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Intelligent Fuzzy PD+I Controller with Stabilizer for Nano Satellite Attitude Control System

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Abstract. This paper discusses the variation of proportional and derivative gains in a system under the control of PD+I controller that uses fuzzy inference method an effort is made to design the fuzzy proportional-derivative (PD) + I controller for a nonlinear the proposed fuzzy PD + I structure shows superior performance in the Nano-satellite attitude control system. Given that 2-input PD type controllers are commonly used to control Nano satellite attitude systems (Innovative Satellite InnoSAT), This paper analysis the performance of Fuzzy PD+I on satellite system. Fuzzy PD+I controller design can control Nano satellite attitude control system nicely and utilized the Fuzzy PD+I controller which optimize the stability of the Nano Satellite control system. In addition, the scheme is robust to variations in nonlinearities, as well as the steady-state gain of the plant. We illustrate the effectiveness of our scheme In MATLAB / SMULINK simulation environment.

1. Introduction

This paper presents a type of fuzzy PD+I controller that uses fuzzy inference method. Given that 2-input PD type controllers are commonly used to control Nano satellite attitude systems, the structure discussed in this paper suggests that the controllers will achieve the same performance made by the general-purpose fuzzy PID controller, with additional enhances to the control performance while addressing a wide range of input and parameter variations. Complexity of the proposed fuzzy PD+I controller is minimized as possible and only two design variables are used to adjust the rate of variations of the proportional gain and derivative gain. This paper utilized the Fuzzy PD+I controller which optimize the stability of the Nano Satellite control system eradicate the steady state error, while the PI controller might face limitations in optimizing the response to the momentary variations. On the other hand, three-input fuzzy systems to construct a fuzzy PID controller can create a hardship in defining the control rules [1].

In order to address these limitations, the fuzzy PID controllers have adopted the use of multiple two-input fuzzy controllers. For example, using the two-input fuzzy system from Ying's work on fuzzy controllers [2], Misir [3] developed a digital PID controller that used the two "two-inputs" controllers. Further work by Li was made to improve the proportional segment of the PID controller using a 36 inputs regions in a two-input fuzzy systems [4]. In addition, Mann [5] examined the inputs and outputs to come up with groupings for the fuzzy PD+I elements to categorize the fuzzy PD+I structures by the



types and numbers of its consisting elements. However, advances in this regard and the development of the PID controllers are largely dependent on the background and use of the researchers and developers. Therefore, attempts to execute direct evaluation of the performance made by the traditional PID controllers and the fuzzy PD+I controllers has proven to be challenging. Yet a comparison might still be possible considering that many attempts to tune the traditional controllers have been developed, and consequently the tuned PID factors can lay the foundation for selecting a fuzzy PID controller. The selection will take into consideration the relation between the fuzzy PD+I controllers and equivalent PID controller [6].

For the purpose of this paper, the traditional PID control has been modified with two-input fuzzy controller to include the varying gains of the proportional and derivation signals. The two signals play the greater role in determining the transient response, while the integral signal has a fixed gain for removing the steady state errors. Therefore, the proposed controller will be referred to as the fuzzy PD+I type. For this comparison, the linear inference method will be performed instead of the gravity method or similar general inference methods as proposed by Mizumoto [7], [8]. For this paper, the designed procedure will use membership functions and control rules following implementing a direct output interference method for the PID output surface. When using the traditional nonlinear inference method, the undesired nonlinearities will become apparent on the fuzzy system's output surface. However, by using the product-sum-gravity method the nonlinearities can be created on the output surface and created to enhance the performance of the controller. Using this approach, the added nonlinearities and its effects can be adapted and controlled depending on the rates of nonlinearities introduced to the proportional and derivative parts [9].

To thoroughly examine this approach, this paper will be organized as follows: Section 2 addresses the structure of the proposed fuzzy PD+I and explain its components. Section 3 describes the design of the two-input fuzzy system with modified PD part. Section 4 focuses on the practical structure of the fuzzy PD+I controller for Nano satellite attitude control system. Section 5 demonstrates the results of the simulation for fuzzy PD+I controller for Nano satellite attitude control system.

2. Structure of Fuzzy PD+I controller with stabilizer

The traditional method of PID control is to use the proportional, integral and derivative signals of the errors of the attitude to create a control signal. It should be taken into consideration that the attitude error promptly changes in the same moment when the reference input change, which might cause the derivative signal of the attitude to shock the system. Therefore, to overcome this issue is the PID structures that relies on the derivative signal for the output signal rather than for the attitude error. Hence, for this paper the structure of the fuzzy controller suggested is shown in Figure 1 consisting a fuzzy PD+linear I structure. In the cases where there is no significant differences between the magnitude of the three gains of the traditional PID controller, it is recommended to use a three-input fuzzy control like fuzzy PI+D or fuzzy PD+I because they will produce more control over the results [10].

2.1. Structure of Fuzzy PD+I controller

Since this paper will only focus on the steady state errors and the transient response, the fuzzy PD+I controller will be used. The fuzzy system used in the proposed structure will only be applied to the proportional and derivative signal of the linear PID controller, in which the integral signal will be relying on the traditional linear method [11]. As explained above the integral signal mainly focuses on eliminating the steady state error. Therefore, the transient outcome is mainly caused by the proportional and derivative signals. To improve the transient response, a two-input fuzzy system will use a verity of gains to control the proportional and derivative parts. The nonlinearities are then added by the fuzzy control rules and membership functions, therefore, accentuating the proportional gain to deal with large attitude errors and promptly decreases the speed of the attitude error. In this case, the nonlinearities of the derivative gain overpowers overshoot and enhances damping until reaching a stability. The fuzzy system in this structure is regulated in response to the maximum range of the reference input signal.

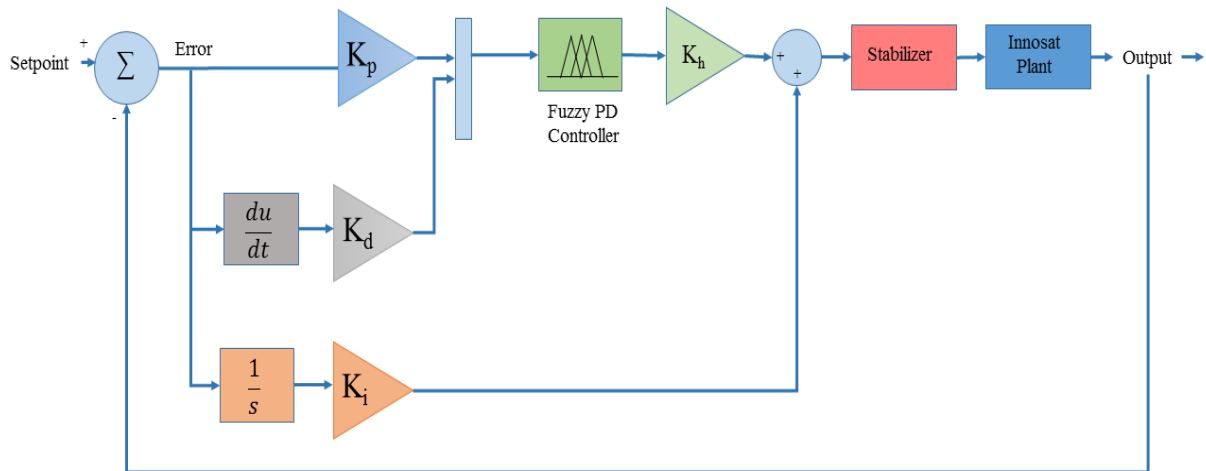


Figure 1. Block diagram of fuzzy PD+I controller

The Euler angles and their derivatives result represent the transfer functions of InnoSAT attitude control can be shown in equation (1), [12]

$$\begin{aligned}\phi(s) &= \frac{s^2 + 0.3051s + 0.2040}{s^4 + 1.1050s^2 + 0.1650} \\ \theta(s) &= \frac{1}{s^2 - 7.1138 \times 10^{-3}} \\ \psi(s) &= \frac{s^2 - 0.3023s + 0.8088}{s^4 + 1.1050s^2 + 0.1650}\end{aligned}\quad (1)$$

2.2. Stabilizer

The stabilizer used in the proposed control scheme is based on lead compensator where the parameters for the compensator can be achieved by the method of root locus. If a plant is dynamic, adjusting the feedback gain alone is not enough. Therefore, some modification or compensation must be made in the feedback to achieve the desired specifications. Typically, the transfer function of lead compensator takes the form [13] :

$$H(s) = K \frac{s + a}{s + b} \quad (2)$$

The transfer function of stabilizer to stabilize the InnoSAT can be expressed by the following equation:

$$H(s) = \frac{s + 1}{s^2 + 40s + 400} \quad (3)$$

Table 1. Rule base for the controller of roll, pitch and yaw angles

Error	Change of Error		
	NE	ZE	PO
NE	LO	LO	ZE
ZE	LO	ZE	HI
PO	ZE	HI	HI

Three similar fuzzy controllers for the three angles roll ϕ , Pitch θ and Yaw ψ , are shown in Figure 2. Table 1 show the memberships for inputs Error, Change of Error, and the list of the rules of fuzzy inference structure (FIS) [14].

3. Fuzzy PD + I Controller Design

The experiment uses computer simulation and is performed using fuzzy PD+I controller for InnoSAT attitude control system. Figure 2 demonstrates the block diagram of the fuzzy PD+I control system. In this system, the transient response of the proportional and derivative actions and their behaviours can be easily recorded and observed. However, the corresponding variations of the integral gain might have limited effect on the transient response, and its associated control rule might not be easily perceived. The proposed controller focuses on improving the transient response. Therefore the considered fuzzy PD+I controller uses two input fuzzy system for the proportional and derivative gains and a normal I controller for the integral gain. In this design, the change of error will be replaced by the derivative of error signal as the derivative signal.

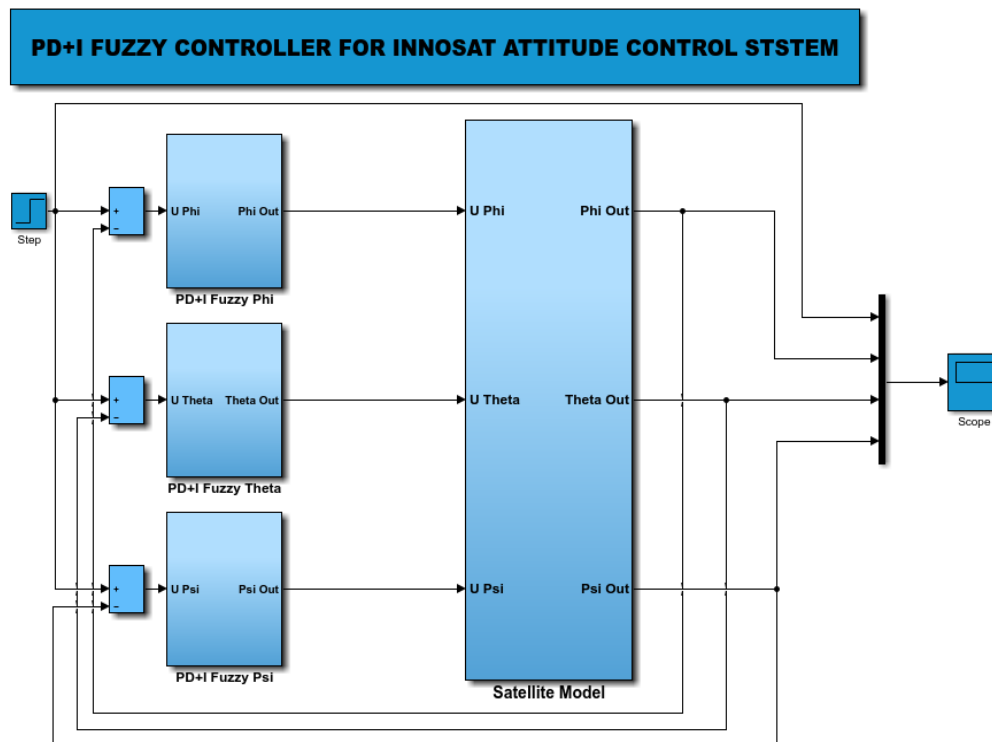


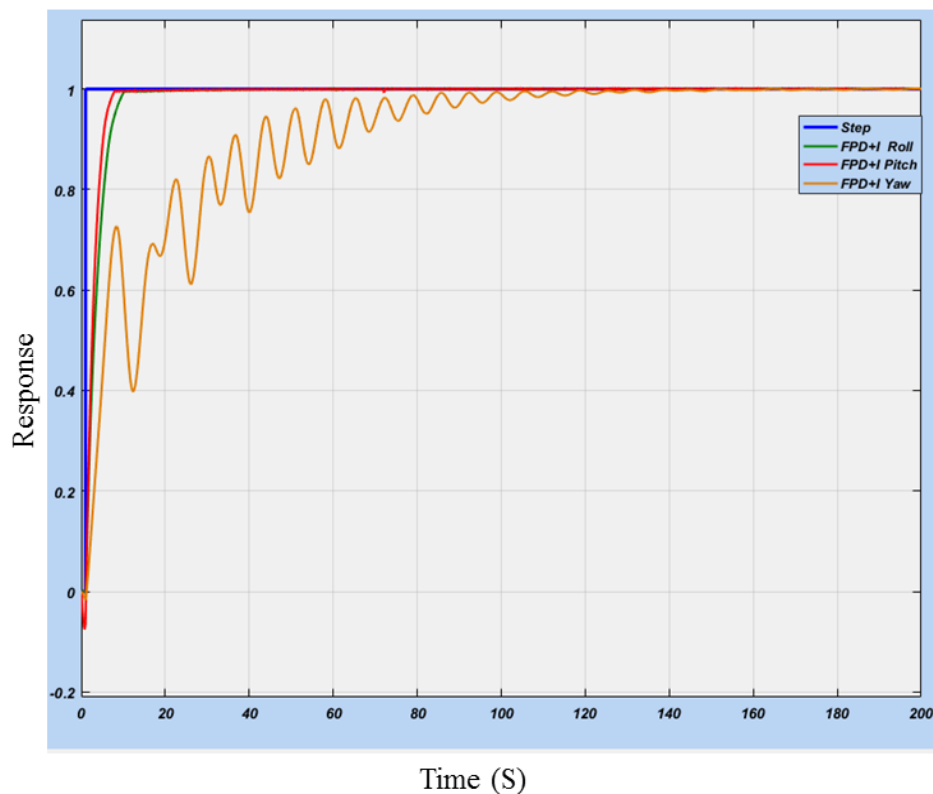
Figure 2. Fuzzy PD+I controller for InnoSAT Attitude Control System.

4. Simulation Results

The simulation was conducted using MATLAB and Simulink. By using the initial Gain Co-efficient parameters for Fuzzy PD+I Controller in Table 2, performance measures of the controller are as shown in Table 3. Under these optimum tuning parameters, the Fuzzy PD+I controller shows a very good performance.

Table 2. Gain Co-efficient Parameter for Fuzzy PD+I Controller

Parameter	Controller		
	K_p	K_d	K_i
Roll $\phi_{(s)}$	50	15	5
Pitch $\theta_{(s)}$	70	14	3
Yaw $\psi_{(s)}$	50	15	5

**Figure 3.** Step response of Fuzzy PD+I with Stabilizer for InnoSAT Attitude Control.**Table 3.** Performance measures of the proposed controlled system

Angle	Delay Time (Td) sec	Rise Time (Tr) sec	Peak Time (Tp) sec	Settling Time (Ts) sec	Peak Overshoot PO%	Steady State Error %
Roll $\phi_{(s)}$	3	5.2	10	15	0.2	0.1
Pitch $\theta_{(s)}$	2	3.8	8	10	0.3	0.1
Yaw $\psi_{(s)}$	6	33.9	117	90	0.5	0.2

Response of the Fuzzy PD+I with Stabilizer for InnoSAT Attitude Control System is shown in Figure 3. During the simulation, the fuzzy PD+I control demonstrated very small overshoot and a rapid rise time for Roll and Pitch. Therefore, the suggested fuzzy PD+I control is less sensitive to the differences of the K_p , K_i , K_d gains. However, the response for Yaw is relatively slow due to unstable original response. In this case the controller has to play two roles, which are to stabilise and then control the Yaw dynamic. Thus a longer time is required to compensate the system response.

5. Conclusion

This paper discusses the design of a fuzzy PD+I controller to improve the attitude control performance of InnoSAT. Two input and one-output fuzzy system has been adapted for the proportional and derivative part of the traditional PID controller. The results proved that using this fuzzy PD+I controller gives additional effectiveness compared to the fuzzy inference method. The fuzzy inference method showed that nonlinearities are implemented only by the fuzzy control rules and membership functions. With comparatively large attitude error, the proportional gain is highlighted by the nonlinearities; alternatively with small attitude error, the derivative gain is emphasized. The fuzzy PD+I controller also has a fast rise time and more effective control on overshoot. The results concluded that with those selected gains and parameters, the fuzzy PD+I controller produced good and robust responses.

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