Pid and Interval Type-2 Fuzzy Logic Control of Double Inverted Pendulum System

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Abstract— **In this study, interval type2 fuzzy logic (IT2FL) and PID controller is designed for swing-up position control of double inverted pendulum (DIP) system. The double inverted pendulum system consists of two rigid bars connected by a revolute joint. Mass of the revolute joint is included in the dynamic model.Rigid bars in the system are assumed to experience planar motion. The pendulum system is connected to the base by means of a revolute joint. Torque provided through a motor mounted to the base is used for position control of the system. PID (Proportional-Derivative-Integral) and interval type2 fuzzy logic controllers are developed by using the same performance criteria for position control of double inverted pendulum system. IT2FL controller is similar with type1 fuzzy logic controller. IT2FL system provides soft decision boundaries, whereas a type-1 fuzzy logic system provides a hard decision boundary. Membership function in interval type2 fuzzy logic set as an area called Footprint of Uncertainty (FOU) which limited by two type1 membership function those are upper membership function (UMF) and lower membership function (LMF).System behaviour is obtained by computer simulation using developed controllers respectively. Computer simulation results are compared in order to evaluate applicability of developed controllers. MATLAB/Simulink software is used in computer simulations.**

Keywords- ***Double inverted pendulum, PID control, interval type2 fuzzy logic controller,swing-up control,simulation.***

I. INTRODUCTION

Control of the mechanical systems such as pendulum and inverted pendulum always is interested by researchers who struggle with design of the controller. Pendulum and inverted pendulum systems commonly are used as test problems to examine ability of using of improved controllers. On the other hand, many of engineering systems can be modelled as pendulum and inverted pendulum. Inverted pendulum system is unstable system which does chaotic motion as structural. Various types of controllers are developed to get the system stable. Optimal control, nonlinear and fuzzy logic based controllers are used [1-8] in such this studies to control the system,

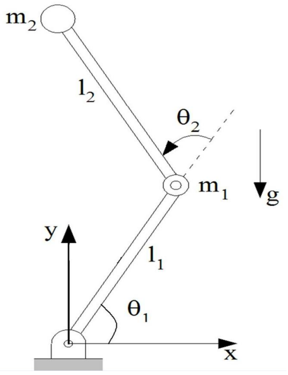

Figure 1. The double inverted pendulum

The most important characteristic of double inverted pendulum system shown in Fig. 1 is that the number of actuator of system is less than system's the number of degree of freedom. Double inverted pendulum system with this characteristic differs from two degrees of freedom of rigid link of robotic systems. The system parameters are given in Table 1. The goals of applied controllers to robotic systems and double inverted pendulum system are different. While the control in robotic systems that taking robot arm to desired position, the purpose of the control of the double inverted pendulum system is that balancing the pendulums on vertical position.

The objective of this study is that various type controllers are designed to balance the pendulums which take apart in serious type double inverted pendulum systems, on vertical position. In range of study; PID and IT2FL controllers are designed. The criterions of performance are determined to test controllers' performances and the performances of controllers which are designed for system are utilized in respect of these criterions.

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TABLE I. THE PARAMETERS OF DOUBLE INVERTED PENDULUM SYSTEM

Parameter	Value	Unit
Mass of First Pendulum, m_1	0. 2	kg
Mass of Second Pendulum, m_2	0. 5	kg
Length of First Pendulum, l_1	0. 1	m
Length of Second Pendulum , l_2	0. 3	m

Intelligent Systems based on fuzzy logic are fundamental tools for nonlinear complex system modeling. Fuzzy sets (of type-1) and fuzzy logic are the basis for fuzzy systems, where their objective has been to model how the brain manipulates inexact information. Type-2 fuzzy sets are used for modeling uncertainty and imprecision in a better way. These type-2 fuzzy sets were originally presented by Zadeh in 1975 and are essentially “fuzzy fuzzy” sets where the fuzzy degree of membership is a type-1 fuzzy set [9, 12]. The new concepts were introduced by Mendel and Liang [13, 15] allowing the characterization of a type-2 fuzzy set with a superior membership function and an inferior membership function; these two functions can be represented each one by a type-1 fuzzy set membership function. The interval between these two functions represents the footprint of uncertainty (FOU), which is used to characterize a type-2 fuzzy set. While traditionally, type 1 FLCs have been employed widely in nonlinear systems’ control, it has become apparent in recent years that the type-1 FLC cannot fully handle high levels of uncertainties as its MFs are in fact completely crisp [16], [19]. The linguistic and numerical uncertainties associated with dynamic unstructured environments cause problems in determining the exact and precise MFs during the sysem FLC design. Moreover, the designed type-1 fuzzy sets can be sub-optimal under specific environmental and operational conditions. The environmental changes and the associated uncertainties might require the continuous tuning of the type-1 MFs as otherwise the type-1 FLC performance might deteriorate [15]. As a consequence, research has started to focus on the possibilities of higher order FLCs, such as type-2 FLCs that use type-2 fuzzy sets. A type-2 fuzzy set is characterised by a fuzzy MF, i.e. the membership value (or membership grade) for each element of this set is a fuzzy set in [0,1], unlike a type-1 fuzzy set where the membership grade is a crisp number in [0,1] [16]. The MF of a type-2 fuzzy set is three dimensional and includes a footprint of uncertainty. It is the third-dimension of the type-2 fuzzy sets and the footprint of uncertainty that provide additional degrees of freedom making it possible to better model and handle uncertainties when compared to type-1 fuzzy sets. It has been shown that interval type-2 FLCs (that use interval type-2 fuzzy sets) can handle the uncertainties and outperform their type-1 counterparts in applications with high uncertainty levels such as mobile robot control [16], [20]. However, manually designing and tuning a type-2 FLC to give a good response is a difficult task, particularly as the number of MF parameters increases.

II. DYNAMIC MODELING OF A DOUBLE INVERTED PENDULUM SYSTEM

The dynamic equation motion of the double inverted pendulum system is derived in terms of the Lagrange formulation,

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_i}\right) - \frac{\partial L}{\partial q_i} = \tau_i \qquad (1)$$

where q_i is the generalized coordinates, $\dot{q}_i$ is the first derivative of the generalized coordinates as to time and τ_i is the applied control torque to i th link.

The generalized coordinate vector is defined as:

$$q = \left[\theta_1 \;\; \theta_2\right] \qquad (2)$$

The control torque is expressed by input vector as:

$$\tau = \left[\tau_1 \;\; 0\right] \qquad (3)$$

The goal of the control that is applied to the double inverted pendulum system is to supply output values of the system equal to reference value. The control action is that produces appropriate input torque to feed to the system for the system realizes desired motion. By another expression, it is that desired output value is obtained from the system, as a result of a applied convenient input value to system. The applied input to the double inverted pendulum system is motor torque and output of the system is angles of pendulums with vertical direction. The purpose of the designed controller for the system is to get the pendulums to unstable equilibrium point in minimum time and to supply motor torque that provides position of the pendulums in tolerance range.

Earlier studies about pendulum systems were realized to find dynamic model by using Euler and Lagrange equations. In this study, dynamic model of the system is obtained by using MATLAB/Simmechanics toolbox. System parameters are used for modelling of system. By means of this approach dynamic modeling becomes easy and clear. Simmechanics modeling and control block diagram of double inverted pendulum system are given in Figure 2.

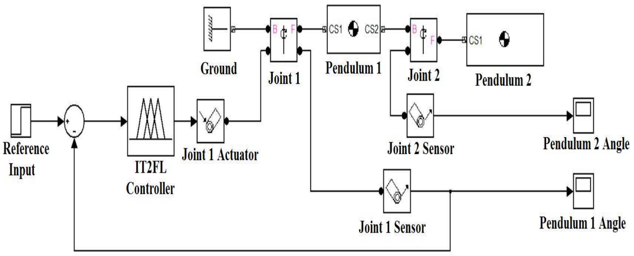

Figure 2. IT2FL control of Simmechanics model.

III. PID AND IT2FL CONTROL OF THE DIP SYSTEM

PID control is composed of effects of the proportional (Kp), derivative (Kd) and integral (Ki) control. PID control has the control effect that combines effects of the three basic controls. In addition to these sometimes PID controllers does not provide sufficient performance for the control of the nonlinear and undefined systems. The control action of PID controller is expressed as follows :

$$u = K_p . e + K_i . \int e dt + K_d . \frac{de}{dt} \tag{4}$$

$$U(s) = (K_p + \frac{K_i}{s} + K_d . s) E(s) \tag{5}$$

In case of using PID controller, effect of changing of the gain parameters concerning with controller to response of the system is denoted in Table 2.

Table 2. The Effect Of Changing Gain Parameters Of The PID Control To The System Response (+ : Increase, - : Decrease , ≈ : Not Change A lot)

Closed Loop Response	Rising Time	Maximum Overshoot	Settling Time	Steady State Error
K_p	-	+	≈	-
K_i	-	+	+	0
K_d	≈	-	-	≈

The performance criterions of designed controller are chosen as,

- Max. oscillation angels of the pendulums ≤ 30 deg.,
- Pendulum's settling time is 2 seconds.

In this study, PID and IT2FL controllers are used for swing-up control of DIP system. For this purpose pendulums' position feedbacks are used for controller. Position feedbacks are compared with desired position signals after that error rates are obtained for inputs of controllers. IT2FL controller's membership functions are given in Figure 3.

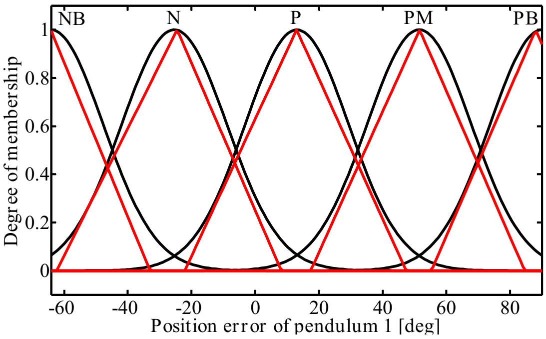

Figure 3. Membership functions of IT2FL controller.

IV. RESULTS AND DISCUSSION

The effectiveness of the proposed controller have been tested by simulation. The objective in this simulation is to tune controllers for swing-up control of double inverted pendulum system. The proposed controllers allow us to command a desired angle position and eliminate oscillations while maintaining a fast response. Objective of control is chosen to get pendulums to vertical position. Position angles are choosen 90^0 and 0^0 for first pendulum and second pendulum respectively. Simulations are done respect to this task. In this way step reference input is given for desired input signal of control system. Feedback signal of first pendulum angle is used to tune controllers. Performances of PID controller are given in Figure 4-5. From these results, it can be said the controller is effective over the system. But according to performance criterions PID controller is not appropriate.

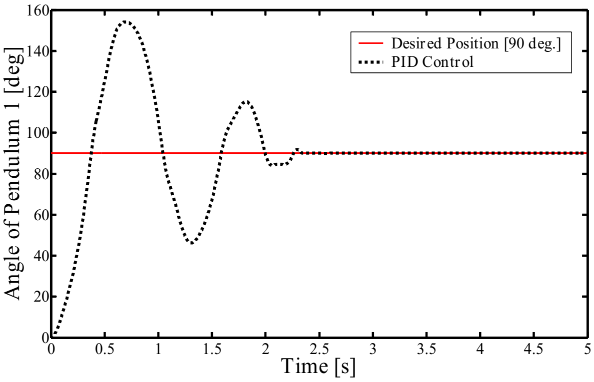

Figure 4. PID control of pendulum 1 angle.

The IT2FL controller increased the PID control performance on same system. Figure 6 and Figure 7 show performances of IT2FL controller. From these results we can say that IT2FL controller provide performance criterions and it is effective for swing-up control of double inverted pendulum system. Visual simulation of controlled system is given in Appendix Figure 8.

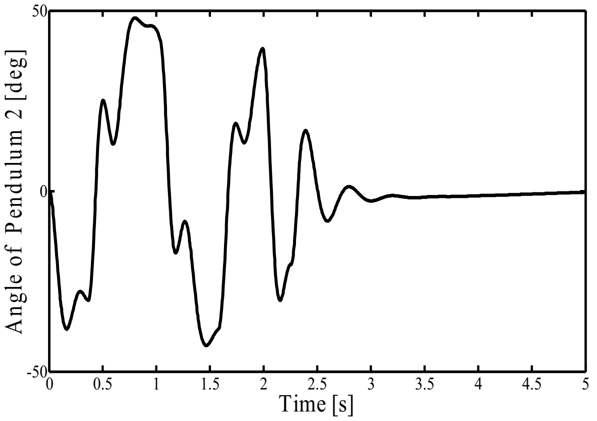

Figure 5. PID control of pendulum 2 angle.

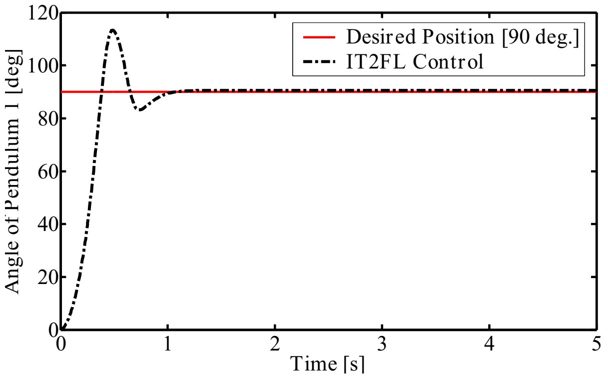

Figure 6. IT2FL control of pendulum 1 angle.

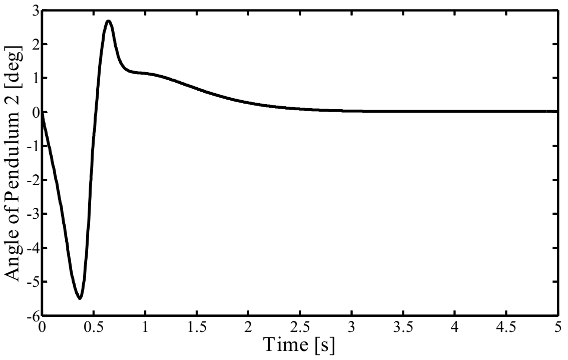

Figure 7. IT2FL control of pendulum 2 angle.

V. CONCLUSIONS

In this study, PID and IT2FL controllers are designed for swing-up control of the double inverted pendulum system. Digital simulations are obtained by using the designed controllers and performances of these controllers are compared according to performance criterions. The performance of the IT2FL controller is compared with PID controller, as a result of it IT2FL controller is better for swing-up control of the system.

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Appendix :

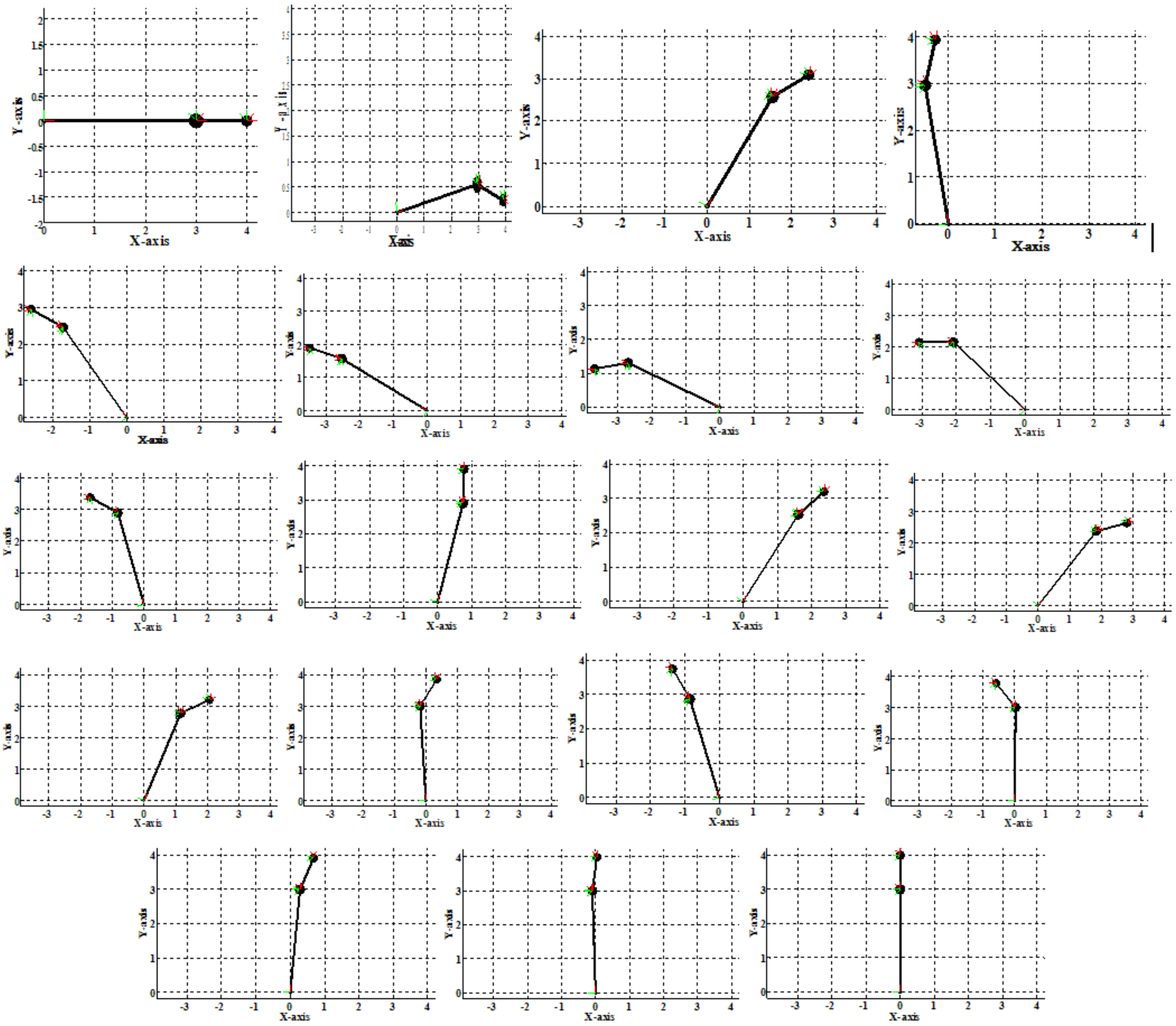

Figure 8. Visiual simulation of the double inverted pendulum system.(under control)