Hybrid Fuzzy PD^2 Controller for Robotic System

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ABSTRACT

This paper proposed a new hybrid structure called a FPD^2 controller for a simple robotic system. The controller consists of a fuzzy PD (FPD) controller part, that has a simple rules base nine rules only, and conventional D controller (CD) part. The CD is added to the FPD to improve the transited performance and to avoid the derivative kick with out add more rules.

The performance of the proposed controller is compared with the response of the conventional PD controller, showing that the FPD^2 has smaller overshot and less settling time over its CPD.

Keywords: Fuzzy Logic Control, Conventional PID Control, Robot System, Fuzzy PD.

1. INTRODUCTION

A main concern of robotic application is to find an effective controller to achieve accurate tracking of desired motions [1]. A robotic system has very strong nonlinear characteristics and often, contains variable and parameters in a real environments [2].

The PID conventional controller is the most frequently control element in industrial world. It is estimated that, at least the 90% of the controllers employed in the industry are PID or its variations. But it needs a quantitative model of the process, which is not always available. Specially if the process is too complex to achieve a good physical description, conventional methods are not able to guarantee the final control aims, and the controller synthesis has to be based mainly on intuitions and heuristic knowledge. So, expert control strategies have been favored since they are based on the operators experience and do not need accurate models. One of the most successful expert system techniques applied to a wide range of control applications has been the fuzzy set, theory, which has made possible the establishment of " intelligent control" [3].

Fuzzy logic control has emerged as an alternative or complements to conventional control strategies in many engineering areas, especially in robotics [4]. Fuzzy logic control offers several unique features that make it a particularly appealing choice fro many control problems [5]:

1. It is inherently robust since it does not require precise, noise- free inputs and can be programmed to fail safely if a feedback sensor quits or destroyed. The output control is a smooth control function despite a wide range of input variations.
2. Since the fuzzy logic controllers processes user-defined rules governing the target control system, it can be modified and tweaked easily to improve or drastically alter system performance.
3. Fuzzy logic control is not limited to a few feedback inputs and one or two control outputs, nor is it necessary to measure or compute rate- of-change parameters in order for it to be implemented.
4. Because of the rule-based operation, any reasonable number of inputs can be processed (1-8 or more) and numerous outputs (1-4 or more) generated, although defining the rule base quickly becomes complex if too many inputs and outputs are chosen for a single implementation since rules defining their interrelations must also be defined.
5. Fuzzy logic can control nonlinear systems that would be difficult or impossible to model mathematically. This opens the door for controlling systems that would normally be deemed unfeasible for automation.

   This paper presents the FPD^2 scheme instead of the conventional PD controller for a simple robot system.

2. Fuzzy Logic Control Design

Fuzzy logic control shown in Fig.1.a developed here is a two- input single- output controller. The two input are derivation from set point error (e) and change of error (Δe). The error is defined as:

$$\theta_r(t) - \theta_c(t) \qquad (1)$$

change of error as follows:

$$\Delta e(t) = \frac{d}{dt} e(t) \qquad (2)$$

Where $\theta_r(t)$ is the reference input signal, $\theta_c(t)$ is the output signal.

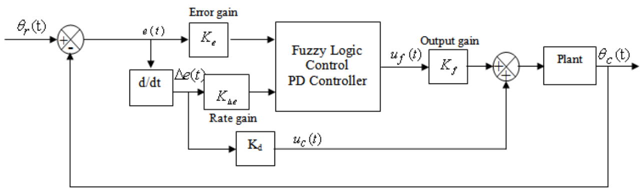

Figure 1.a: Closed loop fuzzy PD^2 Structure proposed.

The tracking error signal (position) and change of the error signal (velocity) are converted into information that the inference mechanism can easily use to activate and apply rules.

The fuzzy controller is composed of the following three-elements as shown in Fig.1.b:

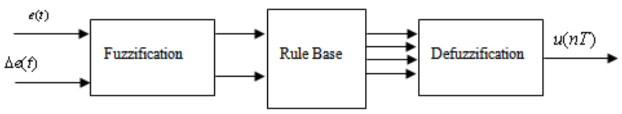

Figure 1.b: Fuzzy logic control.

1) Fuzzification: This converts input data into suitable linguistic values. The third triangular input and output member ship functions of the fuzzy logic control are shown in the Fig. (2). For the system under study the universe of discourse for both e(t), Δe(t) and for output may be normalized from [-5,5], and the linguistic labels are { Negative, Zero, ,Positive }, and are referred to in the rules base as {N, Z, P }.

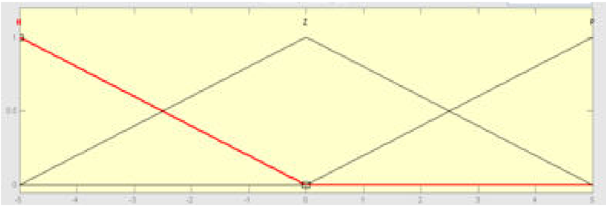

Figure 2: The input and output membership function for FPD controller.

2) 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. For given input and output linguistic label table (1) show the control rules base that used for FPD.

Table 1: Rules base for fuzzy PD controller.

e(t)/Δe(t)	N	Z	P
N	N	N	Z
Z	N	Z	P
P	Z	P	P

The computation of the fuzzy control action signal composed many steps. These steps can be all combined together in what is called control surface because the system has two inputs and one output. The shape of this surface shows how the output value varies with different combination of the two inputs values. Fig. (3) shows the rule surface viewer of the FPD.

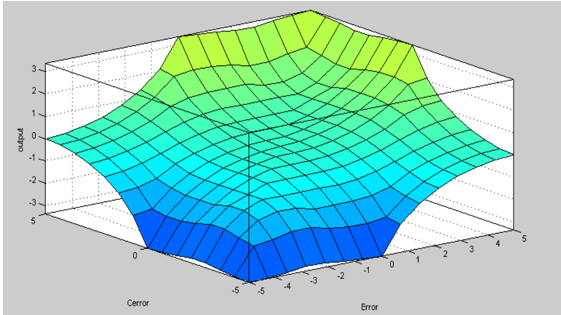

Figure 3: Rule Surface viewer of the FPD controller.

3) Defuzzification: The input for defuzzification is the member ship (certainty) $\mu(u_i)$ from implied fuzzy sets resulted from premise rules and the output is a crisp number. The most popular method, center of gravity or center of area is used for defuzzification [6]:

$$U_f = \frac{\sum_{j=1}^{n} \mu(\mu_j)\mu_j}{\sum_{j=1}^{n} \mu(\mu_j)} \qquad (3)$$

Where $\mu(u_j)$ member ship grad of the element u_j, U_f is the fuzzy control output, n is the number of discrete values on the universe of discourse.

2.1 Derivative of the fuzzy PD^2 Structure

The structure of the FPD^2 divide into two parts as follows:

1- FPD Controller: Derivative action helps to predict the error and proportional-derivative controller uses the derivative action to improve closed-loop stability. The basic structure of a PD controller is [7]:

$$u_{n=}K_p\left(e_n + T_d\frac{e_n - e_{n-1}}{T_s}\right) \qquad (4)$$

The control signal is thus proportional to an estimate of the error T_d seconds ahead, where the estimate is obtained by linear extrapolation. For $T_d = 0$ the control is purely proportional, and when T_d is gradually increased, it will dampen oscillations. If T_d becomes too large the system becomes over damped and it will start to oscillate again.
Input to the FPD controller is the error and derivative of error:

$$\Delta e(n) = \left(\frac{e_n - e_{n-1}}{T_s}\right) \qquad (5)$$

This is a discrete approximation to the differential quotient using a backward difference. Other approximation are possible. The controller output is a nonlinear function of error and change of error:

$$U_f(n) = f(K_e * e_n, K_{\Delta e} * \Delta e(n) \qquad (6)$$

Where f is input-output map of fuzzy controller, using the linear approximation $K_e * e_n + K_{\Delta e} * \Delta e(n)$, then:

$$U_f(n) = \left(K_e * e_n + K_{\Delta e} * \Delta e(n)\right)K_f \qquad (7)$$

$$U_f(n) = K_e * K_f * \left(e_n + \frac{K_{\Delta e}}{K_e}\Delta e(n)\right) \quad (8)$$

By comparison, the gain in (4) and (7) are related the following way:

$$K_e * K_f = K_p \quad (9)$$

$$\frac{K_{\Delta e}}{K_e} = T_d \quad (10)$$

The FPD controller may be applied when proportional control is inadequate. The derivative term reduces overshoot, but it may be sensitive to noise as well as abrupt change of the reference causing a derivative kick. The usual counter-measures may overcome these problems: in former case insert a filter, and in latter use the derivative of the process output instead of the error [7].

2- CD Controller: derivative action for providing phase lead, which offsets phase lag caused by integration. This action is also helpful in hasting loop recovery from disturbances, derivative action can have more dramatic effect on second-order plants than first-order plants [8].

$$U_c(n) = K_d * \Delta e(n) \quad (11)$$

The final control action of the FPD^2 is the sum of the two control action in (8) and (11), then:

$$U_{FPD^2}(n) = U_f(n) + U_c(n) \quad (12)$$

$$U_{FPD^2}(n) = K_e * K_f * e_n + K_{\Delta e} * K_f * \Delta e(n) + K_d \Delta e(n) \quad (13)$$

$$= K_e * K_f \left[e_n + \Delta e(n)\left[\frac{K_{\Delta e} * K_f + K_d}{K_e * K_f}\right]\right] \quad (14)$$

By comparison, the gain in (4) and (14) are related the following way:

$$K_e * K_f = K_p \quad (15)$$

$$\frac{K_{\Delta e} * K_f + K_d}{K_e * K_f} = T_d \quad (16)$$

As compared to the FPD controller we can see in the equations (16,15) the effect of added the CD controller to the FPD controller is only the effect on the T_d when estimated the gains.

3. Description of the Robotic System

This experiment is very similar to the position-control experiments. The idea of this experiment is to get a metal object attached to a robot arm by an electromagnet from position 0^o to a specified angular position with a specified overshoot and minimum overall time [9].

The block diagram of the closed-loop system is shown in Fig.4. the system composed of an angular position sensor (usually an encoder or a potentiometer for position applications). The output can be converted into voltage using the sensor gain value. The closed-loop transfer function in this case becomes:

$$\frac{\theta_m(s)}{\theta_{in}(s)} = \frac{\frac{K * K_m * K_s}{R_a}}{(\tau_e s + 1)\left\{J_m s^2 + \left(B + \frac{K_b K_m}{R_a}\right)s + \frac{K\ K_s K_m}{R_a}\right\}} \quad (17)$$

Where K_s is the sensor gain, and $\frac{a}{l_a}$) may be neglected for small L_a.

$$\frac{\theta_m(s)}{\theta_{in}(s)} = \frac{\frac{K * K_m * K_s}{R_a J}}{s^2 + \left(\frac{R_a B + K_b K_m}{R_a J_m}\right)s + \frac{K\ K_s K_m}{R_a J_m}} \quad (18)$$

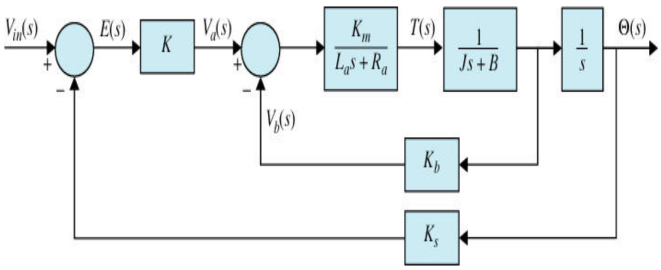

Figure 4: Block diagram of a position control, armature control dc motor.

The parameters of the system are given in the table (3). [9]

Table 2: Positional control system parameters.

Parameters	Description	Value
K_m	Motor constant	0.10 N.m/A
R_a	Resistance of armature of motor	1.35 Ω
L_a	Inductance of armature of motor	0.00056 H
J	Motor an load inertia	0.01173 kg. m^2
B	Friction of load shaft	0.00341 kg. m^2/sec
K_b	Back emf constant	0.10 V/rad/sec

3.1 Description of the Project

The Project chosen here for simulation and comparison are taken from [9], where they were simulated and compared to the conventional PD controller. Consider the system in Fig.5. The system is composed of the dc motor. The rigid is connect to the motor shaft to create a simple robotic system conducting a pick and place operation. A solid disk is attached to the end of the beam through a magnetic device (e.g. a solenoid). If the magnet is on, the disk will stick to the beam, and when the magnet is turned off, the disk is released.

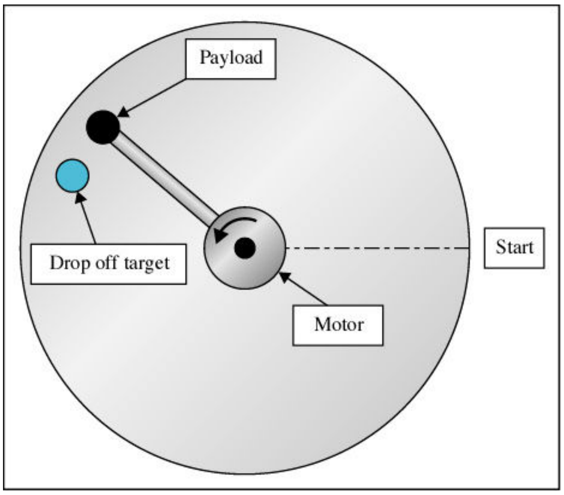

Figure 5: Control of a simple robotic arm and a payload.

The objective of this project is to drop the disk into a hole as fast as possible. The hole is 1 in. (25.4 mm) below the disk as shown in Fig.6. The drop position angle is the angle where the electromagnet turn off, dropping the payload.

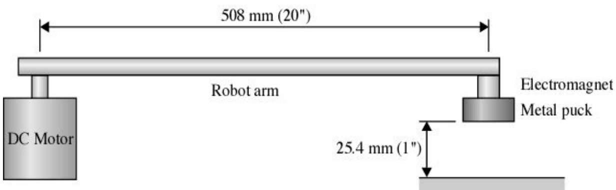

Figure 6: Side view of the robotic arm.

The design criteria is required to move the arm in only one direction from the initial position. The hole location may be anywhere within an angular range of 20^o to 180^o from the initial position. The arm may not overshoot the desired position by more than 5^o. A tolerance of 2% is acceptable (settling time). The objective may be met by looking at the settling time as key design criterion [9].

4. Simulation and Results

This section shown the performance of the suggested structure FPD^2 controller by computer simulation using SIM LAB and VIRTUAL LAB taken from [9], and FUZZY TOOLBOX for a simple robotic system. All simulation based on MATLAB environment.

The electromagnet will never drop the object exactly where it is specified. Since any electromagnet has residual magnetism even after current stops flowing, the magnet holds on for a short time after the trigger is tripped. A time response of the system for conventional proportional gain and derivative gain of 4 and 0.3 respectively [9], and for FPD^2 controller gains are K_e=2, $K_{\Delta e}$=0.1, K_f=23, K_d=0.4,.is shown in Fig.7. This set of FPD^2 gains was obtained by fine-tuning several times till we got the best possible results for fair comparison.

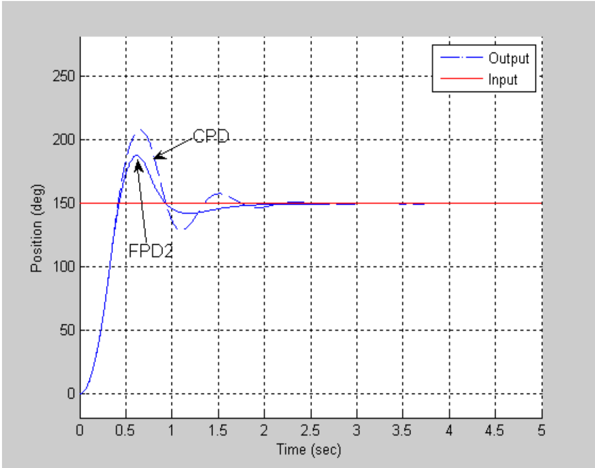

Figure 7: Performance comparison between CPD and FPD^2 at drop angle 150^o.

The system response can also be animated, as shown in Fig.8. this feature makes the problem more realistic. The circular object represents the payload.

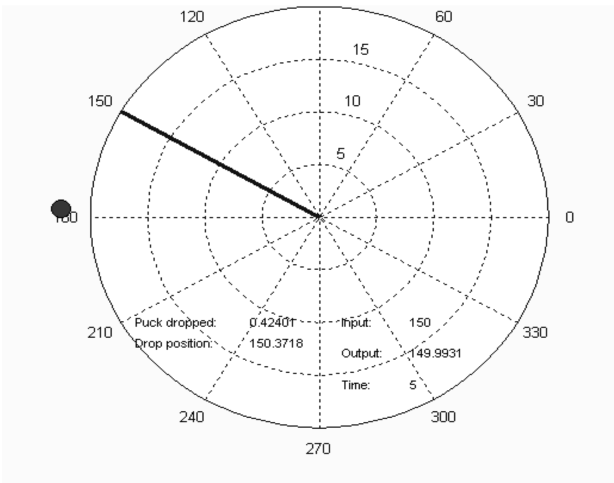

Figure 8: Animated position response at 150^o.

The compression between CPD an FPD^2 controller are done with different drop position angular as shown in Figs. (9,10) and also may be animated as shown in Figs. (11,12).

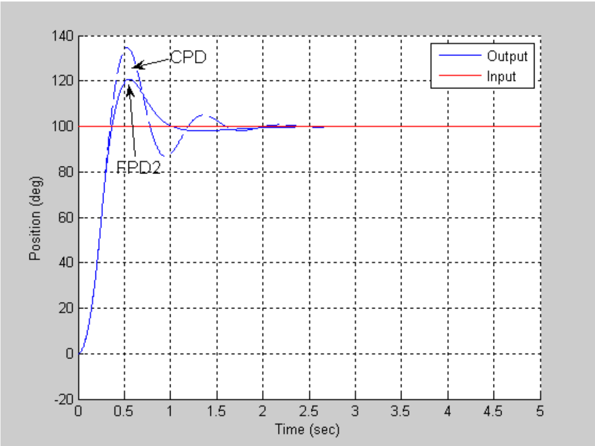

Figure 9: Performance comparison between CPD and FPD^2 at drop angle 100^o.

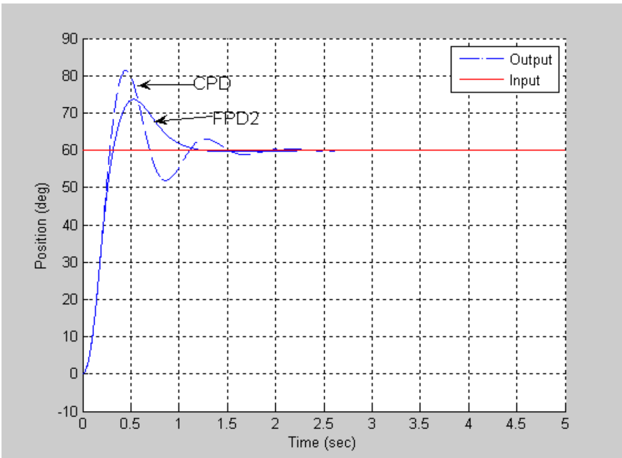

Figure 10: Performance comparison between CPD and FPD^2 at drop angle 60^o.

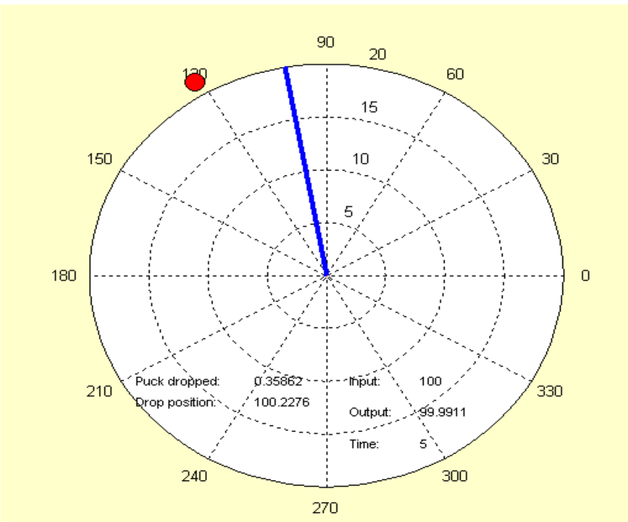

Figure 11: Animated position response at 100^o.

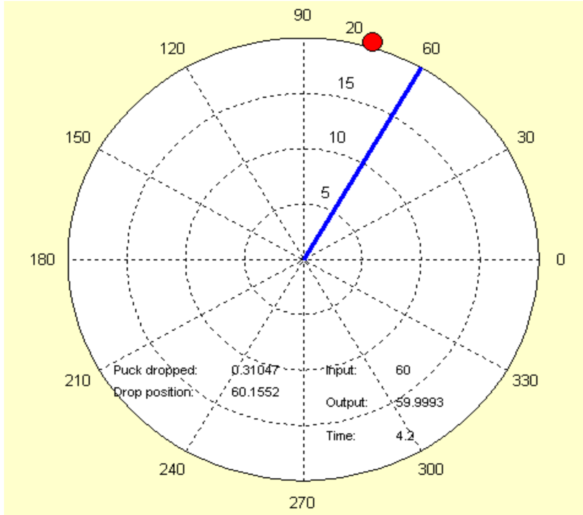

Figure 12: Animated position response at 60^o.

5. Conclusions

A new hybrid structure of FPD^2 controller is designed and implemented for a simple robotic system. This structure has two-input single-output and fairly similar characteristic to its conventional counter part and provides good performance. Since in positional control, the steady state error is more important than other parameters and the FPD^{2}controller designed in this paper is able to achieve zero steady state error in a short time. It is concluded that FPD^2 controller as compared with the conventional PD controller, it provides improvement performance in both transient and the steady states response, FPD^2 has a smaller overshoot , smaller steady state error and has a smaller settling time compared to the conventional PD controller. The added conventional D is achieved by extra two operations only, multiplication by a constant (K_d) and addition of the output (FPD signal). In addition to that the design of FPD^2 controller is relatively simple and produces robust performance using nine rules only and can be implemented very easy.

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