Anadolu Üniversitesi Bilim ve Teknoloji Dergisi A- Uygulamalı Bilimler ve Mühendislik
Anadolu University Journal of Science and Technology A- Applied Sciences and Engineering

2017 - Volume: 18 Number: 4
Page: 819-830
DOI: 10.18038/aubtda.340002
Received: 15 March 2017 Revised: 07 August 2017 Accepted: 15 August 2017

TWO DOF ROBOT CONTROL WITH FUZZY BASED NEURAL NETWORKS

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ABSTRACT

In this study, trajectory control of robotic arm which has two degrees of freedom (DOF) is conducted by using the control methods of Proportional-Derivative (PD), Adaptive Neuro Fuzzy System (Anfis), hybrid PD-Anfis and its performance analysis is carried out. In the design of the robot, forward kinematics, inverse kinematics and dynamic equations are used. Firstly, the PD controller is executed, and then the PD controller and Anfis controller are compared applying to a different controller approach with the Anfis of Matlab/Simulink software. The positive and negative sides of the Anfis controller are compared and hybrid PD-Anfis controller method is conducted as a different approach to eliminate the negative sides. While the system constants K_p and K_v are kept constant by the classical PD control method, the output of PD controller is trained with Anfis in the new method and the output value is adjusted according to the error and the change rate of the error. By this way, outputs which have less error rate and which are able to follow the reference better are obtained.

Keywords: Kinematic, Robot dynamics, PD control, Anfis, Neuro-Fuzzy Control

1. INTRODUCTION

Studies based on classical Proportional-Derivative (PD) robot control are now quite extensive in robot industry [1-2]. However, with the development of technology, robot control methods are being developed increasingly. Some of them are frequently used today in Artificial Intelligence (AI) based control methods, Fuzzy Logic (FL) and Artificial Neural Networks (ANN). Unlike classical methods, these methods have the advantages of being able to make decisions like human, to make comparisons, to offer different solution methods [3]. It has been understood that only FL is insufficient for these methods and that the decision-making ability of the time-varying system should be improved by adding ANN to the system in order to continuously change the control variables [4-6]. However, although AI control methods seem to be an advantage of not requiring mathematical modeling, it has been noted that expert knowledge is necessary and that the FL controller has the disadvantage of trying to find the best solution with too many trials [7].

While ANN has a good learning ability, FL gives better results than ANN in decision making. Therefore, using the Adaptive Neuro Fuzzy Interface (Anfis) which is a combination of these two methods, the robot will have the ability to both learn and to make decisions. Furthermore, this control method is easier than other techniques and does not require much experiment, making the method more useful [8]. There are studies in the literature about robot control with Anfis, but the common idea from some of these studies is that the Anfis controller isn't enough for this application [9]. For this reason, a new approach is proposed in this study, using a hybrid switched PD-Anfis controller, a robot design with less error rate and better tracking the reference than the conventional PD controller was designed.

In the first part of this study, information about robot control technique is given. In the second part, Computed Torque Control (CTC) technique, conventional PD controller and Anfis controller are

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explained for two degrees of freedom (DOF) robot arm. In the third part, training of the system is explained. In the fourth part performance analysis and test results are given and in the fifth part, results of the study and conclusion have been given, respectively.

2. CONTROL TECHNIQUES OF TWO DOF ROBOT ARM

There are some control methods used in robot control systems. Classical control and intelligent control methods are the most important in control systems. These control methods are widely used in robot industry. Each control method has advantages and disadvantages. However, the main aim for the system is to provide robustness, stability and fastness. In this study, PD, Anfis and hybrid PD+Anfis control methods are implemented into the robot arm and test results are compared with conventional PD control method.

2.1. Conventional PD Controller

Conventional PD controller is the most popular control method in many robot implementations because of its steady state and transient response performance in time-invariant systems. Conventional PD control parameters, K_p and K_v are always constant during the process. Therefore, such a controller is inefficient because of the controller contains ambiguity when environmental conditions or dynamics change. In addition, it is inefficient because of time delays and nonlinearity conditions. The structure of a two DOF robot arm is given in Figure 1. In this study, L_1, L_2 are the link lengths, θ_1 and θ_2 represent the angles of rotation of the links relative to the previous link. Length of the both links was chosen 0, 9 meters and the mass of each link was chosen 0, 5 kg which is located at the center of the link.

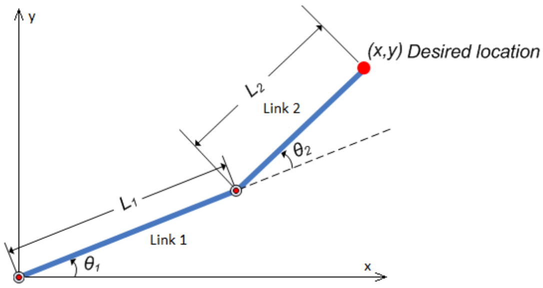


Figure 1. The model of two DOF robot arm.

The dynamic model of a robo t arm is given as follows;

$$\tau = M(q)\ddot{q} + C(q,\dot{q}) + G(q) + F(\dot{q}) \quad (1)$$

In this equation, where τ, $M(q)$, $C(q,\dot{q})$, $G(q)$, $F(\dot{q})$ and n are expresses nx1 dimensional joint torque, nxn dimensional inertia matrix, nx1 dimensional coriolis and centrifugal vector, nx1 dimensional gravity vector, nx1 dimensional friction force vector and the degree of freedom of the robot, respectively. The errors of the robot link variables are;

$$e = q_d - q \quad (2)$$

$$\dot{e} = \dot{q}_d - \dot{q} \quad (3)$$

$$\ddot{e} = \ddot{q}_d - \ddot{q} \quad (4)$$

Where e, $\dot{e}$, $\ddot{e}$ expresses the position, velocity and acceleration error vectors and q_d, $\dot{q}_d$, $\ddot{q}_d$ expresses the desired position, velocity and acceleration of the link variables. The torques required for each joint of the robot arm is calculated from Eq. (1) and the errors from Eq. (2), (3) and (4). Inertia acceleration is obtained as the result of correcting the inverse kinematic of the robot by the controller. The torques applied to each arm is given as input to the calculated torque system, which is set by this control signal. First of all, u is found to improve tracking error using linear system design techniques and then the required joint torques are calculated. This situation is expressed as follows;

$$\tau = M(q)(\ddot{q}_d - u) + N(q,\dot{q}) \tag{5}$$

This is a nonlinear control rule that guarantees tracking of the desired trajectory. The control signal that is obtained from Eq. (5) is expressed as follows.

$$u = \ddot{q}_d + M^{-1}(q)(N(q,\dot{q}) - \tau) \tag{6}$$

If the u signal is selected as the PD feedback controller, the torque value of each joint will be obtained from Eq. (7) and (8).

$$u = -K_v\dot{e} - K_p e \tag{7}$$
$$\tau = M(q)(\ddot{q}_d + K_v\dot{e} + K_p e) + N(q,\dot{q}) \tag{8}$$

The PD control of the two DOF robot arm is shown in Figure 2. As can be seen, the position and velocity information is compared with the desired position and velocity then error feedback is obtained.

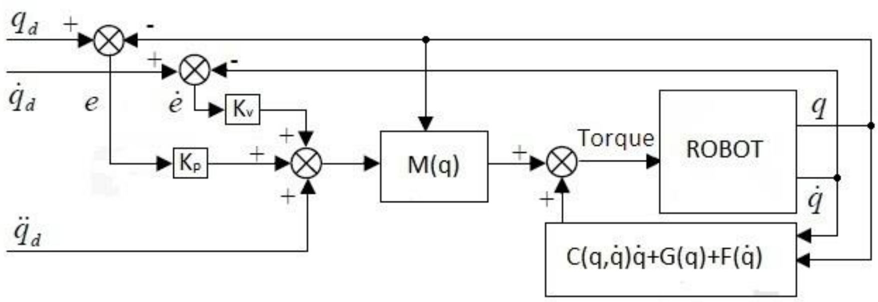


Figure 2. PD control block diagram of the robot arm

2.2. Anfis Controller

All AI techniques have its own abilities such as FL, ANN, genetic algorithms (GA) and expert systems. For example, while ANN is good at learning and describing examples, it is not good at how decisions are made. FL gives very good results in decision making, but it cannot generate the rule automatically in the decision-making process.

Anfis approach is based on the idea of combining ANN's learning ability, finding the most appropriate rules and FL's decision-making like human. In this way, while ANN systems can be given the power to learn and calculate, FL can be given the ability to make decisions like human for the Anfis system. The architecture of the Anfis model proposed is shown in Figure 3.

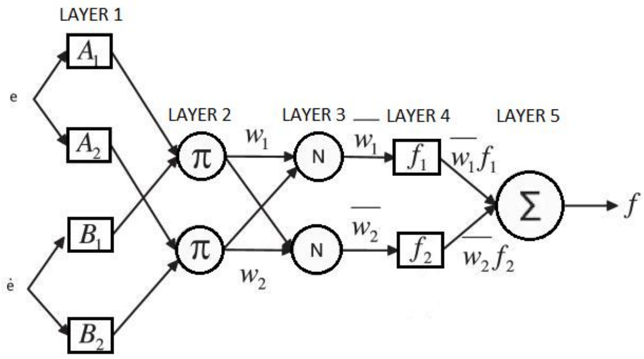


Figure 3. The architecture model of Anfis.

Layer 1: For each joint of the robot, each node corresponds to an input, with the e position error and the $\dot{e}$ position error change. The data received from this layer is transferred to the second layer without any processing or modification.

Layer 2: The layered representation of membership functions in the fuzzy control. Each node in this layer represents a fuzzy cluster and each is expressed by a Gaussian function.

$$t_{ij} = -\frac{(x_{ij}-m_{ij})^2}{(\delta_{ij})^2}, y_{ij} = f_{ij}(t_{ij}) = exp(t_{ij}) \tag{9}$$

Layer 3: Each node in this layer represents a rule and min operator is applied to the inputs of the nodes.

$$t_{ij} = min(x_j, y_k), y_{jk} = f_{jk}(t_{jk}) = t_{jk} \tag{10}$$

Layer 4: Defuzzification method is applied in this layer. A rule which is given at each node is weighted and calculated.

$$a = \sum_{\substack{j=1 \\ k=1}}^{5} w_{jk} y_{jk}, b = \sum_{\substack{j=1 \\ k=1}}^{5} y_{jk}, t_0 = \frac{a}{b}, y_0 = f_0(t_0) = \frac{a}{b} \tag{11}$$

Layer 5: The output value of each node in the fourth layer is summed and results in the real value of the ANFIS system.

Anfis controller adjusts the K_p and K_v parameters of a PD controller using fuzzy adjuster. Coefficients of the conventional PD controller are not suitable for time-varying and nonlinear system because of adjustment trouble. Therefore, it is necessary to adjust the PD parameters automatically. Despite the conventional PD controller, Anfis controller is robust against dynamic changes in the system and does not need to know the whole system model. Therefore, Anfis controller shows the better performance than the conventional PD controller if the system is complex and undefined. The control block diagram in Figure 4 is obtained when the same system is controlled by the Anfis. 2 input and 1 output data obtained from the classical PD controller are used to obtain the Anfis controller.

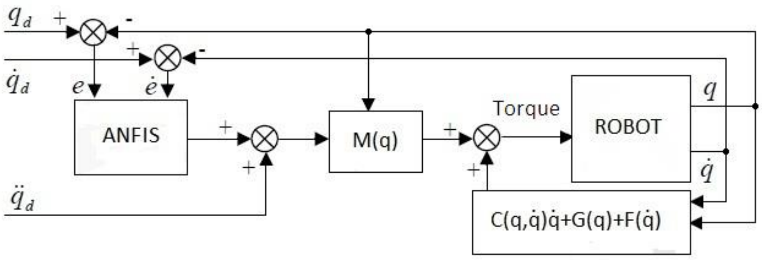


Figure 4. Anfis control block diagram of the robot arm.

Many hybrid switched PD+Anfis control structures have been proposed in the literature [10-14]. The proposed hybrid switched PD+Anfis structure used in this study is shown in Figure 5. In this structure, if the position error (*e*) bigger than the amount of change in position error (*de*), the output will behave like an Anfis controller or vice versa.

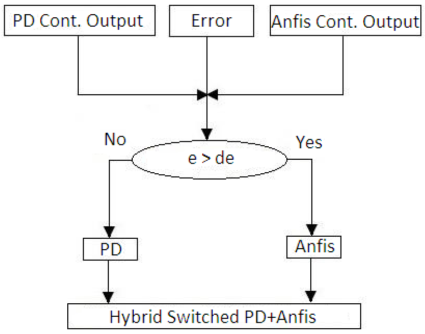


Figure 5. The control block diagram of hybrid switched PD+Anfis controller.

3. TRAINING OF THE SYSTEM

3.1. Determination of the Workspace

When the workspace of two DOF robots is determined, the working angle of the first joint is chosen between 0-90 degrees and the working angle of the second joint is chosen between 0-180 degrees. Figure 6 shows the workspace of the two DOF robot arm. The given limits are the joint angles that the robot arm can reach maximum point, and joints can overlap if more movement is desired.

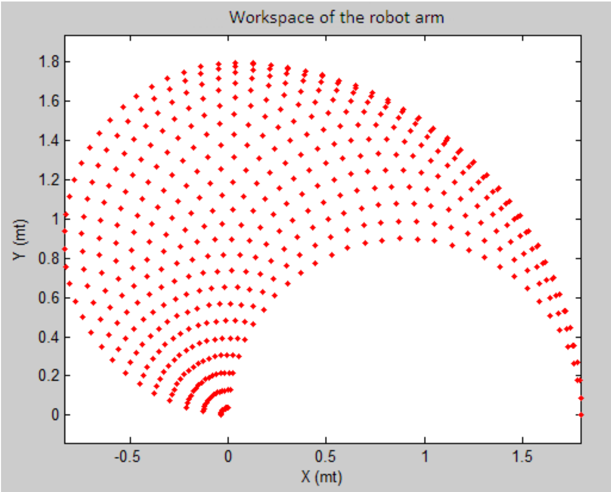


Figure 6. The workspace of two DOF robot arm.

3.2. Training of the System

In this section, the robot is controlled by the PD controller. When the PD controller results are analyzed, the response time of the system is observed to be slow. Then the data at the PD controller output was trained and the Anfis controller was obtained. In the following sections, the training data obtained from the PD controller will be explained.

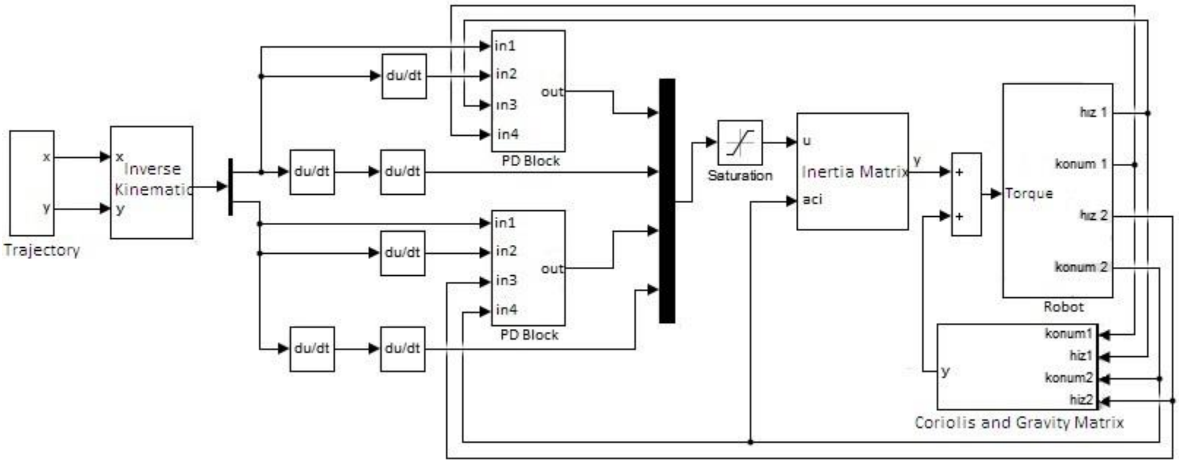


Figure7. The PD control block diagram of two DOF robot arm.

Figure 7 shows the general scheme of controlling a two DOF robot arm with a PD controller and Figure 8 shows the inner structure of PD blocks. The PD coefficients of the system were selected by experimental methods and the best values were tried to be obtained. As can be seen from Figure 8, the robot arm was first run with the PD controller and the data obtained from this controller was used as training data for the Anfis.

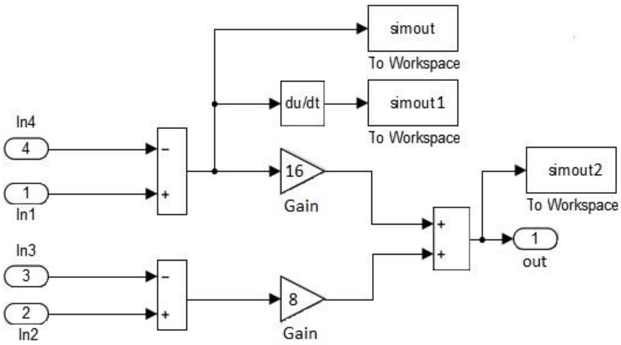


Figure 8. The inner structure of PD controller.

There are two inputs for each parameter in Anfis controller. "*e*" is the error between the desired positions with the output and "*de*" is the amount of the change in the position error, in other words derivative of the error. The PD parameters are adjusted using the fuzzy controller to give nonlinear output according to the changes of error and derivative of error. nx3 dimensional matrix was created in the Matlab workspace as [error; derivative error; output] for the training. The training of the obtained data in the Anfis editor is shown in Figure 9 (a).

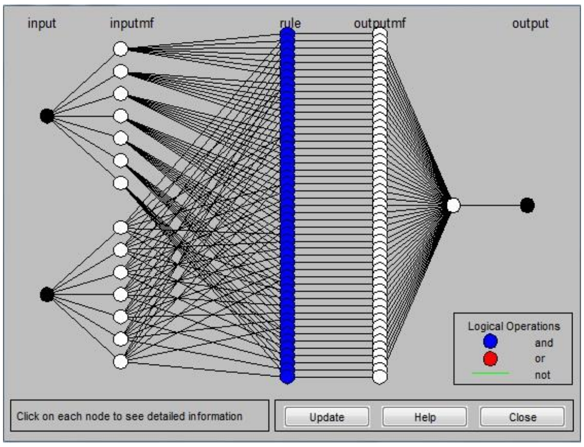


Figure 9. (a) Training of data received from PD controller with Anfis, (b) 5 layered general structure of Anfis.

In this editor, how many membership functions this structure will have, and the type of membership functions must be specified by the expert. The main structure of the created system is given in Fig 9 (b). There are 7x7=49 rule tables in 5 layers and it has 2 inputs (position error and derivative of position error), 1 output and 7 memberships function in Anfis controller. Figure 10 shows the surface view of the data obtained after training.

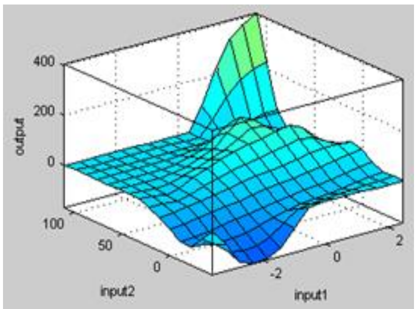


Figure 10. Surface of the trained data.

It can be seen from the Figure 10 that the output signal increases when the position error and the derivative of error increase. The changes of error, derivative error and outputs are presented by linguistic expressions as Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Medium (PM), Positive Big (PB). Because of the coefficients of the conventional PD controller are not often properly tuned for the nonlinear and time-varying system, parameters are tuned by using Anfis controller, which provide a nonlinear changing. In the next part, it will be discussed the impact of this parameter changes on the system.

4. PERFORMANCE ANALYSIS AND TEST RESULTS

The efficiency of the suggested control method is analyzed by quantitative and comparative assessment tests. The control of the system for different conditions of operation is executed using Matlab Anfis editor.

4.1. Movement in A Switched Trajectory

Two points within the workspace are defined for the two DOF robot arm. When the robot is in the start position (1.8, 0), moves to the first point (0.3, 1.4), then moves to the second point (1, 1) after 3 seconds and the joints are required to follow this trajectory. It has been determined for the robot tracking the trajectory fastest and least error of each joint as a performance criterion.

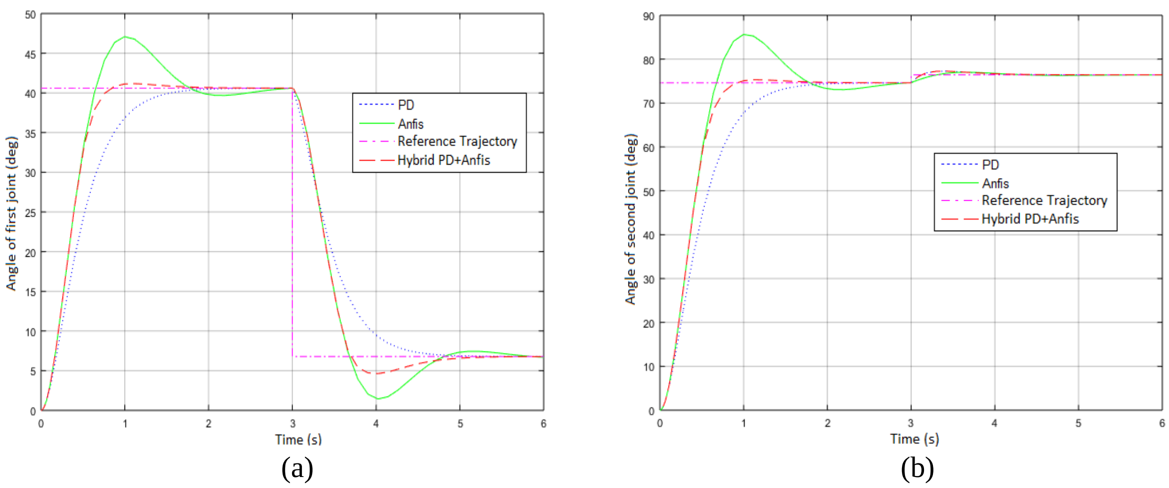
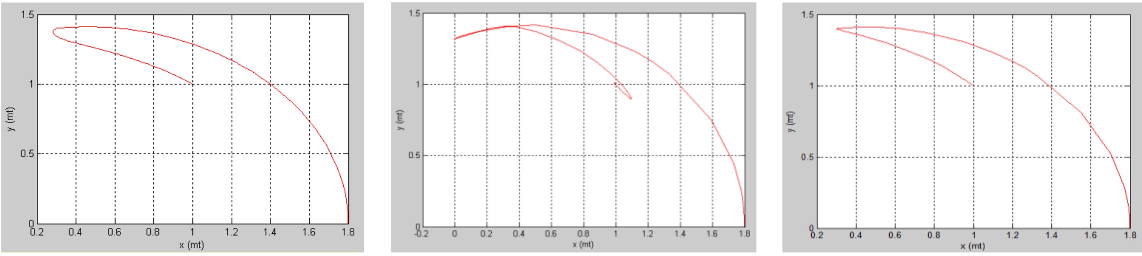


Figure 11. (a) The angle value of the first joint for a switched trajectory, (b) The angle value of the second joint for a switched trajectory.

It can be seen from the Figure11 (a) and (b), the PD controller responds slower than the other methods. The Anfis controller is oscillating despite reaching the reference in a very short time. Also settlement time for the Anfis controller was longer than PD controller. Hence, it is necessary to automatic adjust the parameters of PD control K_p and K_v online with hybrid switched PD+Anfis controller. Although PD+Anfis control method is a combination of these two control methods, it can be seen from the Figure 11 (a) and (b) it reaches reference trajectory in a very short time and then reduces the steady state error like a PD controller.



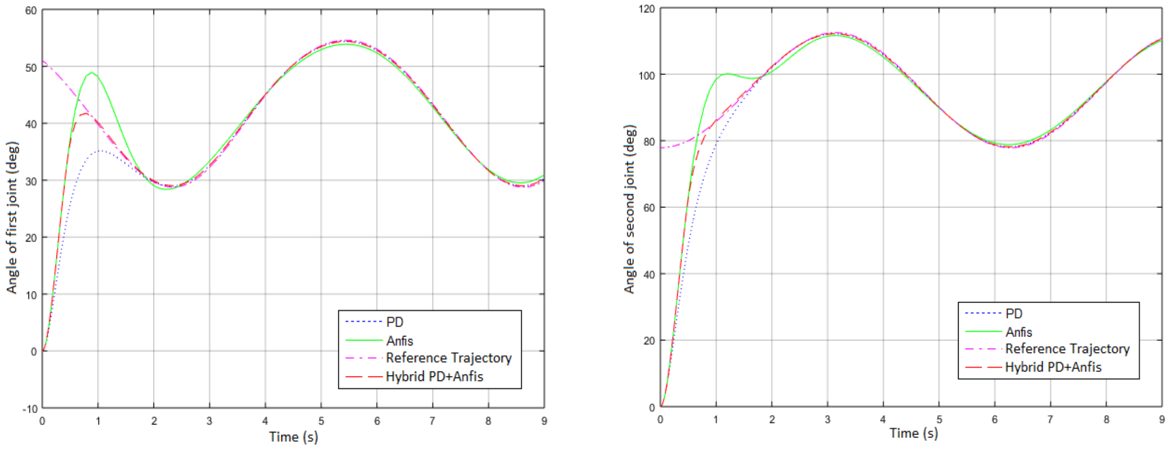
(a) (b) (c)

Figure 12. Robot's end point in x-y coordinates for the switched trajectory: (a) PD controller, (b) Anfis controller, (c) Hybrid Switched PD+Anfis controller.

Figure 12 shows the results of robot's end point with PD, Anfis and Hybrid PD+Anfis controller, respectively. While the trajectory was taken widely in Figure 12 (a), Figure 12 (b) and (c) were taken sharply. For this reason Figure 12 (c) faster than the other methods. Also it can be seen from the Fig 12 (b) there is an overflow. The most suitable trajectory control for the robot is implemented by the hybrid switched PD+Anfis controller.

4.2. Movement in A Circular Trajectory

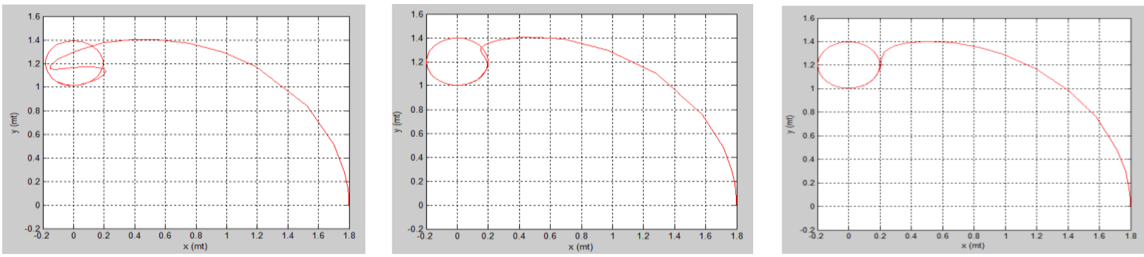
For the two DOF robot arm a circular trajectory with a diameter of 0.2 meters and a center of (0, 1.2) meters is defined within the workspace and joints are required to follow this trajectory. As a result, it can be seen from the Figure13 (a) and (b), the PD controller responds slower than the other methods.



(a) (b)

Figure 13. (a) Angle value of the first joint in a circular trajectory, (b) Angle value of the first joint in a circular trajectory.

The Anfis controller is oscillating despite reaching the reference in a very short time. Also settlement time for the Anfis controller was longer than PD controller. Hence, it is necessary to automatic adjust the parameters of PD control K_p and K_v online by hybrid switched PD+Anfis controller. Although PD+Anfis control method is a combination of these two control methods, it can be seen from the Figure 13 (a) and (b) it reaches reference trajectory in a very short time and then reduces the steady state error like a PD controller.



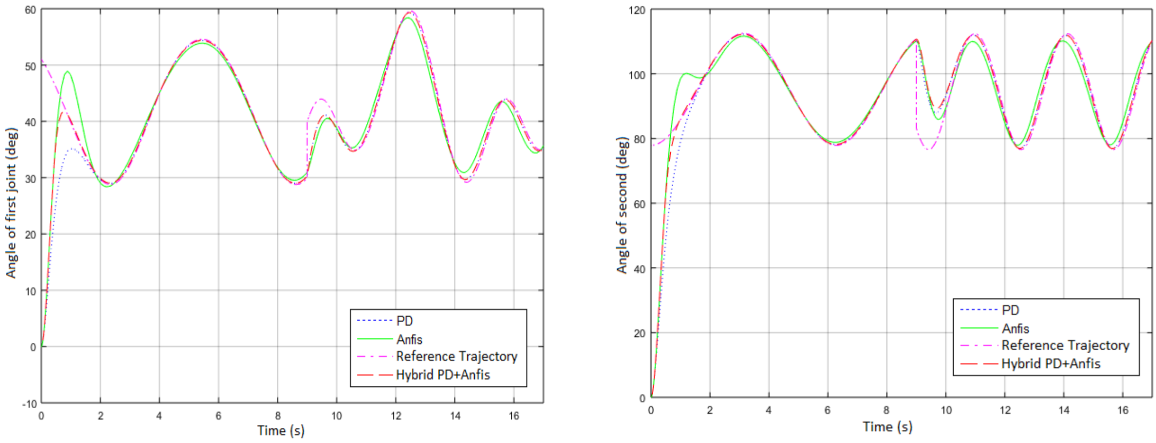
(a) (b) (c)

Figure 14. Robot's end point in x-y coordinates for the circular trajectory: (a) PD controller, (b) Anfis controller, (c) Hybrid PD+Anfis controller.

Figure 14 shows the results of the robot's end point with PD, Anfis and Hybrid PD+Anfis controller, respectively. While the trajectory was taken widely in Figure 14 (a), Figure 14 (b) and (c) were taken sharply. For this reason Figure 14 (c) faster than the other methods and most suitable trajectory control for the robot is implemented by the hybrid switched PD+Anfis controller.

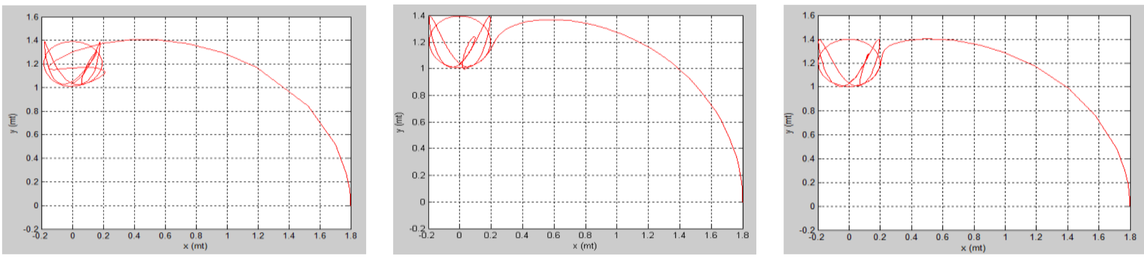
4.3. Movement in A Hybrid Trajectory

Circular trajectory for a two DOF robot arm with a diameter of 0. 2 meters and a center of (0, 1.2) meters was created then a hybrid trajectory defined in the workspace and joints are required to follow this trajectory. It can be seen from the Figure15 (a) and (b), the PD controller responds slower than the other methods. The Anfis controller is oscillating despite reaching the reference in a very short time. Also settlement time for the Anfis controller was longer than PD controller. Hence, it is necessary to automatic adjust the parameters of PD control K_p and K_v online with hybrid switched PD+Anfis controller. Although PD+Anfis control method is a combination of these two control methods, it can be seen from the Figure 15 (a) and (b) it reaches reference trajectory in a very short time and then reduces the steady state error like a PD controller.



(a) (b)

Figure 15. (a) The angle of the first joint in a hybrid trajectory, (b) The angle of the second joint in a hybrid trajectory.



(a) (b) (c)

Figure 16. Robot's end point in x-y coordinates for the hybrid trajectory: (a) PD controller, (b) Anfis controller, (c) Hybrid PD+Anfis controller.

Figure 16 shows the results of the robot's end point with PD, Anfis and Hybrid PD+Anfis controller, respectively. While the trajectory was taken widely in Figure 16 (a), Figure 16 (b) and (c) were taken sharply. For this reason Figure 16 (c) faster than the other methods and most suitable trajectory control for the robot is implemented by the hybrid switched PD+Anfis controller.

5. CONCLUSION

In this study, AI control methods, design and control of the two DOF robot arm was carried out. The study was carried out on three main controllers, PD, Anfis and hybrid switched PD-Anfis controller. There are positive and negative sides of PD controller. The studies show that although the PD controller responds slower, steady state error of the controller is very small than Anfis controller. When the system is tested with the Anfis, it is observed that the Anfis controller is oscillating despite reaching the reference in a very short time. Also settlement time for the Anfis controller was longer than PD controller. To eliminate this problems, a hybrid switched PD-Anfis controller which is a combination of PD and Anfis controllers, was designed and applied to the system. The results show that the hybrid switched PD-Anfis controller significantly reduces the time to reach the reference and keeps the steady state error at very low values. In addition, this study shows that the hybrid switch PD-Anfis controller can be designed with less complicated control structures that can exhibit very good trajectory tracking performance by combining it with PD and AI controllers, which are frequently preferred in robotic control in the literature.

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