A METHOD OF PD-FUZZY CONTROL FOR ACROBOT

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Abstract: In this paper, we design a PD-fuzzy controller which is developed from PID method. The model for testing here is acrobot – a SIMO model which imitates the action of barbell athlete. We create a hardware platform for real experiment. The aim of controlling is keeping link 1 at up-position and link 2 at down-position. Through both simulation and experiment, the PD-fuzzy controller shows better control quality than original PID controller.

Keywords: acrobot, PID control, PD-fuzzy, SIMO system.

1. Introduction

Acrobot is a SIMO system. It has similar structure as pendubot. However, the motor of acrobot is located at link 2 instead of link 1 in case of pendubot. LQR is proved to work well on this model [1]. In that research, from LQR data, a fuzzy controller is created. That fuzzy controller acts successfully. Also, nonlinear methods such as sliding control [2], back-stepping [3], … However, these methods require dynamic equations of system and exact system parameters. Differently, PID method does not need information of dynamic equations or system parameters. Thence, PID is the most popular control method in industry. But, PID is designed for controlling SISO system. Under SIMO system, PID must be transformed to suitable form for control. In [4], PID controller shows its ability in stabilizing acrobot. In this paper, we propose a PD-fuzzy controller for this model. This is a hybrid controller which is developed from PID method. We combine PID and fuzzy to obtain PD-fuzzy method. In this research, we control link 1 of acrobot at up-position, link 2 of acrobot at down-position (Fig. 2). An experimental model is created in laboratory of Ho Chi Minh city University of Technology and Education (HCMUTE). Our PD-fuzzy method is proved to control system successfully in both simulation and experiment.

2. Dynamic Equations

Mathematical structure of acrobot is shown in Fig. 1. There is two links in this system. Lengths of these link are l_1(m) and l_2(m), correspondingly. We assume that the masses of these links are very small. A motor with remarkable mass m_2(kg) is fixed on link 2. The axis f this motor is connected with link 1. At other side of link 2 is fixed with a mass m_2. From [5], dynamic equations of acrobot are shown in (1).

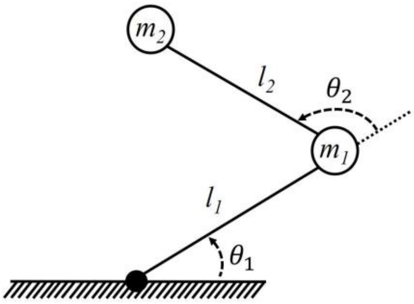


Fig. 1. Mathematical model of acrobot

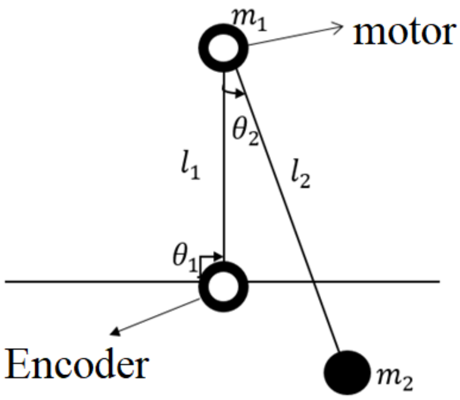


Fig. 2. Equilibrium point

$$\tau(t) = M\left(\theta(t)\right)\ddot{\theta}(t) + C\left(\theta(t),\dot{\theta}(t)\right)\dot{\theta}(t) + G\left(\theta(t)\right) + F\left(\dot{\theta}(t)\right) \tag{1}$$

where: τ (N) is moment that is created by motor; $c_i=\cos\theta_i$; $s_i=\sin\theta_i$; $c_{ij}=\cos(\theta_i+\theta_j)$; θ_1(rad) and θ_2(rad) are angles of link 1 and 2 in Fig. 1; α_1 and α_2 are friction coefficients of each link;

$$M(q) = \begin{bmatrix} l_2^2 m_2 + 2l_1 l_2 m_2 c_2 + l_1^2\left(m_1+m_2\right) & l_2^2 m_2 + l_1 l_2 m_2 c_2 \\ l_2^2 m_2 + l_1 l_2 m_2 c_2 & l_2^2 m_2 \end{bmatrix};$$

$$C\left(\theta,\dot{\theta}\right)\dot{\theta}=\begin{bmatrix}-m_2l_1l_2s_2\dot{\theta}_2^2-2m_2l_1l_2s_2\dot{\theta}_1\dot{\theta}_2\\ m_2l_1l_2s_2\dot{\theta}_2^2\end{bmatrix};$$

$$G\left(q\right)=\begin{bmatrix}m_2l_2gc_{12}+\left(m_1+m_2\right)l_1gc_1\\ m_2l_2gc_{12}\end{bmatrix};$$

$$F\left(\dot{\theta}\right)=\begin{bmatrix}\alpha_1\dot{\theta}_1\\ \alpha_2\dot{\theta}_2\end{bmatrix}$$

In Matlab simulation, acrobot, which is described by (1) is created as in Fig. 3.

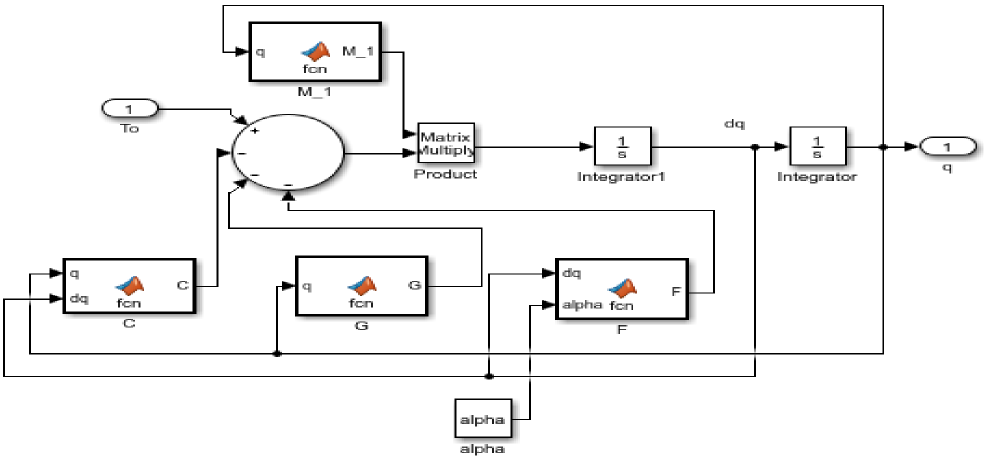


Fig. 3. Blocks that describe model (1) in Matlab

3. Controller Designing

3.1. PID Control

Our controlling structure for acrobot is shown in Fig. 4. Inside PID controller, structure is shown in Fig. 5.

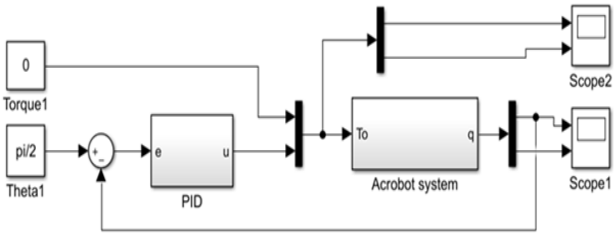


Fig. 4. Structure of PID control for acrobot

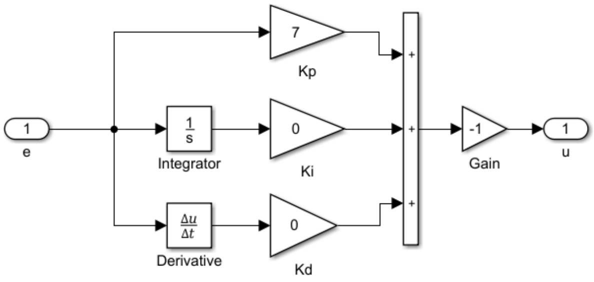


Fig. 5. Structure of PID controller

Without control signal, the link 1 will fall down and balance at down-position. Through this PID controller, we propose to keep link 1 at up-position by rotation of motor.

The rules of PID calibration are:

- Firstly, Kd and Ki are selected to be zeroes. Kp is given a positive small constant value. Value of Kp is increased step by step.

- Secondly, when Kp is big enough, Ki and Kd are calibrated.

3.2. PD-Fuzzy Control

From PD-fuzzy structure for general robot in Fig. 9, a structure of PD-fuzzy is designed for acrobot as in Fig. 10. Membership of inputs and output of fuzzy block in Fig. 5 are shown in Fig. 6 to Fig. 8. These membership functions are standardized to range [-1, 1]. If we need to try different range of inputs and output, parameters K_1, K_2, K_u are selected.

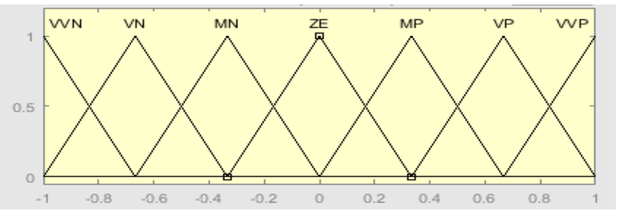


Fig. 6. Membership functions of input 1

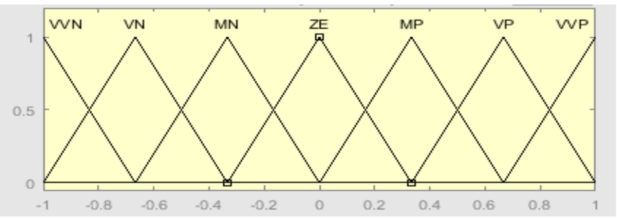


Fig. 7. Membership functions of input 2

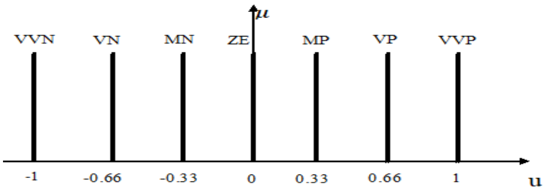


Fig. 8. Membership functions of output

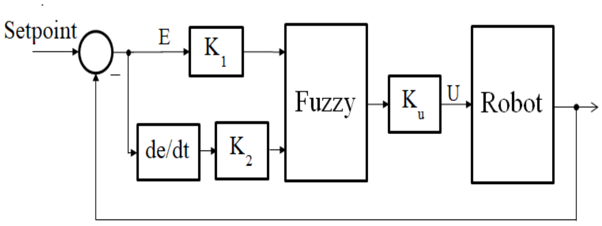


Fig. 9. PD-fuzzy control structure for robot [6]

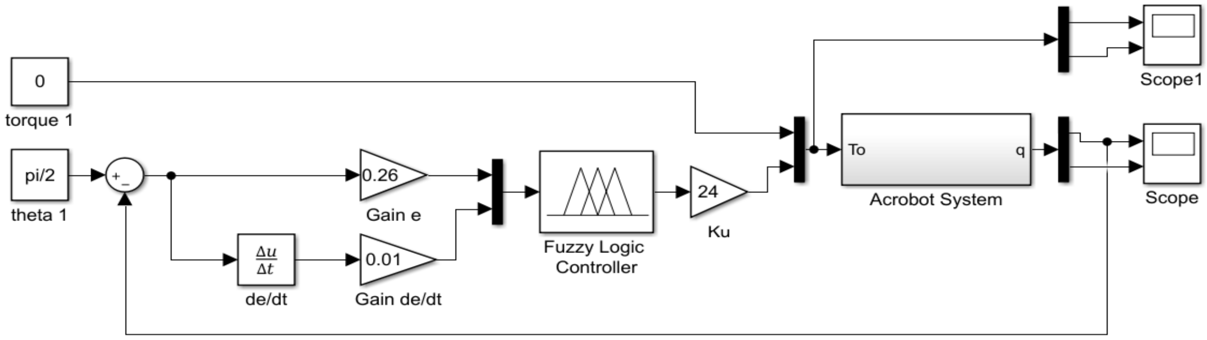


Fig. 10. PD-fuzzy control structure for acrobot

Some fuzzy rules are designed through knowledge of experts are:

- If e is ZE and de/dt is ZE, then, u is ZE
- If e is ZE and de/dt is VVP, then, u is VVN
- If e is MP and de/dt is ZE, then, u is MN
- ...

These rule is listed in Tab. 1

Tab. 1. Table rule of PD fuzzy

e de/dt	VVN	VN	MN	ZE	MP	VP	VVP
VVN	VVP	VVP	VVP	VP	MP	ZE	ZE
VN	VVP	VVP	VP	MP	ZE	ZE	ZE
MN	VVP	VP	MP	MP	ZE	ZE	MN
ZE	VP	MP	MP	ZE	MN	MN	VN
MP	MP	ZE	ZE	MN	MN	VN	VVN
VP	ZE	ZE	ZE	MN	VN	VVN	VVN
VVP	ZE	ZE	MN	VN	VVN	VVN	VVN

4. Simulation

Values of system parameters are selected as

$$m_1=450g;\quad m_2=600g;\quad l_1=0.21m;\quad l_2=0.36m;\quad \alpha_1=1;\ \alpha_2=1;\ g=9.81m/s^2 \tag{2}$$

Then, Matlab simulation results are listed from Fig. 11 to Fig. 13.

Setting time of system under PID method is 15s in **Fig. 11**. Ranges of vibrations of θ_1 and θ_2 is [1.4 1.7] (rad) and [-3.4 -2.8] (rad).

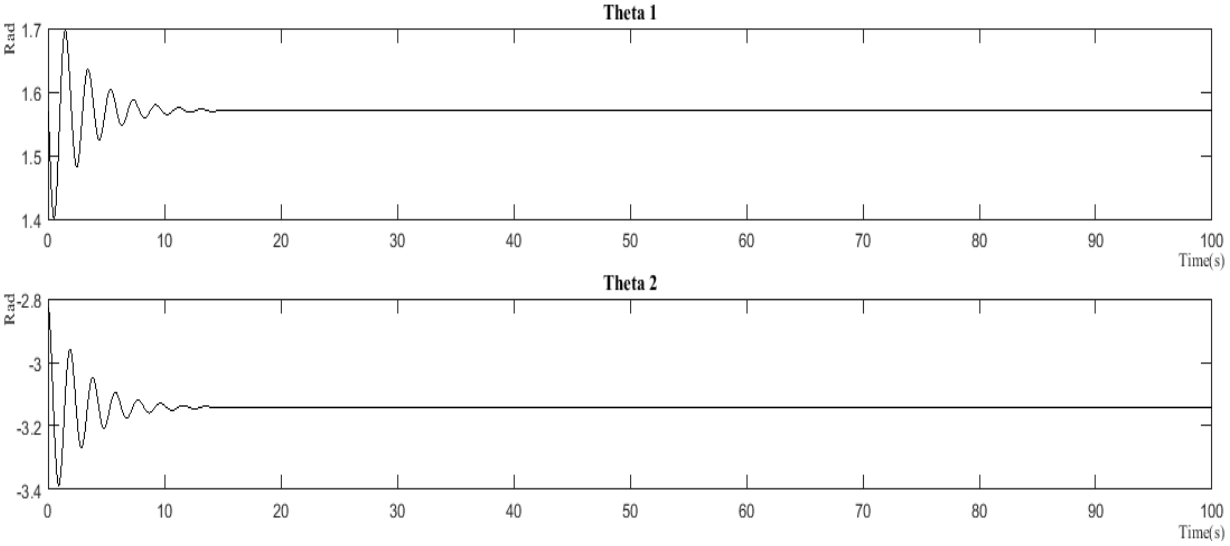


Fig. 11. Responses of system under PID controller

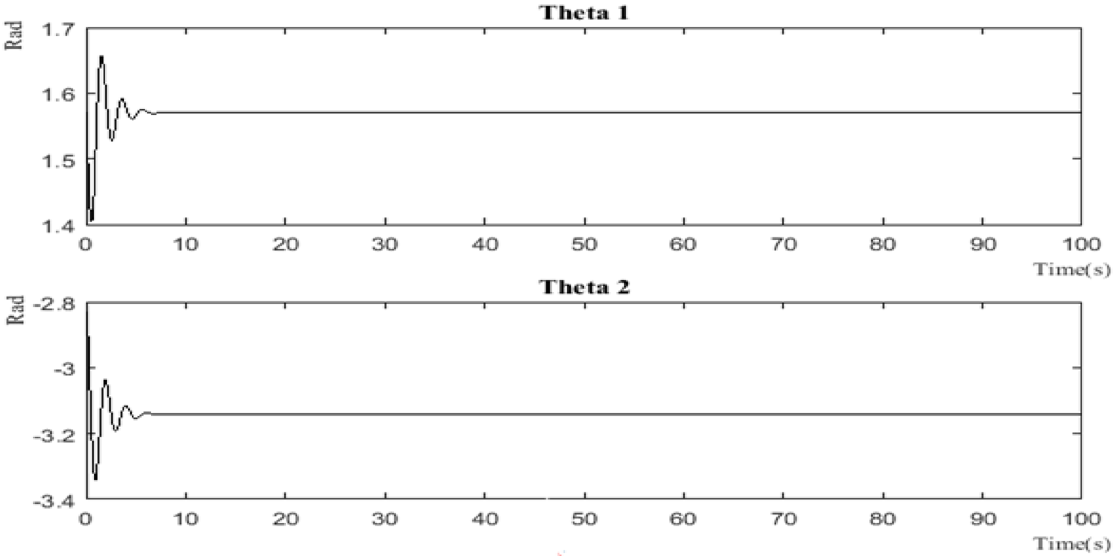


Fig. 12. Responses of system under PD-fuzzy controller

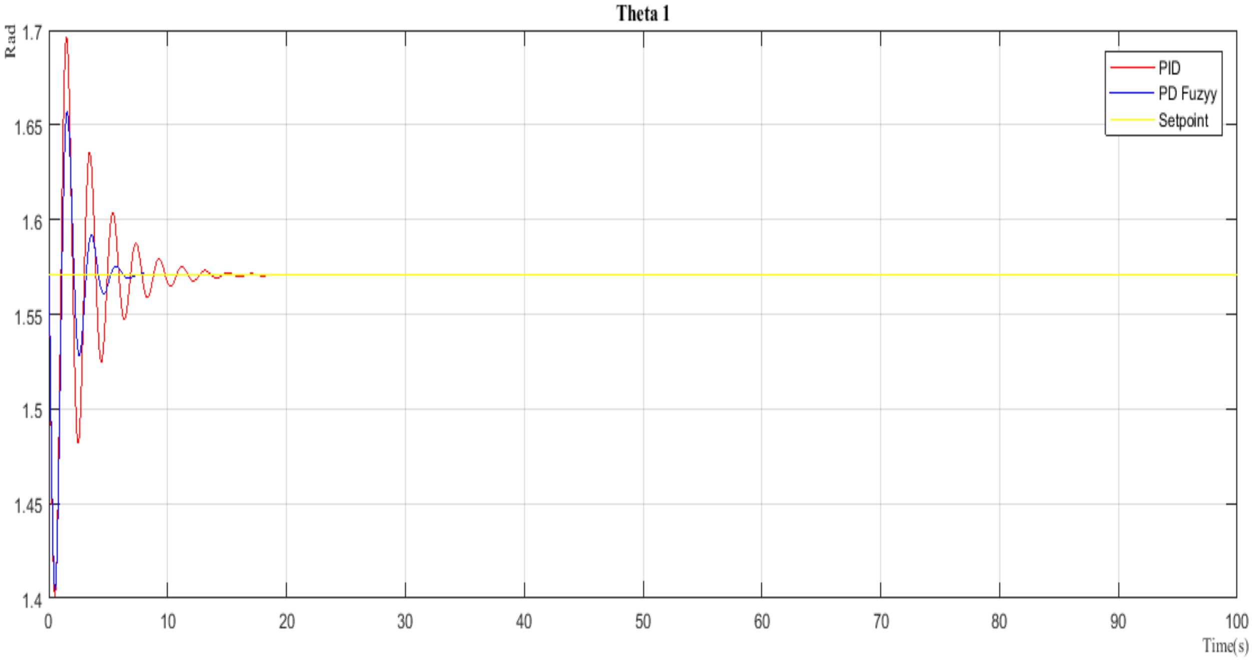


Fig. 13. Comparison of angle θ_1(rad)

Setting time of system under PID method is 15s in Fig. 13. Ranges of vibrations of θ_1 and θ_2 is [1.4 1.65] (rad) and [-3.3 -2.6] (rad).

Thence, vibrations of links and settling time under PD-fuzzy method are smaller than under PID method. The purpose of controlling is keeping link 1 on up-position. Therefore, from **Fig. 11**, Fig. 12, we obtain Fig. 13 to compare the vibration of link 1. It is obvious that responses of system have better control quality under PD-fuzzy controller.

5. Experiment

In Fig. 14 we show an experimental model. We use board STM32F4 as controller. A DC motor is used to control. This motor has a encoder to calculate θ_2. A seperated encoder is used to calculate θ_1. The experimental results are shown in Fig. 15 and Fig. 16. In those figures, U Control is voltage on DC motor; PWM is duty signal of PWM that is supplied to H-bridge; THETA is θ_1(degre); E is the error between set point (SP) and θ_1(degre).

In PID experiment (Fig. 15), control parameters are choose through try-and-error test. These values are

Kp=38; Ki=0.002; Kd=0.5 (3)

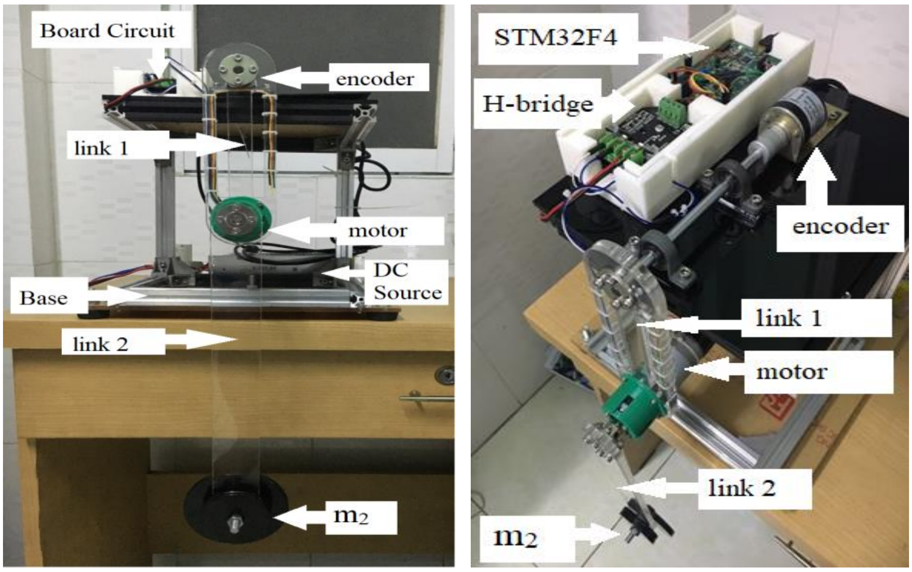
The overshoot is 5.42%, settling time is 11.5s, settling error is 6 degrees.

In PD-fuzzy experiment (Fig. 16), control parameters K1,K2, Ku are choose through try-and-error test. These values are

K1=0.22, K2=0.01; Ku=160 (4)

The overshoot is 4.14%, settling time is 8.5s, settling error is 5.5 degrees.

Thence, from Fig. 15 and Fig. 16, system under PD-fuzzy controller is better than under PID controller: settling time is shorter, overshoot is smaller, settling error is smaller. Hybrid controller shows its better quality control than linear controller



(a) (b)

Fig. 14. Experimental model of acrobot in HCMUTE
(a)- front view
(b)- up-down view

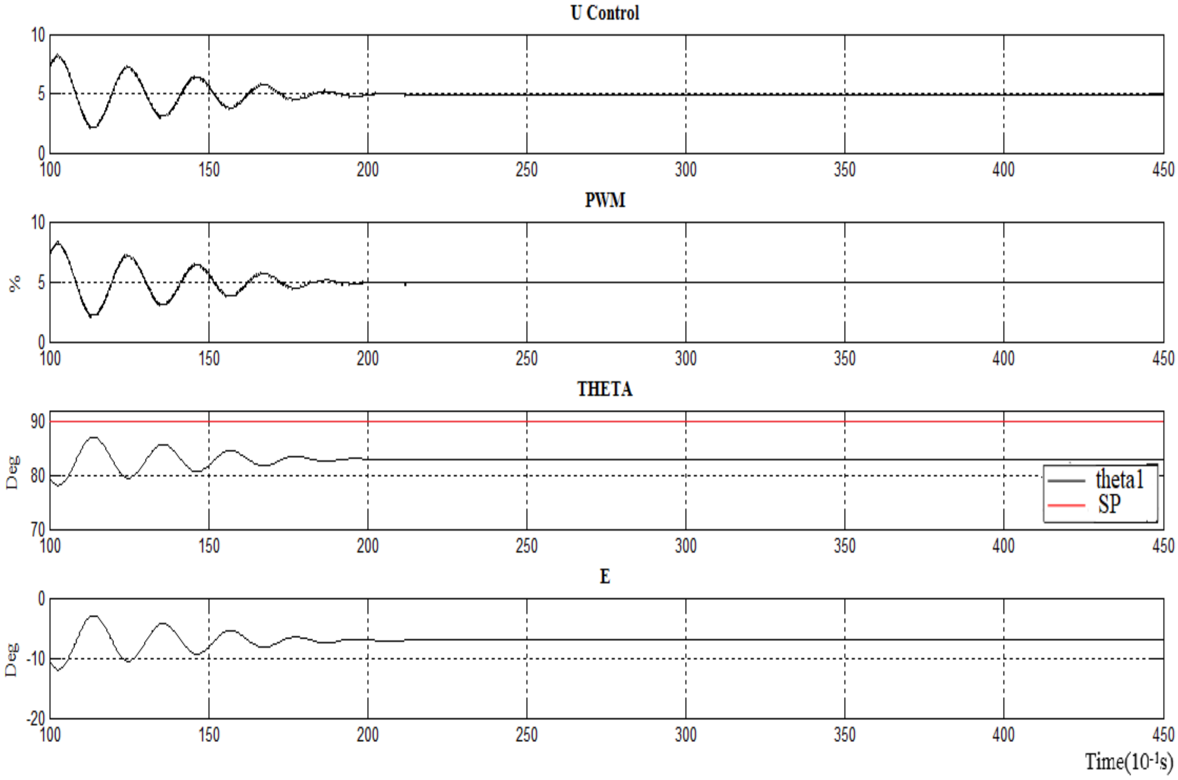


Fig. 15. Response of system under PID controller in 350s (under 100-th second to 450-th second)

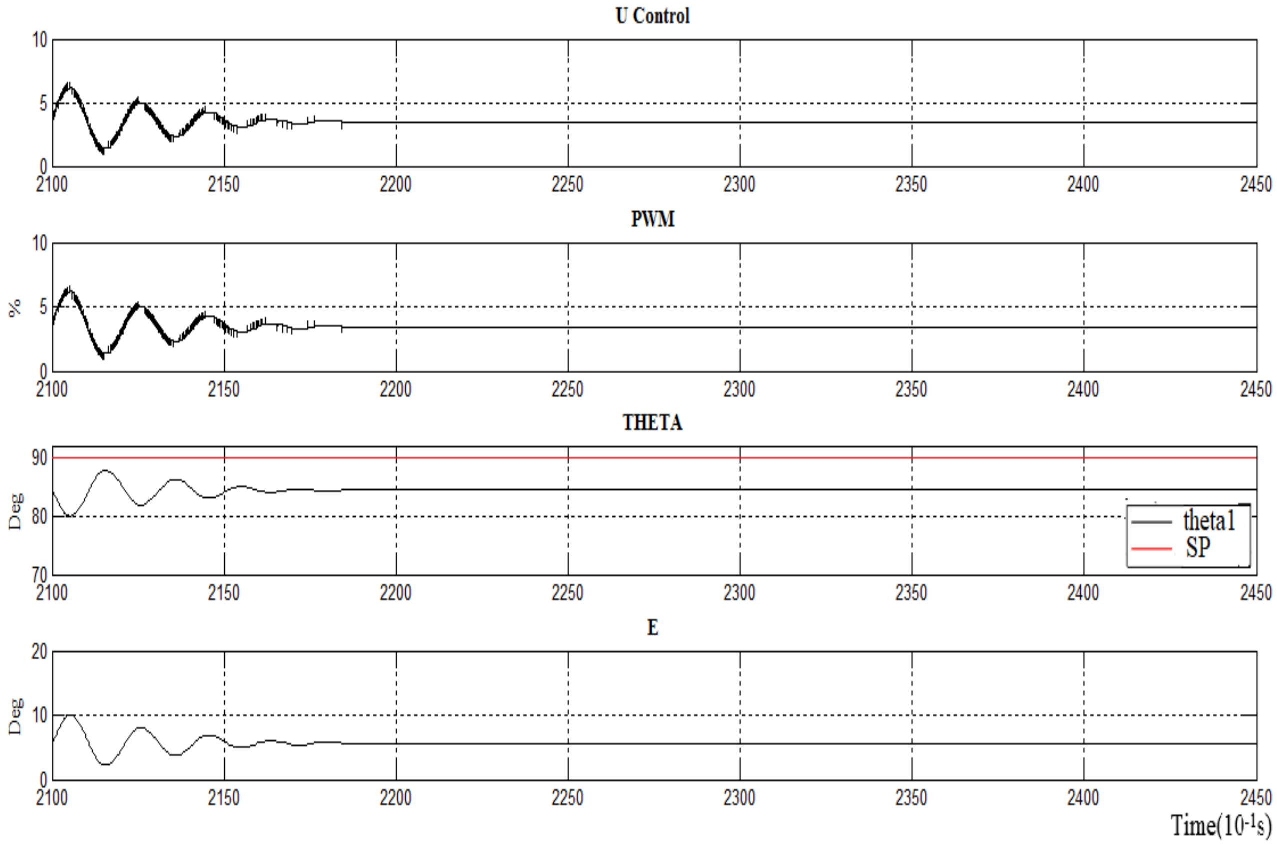


Fig. 16. Response of system under PD-fuzzy controller in 350s (under 2100-th second to 2450-th second)

For better view in comparison, from Fig. 15 and Fig. 16, we obtain Fig. 17. Setpoint of θ_1 is 90^0. Angle of link 1 under PD-fuzzy method is more closed to setpoint than under PID method.

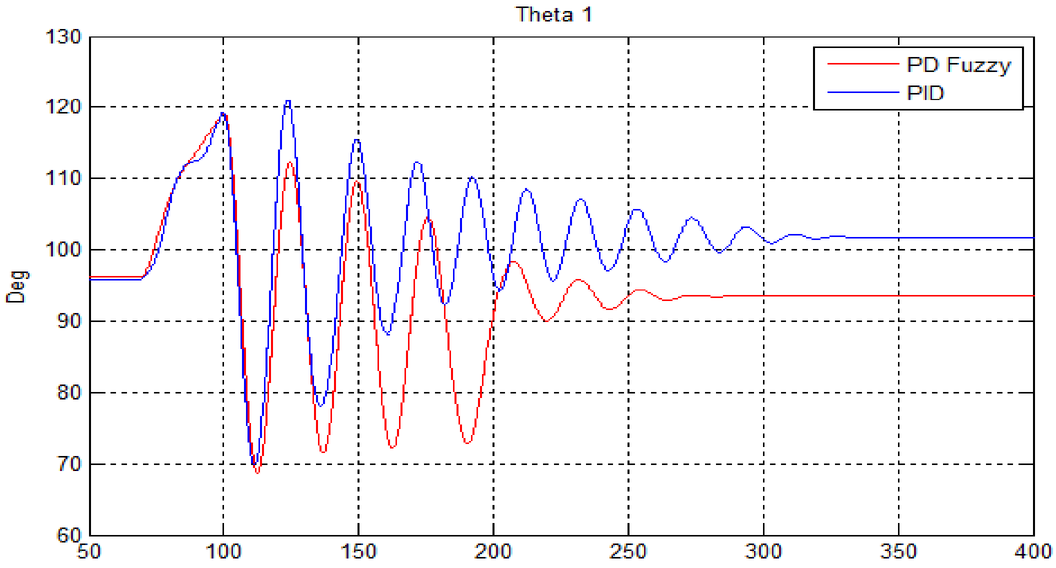


Fig. 17. Comparison of θ_1 (degree))under different control methods

In experiement, PD-fuzzy method shows its better ability in controlling acrobot than PID method. Under this hybrid controller, settling time, overshoot and settling error are improved. A combination of traditional PID and fuzzy algorithm to create a hybrid structure is an idea that can be developed to improve the control quality of controller.

6. Conclusion

In this paper, we present a method of PD-fuzzy to balance the acrobot at up-down position. We also present our hardware platform of acrobot in laboratory to test control algorithm. Hybrid PD-fuzzy method shows it better control quality through both simulation and experiment than traditional PID method. Then, combination of intelligent control (fuzzy) and linear control (PID) is an idea to improve the ability of traditional controller.

7. References

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