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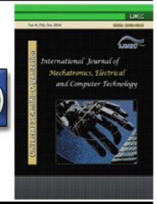

Mathematical Modeling and Performance Comparison of Overhead Cranes Using Soft-Computing Techniques

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Abstract

In this paper an offline control of Overhead crane system has been proposed using fuzzy and ANFIS controllers. The mathematical model of the system has been derived which was further used to build a Simulink of proposed system. The ANFIS controller was designed using data sets generated from results of PID controller. The controllers were compared in terms of settling time, maximum overshoot and undershoot. The study elaborates the effect of variation in magnitude of physical attributes of the crane system i.e. mass of crane, mass of load and length of crane on performance parameters of the system. The system has been simulated in Matlab and simulation results are shown which validates the proposed study.

Keywords: Overhead crane, fuzzy logic, ANFIS, training, Matlab, Performance parameters

1. Introduction

Overhead cranes are widely used in manufacturing plants to transport, load and unload in process products or raw materials [1]. It is composed of a gantry which support a bridge and trolley while rope imposes continue motion to the load [2]. The control objective is to transport the payload to required position as fast as possible without collision with other objects. The acceleration of the crane induces undesirable swing during the motion of the load. Therefore the swing angles must be kept as small as possible with the help of sensors and controllers [3]. Soft-computing control techniques has proved to be very effective in control of these non-linear systems. In the past few decades, researchers have shown keen interest in control of these non-linear systems using fuzzy logic technique. In a study by Solihin et al. [4] proposed a fuzzy-tuned PID controller for anti-swing control of gantry crane. The fuzzy systems were used for tuning of PID gains to achieve robust performance to parameter variations. The experimental results showed the satisfactory performance of the proposed controller. Ranjbari et al. [5] presented a

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fuzzy approach for load swing control of an overhead crane. The quadratic derivative of state variables was added to the conventional model which caused an extra weighting. The controller was designed to keep the load angle zero. The study also compared the results of fuzzy controllers with optimal control method.

Ko [6] proposed a fuzzy PID controller to asymptotically stabilize a three dimensional overhead crane using a hybrid optimization approach. The proposed fuzzy PID controller was adaptive and more flexible as compared to conventional fixed gain PID controller. The tuning of fuzzy PID controller was achieved using GA and PSO method. Cho and Lee [7] presented a fuzzy anti-swing control scheme for three-dimensional overhead crane. The proposed controller consists of a position servo control and a fuzzy logic control. The position servo control was used to control crane position and rope length while the fuzzy controller was used to suppress load swing. Solihin and Wahyudi [8] developed a fuzzy-tuned PID controller design for anti-swing control of gantry crane. The fuzzy controllers were used as gain tuners to improve the robustness and cope up with parameter variations of the proposed system. Li and Yu [9] proposed a control strategy which includes both position regulation and antiswing control of an overhead crane. The fuzzy rules were used to compensate friction, gravity as well as coupling between position and anti-swing control. The paper also introduced a high-gain observer to estimate the joint velocities to realize PD control.

Hayajneh et al. [10] proposed a fuzzy logic control of overhead crane with reduced number of rules. The proposed controller includes two rule bases, one for displacement control and other for swing control. The simulation results showed that by using the proposed controller, overhead crane smoothly travels to destination in short time, with small swing angle and almost no overshoot. Chang [11] proposed a fuzzy logic control of trolley cranes. The power to drive trolley was applied through information of trolley position, load swing and difference between present and previous signals. A switching algorithm has also been investigated for improving the control of trolley and suppress the load swing. Chen et al. [12] presented an intelligent control scheme which combines fuzzy neural network (FNN) and sliding mode control (SMC) with particle swarm optimisation (PSO) for control of bridge cranes. The three FNN were used to control positioning subsystem, lifting-rope subsystem and anti-swing subsystem. Further the parameters were optimized with PSO. The simulation results showed the correctness and validity of proposed method. Benhidjeb and Gissinger [13] performed comparison of fuzzy logic control system with linear quadratic gaussian (LQG) control of an overhead crane. The study examined different possible perturbations of the control algorithm and a complete reference trajectory model was also presented.

Pezeshki et al. [14] employed a model-free adaptive controller (MFAC) using feedback linearization and an adaptive fuzzy sliding mode controller (AFSMC) using fuzzy approximations to control an underactuated overhead crane. Both controllers used trolley position and load swing angle for controlling. External disturbances were also considered to verify the efficiency of proposed controller. Chang [15] provided an effective adaptive fuzzy controller for overhead crane. The proposed method uses trolley position and swing angle information to design the fuzzy controller. An adaptive algorithm was provided for tuning parameters of proposed system. The study illustrates several experiments with different wire length and payload weight to compare feasibility and effectiveness of proposed system. In this study an offline control of overhead crane has been proposed using fuzzy and Adaptive neuro fuzzy inference system (ANFIS) controllers. The ANFIS controller was trained from data sets collected after previous simulation of PID

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controller. The study not only compares the performance parameters of non-linear crane system but also shows the effect of varying physical attributes of crane on performance parameters. The performance parameters considered were settling time, steady state error and overshoot. The physical attributes which were considered to influence the behaviour of performance parameters were mass of crane (M), mass of load (m) and length of crane (L). The results are shown with the help of graphs and tables which proved the validity of proposed techniques.

2. Mathematical modelling and Simulink of Overhead crane

This paper considers motion of Overhead crane on a horizontal surface as shown in Figure 1. [16]. The system comprises of a crane of mass (M), attached to a load of mass (m) with the help of massless and inextensible rod of length (L). The complete system is performing motion under the action of Force (P) and gravity (g). The angle of inclination of rod with the vertical is θ and the surface is assumed to be frictionless following equations of motion were obtained [17].

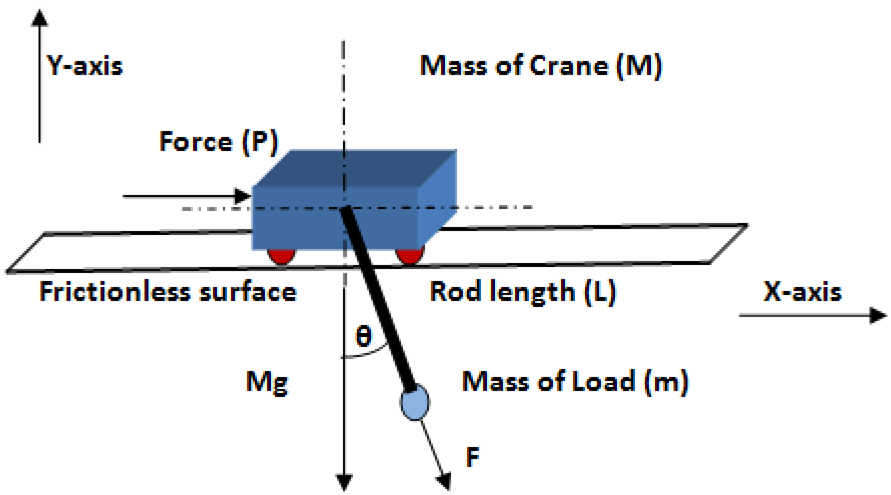


Figure 1: Overhead crane moving on horizontal surface

$$\ddot{\theta}= \frac{-[ucos\theta+msin\theta\,(L\theta^2cos+g)+ Mgsin\theta]}{(M+msin^2\theta)L} \quad (1)$$

$$\ddot{x} = \frac{[u+msin\theta\,(L\dot{\theta}^2+gcos\theta)]}{(M+msin^2\theta)} \quad (2)$$

The above two equations were used for building Matlab-Simulink model of the proposed system as shown in Figure 2.

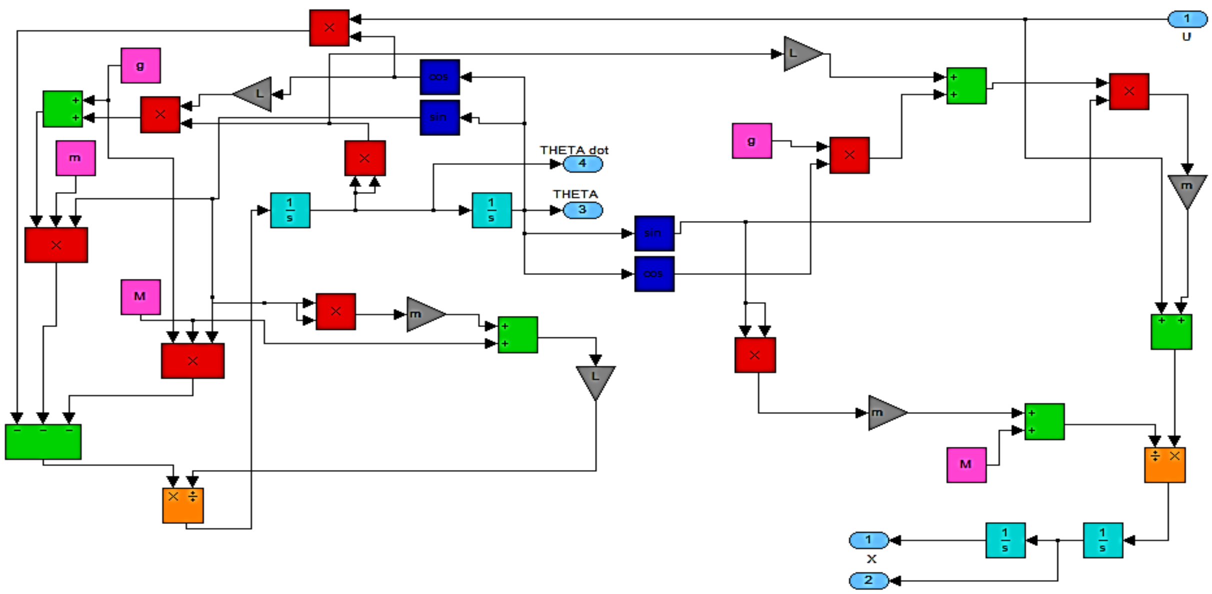


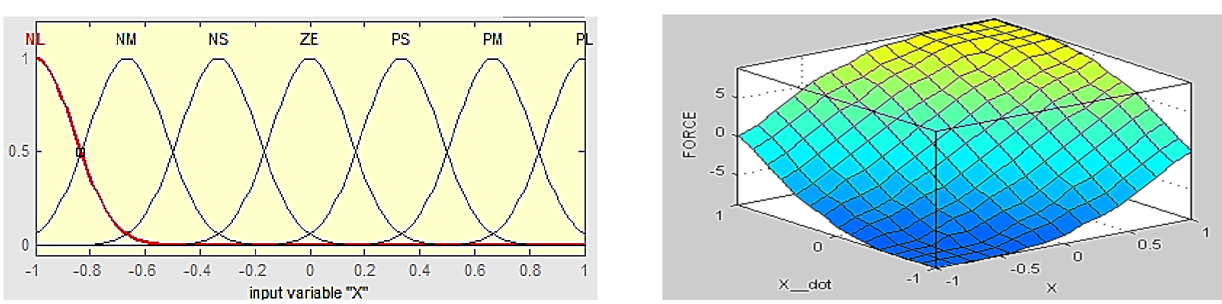
Figure 2: Simulink of Overhead crane

3. Controllers designed for stabilisation of Overhead crane

This study considers two different controllers for stabilisation of Overhead crane system. Both the controllers are briefly discussed below:

3.1 Designing of Fuzzy controllers

Fuzzy logic theory was initially introduced by L.A. Zadeh early in 1965 [18]. It is a computational paradigm which is based on human capability of thinking and decision making and widely used in complex situations when conventional logic fails [19]. In this paper mamdani based fuzzy inference system has been used for designing of fuzzy logic controllers [20, 21]. Two controllers has been designed to control crane position and load angle separately. The input membership function (MF) designed for cart position and surface viewer for crane controller are shown in Figure 3(a) and Figure 3(b) respectively.

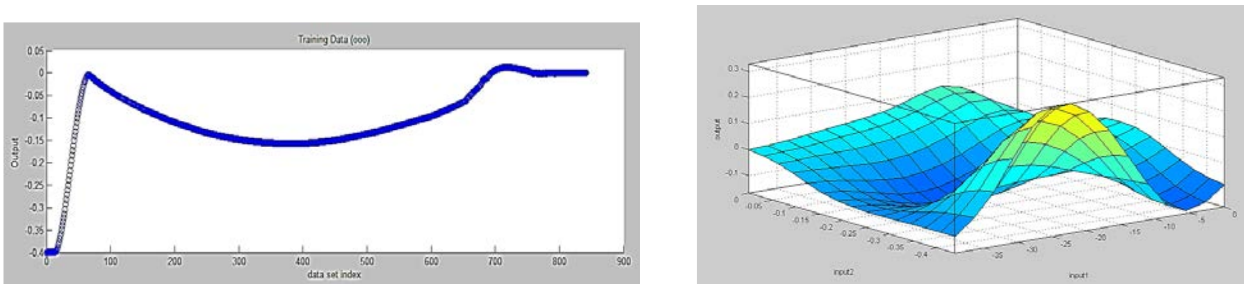


(a) MF for crane position (b) Surface viewer for crane controller

Figure 3: Membership function and Surface viewer for crane controller

3.2 Designing of ANFIS controllers

ANFIS are hybrid learning algorithm based on takagi-sugeno fuzzy inference system [22]. It shows more adaptive and robust behaviour as compared to conventional controllers [23]. ANFIS combines the characteristics of self-learning ability of neural networks and rule based processing of fuzzy logic [24]. The data sets for training of ANFIS controllers were taken from samples collected using PID controllers. The process of data loading and surface viewers obtained after training are shown in Figure 4(a) and Figure 4(b) respectively.



(a) Loading of data samples (b) Surface viewer obtained after training

Figure 4: Loading of samples and Surface viewer after training

4. Simulation results

The simulation of both the controllers were done using different sets of input attributes which illustrates the relationship and influence of attributes on performance parameters. The simulation results for various input sets are shown with the help of tables and figures below.

Experiment: 1

Input parameters: M=1; m=0.5; L=0.1; g=9.81

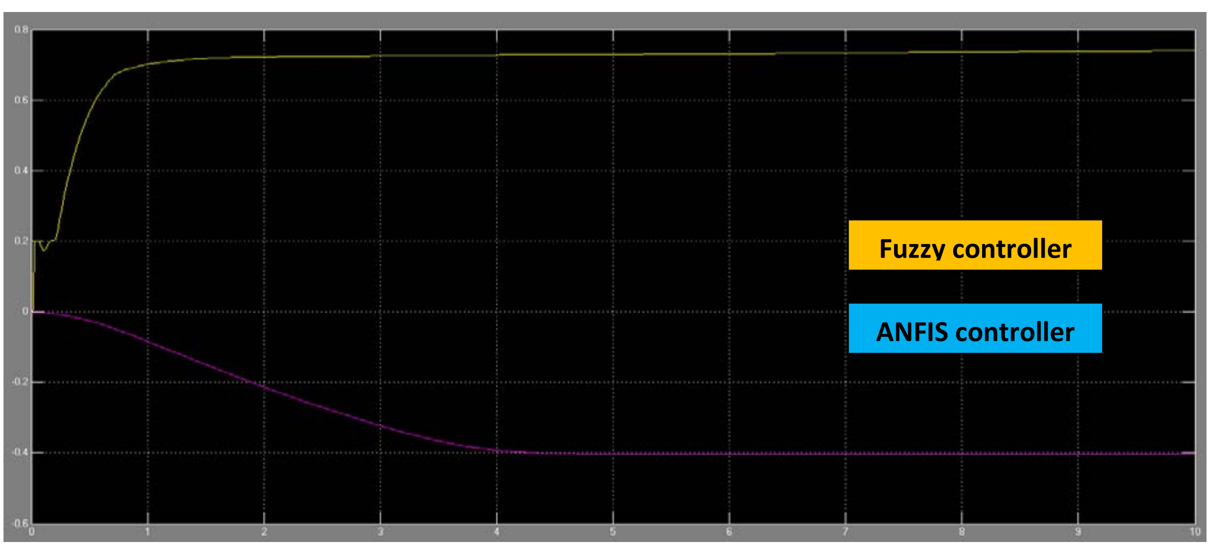


Figure 5: Simulation responses for Crane position

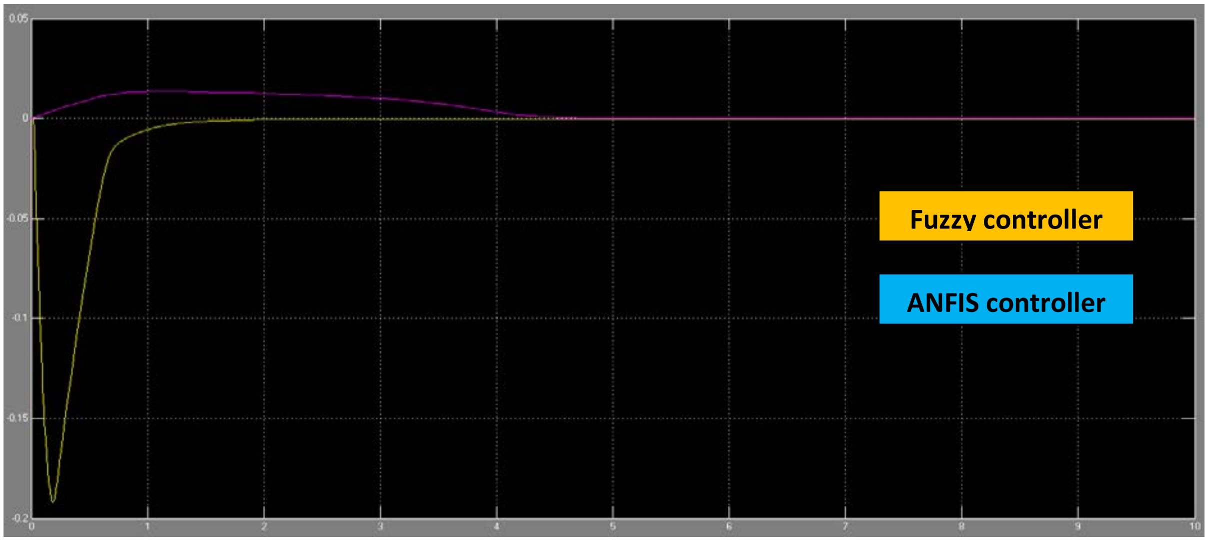


Figure 6: Simulation responses for Load angle

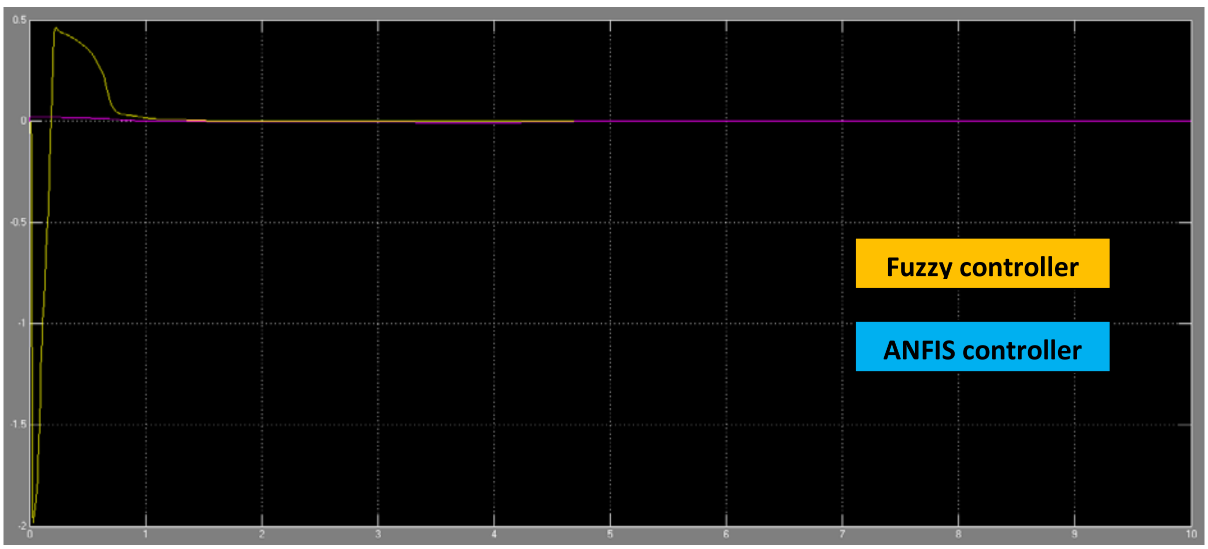


Figure 7: Simulation responses for Load angular velocity

Table 1: Simulation results

Performance parameter	Settling time (sec)		Max. Overshoot (degree)	
Controllers	Fuzzy	ANFIS	Fuzzy	ANFIS
Crane position	1.5 sec	4.0 sec	0.75°	-0.4°
Load angle	1.5 sec	4.4 sec	-0.18°	0.02°
Load angular velocity	1.2 sec	1.0 sec	-1.9° to 0.4°	0.05°

Experiment: 2

Input parameters: M=1.5; m=1; L=0.2; g=9.81

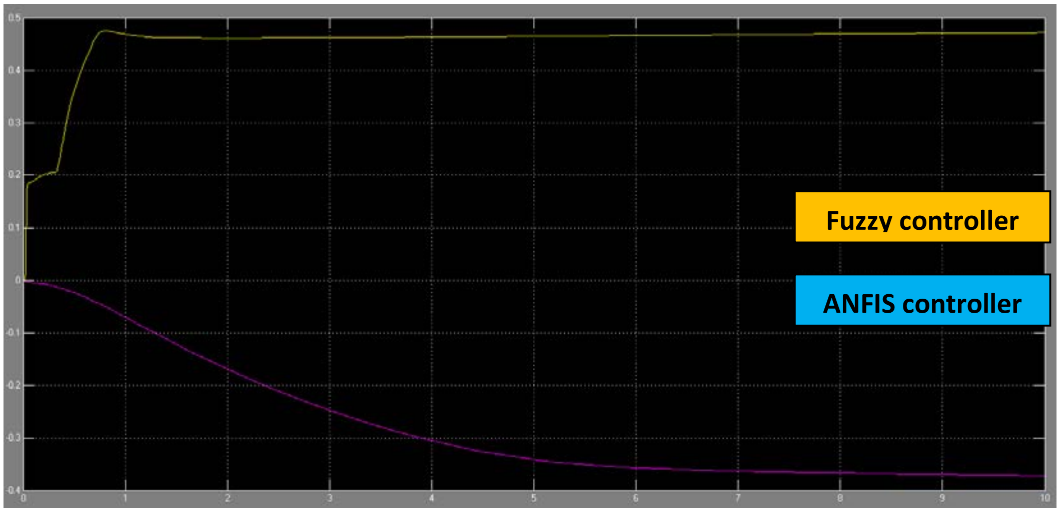


Figure 8: Simulation responses for Crane position

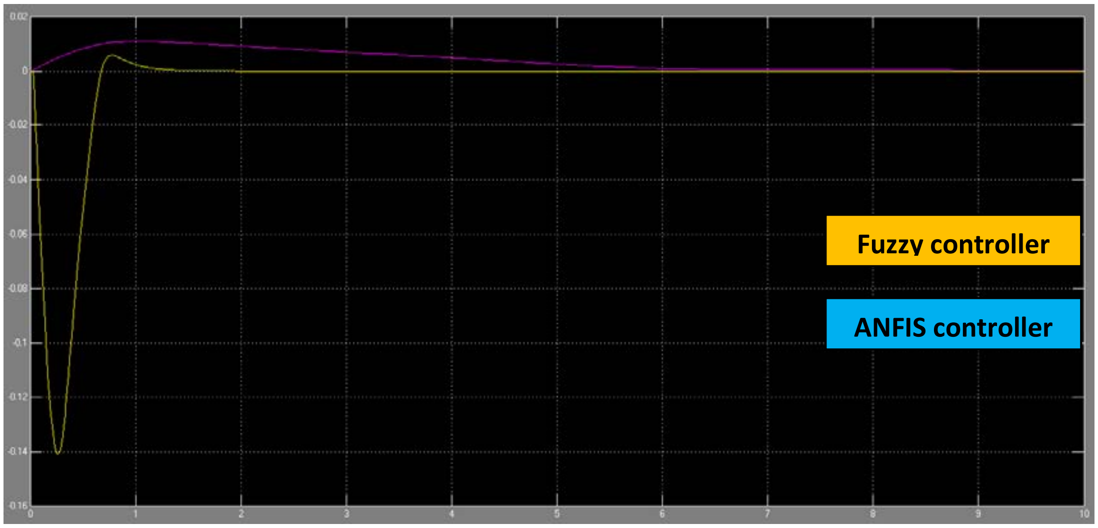


Figure 9: Simulation responses for Load angle

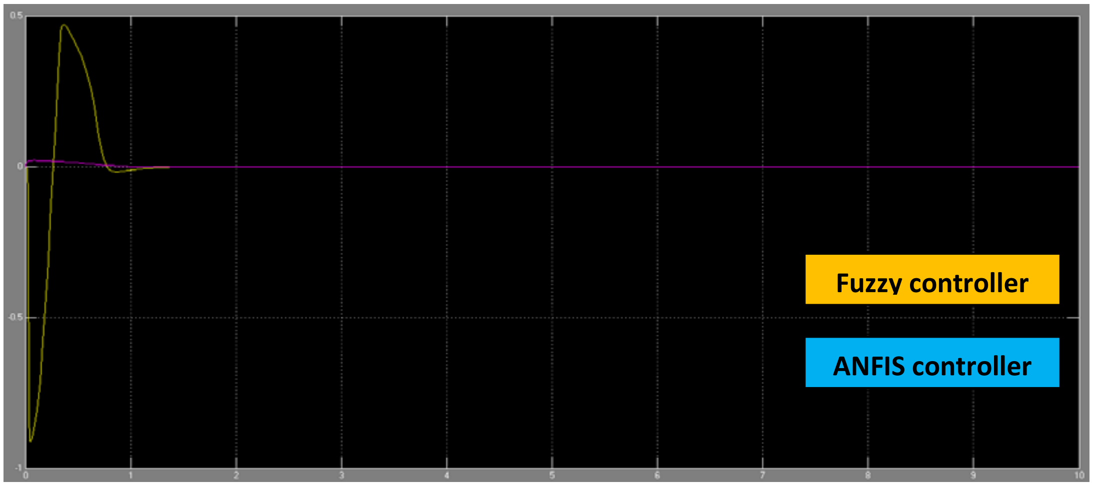


Figure 10: Simulation responses for Load angular velocity

Table 2: Simulation results

Performance parameter	Settling time (sec)		Max. Overshoot (degree)	
Controllers	Fuzzy	ANFIS	Fuzzy	ANFIS
Crane position	1.3 sec	6.0 sec	0.47°	-0.38°
Load angle	1.4 sec	6.0 sec	-0.01°	0.01°
Load angular velocity	1.2 sec	1.2 sec	-0.9° to 0.45°	0.025°

Experiment: 3

Input parameters: M=2; m=1.5; L=0.3; g=9.81

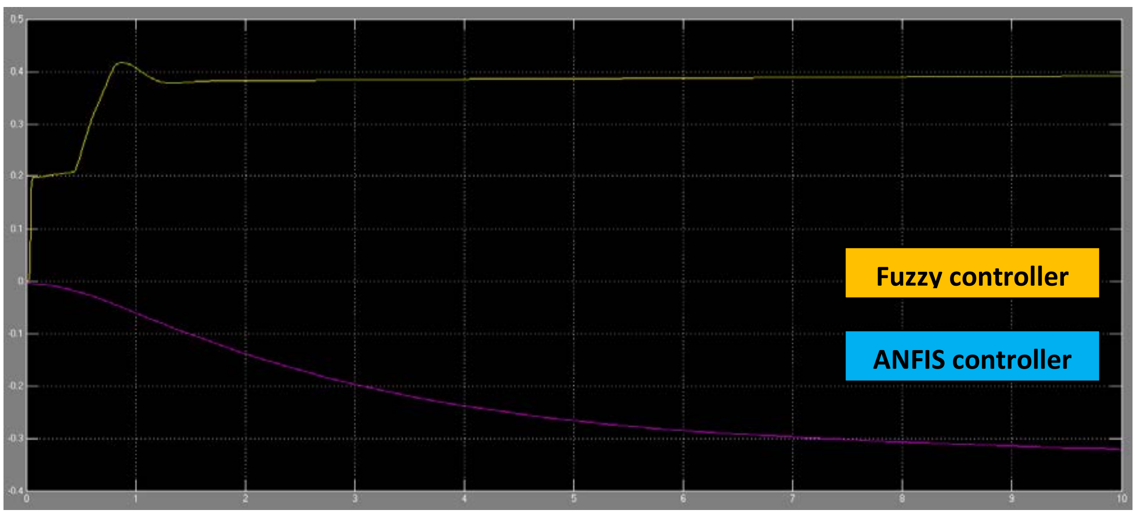


Figure 11: Simulation responses for Crane position

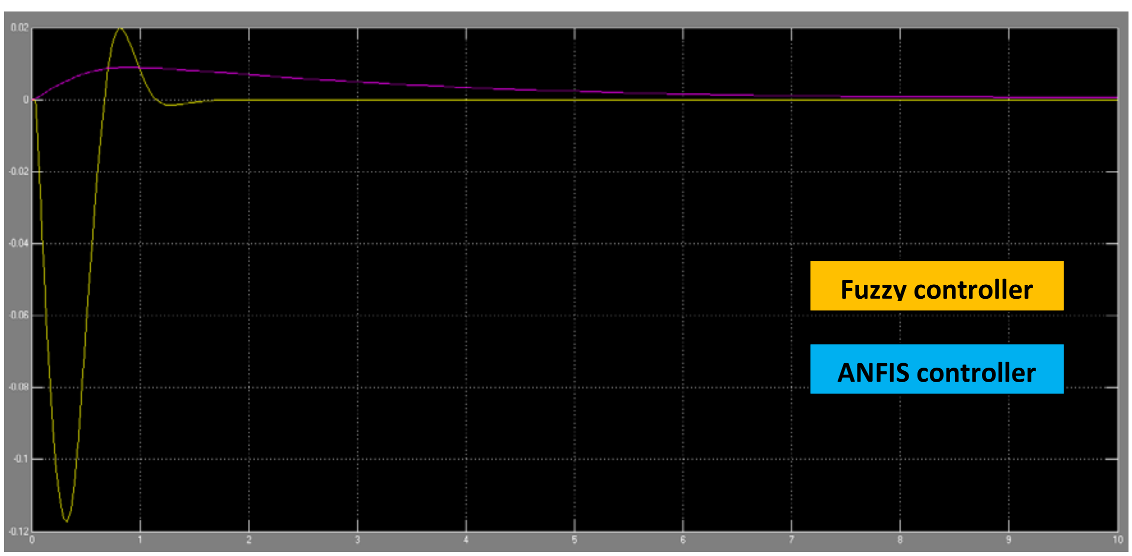


Figure 12: Simulation responses for Load angle

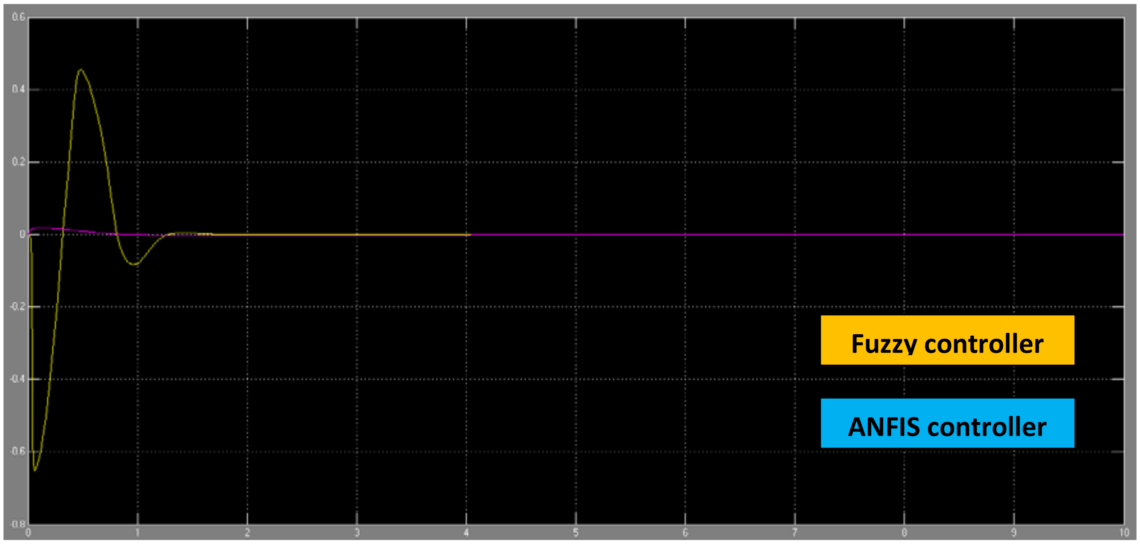


Figure 13: Simulation responses for Load angular velocity

Table 3: Simulation results

Performance parameter	Settling time (sec)		Max. Overshoot (degree)	
Controllers	Fuzzy	ANFIS	Fuzzy	ANFIS
Crane position	1.3 sec	7.0 sec	0.42°	-0.32°
Load angle	1.5 sec	6.0 sec	-0.11° to 0.02°	0.009°
Load angular velocity	1.6 sec	0.9 sec	-0.65° to 0.45°	0.020°

Experiment: 4

Input parameters: M=2.5; m=2; L=0.4; g=9.81

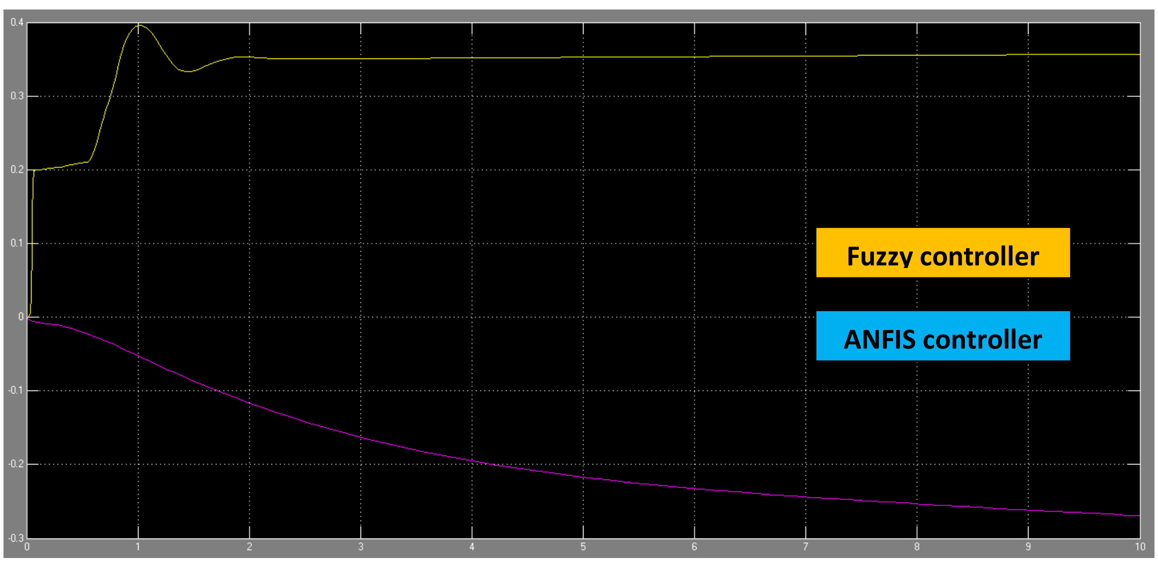


Figure 14: Simulation responses for Crane position

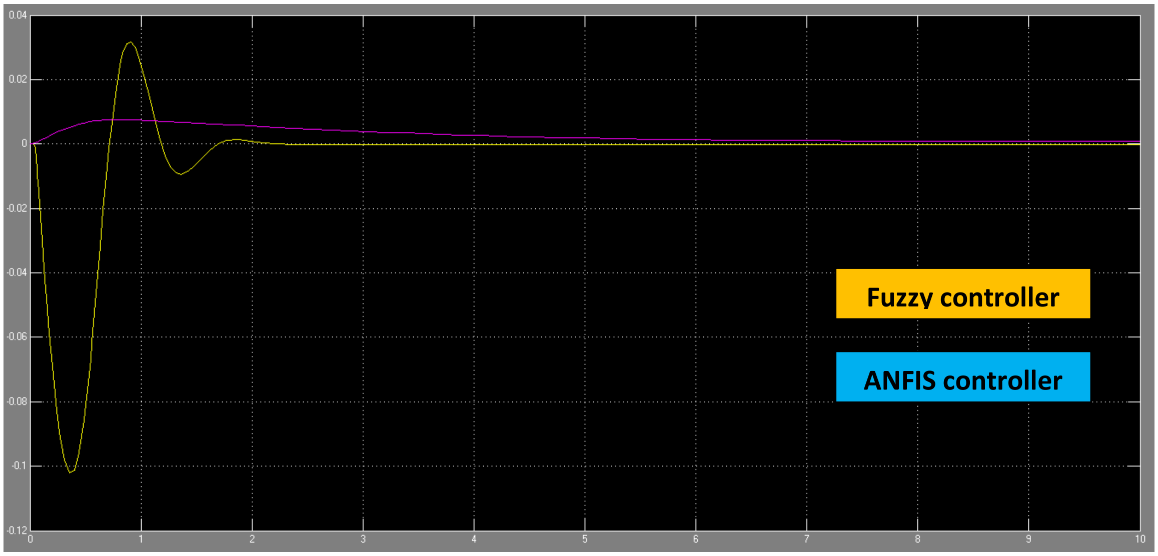


Figure 15: Simulation responses for Load angle

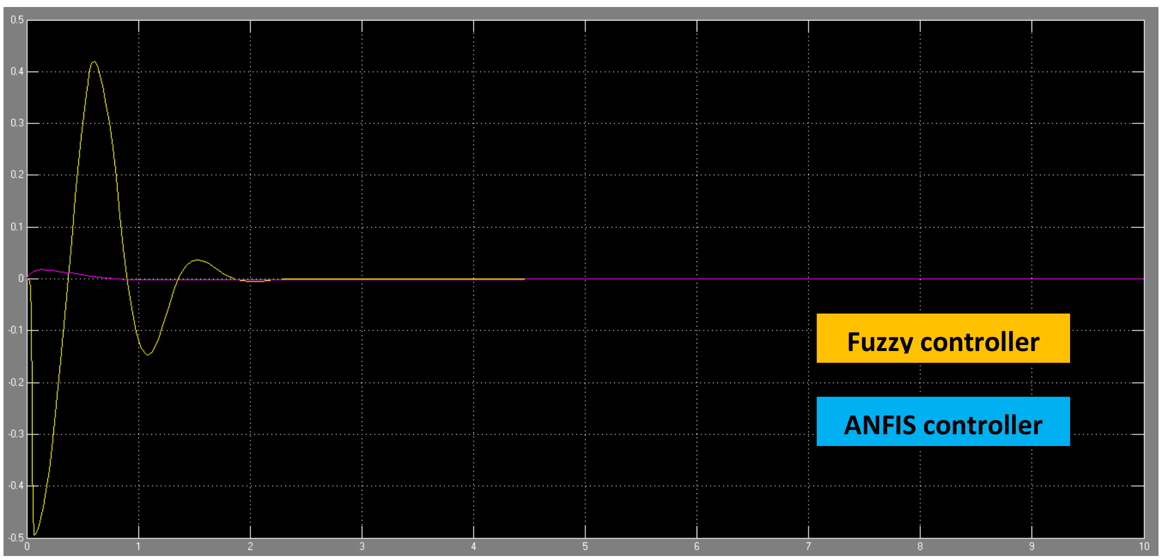


Figure 16: Simulation responses for Load angular velocity

Table 4: Simulation results

Performance parameter	Settling time (sec)		Max. Overshoot (degree)	
Controllers	Fuzzy	ANFIS	Fuzzy	ANFIS
Crane position	2.0 sec	8.0 sec	0.4°	-0.27°
Load angle	2.0 sec	7.0 sec	-0.105° to 0.03°	0.008°
Load angular velocity	2.0 sec	0.8 sec	-0.5° to 0.42°	0.018°

Experiment: 5

Input parameters: M=3; m=2.5; L=0.5; g=9.81

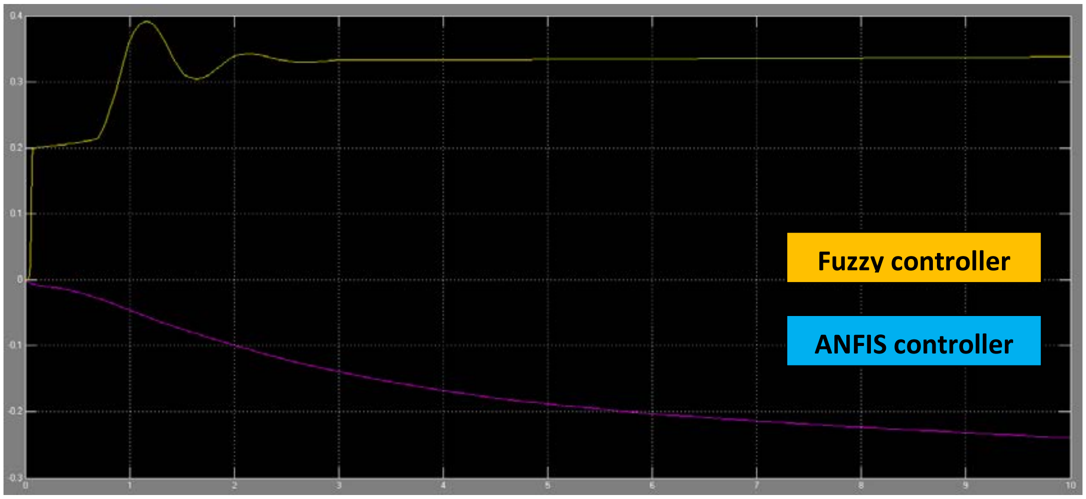


Figure 17: Simulation responses for Crane position

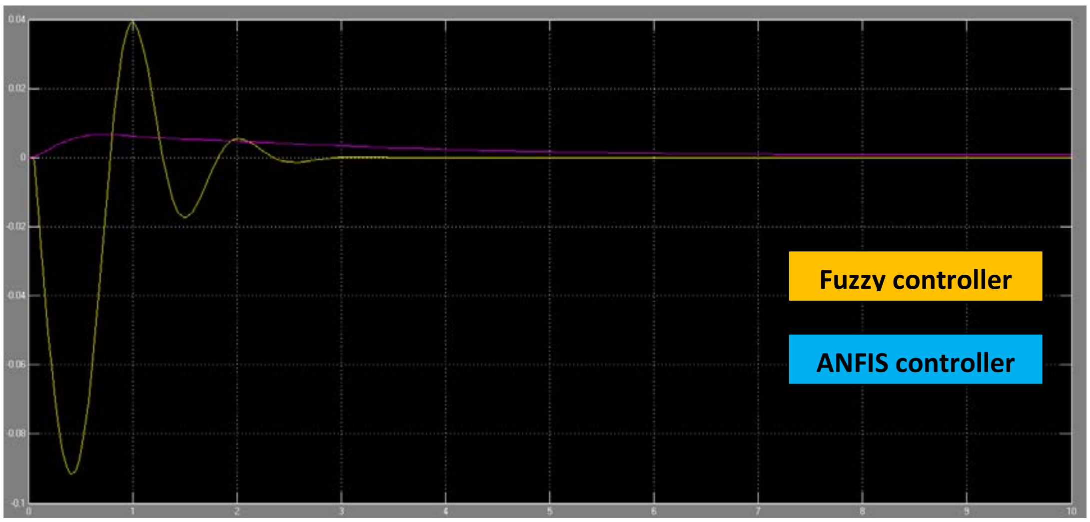


Figure 18: Simulation responses for Load angle

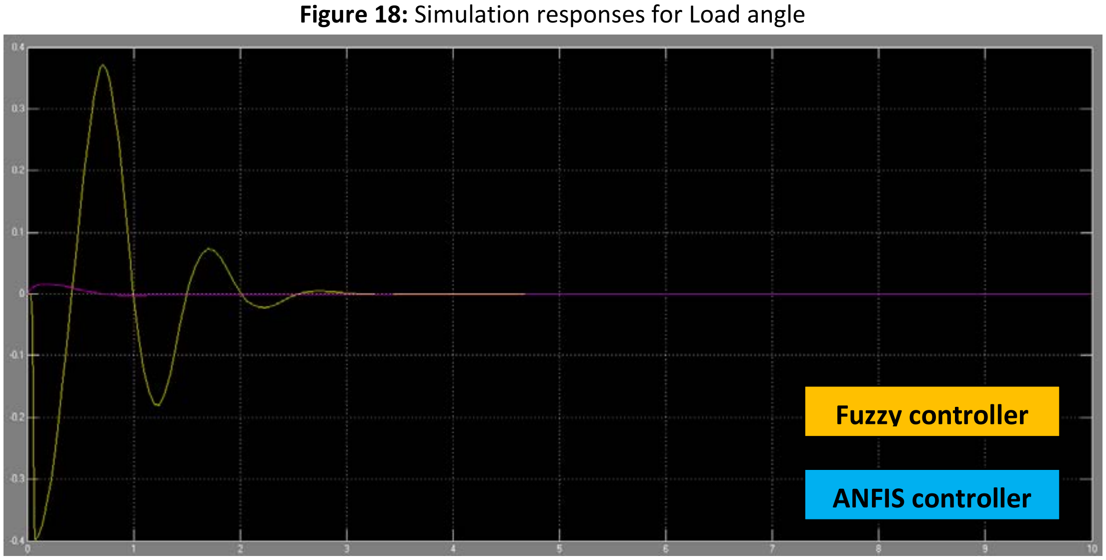


Figure 19: Simulation responses for Load angular velocity

Table 5: Simulation results

Performance parameter	Settling time (sec)		Max. Overshoot (degree)	
Controllers	Fuzzy	ANFIS	Fuzzy	ANFIS
Crane position	2.5 sec	9.0 sec	0.39°	-0.24°
Load angle	3.0 sec	7.0 sec	-0.09° to 0.04°	0.007°
Load angular velocity	3.0 sec	0.8 sec	-0.4° to 0.37°	0.017°

Conclusion

The research objective of an offline position and swing control of an Overhead crane has been successfully achieved. The simulation results showed that both the controllers effectively stabilises the proposed system. The study clearly showed the robust performance of the proposed system under parameter variation. The soft-computing techniques were compared in terms of settling time and overshoot. The tuning of ANFIS controller was done from data sets collected after simulation of PID controller which clearly showed better learning capability of ANFIS controllers. The settling time obtained for crane position and load angle using fuzzy controllers were much less as compared to that of ANFIS controller. It is also observed that the settling time for load angular velocity were much less when ANFIS controller was used. The simulation results also showed that the ranges of overshoot values using ANFIS control were much small as compared to that of fuzzy control. It is further observed that with the increase in mass of crane, mass of load and length of load the settling time obtained for both the controllers increases and overshoots for both the controllers decreases. As an extension to proposed work, other control techniques like neural networks, particle swarm optimisation, genetic algorithm etc can be further applied for control of overhead cranes.

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