



An Adaptive PD-Type FLC and Its Real Time Implementation to Overhead Crane Control

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Abstract: In this study, we proposed an Adaptive Fuzzy PD Controller (AFPDC), where output gain is adjusted, based on the current operating condition of the process, by an online updating parameter (β) that is calculated by normalized error (e_N) and normalized change of error (Δe_N) of the process. The proposed controller is tested on second-order process models including an unstable system. Comparative performance analysis is provided with fuzzy and conventional controllers in terms of several performance indices. Finally, the proposed control approach is investigated on a practical overhead crane to control its cart position as well as swing angle of load. The proposed self-tuning control scheme shows an accurate transfer of load, along with a good swing suppression.

Keywords: Fuzzy control, Crane position control, Swing angle, Self-tuning fuzzy control.

I. Introduction

In most of the industrial processes PID controllers can be used successfully [1, 2]. But, in case of non-linear and integrating systems, the capabilities of PID controllers are significantly reduced. However, fuzzy logic controllers (FLCs) are suitable for such complex systems [3-5]. Unlike PID controllers, FLCs may be designed without any plant model. It has been established that FLCs can overcome some of the limitations of conventional controllers [6]. Sometimes non-fuzzy adaptive schemes may be incorporated to enhance the performance of fuzzy logic controllers [7]. Here, we propose a fuzzy PD controller (FPDC) to take advantages of the derivative action which can anticipate system behavior and accordingly initiates an early corrective action, thus improves the settling time and stability of the system. However, like conventional PD controllers, PD-type FLC's are usually applied for non-minimum, integrating, and some non-linear systems [8, 9].

Fuzzy logic controllers need to be carefully tuned to achieve desired performance. Different self-tuning and adaptive schemes based on fuzzy rules, neural networks and genetic algorithms have been proposed [10-16]. Depending on the instantaneous process trend, Mudi *et al* [10, 11] demonstrated a new self-tuning scheme for PD-type FLC. In their scheme, output scaling factor (SF) is updated using 49 fuzzy *if-then* rules based on operator's knowledge.

Motivated by the encouraging results of [7], instead of a fuzzy rule based tuning scheme, here a simple non-fuzzy adaptive technique is proposed. In the proposed AFPDC, output SF is continuously updated by a gain updating factor β , which is related to e_N and Δe_N of the process under control. Here, the output of the controller is modified in accordance with the present situation of the process under control, thus, it is expected that the proposed AFPDC will improve the close-loop performance. Another important point of our scheme is that it uses significantly reduced number of rules compared to other FLCs [10-12] reported in the literature. The proposed scheme is demonstrated on different second order models with variable dead time and also its effectiveness is tested on a practical overhead crane set-up.

The paper is arranged as follows. Section II describes the proposed scheme of adaptive fuzzy controller. The scheme is demonstrated through simulation experiments in Section III. In Section IV, effectiveness of the proposed scheme is illustrated on a real time system. Finally, conclusion is made in section V.

II. The Proposed Adaptive Fuzzy PD Controller- AFPDC

The output SF of FLC needs to be determined very carefully as it has strong influence on the close-loop performance. Here, as shown in Fig. 1, a non-fuzzy adaptive scheme is implemented for FPDC, where a real time gain updating factor β continuously adjusts the output SF. Different design considerations of AFPDC are discussed below.

A. Membership functions

Triangular membership functions (MF's) for the controller inputs error (e) and change of error (Δe), and the controller output (u) are described on a common interval $[-1, 1]$, as shown in Fig. 2.

20s. Table 2 provides the performance analysis of PID, FPDC, and AFPDC for different dead times. From the performance analysis of non-linear process (5), we find that the AFPDC with only 25 fuzzy rules always outperforms FPDC and PID controllers.

Figure 5: Responses of the system (5) with PID (dashed) and AFPDC (solid) for $L=0$

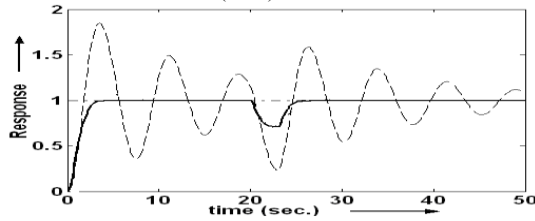


Figure 6: Responses of the system (5) with FPDC (dotted) and AFPDC (solid) for $L=0.3$

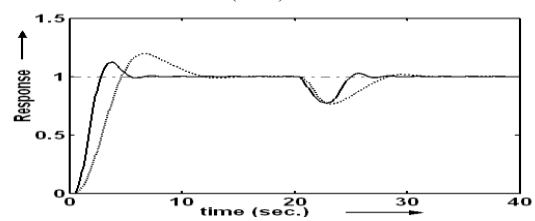


Figure 7: Responses of the system (6) with PID (dashed), FPDC (dotted) and AFPDC (solid) for $L=0$

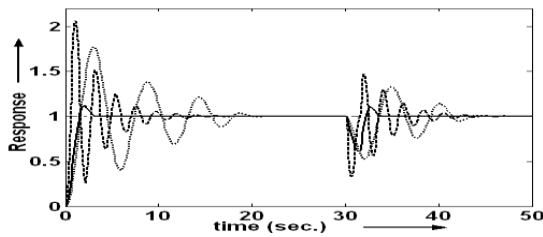


Figure 8: Response of the system (6) with AFPDC for $L=0.1$

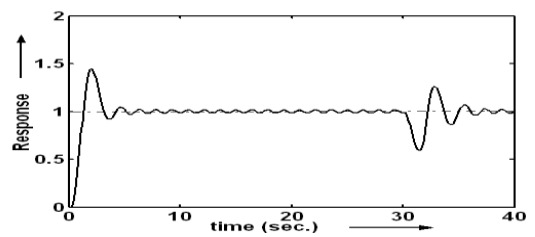


Table 2: Performance analysis of the non-linear process (5)

L	Controller	%OS	t_r (sec.)	t_s (sec.)	IAE	ITAE	ISE
0	PID	85.04	1.8	68.6	13.68	292.16	5.16
	FPDC	7.85	3.4	6.7	3.25	32.50	1.56
	AFPDC	0.0	2.7	3.0	1.71	12.50	0.82
0.1	PID	95.12	1.8	-	23.96	707.21	10.99
	FPDC	12.07	3.7	8.1	3.74	35.90	1.81
	AFPDC	2.17	2.6	2.8	1.88	14.24	0.96
0.3	FPDC	19.66	4.4	11.0	4.97	47.21	2.48
	AFPDC	12.42	2.7	5.1	2.25	13.75	1.22

Table 3: Performance analysis of the unstable process (6)

L	Controller	%OS	t_r (sec.)	t_s (sec.)	IAE	ITAE	ISE
0	PID	106.22	0.6	10.0	4.41	61.75	1.94
	FPDC	77.44	1.6	17.7	6.92	100.71	2.64
	AFPDC	11.84	1.5	2.8	1.31	13.65	0.64
0.1	AFPDC	44.90	1.3	4.1	2.89	65.04	0.90

B. Integrating and unstable System

Let us consider an unstable process with the transfer function:

$$G_p(s) = \frac{ke^{-Ls}}{s(s-1)} \quad (6)$$

This process is unstable in nature because one of its poles is located at the right-half of the s -plane. Here, the PD controller plays an important role in converting this integrating and unstable process (6) into a stable one, because PD controller introduces a zero in the left-half s -plane. It is observed that conventional controllers are unable to provide satisfactory performance as indicated by Fig. 7 and Table 3. As shown in Fig. 8, AFPDC is found to be able to provide stable performance for $L=0.1$, but the PID and even FPDC fail to do so. Table 3 provides the detailed performance comparison of the system with different controllers. Like previous results, here also, AFPDC exhibits highly improved performance compared to others.

IV. Real Time Experiment Result

In this section, experimentation on an overhead crane is carried out to verify the effectiveness of the proposed self-tuning scheme. Overhead cranes are used in different industries for loading and unloading of materials [17, 18]. The main aim of crane control is to reduce the pendulum type motion of the loads and placed the cart in exact location [19]. Various approaches have been reported to solve the problem of load swing [20-22]. But, most of them tried to control the load swing without focusing the position error [23]. Liu *et al* [24] demonstrated their control approach for a linearized two dimensional overhead crane system. Besides, few authors have investigated optimization techniques to control the cranes [25].

In this study, to reduce the design complexity of the crane control system, instead of a single controller, two similar PD-type FLCs are used in parallel, one for the cart position control and the other for load swing control. Position error and its derivative are considered as inputs of the position controller, whereas, error due to load swing and its derivative are used as inputs of angle controller [26]. The overhead cranes have one control input (a cart driving force) and two output variables to be controlled (cart position and load swing angle).

A. Overhead crane set-up

A practical crane set-up manufactured by FEEDBACK (UK), is shown in Fig. 9. The set-up consists of a cart and a load is attached with it. The horizontal movement of the cart causes the load to swing and it depends on the control voltage applied. The optical encoders are installed on the rail for measurement of cart position and the load swing [27]. For effective control of the system a suitable voltage should be applied to the motor for proper positioning of the cart with minimum load swing.

Fig. 10 shows the schematic of an overhead crane, where M , m , l , g , x , θ , and u are the cart mass, load mass, pole length, gravitational force, cart position, load swing angle, and input driving force respectively. The dynamics of the overhead crane set-up [17, 19] can be expressed by:

$$(M + m)\ddot{x} + m\ddot{\theta}\cos\theta + m\dot{\theta}^2\sin\theta + 2m\dot{\theta}\cos\theta - m\dot{\theta}^2\sin\theta = u \quad (7)$$

$$l\ddot{\theta} + g\sin\theta + 2\dot{x}\dot{\theta} + \ddot{x}\cos\theta = 0 \quad (8)$$

Observe that the dynamic model represented by equations (7) and (8) is nonlinear in nature. In the present case, the corresponding values of M , m , l and g are given by 2.4 kg, 0.23 kg, 0.36m and 9.81m/s² respectively [27]. Here, the parameters like stiffness and rope mass are not considered.

Figure 9: Overhead crane set-up

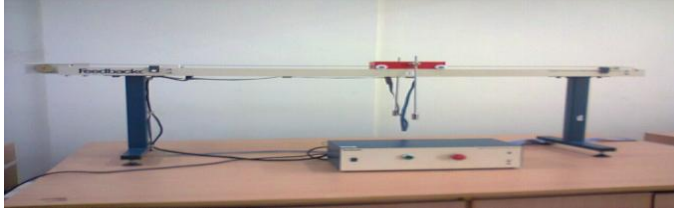
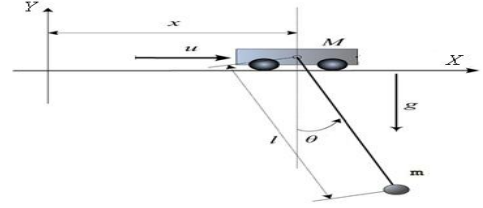


Figure 10: Model of the overhead crane system

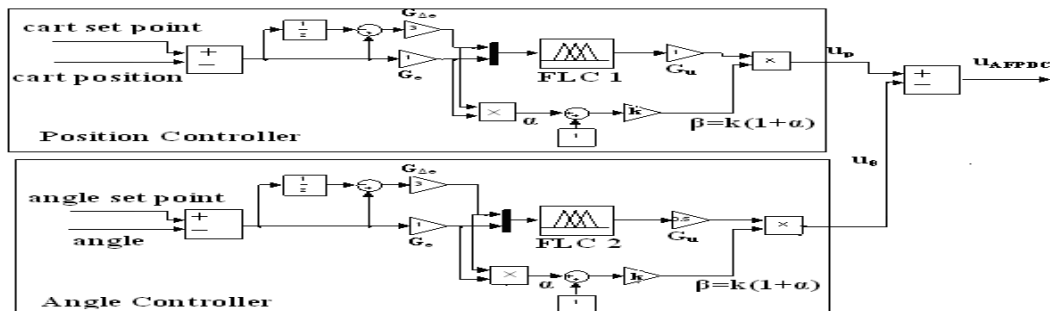


B. Controller design for overhead crane

Fig. 11 shows the two similar FLCs (operated in parallel) with the proposed gain adaptive scheme. The position FLC and the angle FLC are separately dealing with the cart position and swing angle, respectively. The feedback signals from the overhead crane act as the input variables of the controllers. The normalized values of position error (e_p) and change of position error (Δe_p) are considered as the input variables of fuzzy position controller. Similarly, the fuzzy angle controller selected normalized values of swing angle error (e_θ) and change of swing angle error (Δe_θ) as its input variables.

In this study, the left swing and right swing of the load is described as positive swing and negative swing, respectively. u_p and u_θ are the respective outputs for position and angle controller as indicated in Fig. 11. The final output of AFPDC, which is used to drive the cart is $u_{AFPDC} = u_p - u_\theta$. The controller output u_{AFPDC} is used for positioning the load to its desired position with minimum swing. The MFs of e_p , Δe_p , and u_p for position controller, and the MFs of e_θ , Δe_θ , and u_θ for angle controller are same as shown in Fig. 2. The selected ranges of input-output variables for position controller and angle controller are $[-1, +1]$ and $[-20^\circ, +20^\circ]$, respectively. Both position and angle controllers contain the same 25 fuzzy if-then rules as shown in Table 1. Note that, here, both the controllers have only $i/2$ fuzzy atomic clauses in the antecedent part of each rule, where ' $i=4$ ' refers 4 input linguistic variables (e_p , Δe_p , e_θ and Δe_θ). In AFPDC, each input variable of position and angle controller has ' n ' linguistic terms, here $n=5$ (Fig. 2), thus the control rules required for AFPDC is $2.n^{i/2} = 50$. However, a single conventional fuzzy controller for the same purpose may need n^i , i.e., $5^4=625$ rules, which is very much greater than the total number of rules required for AFPDC, which is only 50.

Figure 11: Diagram of AFPDC for overhead crane control



C. Crane control results

Figure 12:(a)Responses for step input (0.3m) using FPDC (dotted line) and AFPDC (solid line)

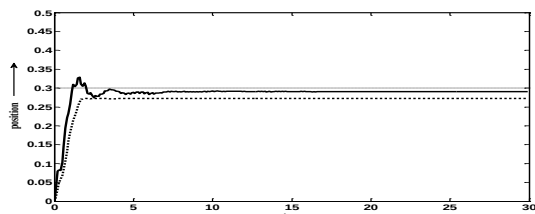


Figure 12: (b) Corresponding swing angle (degree) using AFPDC

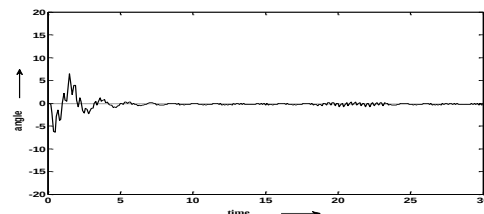


Figure 13:(a)Responses for square input (dash-dot) using FPDC (dotted) and AFPDC (solid line)

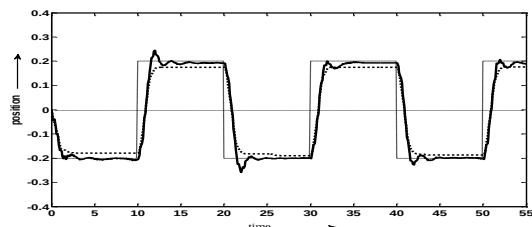
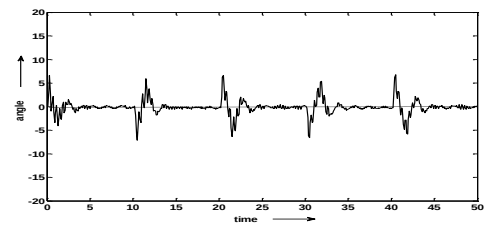


Figure 13:(b) Corresponding swing angle (degree) using AFPDC



The performance of AFPDC is demonstrated on an overhead crane (Fig. 9) with square input and step input with different amplitudes [19, 26]. Mainly the step and square signals are used as references because this type of signals matches the real situation. From Fig. 12(a), Fig. 13(a) and Table 4, we find that AFPDC provide improved performance indices for different types of set point compared to others. We observe that FPDC fails to position the cart in its desired place and it produces an offset of around 10% for a step input of 0.3m. Whereas we notice negligible offset in case of AFPDC.

Fig. 12 (b) and Fig. 13(b) illustrate that the proposed AFPDC makes negligible swing of the load (maximum around 5°) for both the step and pulse type inputs. AFPDC also successfully demonstrates its effectiveness of AFPDC for different step inputs as shown in Fig. 14 without significant load swing. Fig. 15 shows that the PID controller can not suppress the load swing effectively for step input, which is an important consideration for material transfer in industry.

Figure 14: Responses for step inputs (0.2m, 0.3m and 0.35m) using AFPDC at constant speed

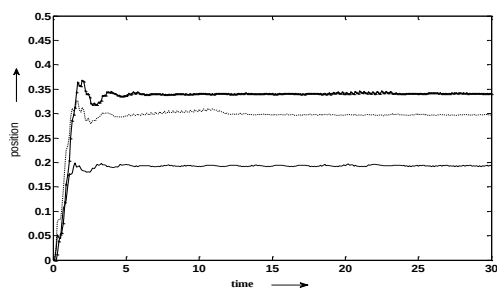


Figure 15: Response for step input (0.3m) and corresponding swing angle using PID

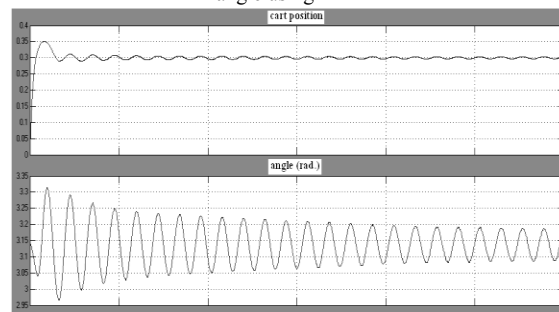


Table 4: Performance analysis of the proposed controllers in overhead crane control

Reference input	FLC	IAE	ITAE	ISE
Step (amplitude 0.3m)	FPDC	7.5129	75.5667	0.6952
	AFPDC	3.6658	26.6158	0.3926
Square (amplitude ± 0.2 m)	FPDC	31.0952	847.3993	6.7693
	AFPDC	24.20	698.23	6.05

V. Conclusion

A simple gain adaptive technique for a PD-type FLC has been proposed. In this study, the close-loop gain of the proposed AFPDC is continuously updated by an online gain modifying parameter β defined on *error* and *change of error*. Even using significantly reduced number of rules, AFPDC outperformed other fuzzy and non-

fuzzy controllers for various systems with varying dead time. We also suggested the dual control scheme to control the overhead crane. Experimental results of an overhead crane control system exhibited that the propose AFPDC successfully placed the cart with minimum load swing during load transfer.

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