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Design and Analysis of Fuzzy Pd 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 explained that the aggregation of a 2-D multigrade relay and a general nonlinear PI controller is the yield of fuzzy controller which govern the control action generated by the multigrade relay.

Keywords: PI controller, PD controller, Fuzzification, If-Then rules, defuzzificztion.

I. 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 reasonable 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 [7]. 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, robustnessagainst nonlinearity/uncertainties. 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 [3]. With its capability to replicate human decision making procedure, the technology seems to be quiet transparent and natural to the humans.

Our prime ambition is to discover the mathematical replica or structure of fuzzy PI/PD controllers and to imply these controller models to regulate the characteristics of systems. 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 [4]. 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 efficient except 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 mathematical replica of intelligent controller replica for regulate, the way the linear controllers are applied is the prime objective of deriving it [1]. 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 ambition 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.

II. ANALYSIS OF SYSTEMS

A. Single link manipulator

The notation Robot is derived from the Czech word "robota" which refers to as forced labour or slave. To define a robot is query of perpetual interest. An industrial robot as a multi-purpose machine armed by a memory device and a input output device for holding things, able to rotate and replace human labor by automated work of movements is referred as robot by the Electric Machinery Law of Japan. Whereas, the definition that has been extracted as feasible in the present state-of-the-art is represented by Association of Robotic Industries in 1979. An industrial robot has been referred to as "a reprogrammable multifunctional manipulator designed to move materials, parts, tools or specialized devices with the assistance of numerous programmed motions for the performance of a different kinds of tasks"

Classification of robots is merely broad statements depicting some important characteristics owned by a robot. Some common means of robot categorization are:

Configuration and Degree of Freedom

a. End Effector, b. Mobility, c. Pay Load Capacity, d. Power Drive, e. Control System, f. Programming System, g. Generation.

In contrast to that, flexible manipulators owns numerous benefits over their other identical twin: they need less amount of material, are light weight, have higher manipulation speed, lower power consumption, require smaller actuators, are flexible and transit able, are secure in applications owing to lesser inertia, have improved back-drive capability owing to removal of gearing, have lower net investment and payload to robot weight ratio is relatively higher.

The regulation of flexible robotic manipulators to uphold precise location is a highly challenging task. Attributing to the adaptable features and distributed virtue of the robotic system, the dynamics are highly non-linear and complex. Problems rises owing to accurate positioning needs, vibration due to robotic system flexibility, difficulty in attaining a precise design and non-minimum phase characteristics of the system. Therefore, flexible manipulators haven't favored in manufacturing industries, owing to un-attained end-point positional accuracy needs in answer to input commands. Thus, the model of control algorithms for flexible systems having nonlinear time-varying and ill-modeled dynamics results in bigger challenges for all conventional methodologies.

A schematic portrait of the single-link flexible robotic manipulator system is shown in diagram below, in which a control torque $\tau(t)$ is implied at the hub of a motor with E, I, ρ, L and IH represent Young's modulus, second moment of area, mass density per unit volume, length, and hub inertia moment.

$w(x,t)$ depicts the elastic deflection of the manipulator at a distance x from the hub ,the angular displacement of the joint in the X0OY0 coordinates is represented by $\theta(t)$, measured with the OX axis. X0OY0 and XOY depict the stationary and maneuvering frames respectively.

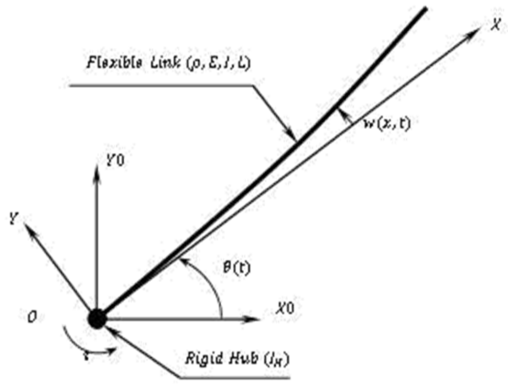

Fig. 1. Flexible manipulator scheme.

The width of the link is assumed to be way higher than its depth, thus granting the manipulator to vibrate notably in the horizontal direction (X0OY0 plane). To minimize complexity developed from time varying lengths, the length of the manipulator is supposed to be consistent. Moreover, the shear deformation, the rotary inertia and the cause of axial force are neglected. For an angular displacement θ and an elastic deflection w, the total displacement y(x,t) of a point with the manipulator at a distance x from the hub can be depicted as a function of the rigid body motion θ(t) and the elastic deflection w(x,t) both.

III. CONFIGURATIONS OF PD CONTROLLERS

Derivative controllers gives the calculated parameter from the rate of change of error. Owing to which, they re-rapid response gives comparatively much faster response than P controllers. Derivative controllers generate higher control amplitudes as result of change in amplitude occurs in spite of error being small. A steady-state error signal, is not acknowledged by D controllers, its rate of change is null regardless of how big the error is. Therefore, d controllers are hardly implied in practical applications. They are mostly applied in aggregation with other control elements, mostly with proportional controller.

In pd controllers (Fig. 2) with proportional + derivative control action, d controllers are manageable variable results from the accumulation of the separate p and d control elements.

Derivative controllers gives the calculated parameter from the rate of change of the error and not – as proportional controllers – from their amplitude. As a consequence, they re-rapid response gives comparatively much faster response than p controllers.

Derivative controllers develops huge control amplitudes just after a variation in amplitude takes place even if the inaccuracy is minute. A steady-state error signal, is not acknowledged by d controllers, because despite of how huge the flaw, its rate of change is zero [6]. As a result, derivative-only controllers are rarely employed in practical utilization. They are mostly situated in association with other control units, usually in association with proportional control**.**

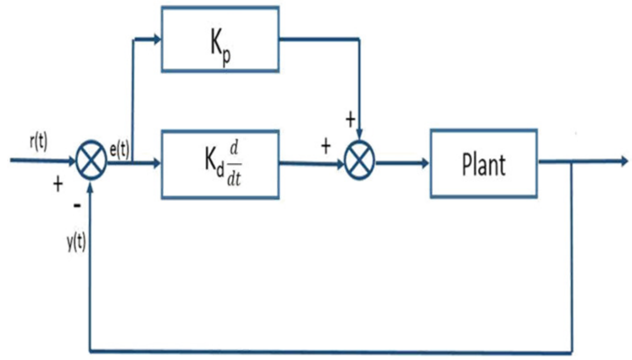

Fig. 2. Structure PD controller.

Continuous-Time Controller

$$u(t) = K_p e(t) + K_d \frac{de(t)}{dt}$$

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

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

In discrete time

Where n denotes sampling instant, T denotes the sampling period and Kp and Kd are the proportional and derivative constants.

Thus, the control action is dependent on the error and change in error [5]. Similar to that, a fuzzy PD controller can also be represented as dependent on error and change of error which becomes the rule base of the fuzzy control system i.e., the output of a fuzzy PD controller is directly computed From e and Δe.

IV. FUZZY LOGIC CONTROLLER

The basic block diagram of Fuzzy Logic Controller which includes a group of steps that follow in the whole process is as shown in Fig. 3.

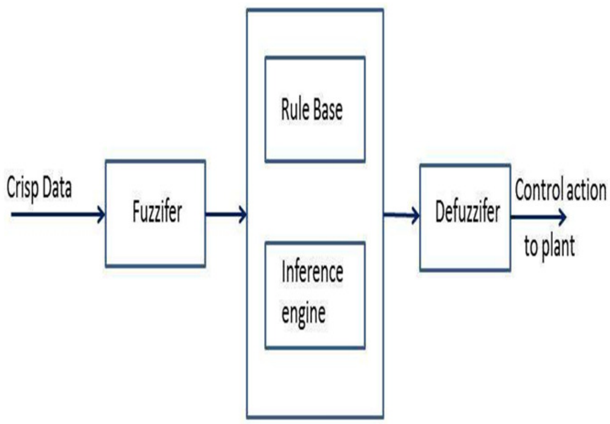

Fig. 3. Structure of a Fuzzy logic controller.

Fuzzy logic control is a control algorithm stationed on a phonemic control planning, which is borrowed from adept knowledge into an automatic control planning. The working of a FLC is stationed on qualitative knowledge concerning the system being controlled .It doesn't require any complex mathematical estimation like the others control system. While the others control system employ complex mathematical estimation to present a design of the controlled system, it only employs simple mathematical estimation to simulate the adept knowledge.

A fuzzy logic controller has four main components as shown in Figure:

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

Fuzzification. The first step in designing a fuzzy controller is to decide which state variables represent the system dynamic performance must be taken as the input signal to the controller. Fuzzy logic employesphonemic variables rather than numerical variables. The procedure of converting a numerical parameter (real number or crisp variables) into a phonemic variable (fuzzy number) is called fuzzification [2]. This is attained with the different types of fuzzifiers. There are generally three types of fuzzifiers, which are used for the fuzzification process; they are

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

Rule base. A decision making logic which is, simulating a human decision process, inters fuzzy control action from the knowledge of the control rules and linguistic variable definitions [9]. The rules are in "If Then" format and formally the If side is called the conditions and the Then side is called the conclusion. The computer is able to execute the rules and compute a control signal depending on the measured inputs error (e) and change in error (de). In a rule based controller the control strategy is stored in a more or less natural language. A rule base controller is easy to understand and easy to maintain for a non- specialist end user and an equivalent controller could be implemented using conventional techniques [1].

Inference Engine. Inference engine is defined as the Software code which processes the rules, cases, objects or other type of knowledge and expertise based on the facts of a given situation. When there is a problem to be solved that involves logic rather than fencing skills, we take a series of inference steps that may include deduction, association, recognition, and decision making. An inference engine is an information processing system (such as a computer program) that systematically employs inference steps similar to that of a human brain.

Defuzzification. The reverse of Fuzzification is called Defuzzification. The use of Fuzzy Logic Controller (FLC) produces required output in a linguistic variable (fuzzy number). According to real world requirements, the linguistic variables have to be transformed to crisp output. There are many defuzzification methods but the most common methods are as follows:

i) Center of gravity (COG)
ii) Bisector of area (BOA)
iii) Mean of maximum (MOM)

V. SIMULATION RESULT

A. Single Link Manipulators

Figure 4 depicts the step responses attained with distinct cl asses of fuzzy PD controllers for single link manipulator arm. The time domain performance data is given in Table 1.

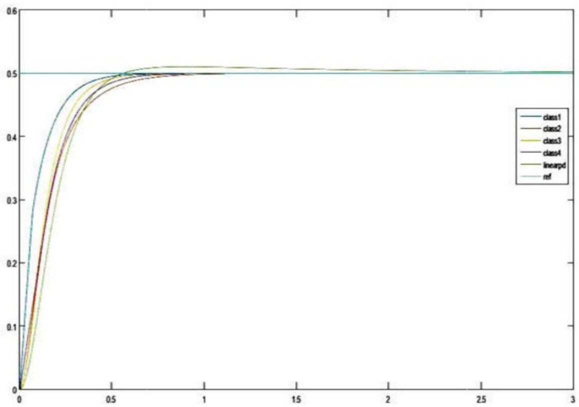

Fig. 4. Comparison of performances of fuzzy PD controller and linear PD Controller.

Table 1: Fuzzy PD and linear PD controllers.

	Class-1	Class-2	Class-3	Class-4	PD-linear
Rise Time(t_r)	0.23	0.32	0.258	0.31	0.34
Settling Time(t_s)	0.75	0.9	0.75	0.88	2.5
Peak over-shoot (M_p)	0	0	0	0	2.06%

VI. 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 global two-dimensional multi-level 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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