Modeling and analysis of fuzzy pi controllers using multiple fuzzy sets

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Abstract

Using multiple symmetric fuzzy sets (N1>= 3 for the input e, N2>= 3 for the input ∆e, and N3>=5 for the output) on the inputs of different universes of discourse mathematical conception of contrasting fuzzy PI/PD controllers is done. It is possible to attain 8 antithetic models of controllers. The elemental units of these controller configurations includes components like Rule Base, Fuzzifier and Defuzzifier, Fuzzy Inference Engine and most significantly a rule base containing Bounded Sum / Maximum t-conorm (OR operator), Mamdani Minimum/Larsen Product inference, linear rules, Algebraic Product / Minimum t- norm (AND operator), and Cos defuzzification method. Based on both instinctive and adept knowledge, structure parameters can be designed as linguistic variables and which resulted in design of their respective membership functions. In the form of IF-THEN rules, Fuzzy logic control aims to incorporate intuition, which directs towards conclusions from these rules. Thus, nonlinear system with extreme complication and unstability can be efficiently regulated based on fuzzy rules without trading with error-prone mathematical models. It is depicted that the aggregation of a 2-D multigrade relay and a general nonlinear PI controller is the production of fuzzy controller that governs the control action obtained by the multilevel relay.

Keywords

PI controller, PD controller, Fuzzification, If-Then rules, Defuzzificztion.

1.Introduction

To derive the conclusions from the past conclusions fuzzy logic controllers (FLC) can be designed to out vie the human like thinking. It will bring more ease to solve the control problems which are hard to depict by mathematical models. It is also applicable to plants of higher order systems. The prime motive is their simplicity of operation, ease of designs in-expensive maintenance low cost and effectiveness for most linear systems. Zadeh has given the groundwork of all such systems, where the fuzzy control logic was illustrated by IF-THEN statements. Owing to their knowledge based nonlinear characteristics in order to regulate entities that have nonlinearities, control scheme must handle the repercussions of all these, fuzzy controllers are thrivingly applied. Since most control strategies, based on mathematical model are constrained in their capability to improve transient responses as they have been mainly targeting on stability, robustness against nonlinearity/uncertainties[2]. We need to have a controller which can efficiently inculcate nonlinear properties and unmodled effects in to its basic design and simultaneously work upon to improve transient responses in all these cases and therefore we opt for fuzzy PI and PD controllers. With its capability to replicate human decision making procedure, the technology seems to be quiet transparent and natural to the humans [5].

Our objective is to find the mathematical replica or structure of fuzzy PI/PD controllers and to imply these controller models to regulate the behavior of plants. These mathematical models depend on factors like membership functions, triangular norms, triangular co-norms and defuzzification methods. So in this context, fuzzy controller does not have a single fixed model. In short, fuzzy logic is a car with an engineer and driver’s seat. With proper design of component along with set of rules, fuzzy control all set to evade the detrimental and complex control problem. Once mathematical modeling is done, we need not have to care about the constituents (fuzzification, defuzzification, control rules, inference method) of the controller.

In the fuzzy control design methodology, a set of rules which basically describes by what means the control process is written down and then it is incorporated into fuzzy controllers which emulate the judgement making process of an individual. The most significant unit of a fuzzy logic controller is an array of linguistic regulating rules linked by the two fold idea of the fuzzy inference and compositional rules of inference. Fuzzy logic control is simple, effective and efficientexcept from being a extensively used technology these days. The fundamental objective of using fuzzy control is to cater a user-friendly protocol for describing and implementing the ideas we have about how to attain highly efficient performance control. To use the design of fuzzy controller replica for regulate, the way the linear controllers are applied is the prime objective of deriving it. One doesn't have to coordinate with the constituents of fuzzy controllers once mathematical designs of fuzzy controllers are made available. To continue to reveal mathematical designs of the general fuzzy PI and PD controllers is the primary aim of this thesis. As few of the systems designed herein are efficient and completely distinct from the systems already available in the literature therefore the results illustrated inside thesis are significantly fruitful to control community.

This paper is organized into six sections. The introduction is discussed in section I. Section 2 deals with brief about dc series motor and single link manipulator. Section 3 discusses about Configuration of PI and PD controllers. It also explains about each of its components. Section 4 deals with basics of fuzzy logic controller. Section 5 represents simulation results. Finally, in section 6 the conclusion is presented.

2.Analysis of system

D C Series Motor Roughly every mechanical task that we observe in our surroundings is completed by an electric motor. Electric machines are a medium of transforming energy. Motors intake electrical energy as input and produce output as mechanical energy. Electric motors are applied to power large variety of devices we employ in routine life. [3-5] If electrical energy is applied to a conductor existing normally to a magnetic field, the association of flowing current inside the conductor and the magnetic field will generate mechanical force[6]. There are two specifications which are significant in producing force on the conductor. The conductor is supposed to be carrying current, and must be inside a magnetic field. When these two specifications persist, a force will be executed on to the conductor, which will try to shake the conductor in a normal to the magnetic field.

The force exercised on the conductor can mathematically be written as follows.
F = B i l Newton
Where l is the length of conductor and i the value of current flowing in the conductor, B is the density of the magnetic field. Fleming's Left Hand Rule is implied to know the direction of motion.

We have considered a nonlinear second order plant in Figure given below. This plant is a DC series motor whose nonlinear dynamics can be conveyed with the help of differential equations shown below.

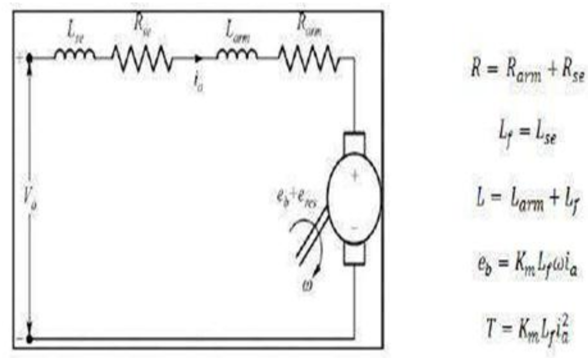

Figure 1 DC series motor

Differentials Equations

$$J\left(\frac{dw}{dt}\right)=\mathrm{T}-\tau_L-D_w$$
$$L\left(\frac{di_a}{dt}\right)=\mathrm{V}-e_b-i_a\mathrm{R}$$

where is the speed to be controlled, V is the input voltage a is the armature current, L is the load torque, J is the moment of inertia of the motor, D is the viscous friction coefficient, Km is the motor torque constant, L f is the field inductance, Ra and La are the armature resistance and inductance, respectively.
Speed Control of DC Mo tors: The speed of a motor is governed by the following relation:

$$N = \frac{V - I_a R_a}{Z\phi}\left(\frac{60A}{p}\right) = K\,\frac{V - I_a R_a}{\phi}$$

Where Ra= armature circuit resistance. The speed can be regulated by varying:

1. Flux/pole, Φ (Flu x Control)
2. Resistance Ra of armature circuit (Rheostatic Control) and (iii) Applied voltage V (Voltage Control).
3. Applied voltage V (Voltage Control).

3.Configurations of Pi controllers

The summation of the proportional mode and the integral mode consequence in proportional-integral controller mode. Few conveniences of the two control actions can be attained from PI control mode[7]. To have an expression for PI mode, which is pictured below equations for the proportional mode and integral mode are implied

P = Kp ep + Kp Kt∑ep dt+ pt(0) (1)

Where
Pt (0) = Integral term value at t = 0
The proportional gain, by model, varies the total integration mode gain, but the integration gain, can be individually varied. As a consequence, the proportional offset occurred, when a load variation required a new nominal controller output, and this cannot be applied except by a stable error from the set point. In the proportional integration mode, the integral function offers the required controller output, thus granting the error to be null post load variation. Post load variation, the integral characteristic gives a 'reset' of the null error output. With the assistance of a sum of proportional plus integral action that lastly drops the error at a negligible value the controller output is attained [8]. This mode is also referred to as Proportional plus reset action controller.
The analytical depiction of transfer function is given by
Kp + (KI/s)

The controller output is sealed at the position that the integral term had, when the error equates negligible value at the instant when the error is zero.
If the error isn't negligible, the proportional term devotes an amendment and the integral value begins to deviate the parametric term, which is attained, depending on the notation of the error and its direction [1]. The integral term will not attain negative value; thus settling at zero, if the flaw and the reaction drags the area to a negative point of value.

The integral action adjustment is the integral time T1 (=KI). For a step deviation 'e', the integral time or reset time is the time for proportional action. The 'Reset rate' is defined by the number of times per minute that the proportional part of the output characteristic is repeated. Reset Rate as a result is the inverse of integral type and referred to as 'repeats per minute. The linear PI controller is a single input and single output controller having error as the input and control effort as the output. The general structure of PI controller is as shown in Figure 2

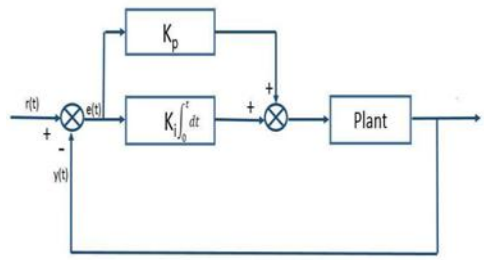

Figure 2 Structure of PI Controller

In discrete time is obtained using a fuzzy rule base that provides an incremental controllable, e and e. The classical PI controller is linear, whereas the fuzzy PI controller is nonlinear.

4.Fuzzy logic controller

The basic block diagram of Fuzzy Logic Controller which includes a set of steps that follow in the entire process is as shown in Figure 3.

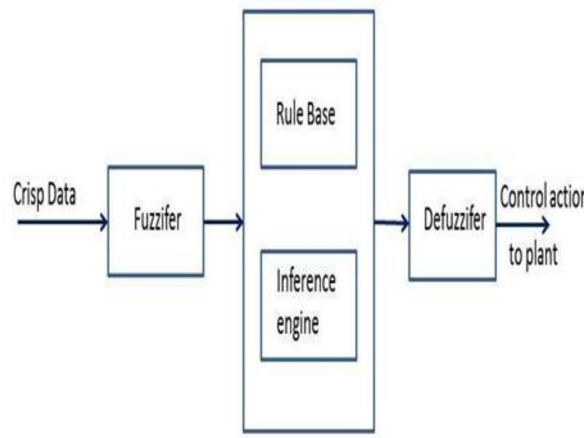

Figure 3 Structure of a Fuzzy logic controller

Fuzzy logic control is an algorithm stationed on a phonemic control planning, which is borrowed from adept knowledge into a mechanized control strategy. The process of a FLC is stationed on qualitative knowledge concerning the plant being controlled .It doesn't need any complex mathematical estimation like the others control system. However, the others control system employ complex mathematical estimation to give design of the controlled model, it only applies plain mathematical estimation to simulate the adept knowledge.

Four main components of a fuzzy logic controller is depicted below:

1. Fuzzification
2. Inference engine
3. Rule base
4. Defuzzification

Fuzzification

The primitive step in modeling a fuzzy controller is to elect which state variables embody the plant dynamic performance must be considered as the input signal to the controller. Fuzzy logic applies phonemic variables rather than numerical parameters. The procedure of converting a numerical variable into a phonemic variable is called fuzzification. This is attained with the help distinct kinds of fuzzifiers. There are usually three types of fuzzifiers that are employed for the fuzzification ; they are:

1. Singleton fuzzifier
2. Gaussian fuzzifier
3. Trapezoidal or triangular fuzzifier

Rule base

A verdict generating logic that is, processing a human decision process, inters fuzzy control action from the knowledge of the control rules and phonemic parameter definitions [9-10]. The rules are in "If Then" patternn and formally the If side is called the conditions and the Then side is called the conclusion. The computer is capable to accomplish the rules and estimate a control signal relying upon the measured inputs error (e) and change in error (de). In a rule stationed controller the control strategy is saved in approximately a natural language. A rule base controller is simple to perceive and basic to maintain for a non- specialist end user and an identical controller could be implemented using conventional techniques

$$\frac{u[nT]-u[(n-1)T]}{T} = K_p\frac{e[nT]-e[(n-1)T]}{T} + K_i e[nT]$$

$$\frac{\Delta u[nT]}{T} = K_p\frac{\Delta e[nT]}{T} + K_i e[nT]$$

$$\Delta u[nT] = K_P \Delta e[nT] + K_i T e[nT]$$

Inference Engine

Inference engine is referred as the Software code that synthesizes the rules, cases, objects or other kinds of knowledge and adepts based on the theories of a given condition. When there exists a doubt to be answered which includes logic instead of fencing skills, we take an array of inference gradation which may inulcate deduction, association, recognition, and decision making. An inference engine is an information processing model (such as a computer program) that systematically applies inference grades identical to that of a human brain.

Defuzzification

The contrast of Fuzzification is referred Defuzzification. The use of Fuzzy Logic Controller (FLC) develops desired output in a phonemic parameter (fuzzy number). Suitable to real world applications, the phonemic parameters need to be converted to crisp output. There are numerous defuzzification process but the most feasible procedures are as given [11]:

1) Center of gravity (COG)
2) Bisector of area (BOA)
3) Mean of maximum (MOM)

5. Simulation result

DC series motor

In our simulation analysis, we have supposed a nonlinear second order system in Figure 4. The fundamental goals of this simulation analysis is to study fuzzy with linear PI controllers. The time domain characteristics data is given in Table 1. The controller output is depicted in Figure 4.The step outputs gained with distinct classes of fuzzy PI controllers are depicted in Figure 5 which also depicts the corresponding response obtained with the conventional PI controller.

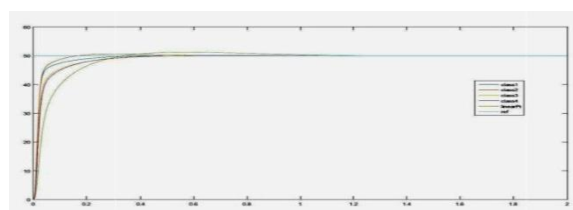

Figure 4 Comparison of performances of fuzzy PI controller and linear PI controller

Table 1 Fuzzy PI and linear PI controllers

	Classs-1	Class-2	Class-3	Class-4	PI- linear
Rise Time(tr)	0.053	0.0443	0.081	0.02	0.166
Settling Time(t_s)	0.55	0.75	0.55	0.47	1.25
Peak over-shoot (M_p)	0.06%	1.2%	0.034%	0.182%	2.5%

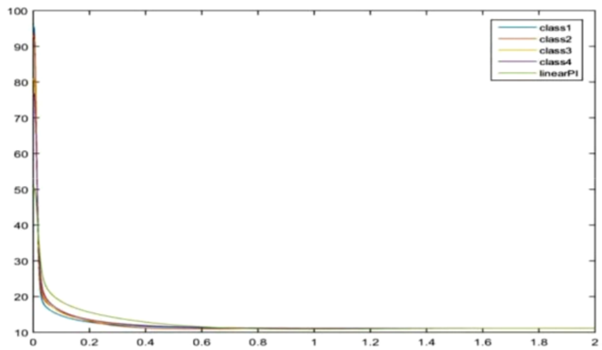

Figure 5 Outputs of Fuzzy PI and linear PI controllers

6. Conclusion

Mathematical designs of four distinct categories of general fuzzy PI/PD controllers are developed via triangular type input membership functions, algebraic product/minimum AND operation, bounded sum/maxi-mum OR operation, Larsen product inference method, and COS defuzzification method. Using N1 number of symmetric triangular membership functions on the input variable (es (k)), N2 number of symmetric triangular membership function on the input variable (es (k)), N1 + N2-1 number of symmetric fuzzy sets for the output variable, it has been depicted or proved that each resulting controller is equivalent to the summation of a universal 2-D multi-grade relay and a fuzzy PI/PD controller. After studying the characteristics of the fuzzy controller, it has been found that all the four classes of fuzzy controllers exhibit desirable control properties. The results shown in this report are important and useful, as they are more general and exact. Finally, some numerical examples together with their simulation results are inculcated to show the effectiveness of the nonlinear two-term controllers. Simulation results certify the dominance of the fuzzy nonlinear PI and PD controllers over the conventional linear PI and PD controllers in improvising the response.

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