{4500K}{s(s+361.2)} \)
V. DESIGN of PD CONTROLLER

Transfer function of PD controller is given by $K_p + K_d s$. Let the performance specifications are as follows:
- Steady state error due to unit-ramp input $\leq 0.000443$
- Maximum overshoot $\leq 5\%$
- Rise time, $tr \leq 0.005$ sec
- Settling time, $ts \leq 0.005$ sec

Since the steady state error due to unit-ramp input, $ess = 0.000443$

The ramp error constant, $K_v = 1/ess = 1/0.000443 = 2257.34$

$K_v = L_t s \rightarrow 0 sG(s)H(s) = L_t s \rightarrow 0 s \frac{4500K}{s(s+361.2)} = 2257.34$

From this we get $K = 181.17$

With the PD controller the forward path gain of the system becomes

$G(s) = \frac{815265(K_p + K_d s)}{s(s+361.2)}$

The closed loop transfer function is

$\frac{\theta_y(s)}{\theta_r(s)} = \frac{815265(K_p + K_d s)}{s^2 + (361.2 + 815265K_d)s + 815265K_p}$

The ramp error constant is

$K_v = \lim_{s \rightarrow 0} sG(s) = \frac{815265K_p}{361.2} = 2257.34K_p$

The steady state error due to unit-ramp input, $ess = 1/K_v = 0.000443/K_p$

The characteristic equation is

$s^2 + (361.2 + 815265K_d)s + 815265K_p = 0$

We can arbitrarily set $K_p = 1$ which is acceptable from the steady state error requirement.

The damping ratio of the system is

$\zeta = \frac{361.2 + 815265K_d}{2\sqrt{361.2 \times 815265K_p}}$

which clearly shows the positive effect of $K_d$ on damping.

Then we get $K_d = 0.00177$

The transfer function of the PD controller for the given system is

$K_p + K_d s = 1 + 0.000177s$

VI. SIMULATION

The closed loop transfer function of the position control system without PD controller is given by $\text{closed loop } \frac{\theta_y(s)}{\theta_r(s)} = \frac{815265}{s^2 + 361.2s + 815265}$

The closed loop transfer function of the position control system with PD controller is given by $\text{closed loop } \frac{\theta_y(s)}{\theta_r(s)} = \frac{815265 + 1443.02s}{s^2 + 1804.22s + 815265}$

VII. DESIGN and SIMULATION of FUZZY LOGIC PD CONTROLLER

For this design two input variables – error $(e)$ and change of error $(de)$ and an output variable - control $(u)$. We can define these variables in MATLAB using fuzzy logic FIS editor.
The name of the FIS editor is ‘position’. In the FIS editor we can define some other parameters like type of defuzzification method etc. The defuzzification method chosen here is cetroid method. By using FIS editor we can select rule editor, membership editor etc.

In this design five membership functions namely, Negative Big(NB), Negative Small(NS), Zero(ZE), Positive Small(PS), and Positive Big(PB) are defined. For the inputs ‘e’ and ‘de’ the membership functions NS, ZE and PS are triangular in shape and NB and PB are trapezoidal in shape. For the output ‘u’ all are triangular in shape. We also have to select the range for universe of discourse(UOD) for the three variables. Here the range [-1 1] is selected for the three variables.

We have to develop different ‘If–Then’ rules connecting the 3 variables. The rules are entered using the Rule editor window.

The different rules used in this design are shown below:

<table>
<thead>
<tr>
<th>e / de</th>
<th>NB</th>
<th>NS</th>
<th>ZE</th>
<th>PS</th>
<th>PB</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB</td>
<td>NS</td>
<td>NS</td>
<td>NB</td>
<td>NB</td>
<td>ZE</td>
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<td>NS</td>
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<td>PB</td>
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</table>

The fuzzy logic controller is obtained from the fuzzy logic tool box. Then the fuzzy logic controller should be renamed as ‘position’ which is the name of the design. The given transfer function is the transfer function of the position control system already designed. From the simulation results we can see that...
step response of fuzzy logic PD controller is almost similar to conventional PD controller.

Surface viewer is a three dimensional plot which is obtained in the MATLAB fuzzy logic environment shows the mapping between the input and the output values.

![Figure 15. Surface Viewer](image)

VII. CONCLUSION

One of the principal applications of fuzzy logic is in control system design. Fuzzy logic controllers (FLC) can be used to control systems where the use of conventional control techniques may be problematic. The tuning of fuzzy controllers has tended to rely on human expert knowledge, gained through experience, intuition or experimentation. In this study the use fuzzy logic was evaluated in respect of designing a Fuzzy Logic Proportional Derivative (PD) Controller for a simple position system. The application of fuzzy logic is not limited to a particular field. It can be applied to many other fields of control system like adaptive control, optimal control, non-linear system design etc. By using different software tools like MATLAB fuzzy logic can be implemented very easily. But when the number of rules and fuzzy sets is large, or when the expert knowledge is lacking, tuning of fuzzy systems becomes more complex and time-consuming. Designing of a fuzzy logic controller can prove a lengthy process when performed heuristically. To overcome this difficulty now a days fuzzy logic technique is incorporated with some other artificial intelligence like artificial neural networks (ANN), genetic algorithm (GA) etc.

REFERENCES