Performance Based Comparison between Various Z-N Tuninng PID and Fuzzy logic PID Controller in Position Control System of DC Motor

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Abstract: The objective of this paper is to compare the time specification performance between conventional controller and artificial intelligence controller in position control system of a DC motor. The scope of this research is to apply direct control technique in position control system. Two types of controller namely PID and fuzzy logic PID controller will be used to control the output response. This paper was written to reflect on the work done on the implementation of a fuzzy logic PID controller. The fuzzy controller was used to control the position of a motor which can be considered for a general basis in any project design containing logic control. Motor parameters were taken from a datasheet with respect to a real motor and a simulated model was developed using Matlab Simulink Toolbox. The fuzzy control was also designed using the Fuzzy Control Toolbox provided within Matlab, with each rule consisting of fuzzy sets conditioned to provide appropriate response times with regards to the limitations of our chosen motor. The Fuzzy Inference Engine chosen for our control was the Mamdani Minimum Inference engine. The results of the control provided response times suitable for our application.
Key words: PID, fuzzy logic, position control system, DC motor, Z-N method

1. Introduction

Because of their high reliabilities, flexibilities and low costs, DC motors are widely used in industrial applications, robot manipulators and home appliances where speed and position control of motor are required. PID controllers are commonly used for motor control applications because of their simple structures and intuitionally comprehensible control algorithms. Controller parameters are generally tuned using hand-tuning or Ziegler-Nichols frequency response method. Both of these methods have successful results but long time and effort are required to obtain a satisfactory system response. Two main problems encountered in motor control are the time-varying nature of motor parameters under operating conditions and existence of noise in system loop. Analysis and control of complex, nonlinear and/or time-varying systems is a challenging task using conventional methods because of uncertainties. Fuzzy set theory (Zadeh, 1965) which led to a new control method called *Fuzzy Control* which is able to cope with system uncertainties. One of the most important advantages of fuzzy control is that it can be successfully applied to control nonlinear complex systems using an operator experiences or control engineering knowledge without any mathematical model of the plant (Assilian, 1974), (Kickert, 1976).

There are many papers about DC motor fuzzy control system design. Lin et. al. compared PID and FLC for position control and observed that FLC performed better than PID (Lin, 1994). Azevedo et. al. have shown that FLC is less sensitive than PID to load variations (Azevedo, 1993). Bal et. al. designed an FLC for an ultrasonic motor which has a different operation principle than electromagnetic motors (Bal, 2004). Mishra et. al. made a comparison between PID and FLC for servomotor control and described that PID parameters had to be tuned again under variations of plant parameters or noise wherever FLC parameters had not (Mishra, 1998). Kwon et. al. designed a PI controller for a brushless DC motor and built an adaptive fuzzy tuning system to modify the controller parameters under load variations during operation (Kwon, 2003). M.H. Zadeh et. al. explained that one of the best methods for control of a DC motor with time-varying parameters was fuzzy sliding mode control (Zadeh, 2006). Namazov et. al. designed a relay type fuzzy controller in control of double integrator systems which can be used to model many mechanical, hydraulic and electrical objects such as DC motors and observed that fuzzy controller was able to reject the noise signal

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applied to the input of system (Namazov, 2007). DC motor control is generally realized by adjusting the terminal voltage applied to the armature but other methods such as adjusting the field resistance, inserting a resistor in series with the armature circuit are also available (Chapman, 2005).

Ziegler-Nichols frequency response method is usually used to adjust the parameters of the PID controllers. However, it is needed to get the system into the oscillation mode to realize the tuning procedure. But it's not always possible to get most of the technological plants into oscillation. The proposed approach uses both fuzzy controllers and response optimization method to obtain the approximate values of the controller parameters. Then the parameters may be slightly varied to obtain the user-defined performance of the real-time control system. Thus, it's an actual problem to design adaptive PID controllers without getting the system into the oscillation mode.

2. MATHEMATICAL MODELLING OF A DC MOTOR

As reference we consider a DC shunt motors as is shown in figure 1.

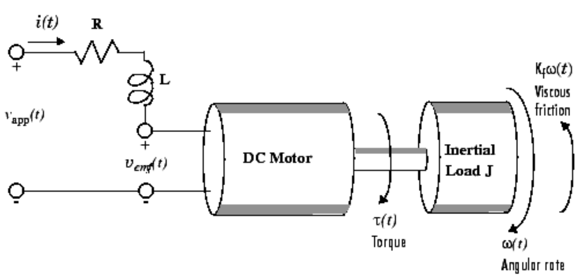

Fig 1. DC motor model

$$v = Ri + L\frac{di}{dt} + e_b \quad (1)$$

$$T_m = K_T\, i_a(t) \quad (2)$$

$$T_m = J\frac{d^2\theta(t)}{dt^2} + B\frac{d\theta(t)}{dt} \quad (3)$$

$$eb = e_b(t) = K_b\frac{d\theta(t)}{dt} \quad (4)$$

Simplification and taking the ratio of θ(s)/ v(s) we will get the transfer function as below,

$$\Theta(s) / v(s) = K_b / [J\, L_a\, S^3 + (Ra\, J + B\, La)S^2 + (Kb^2 + Ra\, B)S] \quad (5)$$

Where, R=Ra=Armature resistance in ohm,
L=La=Armature inductance in henry,
i=ia= Armature current in ampere ,
v= Va=Armature voltage in volts,
eb=e(t)=Back emf voltage in volts,
Kb=back emf constant in volt/ (rad/sec),
K= Kt=torque constant in N-m/Ampere,
Tm=torque developed by the motor in N-m,
θ(t)=angular displacement of shaft in radians,
J=moment of inertia of motor and load in Kg-m2/rad,
B=frictional constant of motor and load in N-m/ (rad/sec)

A. *Numerical Values*

The DC motor under study has the following specifications and parameters

a) Specifications

5hp, 230 volts, 10 amperes, 1500rpm

b) Parameters:

Ra=2.45 ohm, La=0.035 H, Kb=1.2 volt/ (rad/sec), J=0.022Kg-m2/rad, B=0.5*10^-3 N m/ (rad/sec).

The overall transfer function of the system is given below,

$$\frac{\theta(s)}{v(s)} = \frac{1.28}{0.00013919s^3 + 0.0000007648s^2 + 0.0002468s}$$

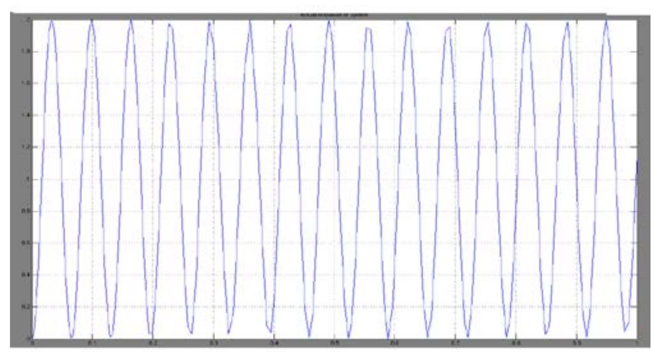

Fig 2. Response of original system without controller

3. PID Controller

PID stands for Proportional-Integral-Derivative. This is a type of feedback controller whose output, a control variable (CV), is generally based on the error between some user-defined set point (SP) and some measured process variable (PV). Each element of the PID controller refers to a particular action taken on the error. There are many situations that require some type of servo-control system.

This section reviews the fundamental of PID controllers and presents detailed simulations or design for development of DC motor controller. PID controllers are commonly used to regulate the time-domain behavior of many different types of dynamic plants. These controllers are extremely popular because they can usually provide good closed loop response characteristics, can be tuned using relatively simple rules and are easy to construct using either analogue or digital components.
Electric motor converts electrical energy into the mechanical motion and are broadly classified into two different categories: DC (Direct Current) motor and AC (Alternating Current) motor. DC motors are widely used in industrial system, such as robotic manipulators, because their control is relatively simple and they are reliable for a wide range of operating conditions. DC motors are usually modeled as linear systems and then linear control approaches are implemented. However, most linear controllers have unsatisfactory performance due to the changes of motor-load dynamics and due to nonlinearities introduced by the armature reaction. Neglecting the impact of external disturbances and of nonlinearities may risk the stability of the closed loop system. For this reason, the DC motor control using the conventional PID controllers are inadequate and more effective control approaches are needed. Here, the test system with conventional PID controller tuned by Ziegler Nichols method is compared with Fuzzy based PID controller. The results with Fuzzy based PID controller has been found to outperform the Ziegler Nichols tuned PID controllers.

3.1 Tuning and Its Purpose

A PID may have to be tuned when

a) Careful consideration was not given to the units of gains and other parameters.

b) The process dynamics were not Well-understood when the gains were first set, or the dynamics have (for any reason) changed.

c) Some characteristics of the control system are direction-dependent

d) You (as designer or operator) think the controllers can perform better.

3.1.1 Trial and error method

This process is a very time consuming process as a lot of permutations and combinations are involved. Though much iteration is performed the final result is not satisfactory. A balance is not obtained between the rise time and % overshoot even though a lot of possible combinations of the gains are incorporated. Continuous cycling may be objectionable because the process is pushed to the stability limit. Consequently, if external disturbances or a change in the process occurs during controller tuning, it results in unstable operation. The tuning process is not applicable to processes that are open loop unstable because such processes typically are unstable at high and low values of K_c but are stable at an intermediate range of values. All the time response specifications cannot be balanced using trial and error method.

3.1.2 Ziegler Nichols method

Ziegler Nichols formula ensures good load disturbance attenuation, but it generally provides a poor phase margin and therefore it produces a large overshoot and settling time in the step-response. The Ziegler-Nichols rule is a heuristic PID tuning rule that attempts to produce good values for the three PID gain parameters:

1. *Kp* - the controller path gain
2. *Ti* - the controller's integrator time constant
3. *Td* - the controller's derivative time constant

Given two measured feedback loop parameters derived from measurements:

1. the period *Tu* of the oscillation frequency at the stability limit
2. the gain margin *Ku* for loop stability

with the goal of achieving good regulation (disturbance rejection).

3.1.2. a. Ziegler-Nichols Open-Loop Point of Inflection (POI) PID Tuning Method

The Ziegler Nichols Open-Loop Point of Inflection (POI) PID Tuning Method is nearly identical to the "Reaction Curve" Method. The open loop step change is conducted in the same manner under the same conditions as in the reaction curve method. The only difference is in the determination of the delay factor, D. Instead of determining the D value as in Fig.3, the following values are acquired from the graphical analysis:

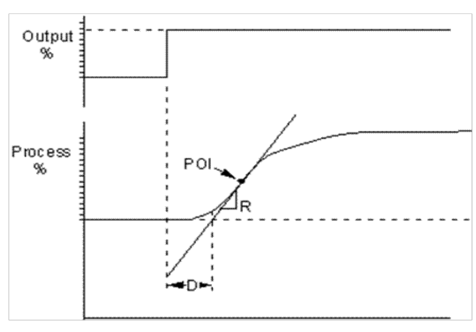

Fig. 3 Graphical analysis for Ziegler Nichols Open-Loop Reaction Rate PID Tuning Method

Where:

t_{POI}, is the time from the initiated change in output to the point of inflection, s ΔCV_{POI}, is the controlled variable change at POI,% R, is the rate of change of controlled variable at POI (same as Reaction Curve Method), %/s ΔMV, is the change of output (manipulated variable),% and then

$$D = t_{POI} - \Delta CV_{POI} / R \quad (6)$$

Parameters for P, PI, and full PID control are then calculated using the same formulae as in the ZN Reaction Curve Method.

controllers	K_C	T_I	T_D
P	ΔMV / (D x R)	-	-
PI	0.9ΔMV / (D x R)	3.3D	-
PID	1.2ΔMV / (D x R)	2.0D	0.5D

Table 1. Calculation of PID Parameters based on Ziegler Nichols Open-Loop Point of Inflection PID Tuning Method

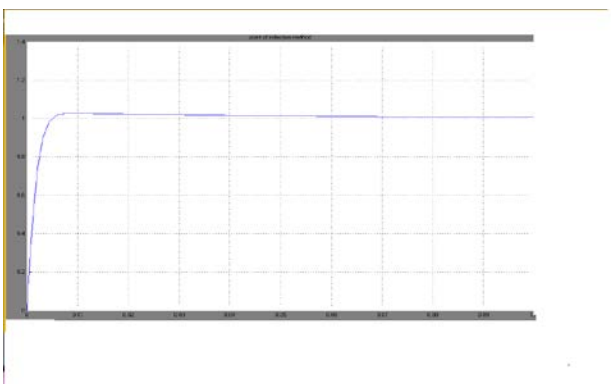

Fig 4. Response of the system with tuning based on POI method

3.1.2. b. Tuning based on stability margins

Ziegler-Nichols closed loop tuning is based on stability margins. To identify process
Parameters:
1. Turn off both integral and derivative action in the controller. This can usually be
accomplished by putting zeros in the integral and derivative tuning parameters.
2. Set the proportional gain (Kc) to a small value.
3. Put the controller in Auto mode.
4. Make a small step in the controller setpoint.
5. Observe the process response.
6. If the controller does not continually cycle (stability limit), increase the controller
gain (Kc) and repeat from step 4.
7. Once the controller continually oscillates, the controller gain is the ultimate gain Kcu.
8. Measure the period of the cycle and this is the ultimate period Pu.

Ziegler-Nichols Stability Margin			
Controller Type	K_c	τ_I	τ_D
P	$0.5K_{cu}$	—	—
PI	$0.45\ K_{cu}$	$\frac{P_u}{1.2}$	—
PID	$0.6K_{cu}$	$\frac{P_u}{2.0}$	$\frac{P_u}{8.0}$

Table 2. Calculation of PID Parameters based on Ziegler Nichols Stability Margin Tuning Method

K_{cu} = Ultimate gain (Minimum gain with P-only control that causes system to cycle continuously)

P_u = Ultimate period of oscillation

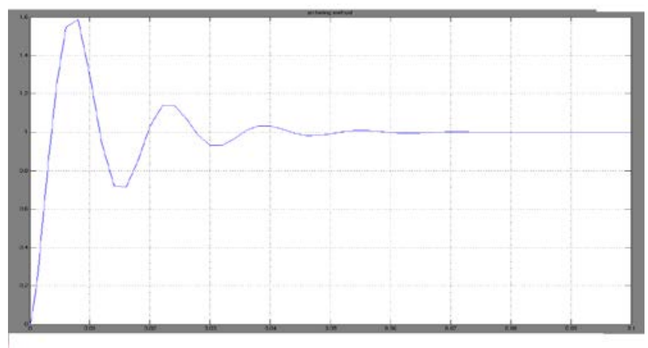

Fig 5. Response of the system with tuning based on stability margin

3.2 FUZZY LOGIC

A. Introduction

Fuzzy logic emerged into the mainstream of information technology in the late 1980s and early 1990s. Fuzzy logic is a derivative from classical Boolean logic and implements soft linguistic on a continuous range of truth values to be defined between conventional binary. It can often be considered a suspect of conventional set theory. Since fuzzy logic handles approximate information in a systematic manner, it is ideal for controlling non-liner systems and fro modeling complex systems where an inexact model exists or systems where ambiguity or vagueness is common. A typical fuzzy system consists of a rule base, membership functions and an inference procedure [9]. Today, fuzzy logic is found in a variety of control applications including chemical process control, manufacturing and in such consumer products as washing machines, video cameras and automobiles. Fuzzy logic is a suspect of conventional Boolean logic that has been extended to handle the concept of partial truth- truth-values between “completely true” and “completely false”.Fuzzy theory as a single theory, we should regard the process of fuzzification as a methodology to generalize ANY specific theory from a crisp (discrete) to a fuzzy (continuous) form. Thus, recently, researchers have also introduced “fuzzy calculus” and “fuzzy differential equations”

B. Fuzzy Rule Base

Fuzzy logic has been centered on the point that it makes use of linguistic variables as its rule base. If a variable can take words in natural language as its values, it is called linguistic variable, where the words are characterized by fuzzy sets defined in the universe of discourse in which the variable is defined. Examples of these linguistic variables are slow, medium, high, young and thin. There could be combinations of this variable too, like “slow-young horse”, “a thin young female.” These characteristics are termed atomic terms while their combinations are called compounded terms. In the real world, words are often used to describe characteristics rather than numerical values. For example, one would say “the car was going at 100 miles per hour.” Terms such as slightly, very, more or less, etc. are called linguistic hedges since they add extra description to the variables, i.e. very – slow, more or less, slightly high, etc. At the heart of the fuzzy rule base are the IF-THEN rules.

A fuzzy IF-THEN rule is expressed as,

IF<fuzzy proposition>,

THEN <fuzzy proposition>.

Propositions are linguistic variables or atomic terms as described previously. This type of rule-based system is different from the classical expert systems, In that, rules may not necessarily be derived from human expertise; they may also be derived from other sources. Three types of linguistic variable forms exist.

1. Assignment statements

2. Conditional statements

3. Unconditional statements

C. Fuzzy Logic Controller Design

The traditional control design paradigm is to form a system model and develop control laws from analysis of this model. The controller may be modified based on results of testing and experience. Due to difficulties of analysis, many such controllers are linear. The fuzzy controller approach should be reversed to some extent. General control rules relevant to a particular system based on experience are introduced and analysis or modeling considerations come later.

This rule implements a control concept for anticipating the desired position and reducing the control level before the set point is reached in order to avoid overshoot.

The quantities “small” and “large” are fuzzy quantities. A full control design requires developing a set of control rules based on available inputs and designing a method of combining all rule conclusions. The precise fuzzy membership functions depend on the wide range of inputs and the general response characteristics of the system. Within power systems, fuzzy logic controllers primarily using MATLAB – FIS Editor have been proposed

The structure of the Fuzzy Logic Controller (FLC) and its design consist of the following steps

1) Identification of input and output variables.
2) Construction of control rules.
3) Establishing the approach for describing system state in terms of fuzzy sets, i.e., establishing fuzzification method and fuzzy membership functions.
4) Selection of the compositional rule of the inference.

3.3 Membership Functions

The membership functions consist of the seven linguistic terms:

* Negative Large Large (NLL)
* Negative Large (NL)
* Negative Small (NS)
* Zero (Z)
* Positive Small (PS)
* Positive Large (PL)
* Positive Large Large (PLL)

The input e presented in Figure 6 consists of all seven terms to increase response with respect to the error. The input ce and output cu both have five terms as shown in Figures 7 and 8 since it was optimal to keep them at a lower degree of precision. All membership functions were chosen to be of the triangular and trapezoidal type, mostly due to its common use during class and straightforward implementation.

3.4 Fuzzy Rule Base

The input e uses seven membership functions, while ce uses five, which required a rule base consisting of 35 rules. The resulting rule base can be seen in Table 2.

The rule base was developed to present smooth, gradual transitions to an error relative to zero error by attempting to decrease the change in error, ce.

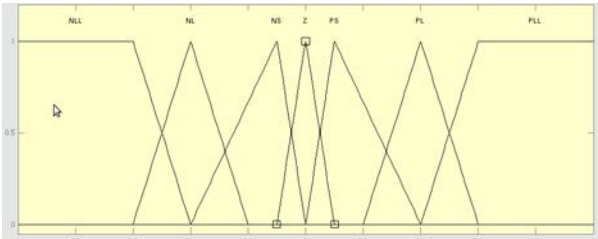

Fig 6. Membership function for e, µe(x1)

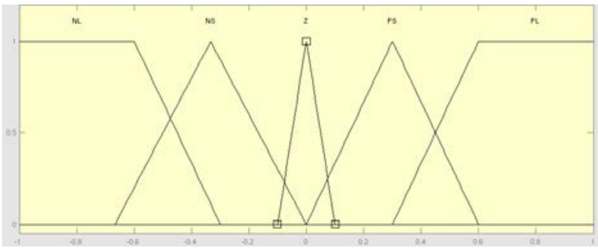

Fig 7. Membership function for ce, µce(x2)

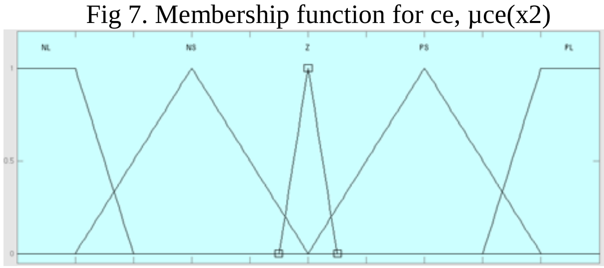

Fig 8. Membership function for cu, µcu(y)

Ce /e	NL	NS	Z	PS	PL
NLL	NL	NL	NL	NS	NS
NL	NL	NL	NS	NS	Z
NS	NL	NS	NS	Z	Z
Z	NS	Z	Z	Z	PS
PS	Z	Z	PS	PS	PL
PL	Z	PS	PS	PL	PL
PLL	PS	PS	PL	PL	PL

Table 3: Membership Rule Base

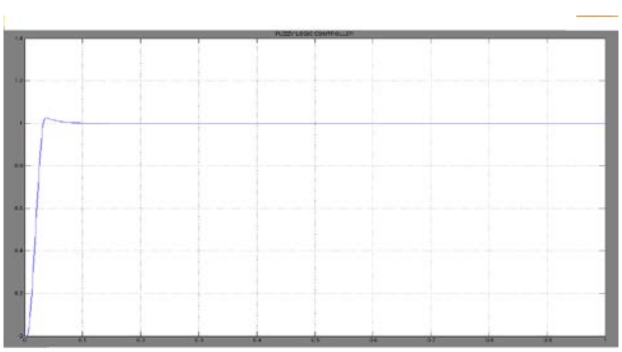
Fig 5. Response of the system based on the fuzzy logic controller

4. Performance analysis

The most desirable performance requires the Controllers to have the smallest possible value for the rise time, overshoot and the settling time. It is also required for the final value should be as close as possible to the desired value which is unity. From the table, it can be seen that the fuzzy logic controller can produce a desirable response performance with the use of only the proportional, Integral and Derivative Component (PID). When compared to the conventional PID controller, the fuzzy logic PID controller shows a better performance in terms of raise time while it exhibits a slightly lesser performance in terms of peak value and settling time.

Performance metric	With controller (various PID tuning)		
	ZN-POI	ZN-SM	FLC
Raise time	0.017	0.0245	0.0218
Settling time	0.29	1.00	0.155
Peak value	1.0301	1.5765	1.025
Final value	1.000	1.000	0.9985
Over shoot	0.030	0.576	0.025

5. CONCLUSION

The designed PID with Fuzzy based has much faster response than response of the classical method. The classical method is good for giving us as the starting point of what are the PID values. However the Fuzzy logic designed PID is much better in terms of the peak value and the settling time than the conventional method. Finally the fuzzy based PID controller provides much better results compared to the conventional methods. In this paper, implementation of the fuzzy based PID controller for the DC motor position control system is covered.

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