Dynamic Performance Analysis of Self-Tuning Fuzzy-PID Controller for the Inverted Pendulum System

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Abstract— **Creating a very real system sub-model of the inverted pendulum system, nonlinear dynamic model and unstable equilibrium points is one of the major reasons for preferring research purposes. The coefficients of the conventional PID controller are not often properly tuned for the nonlinear plant with unpredictable parameter variations. Hence, it is necessary to automatically tune the PID parameters. In this paper, self -tuning Fuzzy- PID controller is developed to improve the performance of the inverted pendulum.**

Keywords-- Self-Tuning Fuzzy PID Controller, Inverted Pendulum.

I. INTRODUCTION

PID controllers are widely used in many industrial applications. Due to being constant the parameters of classic PID controllers, it doesn't always show effective performance in time-varying and nonlinear systems. In 1965, together with the concept of fuzzy logic put forward by Lotfi A. Zadeh fuzzy logic controller (FLC) has emerged and has yielded very successful results in many applications. The most important feature of the fuzzy logic controller system without the need of any mathematical model is based on the knowledge and experience of experts. This feature has made intriguing FLC and allows the use in many industrial applications. As to Self Tuning Fuzzy -PID controller according to the response of the system PID controller Kp, Ki and Kd gains without constant parameters It is based on the principle discovered by fuzzy logic controller[1-9]. In this study, for the control of the inverted pendulum nonlinear dynamical systems Self-Tuning Fuzzy PID controller dynamic performance was examined.

II. THE INVERTED PENDULUM SYSTEM

The inverted pendulum system as seen figure 1 consists of its length l, its mass m intensive accepted bar endpoints, M mounting a vehicle at point P on the asteroid belt. The angle (Θ) with vertical position rod's passing through the point P and the distance (x) from a reference point on the horizontal axis are represented Θ and x. Rod movement is constrained to the xy plane mounted vehicle able to move only along the x axis[13]. Rod's mass center of gravity(x,y) coordinate plane equation (1) and equation (2) it can be expressed as in,

$$x_G = x + l\sin\theta \tag{1}$$

$$y_G = l\cos\theta \tag{2}$$

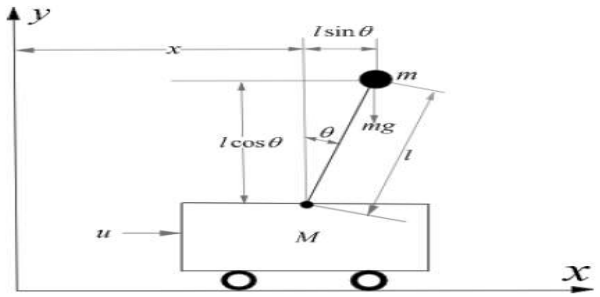


Fig. 1. Inverted pendulum control system

When Newton's second law of motion is applied in the x direction, in equation (3) differential equation is obtained.

$$M\frac{d^2x}{dt^2} + m\frac{d^2x_G}{dt^2} = u \tag{3}$$

If differential equation in equation (1) is substituted equation(3), equation (4) is obtained.

$$(\mathrm{M}+\mathrm{m})\ddot{x} - ml(\sin\theta)\dot{\theta}^2 + ml(\cos\theta)\ddot{\theta} = u \tag{4}$$

Secondly, applied to the point P m is the mass of Newton's second law of motion around differential equation in equation (5) is obtained.

$$m\frac{d^2x_G}{dt^2}l\cos\theta - m\frac{d^2y_G}{dt^2}l\sin\theta = mgl\sin\theta \tag{5}$$

Equation (1) and equation (2) above if instead of written statements, equation(6) is obtained.

$$\mathrm{m}\ddot{x}\cos\theta + ml\ddot{\theta} = mg\sin\theta \tag{6}$$

Nonlinear system model given with equation (4) and equation (6) can be written as follows with state variables:

$$x_1 = x,\ x_2 = \dot{x},\ x_3 = \theta,\ \dot{x}_1 = x_2\ \dot{x}_3 = x_4$$

$$\dot{x}_2 = \frac{ml\sin(\mathrm{x}_3)\,\mathrm{x}_4^2 - mg\sin(\mathrm{x}_3)\cos(\mathrm{x}_3) + u}{M + m - \mathrm{m}\cos^2(\mathrm{x}_3)}$$

$$\dot{x}_4 = \frac{-ml\sin(\mathrm{x}_3)\cos(\mathrm{x}_3)\,\mathrm{x}_4^2 + (M+m)\,\mathrm{g}\sin(\mathrm{x}_3) - \mathrm{u}\cos(\mathrm{x}_3)}{l(M + m - \mathrm{m}\cos^2(\mathrm{x}_3))}$$

The value of the inverted pendulum system are given in Table 1.

TABLE I
THE INVERTED PENDULUM SYSTEM VALUES

Parameters	Symbol	Value	Unit
Mass of vehicle	M	2,4	kg
Mass of inv. pendulum	m	0,23	kg
Length of inverted Pendulum rod	l	0,36	m
Acceleration of gravity	g	9,8	m/sn^2
Runway length	L	0,5	m

III. SELF TUNING FUZZY PID CONTROLLER DESIGN

Fuzzy logic was first put forward in 1965 by Lotfi A. Zadeh. Since then the importance of extant increasingly fuzzy logic, expression of uncertainty and established to work with uncertainty can define as a solid mathematical order. Because it has the logic classical logic is a component element of a cluster or not modelling and control of complex systems is difficult with classical logic method. Because data must be complete and clear [11-12].

There is no certainty in fuzzy logic and there are more qualitative definition. The most interesting of fuzzy logic side of the experts of the information embedded into the controller system is monitored. So the system does not need any mathematical model. FLC, with general structure, makes up of four basic components as fuzzification, fuzzy inference, flushing and knowledge base.

The aim of the Self-Tuning Fuzzy-PID controller is to find out by forming with fuzzy logic controller gain parameters suitable for system PID gain values. Because PID gain parameters are constant with time, it cannot give successful results for nonlinear and time-varying systems. PID controller's adverse conditions take away by automatically adjusting Self-Tuning Fuzzy-PID and PID gain values [13]. In Self-Tuning Fuzzy-PID for Kp, Ki, Kd gain parameters are respectively selected minimum and maximum range values [Kpmin, Kpmax], [Kimin, Kimax], [Kdmin, Kdmax]. When selecting this range, Kp, Ki, Kd gain parameters found for the PID controller is taken reference. The angular position and linear position control for the inverted pendulum Kp, Ki, Kd values for the selected range of gains and mathematical equations are given below.

Kp € [5-15], Ki € [0.00001-0.00004], Kd € [2.5-7.5].

$$K_p' = \frac{K_p - K_{p\min}}{K_{p\max} - K_{p\min}}$$

$$K_i' = \frac{K_i - K_{i\min}}{K_{i\max} - K_{i\min}} \qquad (7)$$

$$K_p' = \frac{K_d - K_{d\min}}{K_{d\max} - K_{d\min}}$$

Self-Tuning Fuzzy-PID controller block diagram is given in figure 3.

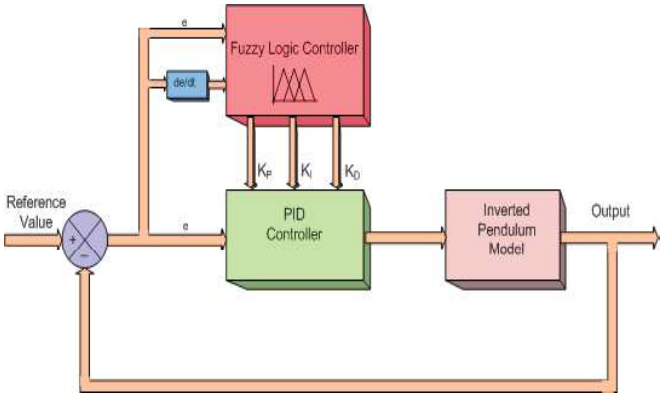


Fig. 3. Fuzzy-PID Controller Block Diagram

Input and output variables in FLC blur process is converted into a symbolic expression. Linguistic variables used in the designed controller including NL(Negative Large), N (Negative), Z (Zero), P (Positive), PL (Positive Large) five variables were used. The choice of membership functions for each input supplied to the system is completely arbitrary. There can be triangle, trapezoid, sinusoid, cauchy, bell, sigmoid, gaussian types. In figure 4 fuzzy logic system with 2 inputs and 3 outputs are shown. In figure 4 FLC has 2 inputs. These can be defined error (e) and error change (de). The outputs is constituted for Kp, Ki and Kd. Error (e) and error change (de) used in the angular and linear position control, triangle membership functions formed for Kp, Ki and Kd are given in figure 5-6-7-8-9 [14].

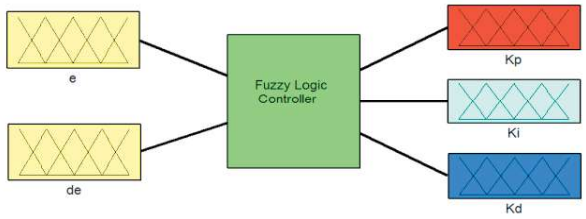


Fig. 4. Fuzzy Logic Control System

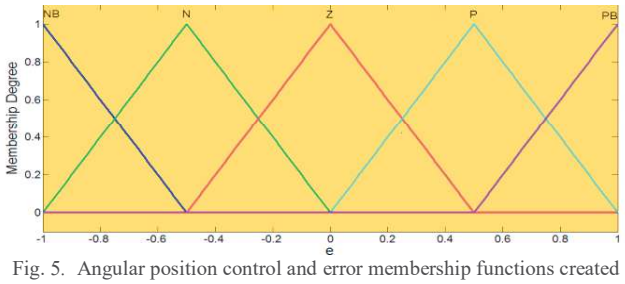


Fig. 5. Angular position control and error membership functions created for linear position control

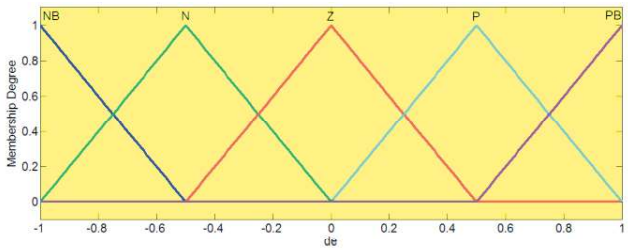


Fig. 6. The error exchange membership functions for angular position control and linear position control

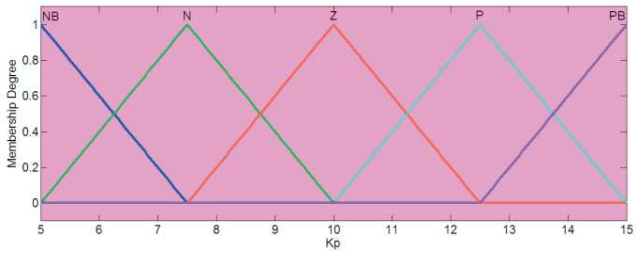


Fig. 7. The membership functions created for Kp in angular position control and linear position control

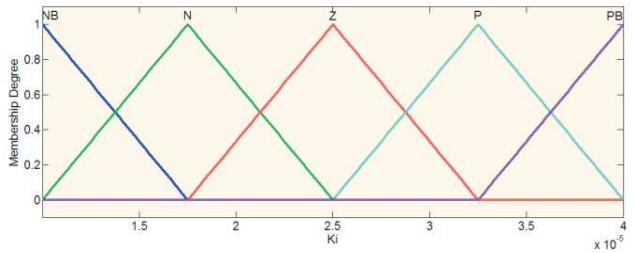


Fig. 8. The membership functions created for Ki in angular position control and linear position control

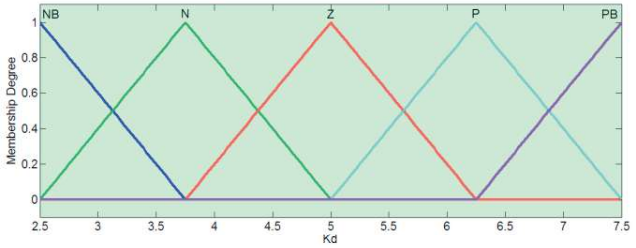


Fig. 9. The membership functions created for Kd in angular position control and linear position control

Rule base created for the outputs of Kp, Ki and Kd is given table 3-5.

TABLE III
TABLE RULES FOR Kp

Kp		de				
		NB	N	Z	P	PB
e	NB	NB	NB	NB	N	Z
	N	NB	N	N	N	Z
	Z	NB	N	Z	P	PB
	P	Z	P	P	P	PB
	PB	Z	P	PB	PB	PB

TABLE IV
TABLE RULES FOR Ki

Kİ		de				
		NB	N	Z	P	PB
e	NB	PB	PB	PB	N	NB
	N	PB	P	P	Z	NB
	Z	P	P	Z	N	NB
	P	Z	P	N	N	NB
	PB	Z	N	NB	NB	NB

TABLE V
TABLE RULES FOR Kd

Kd		de				
		NB	N	Z	P	PB
e	NB	NB	NB	NB	P	PB
	N	NB	N	N	Z	PB
	Z	Z	N	Z	P	PB
	P	Z	N	P	P	PB
	PB	Z	P	PB	PB	PB

IV. SIMULATION STUDIES

Inverted pendulum system is conventional materials known in the literature to test the dynamic nonlinear controller types. The problem that will examine aims using a control input two output state variables car's condition linear position and angular position of the pendulum around unstable equilibrium self-tuning control with Fuzzy-PID controller. The depth of the problem constitutes simultaneous control of the linear position and angular position variable. In Matlab/Simulink for controlling inverted pendulum system Self-Tuning Fuzzy-PID model is formed in figure 10.

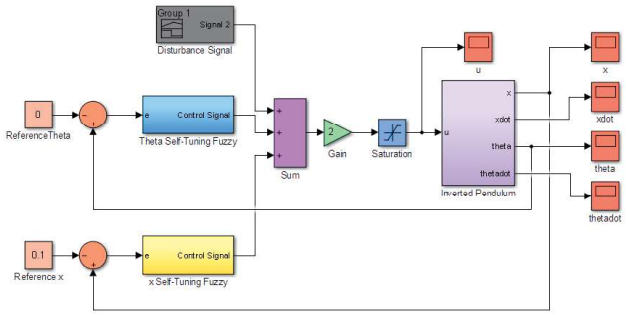


Fig. 10. *Self-Tuning Fuzzy-PID controller formed for İnverted pendulum system control*

0.4N distorting amplitude was implemented to the system in 25. and 45. seconds. Disruptive impact mark designed for system has been given in figure 11.

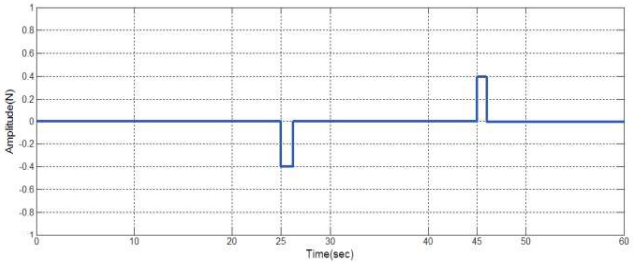


Fig. 11. Disruptive impact mark designed for inverted pendulum system

Initial angular position to control the angular position of the pendulum has been taken 0.15 radiant. Initial line position to control the car's line position has been taken 0.05m. For the inverted pendulum line position and angular

position controllers Self-Tuning Fuzzy-PID controller system response is given in figure 12-13.

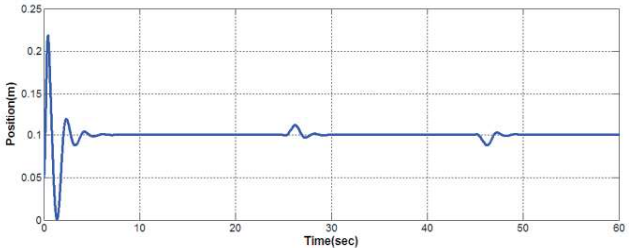


Fig. 12. Belonging to control of linear position(x) the response of Self Tuning Fuzzy-PID controller

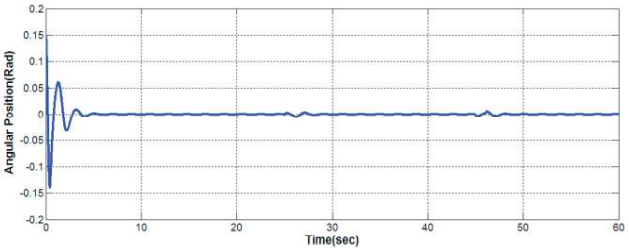


Fig. 13. Belonging to control of angular position(theta) the response of Self Tuning Fuzzy-PID controller

V. Conclusion

Classical control systems cannot show desired performance features in the changing state conditions. By modeling these systems to changing state conditions a proper classical control system design is quite difficult.

Upon analyzing the simulation results, for the linear and angular position of the inverted pendulum control disruptive is applied to the system in 25 and 45 seconds. Self-Tuning fuzzy-PID controller in terms of rise time, settling time, maximum exceed control parameters before and after disturbance is seen quite good performance.

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