The analysis of inverted pendulum control and its other applications

Anjali Goswami[1]

Abstract

In this paper I am discussing the modeling and simulation study of basically two control strategies of an inverted pendulum system are presented. The inverted pendulum represents a challenging control problem, which continually moves toward an uncontrolled state. Certain modern techniques are now available because of the development of artificial intelligence and soft computing methods. Fuzzy control based learning makes the system more reliable and taking the advantage of precise control at different levels of existence as fuzzy is applicable to non value zero to full value as one, rest of the interim values are also considered [3]. ANFIS is one of an example of fused neuro fuzzy system in which the fuzzy system is incorporated in such a framework which is adaptive in nature [7]. The fuzzy controllers are used to sort out the problem of inverted pendulum [5].

[1] Jagannath Gupta Institute of Engineering and Technology, Mathematics Sitapura, Jaipur, 302022, India.

1 Introduction

Inverted Pendulum is a such type of model in which, an automatic aircraft landing system, the attitude control of a space booster rocket and a satellite stabilization of a cabin in a ship, aircraft stabilization in the turbulent air-flow etc. To solve such problem with non-linearity and time variant system, there are alternatives such as a real time computer simulation of these equations or linearization. The inverted pendulum is a highly nonlinear and open-loop unstable system [5, 6, 8]. This means that standard linear techniques cannot be modeled as the nonlinear dynamics of the system. In the Neuro-Fuzzy systems the neural networks (NN) are incorporated in fuzzy systems, which can use fuzzy knowledge automatically by learning algorithms of NNs. They can be visualized as a mixture of local experts. Adaptive Neuro-Fuzzy inference system (ANFIS) is one of the of Neuro Fuzzy systems in which a fuzzy system is incorporated in the framework of adaptive networks. ANFIS constructs an input-output mapping based both on human knowledge i.e. rules and on generated input-output data pairs. ANFIS forms an input output mapping based both on human knowledge (based on fuzzy if then rules) and on generated input output data pairs by using a hybrid algorithm that is the combination of the gradient descent and least square estimates. ANFIS is not a black box model and optimization techniques can be well applied to it, which is computationally efficient and is also well suited to mathematical analysis.

2 Architecture using by Nuero Fuzzy

In ANFIS, Takagi-Sugeno type fuzzy inference system is used [5]. The output of each rule can be a linear combination of input variables plus a constant term or can be only a constant term. The final output is the weighted average of each rule's output. Basic ANFIS architecture that has two inputs x and y and one output z is shown in Figure 1. The rule base contains two Takagi-Sugeno if-then

rules as follows.

if x is A1 and y is B1 , then f = p x + q y + r If x is A2 and y is B2 ,
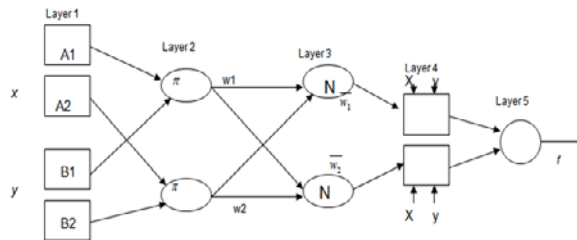then f = p x + q y + r

Figure 1

3 Fuzzy logic controller for Inverted Pendulum

It can be built into anything from small, hand-held products to large computerized process control systems. It uses an imprecise but very descriptive language to deal with input data more like a human operator. It is very robust and forgiving of operator and data input and often works when first implemented with little or no tuning. In this study, a very new technique, fuzzy controller, has been employed for stabilization of the inverted pendulum. Fuzzy controller, when inverted pendulum is considered, is a very good choice for control strategy.
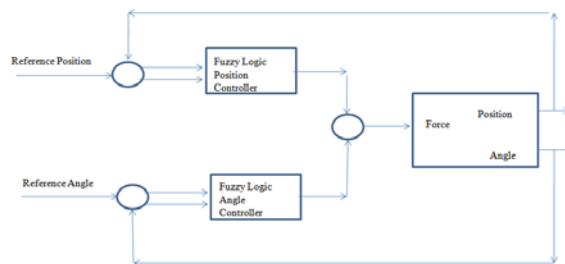

Figure 2

Here it is possible to give two inputs to the FLC as shown in Figure 2. The proposed defuzzification methods for the FLC are Sugeno or Mamdani. This is because both of these techniques are commonly used in designing the FLC [7, 9].
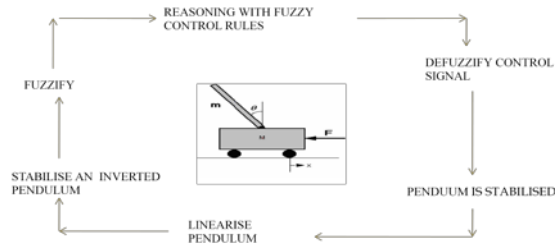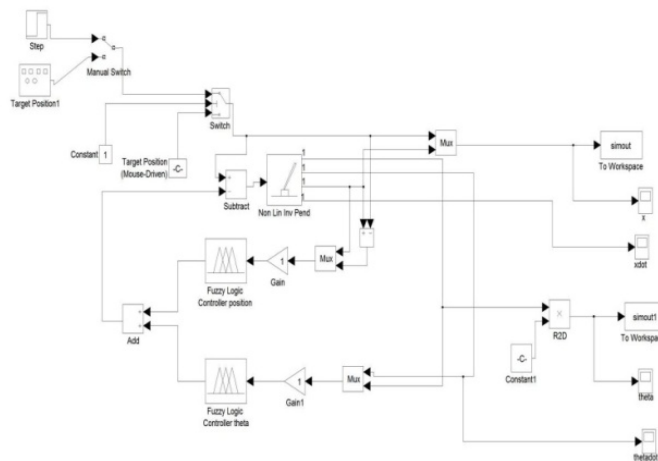

Figure 3

Figure 4

4 ANFIS learning algorithm

In the forward pass the algorithm uses least-squares method to identify the consequent parameters on the layer 4 in Figure 1.

From the proposed ANFIS architecture (Figure 3.11), the output f can be

defined as

$$f = \frac{w_1}{w_1 + w_2} f_1 + \frac{w_2}{w_1 + w_2} f_2 \tag{1.1}$$

$$f = \bar{w}_1(p_1 x + q_1 y + r_1) + \bar{w}_2(p_2 x + q_2 y + r_2) \tag{1.2}$$

where p_1, q_1, r_1, q_2 and r_2 are the linear consequent parameters. The methods for updating the parameters are listed as below:

1. Gradient decent only: All parameters are updated by gradient decent back propagation.

2. Gradient decent and One pass of Least Square Estimates (LSE): The LSE is applied only once at the very beginning to get the initial values of the consequent parameters and then the gradient descent takes over to update all parameters.

3. Gradient and LSE: This is the hybrid learning rule. Since the hybrid learning approach converges much faster by reducing search space dimensions than the original back propagation method, it is more desirable. In the forward pass of the hybrid learning, node outputs go forward until layer 4 and the consequent parameters are identified with the least square method. In the backward pass, the error rates propagate backward and the premise parameters are updated by gradient descent.

5 Pendulum Inverted with ANFIS

Now for the control of inverted pendulum ANFIS is used here. ANFIS employs a type of inference mechanism which is slightly differently as used in FIS, here Sugeno type of inference mechanism is used to design the controller [10, 12]. In Sugeno inference mechanism the output is linear combination of input membership function. The position controller and angle controller uses 2 input and one output and for that rule base is also formed. Following are the figures which

show that how we have used the position and angle as to control the inverted pendulum.
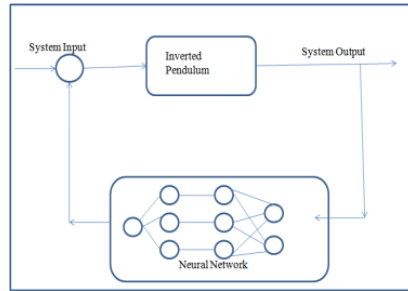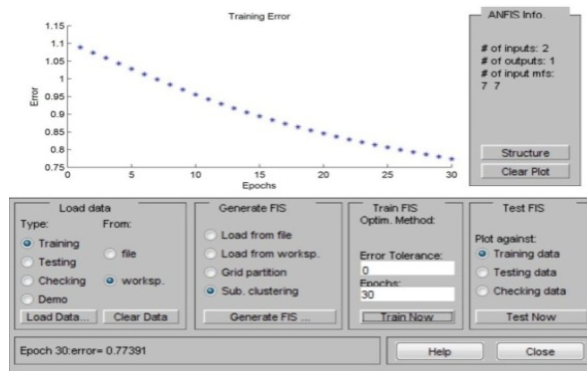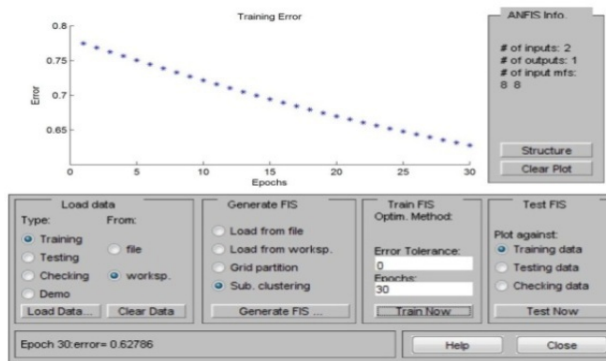

Figure 5

Figure 6

Figure 7

Above two figures shows 2 sets of training error with ROI .50, 0.48 resp. for position control.

Figure 8

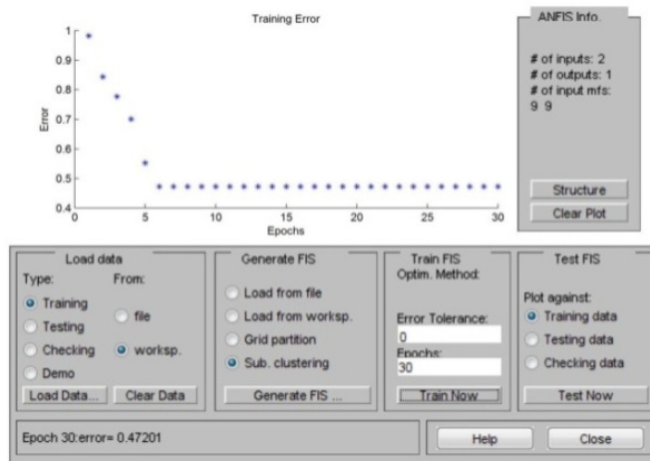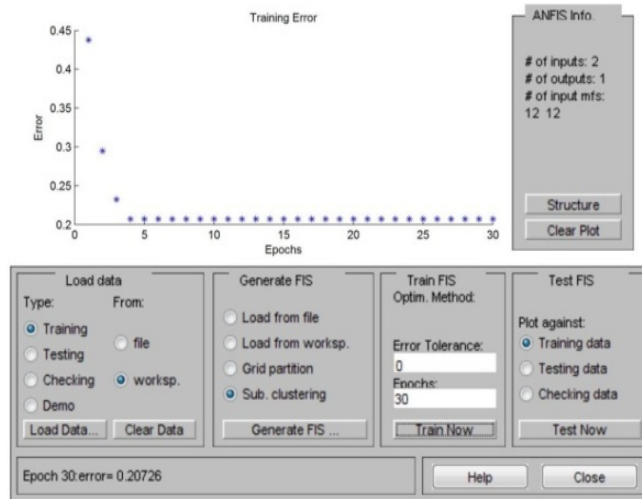Figure 9

Figure 10

Table 1

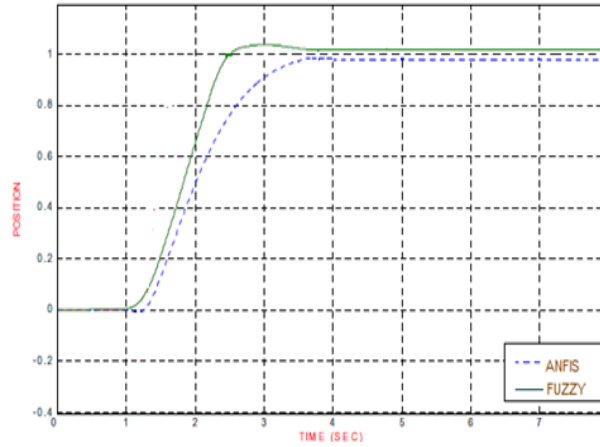| Response of Cart Position		
Characteristics	Fuzzy	ANFIS
Rise time (Tr) in sec	2.2	2.6
Settling time(Ts) in sec	3.2	3.5
Steady State error	0.14	0.2
Maximum Overshoot	0.13	0.01
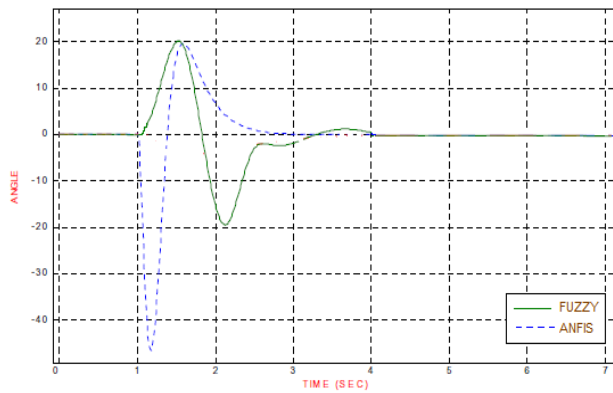
Figure 11

Table 2

Response of Cart angle with vertical		
Characteristics	Fuzzy	ANFIS
Settling time(Ts) in sec	3.8	2.3
Steady State error	0	0
Maximum Overshoot in deg	19 to -19	19 to -38

6 Conclusion

Using fuzzy approach and the ANFIS approach it shows that ANFIS provides better performance when it comes to a relationship which is non linear between input and output. The reliability and its special characteristics are very good. We can go for ANFIS approach, if we have input output pairs of training data set and the system shows some nonlinear behavior. By applying some other Neuro fuzzy architectural techniques like FALCON or GARIC or NEFCON, we can control the inverted pendulum.

References

[1] L.A. Zadeh, Fuzzy Sets, *Information and Control*, **8**, (1965), 353-383.

[2] P.J. King and E H Mamdani, The Application of Fuzzy Control System to Industrial rocess, *Automatica*, **13**, (1977), 235-242.

[3] E.H. Mamdani, Application of fuzzyalgorithms for control of simple dynamic plant, in *Proceeding of IEEE*, **121**, (1977), 1585-1588.

[4] T. Takagi and M. Sugeno, Fuzzy identification of systems and its applications to modeling and control, *IEEE Transaction on System*, Man, Cybernetics, **SMC-15**(1), (Jan., 1985), 116-132.

[5]   Cheun Chien Lee, Fuzzy Logic in Control System: Fuzzy Logic Controller –
      Part I & 11, *IEEE Transactions on System, Man, and Cybernetics*, **20**(2),
      (1990), 403-435.

[6]   M.M. Gupta and Ching J. Qi, Fusion of Fuzzy Logic and Neural Networks
      with Applications to Decision and Control Problems, in *Proceedings of the
      American Control Conference*, (1991), 30-31.

[7]   Jyh-Shing Roger Jang, Man and Cybernetics, *IEEE Transactions on System*,
      23(3), (May/June, 1993).

[8]   Lawrence Bush, Fuzzy Logic Controller for the Inverted Pendulum Problem,
      IEEE control System Magazine, (November 27, 2001), 238-245.

[9]   Changsheng Yu and Li Xu, Development of Inverted Pendulum System and
      Fuzzy Control Based on MATLAB, in *Proceedings of the 5th World
      Congress on Intelligent Control and Automation*, (June, 2004), 298-307.

[10] Dario Maravall, Changjiu Zhou and Javier Alonso, Hybrid Fuzzy Control of
      the Inverted Pendulum via Vertical Forces, Wiley Periodicals Inc., (March,
      2005), 635-641.

[11] Songmoung Nundrakwang, Taworn Benjanarasuth, Jongkol Ngamwiwit and
      Noriyuki Komine, Hybrid controller for Swinging up Inverted Pendulum
      system, in *Proceeding IEEE of System Man and Cybernetics*, **4**, (June, 2005),
      750-758.

[12] L Rajaji, C. Kumar and M Vasudevan, Fuzzy and ANFIS based soft starter
      fedinducti n motor drive for high performance, in *Proceeding of Asian
      Research Publishing Network Journal of Engineering and Applied Sciences*,
      3(4), (August, 2008).