Advanced Dynamic Path Control of the Three Links SCARA using Adaptive Neuro Fuzzy Inference System

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1. Introduction

The very precise control of robot manipulator to track the desired trajectory is a very tedious job and almost unachievable to certain limit with the help of adaptive controllers. This task is achievable to certain limit with the help of adaptive controllers but these controllers also have their own limitation of assuming that the system parameters being controlled change relatively very slow. With reference to the tasks assigned to an industrial robot, one important issue is to determine the motion of the joints and the end effectors of the robot. Therefore, the purpose of the robot arm control, as Fu et al (1987) wrote in one classical works on robotics, is to maintain the dynamic response of the manipulator in accordance with some prespecified performance criterion. Among the early robots of the first generation, non-servo control techniques, such as bang-bang control and sequence control were used. These robots move from one position to another under the control or limit switches, relays, or mechanical stops. During the 1970s, a great deal of work was focused on including such internal state sensors as encoders, potentiometers, tachogenerators, etc., into the robot controller to facilitate manipulative operation ((Inoue, H.,(1974) and Wills, et al (1975)) . Since then, feedback control techniques have been applied for servoing robot manipulators. Up till now, the majority of practical approaches to the industrial robot arm controller design use traditional techniques, such as Proportional and Derivative (PD) or Proportional-Integral-Derivative (PID) controllers, by treating each joint of the manipulator as a simple linear servomechanism. In designing these kinds of controllers, the non-linear, coupled and time-varying dynamics of the mechanical part of the robot manipulator system are completely ignored, or dealt with as disturbances. These methods generally give satisfactory performance when the robot operates at a low speed.
However, when the links are moving simultaneously and at a high speed, the non-linear coupling effects and the interaction forces between the manipulator links may degrade the performance of the overall system and increase the tracking errors. The disturbances and uncertainties in a task cycle may also reduce the tracking quality of robot manipulators. Thus, these methods are only suitable for relatively slow manipulator motion and for

limited-precision tasks can be found in the work by Sciavicco (1996). The Computed Torque Control (CTC) is commonly used in the research community. The CTC law has the ability to make the error asymptotically stable if the dynamics of the robot are exactly known .Paul, R.C (1972). However, manipulators are subject to structured and/or unstructured uncertainty. Structured uncertainty is defined as the case of a correct dynamic model but with parameter uncertainty due to tolerance variances in the manipulator link properties, unknown loads, inaccuracies in the torque constants of the actuators, and others. Unstructured uncertainty describes the case of unmodeled dynamics, which result from the presence of high-frequency modes in the manipulator, neglected time-delays and nonlinear friction. It has been widely recognized that the tracking performance of the CTC method in high-speed operations is severely affected by the structured and unstructured uncertainties.
To cope with the problem, some adaptive approaches have been proposed to maintain the tracking performance of the robotic manipulator in the presence of structured uncertainty. Dubowsky(1979). To overcome the above mentioned drawback in manipulator motion control, the chapter proposed a Tuned-ANFIS controller for three links Selective Compliant Articulated Robot Arm (SCARA) manipulators. The proposed Tuned-Adaptive Neuro Fuzzy Inference System (ANFIS) controller is designed to overcome the unmodeled dynamics in the presence of structured and unstructured uncertainties of SCARA. The proposed Tuned-ANFIS Controller combines the advantages of fuzzy and neural network intelligence, which helps to improve the overall learning ability, adaptability of the ANFIS controller and also to achieve robust control of SCARA in unmodeled dynamic control. This Tuned-ANFIS Controller has been applied to the Continuous Path Control of SCARA. The result obtained through the tuned ANFIS is encouraging and shows very good tracking performance. The chapter is structured as follows, Section 2 Overview of SCARA robot control system, Section 3 describes the proposed Adaptive Neuro Fuzzy Inference System and Section 4 presents the ANFIS architecture and learning algorithm and simulation of Continuous Path Motion (CPM) of real-world applications of SCARA Robot Manipulator. Finally, conclusions are summarized in Section5.

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2. Overview of SCARA Robot Control System

The SCARA acronym stands for Selective Compliant Assembly Robot Arm or Selective Compliant Articulated Robot Arm. SCARA is normally used in industries for pick and place operation, etc.

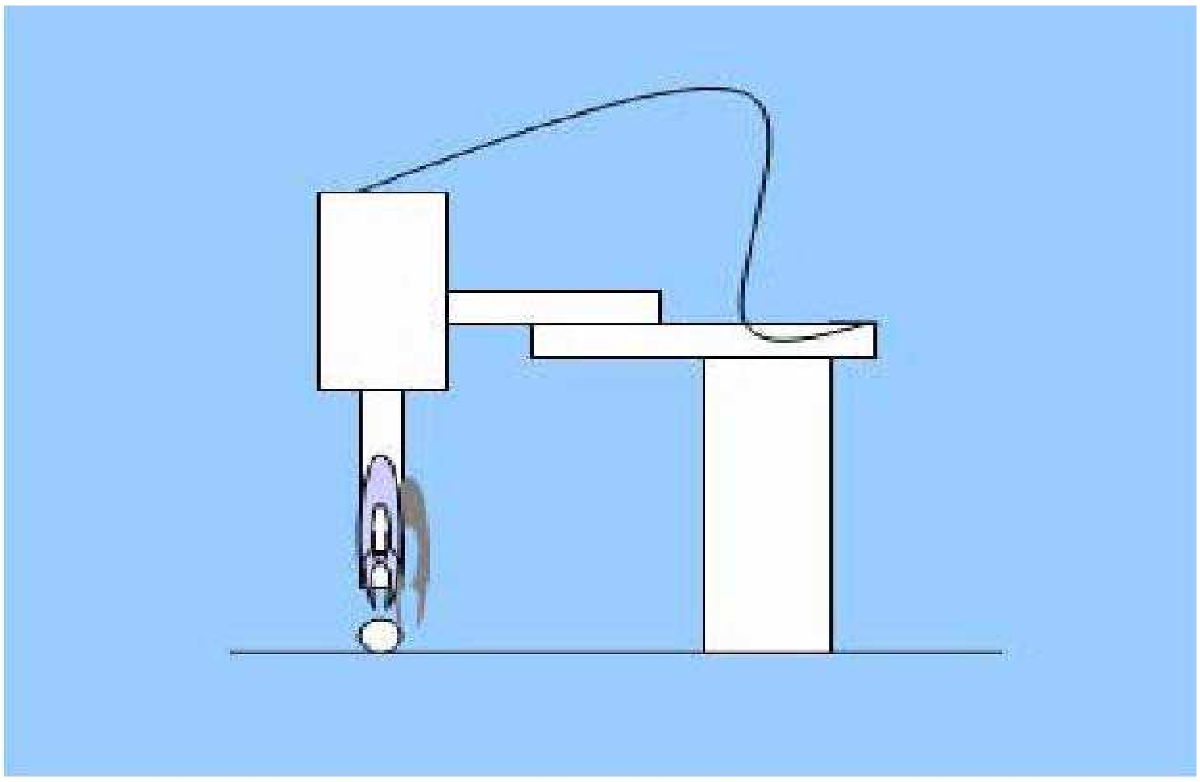


Fig. 1. Shows the SCARA Robot

The figure 1 shows the model picture of SCARA with two vertical revolute joint and one vertical prismatic joint used in this experiment. In this experiment, the dynamical model of SCARA robot is derived using Newton Euler formulation is used for simulating the CPM control using ANFIS and PD Controller. Robot Manipulator control action are exercised in the joint co-ordinates. Moreover, the dynamical model of the three links SCARA is given in many robotics books and papers. The figure 2 shows the basic ANFIS feedback control system for the CPM control of SCARA Manipulator used in this experiment.

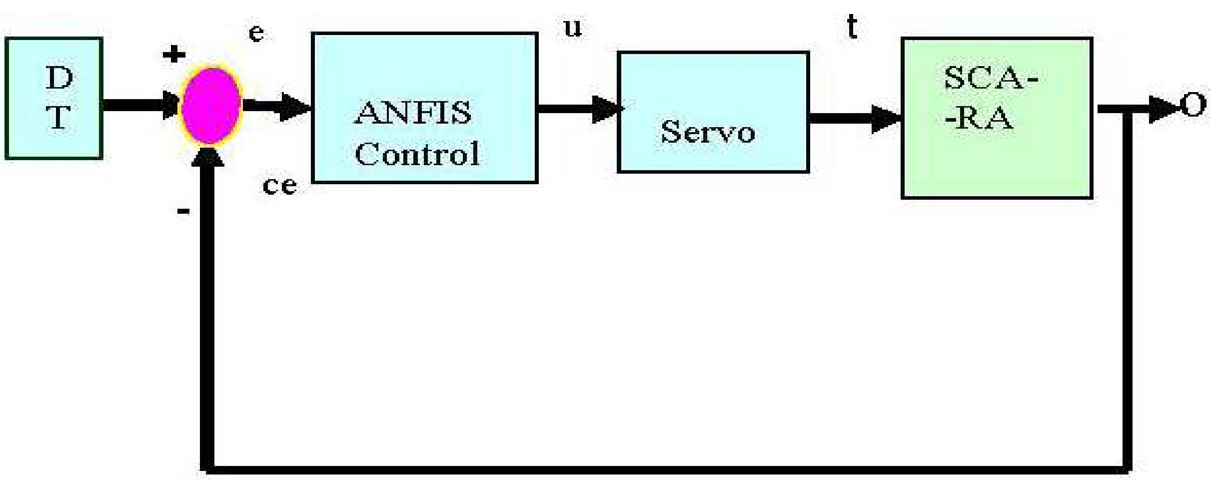


Fig. 2. Shows the ANFIS feedback control system for Continuous Path Motion control of SCARA

The feedback control system consists of ANFIS controller, servo actuating system for the SCARA Robot manipulator system and the SCARA robot manipulator system. The whole feedback system is simulated using Desired Trajectory (DT) generator to achieve minimum tracking error. The ANFIS controller is designed for the two control input viz, error (**e**) and change in error (**ce**) and one output as a control signal (**u**). In order to achieve the feedback control design, the output of the SCARA joint torque angles (**o**) is fedback to the system. As a result the error and change error obtained at the adder of the feedback control system is given as the input to ANFIS controller for the SCARA CPM control. The ANFIS output control signals (u) are usually weak signals, which cannot able to drive the SCARA joints directly, so the signal (u) is amplified and actuated by the servo control system for SCARA manipulator joints. The outputs (**t**) of the servo system are given to individual manipulator links of the SCARA. The simulation model of ANFIS controller architecture is described elaborately in the section 3.

3. Adaptive Neuro Fuzzy Inference System

Adaptive Neuro Fuzzy Inference System (ANFIS) is an artificial intelligence technique, which creates a fuzzy inference system based on the input-output model data pairs of the system. The membership functions of the ANFIS are tuned based on the nature of the input-output obtained from system or system model. The tuning of the ANFIS membership functions are done by using the Back Propagation (BP) algorithm or using least square method in combination with BP algorithm. ANFIS structures with fuzzy IF-THEN-rule based models whose consequent constituents are constants, membership functions, and linear functions as shown in figure 3. The Fuzzy logic can also be used to map complex nonlinear relations by a set of IF-THEN rules. The membership functions are designed by intuitive human reasoning. This causes three different problems. One, for different control applications, a new set of membership functions have to be developed, second, latent stability problem., Rong-Jong Wai(2003) and third, once these membership functions are developed and implemented there is no means of changing them. This means fuzzy logic lacks a learning function. In the past decades, there is a growing interest in Neural-Fuzzy Systems (NFS) as they continue to find success in a wide range of applications. Unfortunately, it has broaden the application spectrum, this paved the way to discover that most existing neural-fuzzy systems. ((Berenji(1992), Jang(1993) and Lin(1996)) exhibit several major drawbacks that may eventually lead to performance degradation. One of the drawbacks is the curse of dimensionality or fuzzy rule explosion. This is an inherent problem in fuzzy logic control systems; that is, too many fuzzy rules are used to approximate the input-output function of the system because the number of rules grows exponentially with the number of input and output variables. Another drawback is their lack of ability to extract input-output knowledge from a given set of training data. Since neural-fuzzy systems are trained by numerical input output data, the cause-effect knowledge is hidden in the training data and is difficult to be extracted. Another drawback is their inability to re-structure the internal structure. i.e. the fuzzy term sets and the fuzzy rules in their hidden layers.

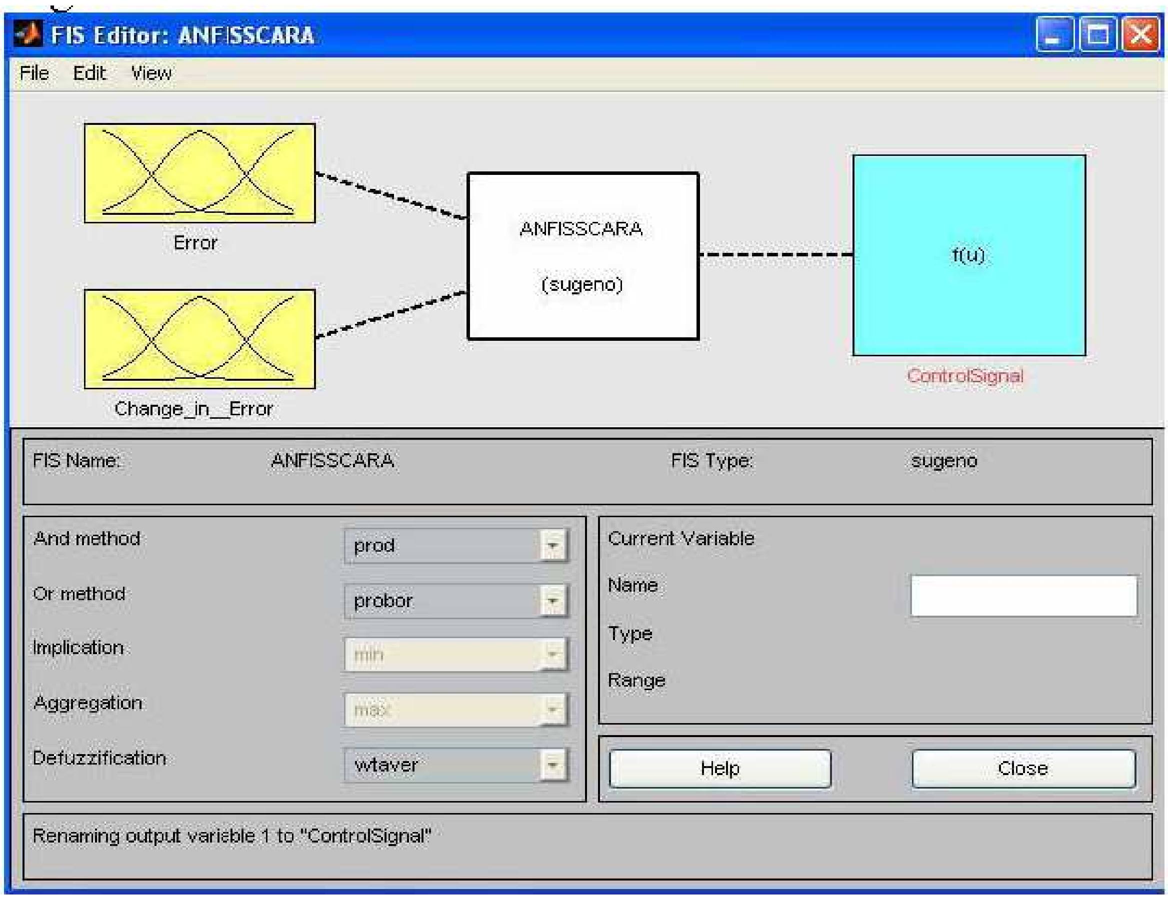


Fig. 3. The architecture of Sugeno Adaptive Neuro Fuzzy Inference System (ANFIS)

In addition, this chapter proposes a systematic approach for establishing a concise ANFIS that is capable of online self-organizing and self-adapting its internal structure for learning the required control knowledge that satisfies the desired system performance. The initial structure of the proposed ANFIS has no rule or term set node. The rule nodes and the term-set nodes are created adaptively and dynamically via simultaneous selforganizing learning and parameter learning procedures. In order to optimize the existing structure, the established rules and term sets are re-examined based on a significance index and similarity measure. Wang(1999). Thus, the rules with the index values below a prespecified threshold are pruned and the highly similar input term sets are combined. The back propagation algorithm and/or the recursive least square estimate are incorporated into the ANFIS to optimally adjust the parameters. This pruning of rule nodes and term-set nodes will result in a more concise ANFIS structure without sacrificing the system performance.

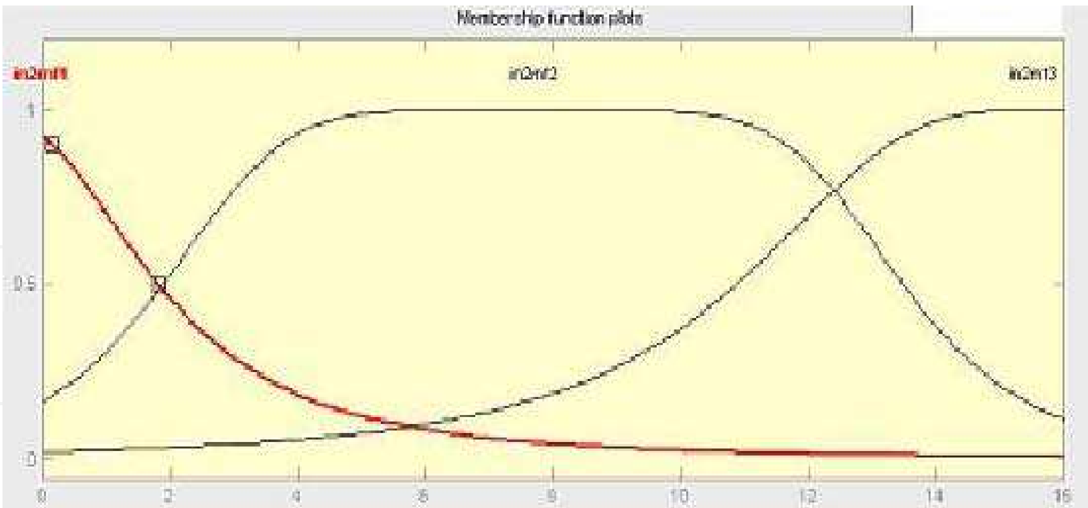


Fig. 4. Membership functions before ANFIS learning

the hybrid learning rule, a computational speedup may be possible by using variants of the gradient method or other optimization techniques on the premise parameters. Since ANFIS and radial basis function networks (RBFNs) are functionally equivalent, a variety of learning methods can be used for both of them. Figure 4 and 5 shows the membership function of the input before training and after training.

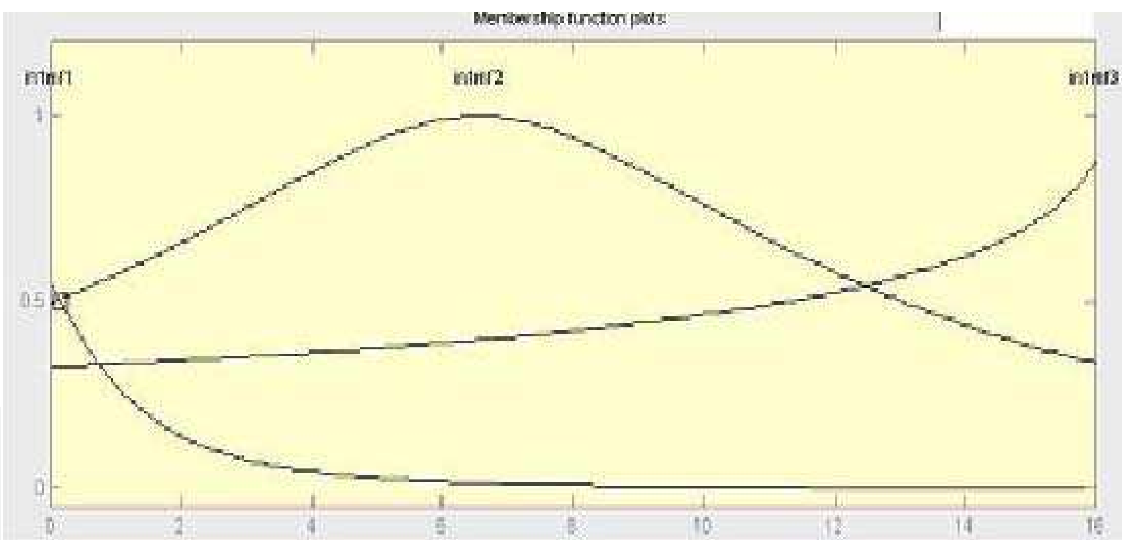


Fig. 5. Membership functions after ANFIS learning

4. Design of ANFIS Controller for SCARA

This section discuss the tracking and adaptability features of the ANFIS control applied to a three-link SCARA manipulator are tested using simulation. Figure 5 shows the architecture of the fuzzy system with the ANFIS approach. The ANFIS methodology is used to estimate the parameters of the membership functions and the consequent functions. In this experiment, ANFIS network is implemented with help of MATLAB, ANFIS toolbox. ANFIS Input variable consist of error (e) and change in error (ce), which has been describes by low, medium and high membership function in the ANFIS network. The training data (control signal data) is obtained from the dynamic model of SCARA. The designed Sugeno -ANFIS network is trained for SCARA control signal. The back propagation algorithm and/or the recursive least square estimate are incorporated into the ANFIS to optimally adjust(tuned) the parameters (linguistic variables) of the membership function. It is found that there is a significant difference between the ANFIS membership functions before and after training as shown in the figures 4 and 5 respectively.

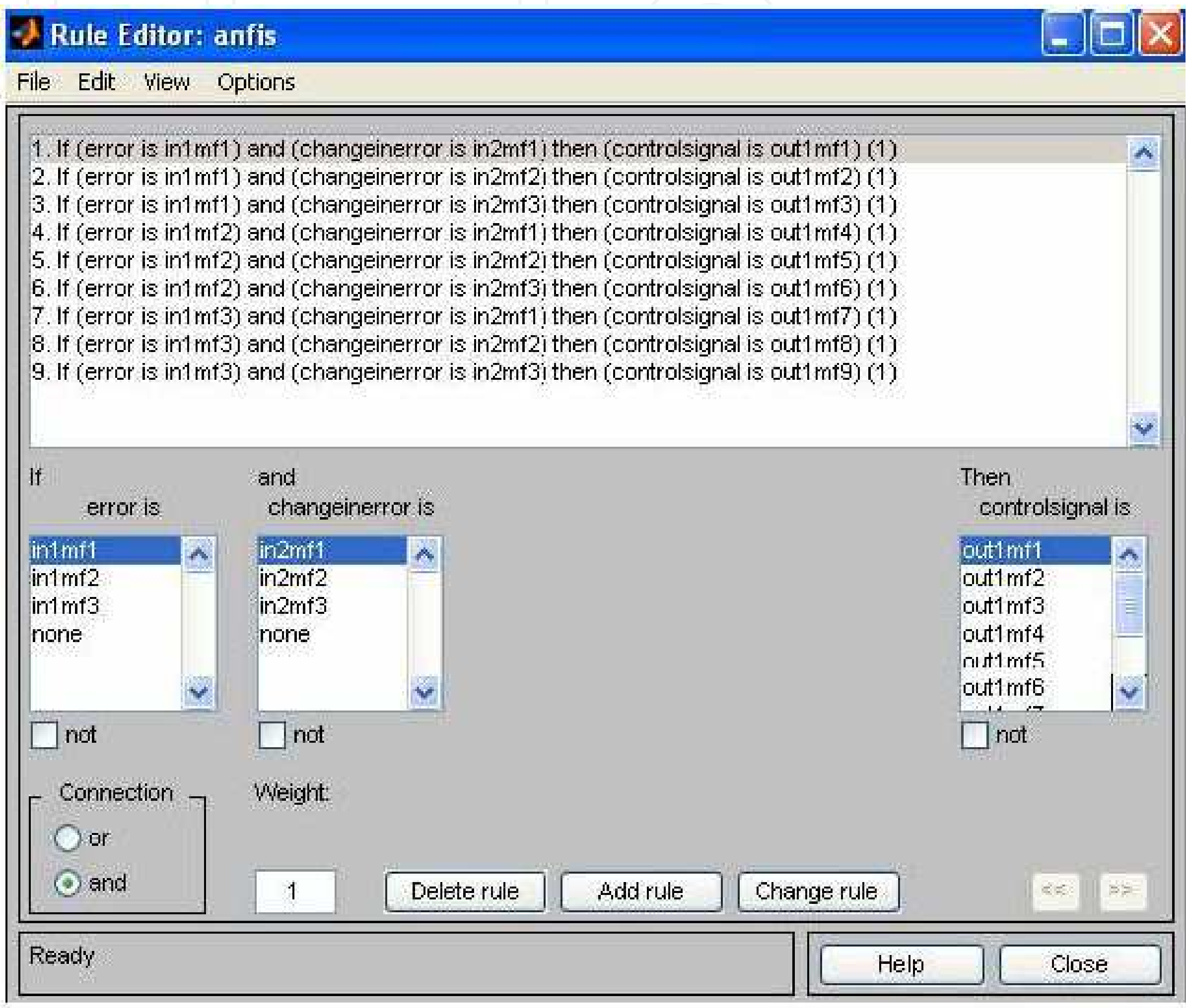


Fig. 6. Generated rule base of the ANFIS structure.

This show the membership functions learns the training data and adjusts its shapes according to the dynamics of the system. The nine rules are used to model the fuzzy part of the ANFIS controller as shown in figure 6 and three membership functions for each linguistic input variable. The fuzzy rules generated by the ANFIS method are shown in figure 6. Figure 7 and 8 shows the loading and training of ANFIS structure using the SCARA dynamic data. The ANFIS structure is trained for 50 epochs, with error tolerance of 0. and the performance Mean Square Error (MSE) is found to be 0.0064759. Figure 9 shows the fuzzy rule viewer of MATLAB, which is used for predetermine the output of the model for specific input values.

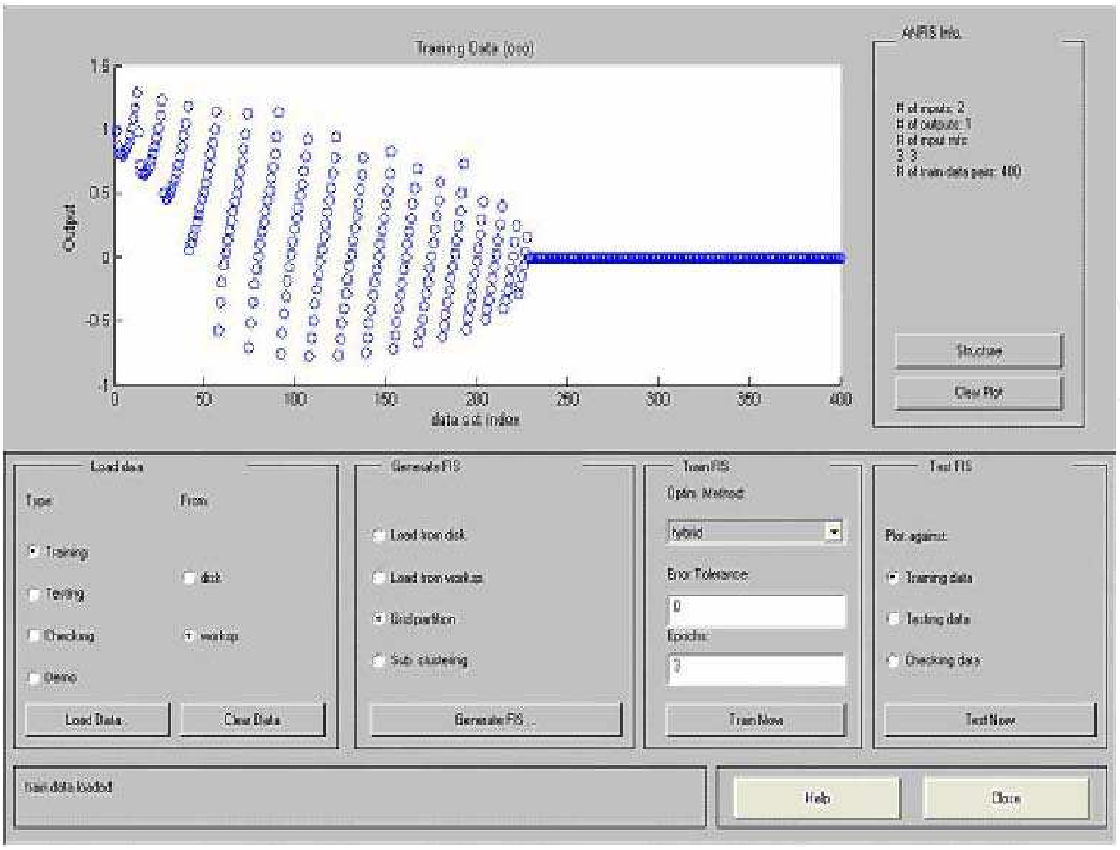


Fig. 7. Loading Training data for ANFIS structure.

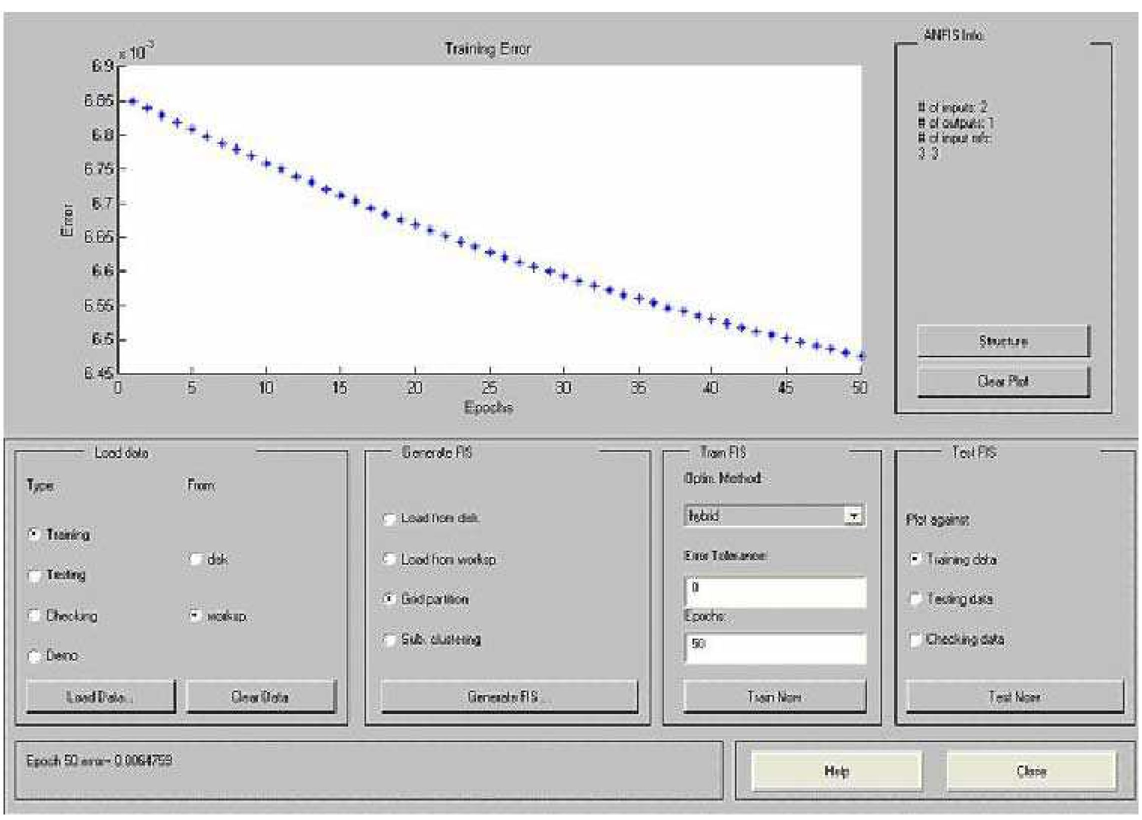


Fig. 8. Training when error tolerance is chosen to be 0 and number of epochs is limited to 50.

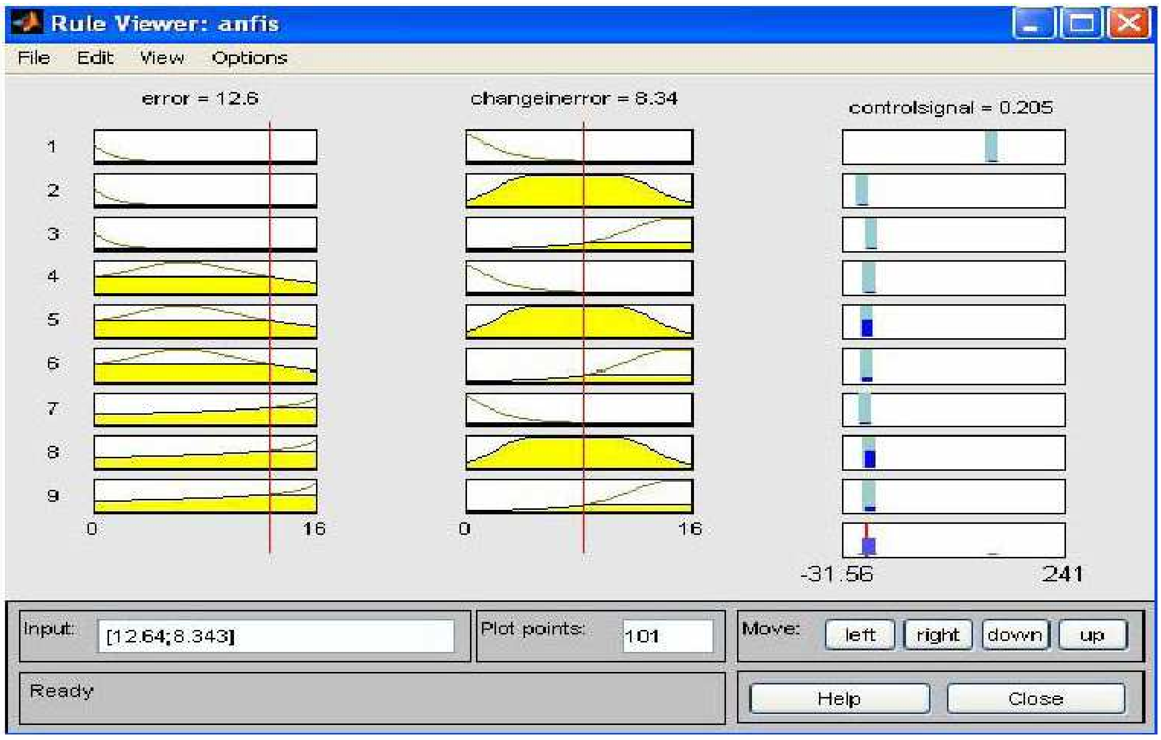


Fig. 9. Rule viewer of ANFIS structure

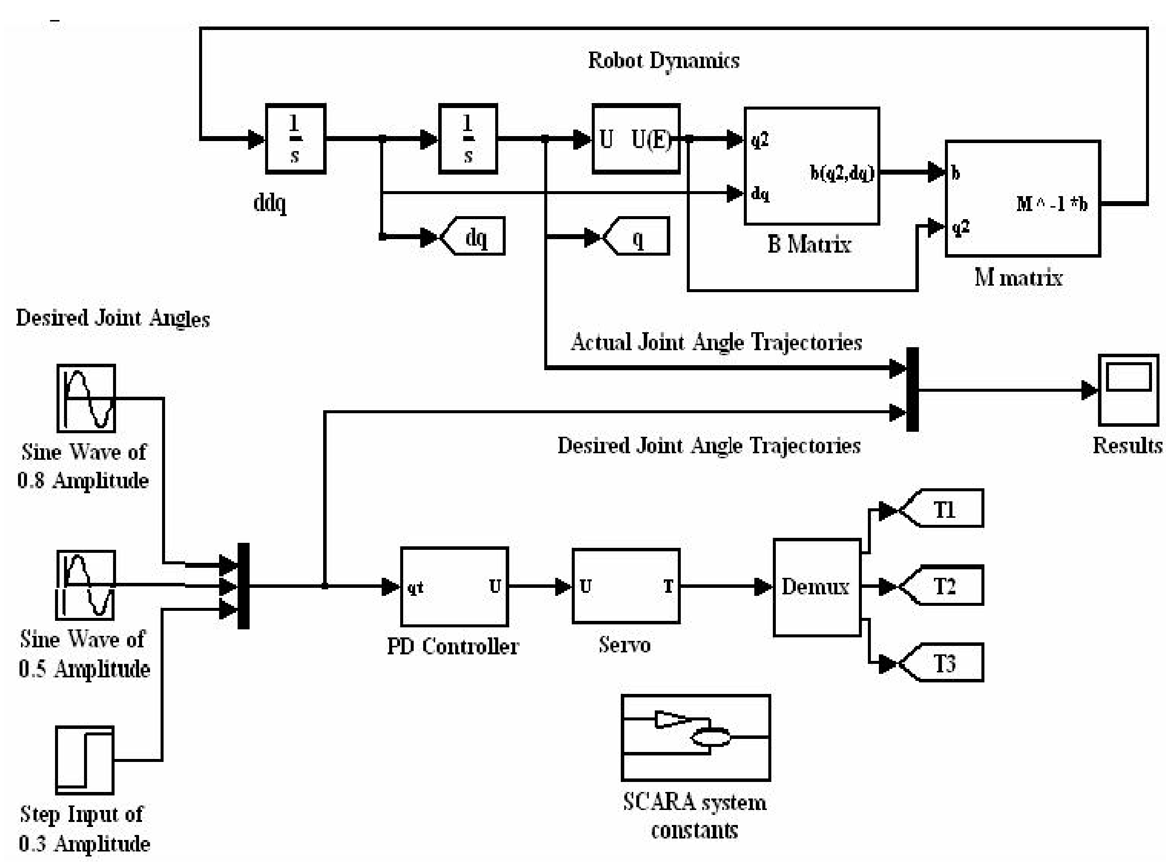


Fig.10. Simulation model of the step/sinusoidal trajectories tracking of three-link SCARA manipulator with PD controller for joint angles (q1 (t) = 0.8sin (t), q2 (t) = 0.5sin (t)) and joint distance (q3 (t) = 0.3m)

4.1 Continuous Path Control & Experimental Results.

The Continuous Path Motion (CPM), sometimes called controlled-path motion, Schilling (1990). Normally SCARA's are used for pick and place applications in many industries. The positioning and controlling of SCARA End effectors and manipulator are more challenging control problem. The upcoming simulation results with tuned control parameters of ANFIS controller, have achieved a very good tracking performance compared to conventional PD controllers. The figure 10 shows the simulation model of a three-link SCARA manipulator with PD controller for the given joint angle trajectories. This SCARA dynamic model is constructed using MATLAB Simulink software. SCARA is initially tuned for PD values as per the dynamics of the system and its environment. The designed model is experimented with desired trajectories (qd (t) = 0.8sin (t), q 2(t) = 0.5sin (t)) and joint distance (q3 (t) = 0.3m) as shown in figure 10. The figure 11 shows good trajectory characteristics at the joint distance, but some tracking error for the sinusoidal trajectories.

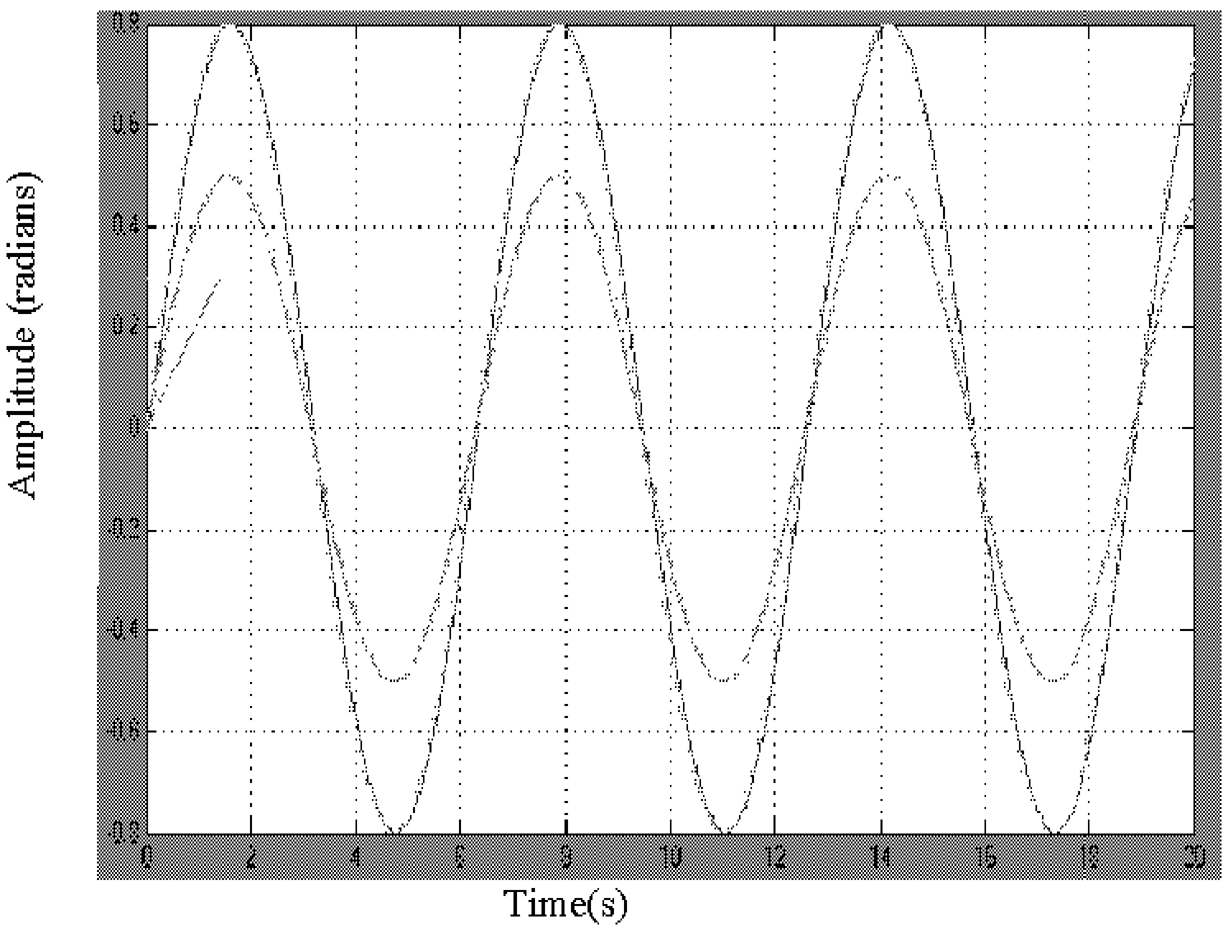


Fig. 11. The step/ sinusoidal trajectories tracking of three-link SCARA manipulator with PD controller for joint angles viz, (q 1 (t) = 0.8sin (t), q 2 (t) = 0.5sin (t)) and joint distance (q3 (t) = 0.3m)

The figure 12 depicts the simulation model of three-link SCARA Manipulator with ANFIS controller for joint angles (q (t) = 0.8sin (t), q 2(t) = 0.5sin (t)) and joint distance (q3 (t) = 0.3m). The ANFIS model for SCARA is designed as per the design discussed in section 4 of this chapter. The trained ANFIS network model is shown in figure 12 is modeled by using

ANFIS tool and Simulink software. From the figure 13 it shows ANFIS controller is able to cope with the uncertainty and model deficiency of the system. The actual trajectories and desired trajectories in ANFIS network almost overlaid each other. Figure 11 and figure 13 together reveal the tracking performance of PD and ANFIS controller. The results are compared with a classical PD controller and with an ANFIS controller Sugeno (1999), to measure how much the adaptive neuron fuzzy approach can improve the performance. Of course, the neuro-fuzzy controller (designed with ANFIS) was better in tracking and adaptability than the other controllers.

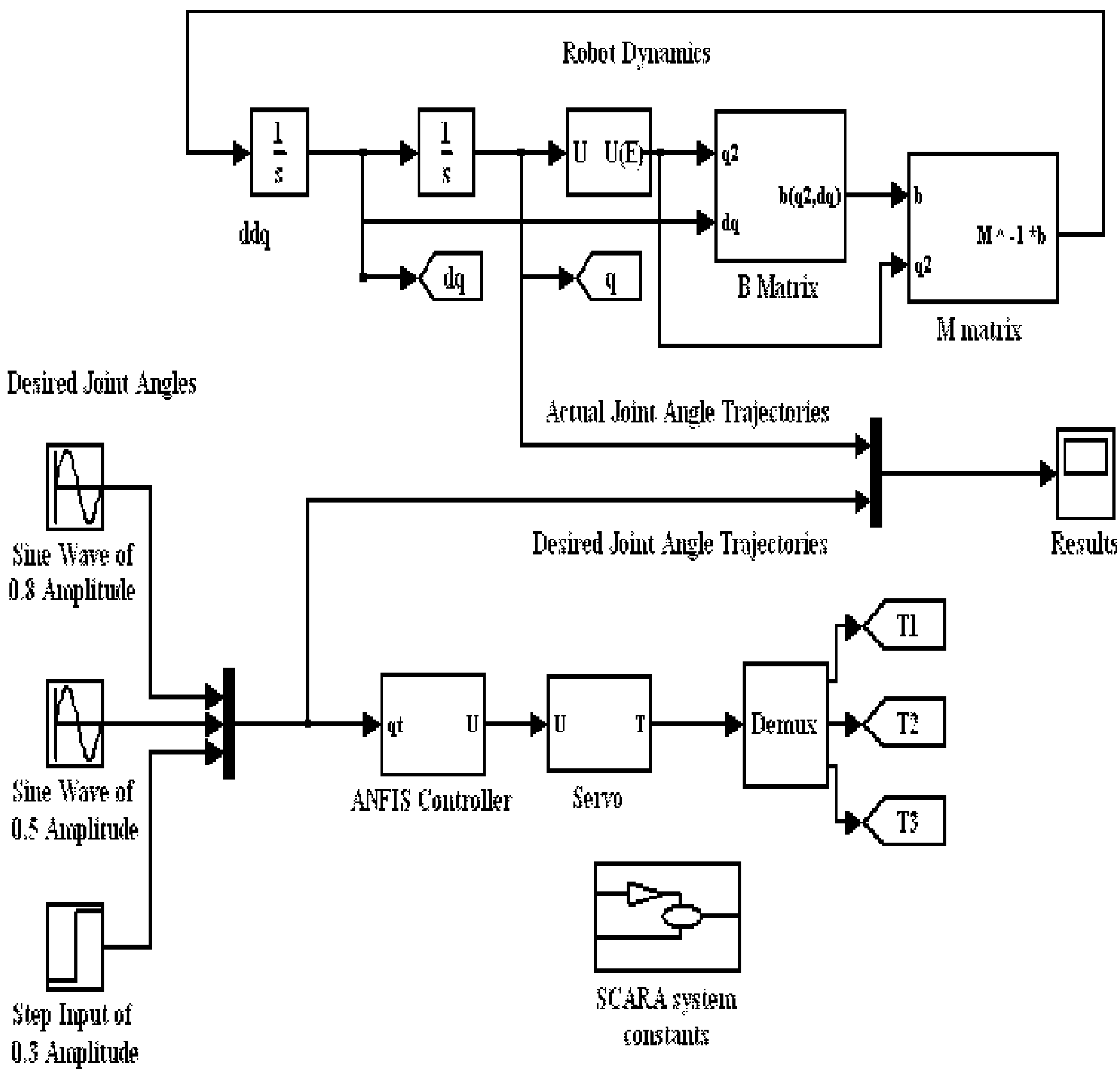


Fig. 12. Simulation model of the step/sinusoidal trajectories tracking of three-link SCARA manipulator with ANFIS Controller (q1 (t) = 0.8sin (t), q 2 (t) = 0.5sin (t)) and joint distance (q3 (t) = 0.3m)

Another advantage of this method over classical quantitative controllers is that, it does not require a fixed sampling time. Therefore, the proposed design confirms the fact that ANFIS control is relevant to the control fast of non-linear processes such as robot manipulator controls where quantitative methods are not always appropriate. From the response shown in figure 13 is very clear that ANFIS controller gives no tracking error,i.e the response of the desired trajectories is almost superimposed with the actual one, Thus the ANFIS controller gave the best results when compare to conventional PD controller. It is very clear from figure 11, the tracking performance of the conventional PD controller is not that appreciable since it is not able cope up with sudden change in the state this leads to some tracking error in its response and also it is not able to follow faithfully as the ANFIS controller does.

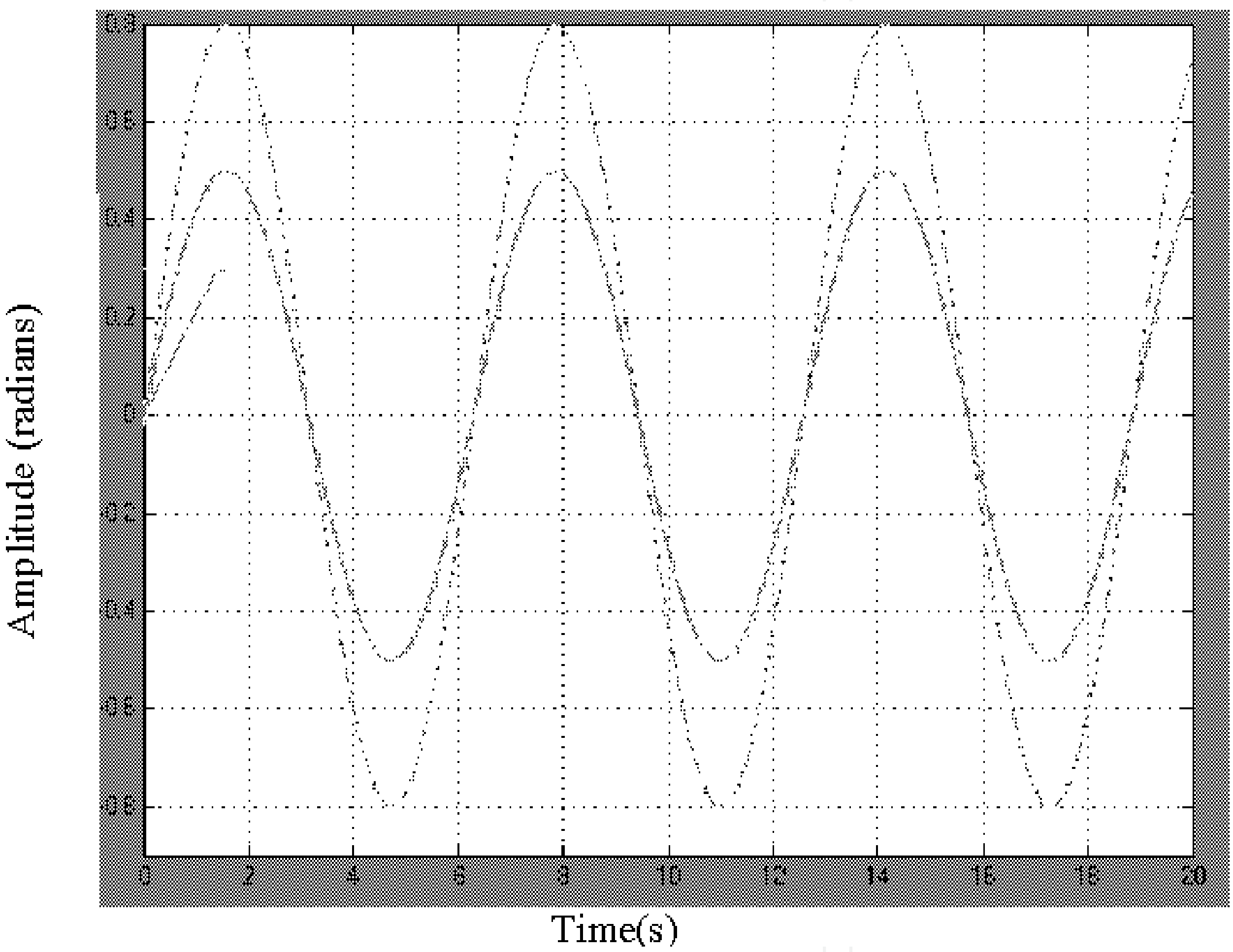


Fig. 13. The step/ sinusoidal trajectories tracking of three-link SCARA manipulator with ANFIS controller for joint angles. With (q1 (t) = 0.8sin (t), q 2 (t) = 0.5sin (t)) and joint distance (q3 (t) = 0.3m).

The figure 13 shows the ANFIS controller response of the SCARA for the given desired joint angle trajectories. It is found that actual trajectories of the SCARA are almost merged with the desired trajectories. From this inference, it is concluded that the ANFIS training is completely satisfied and SCARA tracking error is almost nearly zero.

5. Conclusions

In this chapter, the feasibility of ANFIS control for a three link SCARA manipulator has been proved and illustrated by simulation. The best parameters for the fuzzy controller were determined by using the ANFIS methodology and by using simulations of the SCARA manipulator dynamics. ANFIS take only few number of iteration to complete the training of membership functions. A simulation tool (i.e., Neuro-Fuzzy logic toolbox (ANFIS)) was used to validate experimentally the tracking ability and the insensibility to SCARA System parameter changes. The ANFIS controller presented very interesting tracking features and was able to respond to different dynamic conditions. In addition, the fuzzy control computation is very inexpensive, and this regulator could be used for the control of machine tools and robotics manipulators [11] without significantly increasing the cost of the drive. The proposed design confirms the fact that fuzzy control is relevant to the fast control of non-linear processes such as SCARA manipulator control where quantitative methods are not always appropriate. Thus, the results obtained using the ANFIS controllers are encouraging when compared to conventional PD controller.

6. References

H. R. Berenji and P. Khedkar (1992). Learning and Tuning Fuzzy Logic Controllers through Reinforcements, *IEEE Trans. Neural Networks*, vol.3, no.5, pp.322-320.

Dubowsky. S. and Desforges, D.T (1979). The application of Model Referenced Adaptive control to Robotic Manipulators, *Transactions of ASME, Journal of Dynamic System*. Vol 101, 193-200

Fu, K.S.; Gonzalez, R.C. and Lee, C.S.G., (1987). *Robotics: Control, Sensing, Vision, and Intelligence*. McGraw Hill, New York.

Inoue, H., (1974) Force Feedback in Precise Assembly Tasks, *MIT Artificial Intelligence Laboratory Memo 308*, MIT, Cambridge, Mass.

J. R. Jang (1993). ANFIS: Adaptive-Network-Based Fuzzy Inference System, *IEEE Trans. Syst. Man Cybern.,* vol.23, no.3, pp.665-685.

C. T. Lin and C. S. G. Lee (1996) Neural Fuzzy Systems: *A Neuro-Fuzzy Synergism to Intelligent Systems*, Prentice Hall PTR, 393 Pages.

Paul, R.C (1972). Modellings, trajectory, Cancellation and Servoing of Computer Controlled Arm, *A.I.Memo 177*, Stanford Artificial Intelligence Lab., Stanford University. California.

Rong-Jong Wai (2003). Tracking control based on neural network strategy for robot manipulator, *Elsevier, Journal of Neuro computing*. Vol.51, 425- 445.

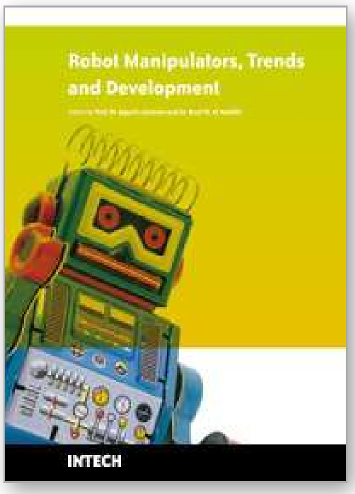
R.J. Schilling (1990). Fundamentals *of Robotics*, Prentice-Hall.

Sciavicco. L. and Siciliano. *B (1996). Modelling and Control of Robot Manipulators*. McGraw-Hill Companies. Inc.

M. Sugeno (1999). On Stability of Fuzzy Systems Expressed by Fuzzy Rules with Singleton Consequents, *IEEE Trans. on Fuzzy Systems*, vol.3, no.2, pp 201-222.

J. S. Wang, C. S. G. Lee, and C. H. Juang (1999). Structure and Learning in Self-Adaptive Neural Fuzzy Inference System, Proc. *of the Eighth Int'l Fuzzy Syst. Association World Conf.*, Taipei, Taiwan, 935-980, August 13-20.

Will. P. and Grossnlan. D (1975). An Experimental System for Computer Controlled Mechanical Assembly. *IEEE Trans. EICYY Devices*, Vol 29, 42-48.



Robot Manipulators Trends and Development

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This book presents the most recent research advances in robot manipulators. It offers a complete survey to the kinematic and dynamic modelling, simulation, computer vision, software engineering, optimization and design of control algorithms applied for robotic systems. It is devoted for a large scale of applications, such as manufacturing, manipulation, medicine and automation. Several control methods are included such as optimal, adaptive, robust, force, fuzzy and neural network control strategies. The trajectory planning is discussed in details for point-to-point and path motions control. The results in obtained in this book are expected to be of great interest for researchers, engineers, scientists and students, in engineering studies and industrial sectors related to robot modelling, design, control, and application. The book also details theoretical, mathematical and practical requirements for mathematicians and control engineers. It surveys recent techniques in modelling, computer simulation and implementation of advanced and intelligent controllers.