

# ANFIS-PID Controller for Arm Rehabilitation Device

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**Abstract—** In this paper, the arm rehabilitation device controller based on fuzzy logic techniques is presented. Patients who has post-stroke may lose control of their upper limb. If they are treated with functional rehabilitation training, the patients can rehabilitate their motion functions and working abilities. These rehabilitation devices are used to recover the movement of arm after stroke. Many controllers had been used for the rehabilitation device and one of them is ANFIS-PID controller where Adaptive Neuro-Fuzzy Inference System (ANFIS) technique is the combination of fuzzy logic and neural network system. The objectives of this project are to develop arm rehabilitation device controller based on the ANFIS-PID technique. The development of ANFIS is purposely as an inverse model to the system and proportional-integral-derivative (PID) controller as a feedback control. EMG model is integrated to the control system as reference where Artificial Neural Network (ANN) is used to model the EMG to position relationship. Simulation is conducted using MATLAB to validate the system performance that is integrated with EMG model. Then the performance is compared between ANFIS-PID controller and PID alone controller. ANFIS-PID controller reduced more tracking error compared to PID controller and demonstrates better results when disturbance is applied to the control system.

**Keywords—** EMG, ANFIS-PID, Rehabilitation, Artificial Neural Network, Disabilities

## I. INTRODUCTION

Stroke is the third largest cause of death in Malaysia [1]. Ever year estimated about 40,000 people in Malaysia suffer from stroke and it is examined to be the single typical cause of severe disability. It also mentions that “Current robots tend to exercise only the proximal arm, and then improve motor skills at the shoulder and elbow but not those of wrist and hand; consequently, robots that only train the shoulder and elbow are limited in their ability to improve completion of Activities of Daily Living (ADL)[2]”. Besides, various control techniques have been proposed and researched to solve the motion control problems, but the neural network and fuzzy logic are most reported design that relies on control techniques[3].Artificial neural network and fuzzy logic is used by the researchers to control many types of human movements such as walking, cycling, free swing legs, swimming and some others movement. To compare with conventional, these techniques are a bit different and have unique abilities in identifying the relationship of mathematical in a complex system and operating of nonlinear system [4]. Furthermore, for the fuzzy modeling method, the neuro-adaptive learning technique gives a procedure to get information about the data set and hence the fuzzy logic able to evaluate the membership function parameters that enable the associated fuzzy inference system to follow the input and output data given [5]. ANFIS control algorithm is better performance due to its robustness in nonlinear systems [5]. ANFIS also generate intelligent self-learning by combining the fuzzy logic with the neural networks which led to many applications in the past time. Established on Sugeno type of inference system ANFIS has special architecture which able the use of hybrid learning algorithm [6]. This present paper purposes to develop an adaptive controller that gives a good performance compared to PID controller even when integrated with EMG model via simulation.

## II. RELATED WORK

In paper [7], fuzzy logic incorporating with the hybrid controller was developed to restriction the motion in the desired direction and to maintain a constant force along the moving direction. The planned movements of circular or linear trajectories were considered. The controller was stable in the implementation range of forces and movements. To quantitatively assess the progress of rehabilitation, offline analyses of data were used. The upper limb of subjects can be conducted by the robot in linear and circular movements under predefined external force levels and a desired force is applied along the tangential direction of the movements [11].

On the other hand, [12] in a new control architecture which is development of high-level controller design is presented that work in combination with the low-level controllers where it can dynamically determine the task

updates based on patient's performance. The safety related events is monitored in an automated manner and generate an accommodating plan of action such as, MIT Manus uses impedance controller while MIME uses PID controller for movement assistance. However, each low-controller and high-controller may require different types of inputs and outputs so they cannot communicate directly [12].

Meanwhile, for the fuzzy logic controller used in stability analysis where the main advantages of this technique seem to be the possibility of applying "rule of the thumb" experience and it does not need a model of the process. Whereas, the disadvantages of this method seem to be lack of appropriate tools for analysis of the controller performance such as stability, optimality, etc [13].

On the other hand, many control application is extensively used such as PID controller because of its potency and implicitly. PID controller has been used a long time in the field of engineering and commonly the three controller gain parameter is fixed. But the PID controller limitation is it is terrible in dealing with system uncertainty which is parameter variations and external disturbance [15].

Based on paper [4], the composed method is used which is the evolved ANFIS works as an inverse model to the system and PID controller at the feedback of the system. The ANFIS-PID is designated to control knee joint during sit to stand movement to quadriceps muscles through electrical stimuli. Referred to the simulation results, the ANFIS-PID successes improving sit to stand execution compared to the PID controllers. The results of this study give better performance compared to the other studies which use Fuzzy Logic or Neural Network intelligent techniques concerning to minimizing errors during tracking desired motion. In conclusion of this study, ANFIS-PID controller indicates a slightly better performance rather than the ANFIS alone controller and PID controller.

### III. METHODS

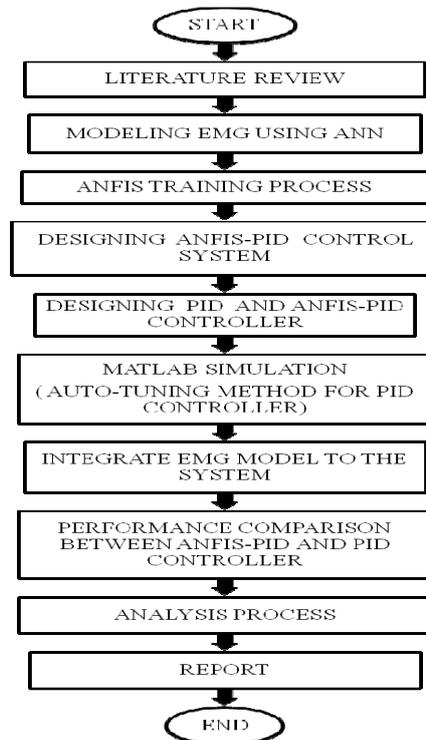


Fig.1. Flowchart of the project

Fig. 1 show the process of this research works where the ANFIS-PID and PID controller is designed and the performance of the controller is compared between each other.

#### A. Modeling EMG-Position using ANN

ANN is designed for a given exertion that required the number of hidden units and numbers of units in input and output layers. In the Neural Fitting tool where the data for the inputs and targets data is selected based on the fitting problems. A Lavenberg-Marquardt training back propagation algorithm is used for this project to model the EMG. Then the number of hidden neuron is adjusted until the training process minimized the error and network performance gives a good result [18]. The network performance is referred on Mean Squared Error (MSE), Regression (R) and the characteristics of the training and validation performance as well.

*B. Block Diagram of ANFIS-PID Control System*

ANFIS-PID controller is designated that incorporate with two elements; ANFIS controller and PID controller with a fixed parameter. The plant indicates the arm position model. The ANFIS inputs and outputs are trained successfully to imitate the inverse dynamics of the plant [4]. The ANFIS controller provides some Fuzzy rules and memberships functions with inverse input and output [16]. Moreover, a PID feedback controller is combined in parallel to the ANFIS control system to compensate for the residual tracking errors that caused by the disturbances and modeling errors [17]. The configuration of the block diagram of ANFIS-PID control system is as shown in Fig. 2.

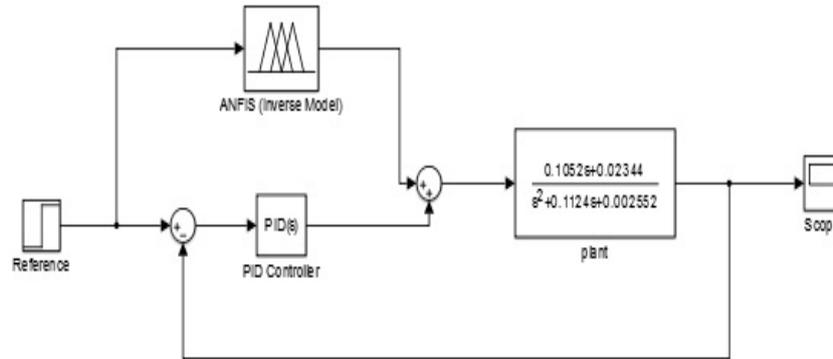


Fig. 2. Configuration of the block diagram of ANFIS-PID control system

**IV. RESULT AND DISCUSSION**

*A. Modeling EMG-Position using ANN*

To achieve the satisfactory results, the network performance is optimized for several times and Lavemberg-Marquadt algorithm is used to train the network where Mean Squared Error (MSE) and Regression (R) are measured to see the performance of the network[19].

Based on Figure 3, the best validation performance of the network is 0.15242 at epoch 487. As the validation set error and test set error shown a similar behavior, it is an acceptable result. Along the epoch during the training, the MSE decrease quickly as shown in the Fig. 3.

From Fig. 4, it shown that the regression for the training, test and validation produces quite well curve fitness where all the regressions value is near to 1.000 and give an optimal value for the model.

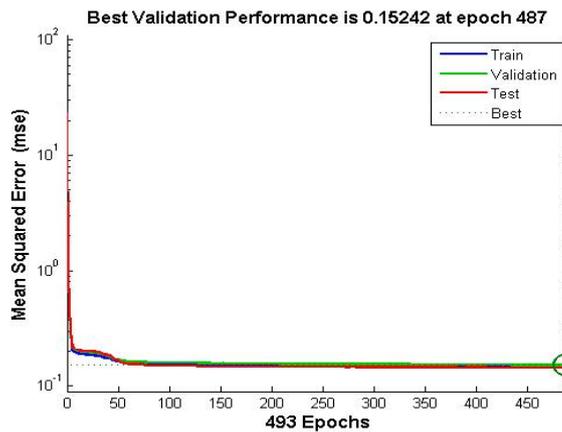


Fig. 3. Validation Performance

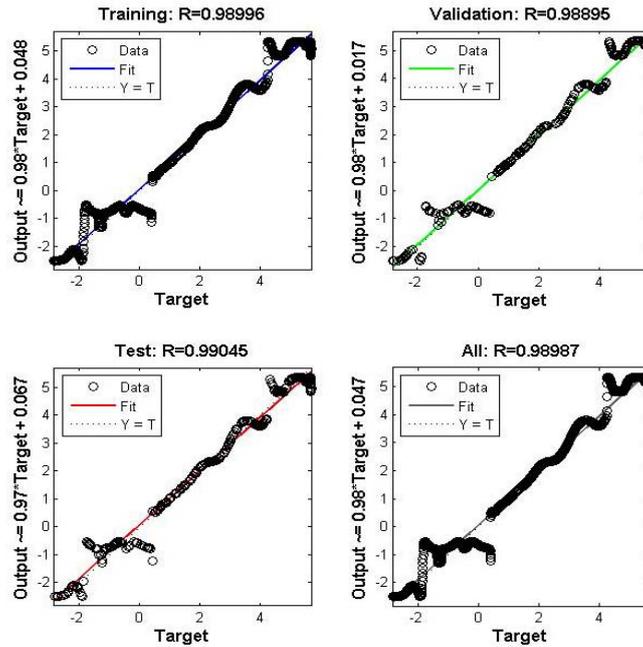


Fig. 4. Regression Test

This neural network model can represent the relationship between the EMG signal and arm position as it produces a good performance result as shown in Fig. 5. This model can be use for motor position reference of the arm rehabilitation devices.

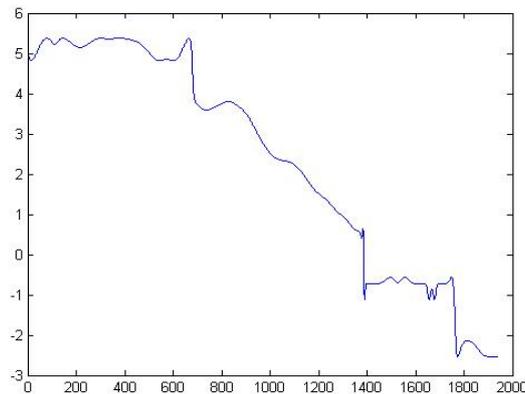


Fig. 5. The output of the neural network model

**B. Designing ANFIS-PID Controller**

From Fig. 6, it shows the block diagram of the control system. It consists of two controllers which are ANFIS controller and fixed parameter proportional-integral-derivative (PID) controller and thus designates the ANFIS-PID controller [20]. By using the step input set point, ANFIS could calculate the required stimulus activation of the plant after it trained to mimic the inverse dynamics of the plant successfully. PID feedback controller is applied in parallel to the ANFIS controller to make up for the residual tracking errors that caused by the modeling errors and disturbances. Two different control system configurations is used which are ANFIS-PID controller and PID controller, their control performances is compare then.

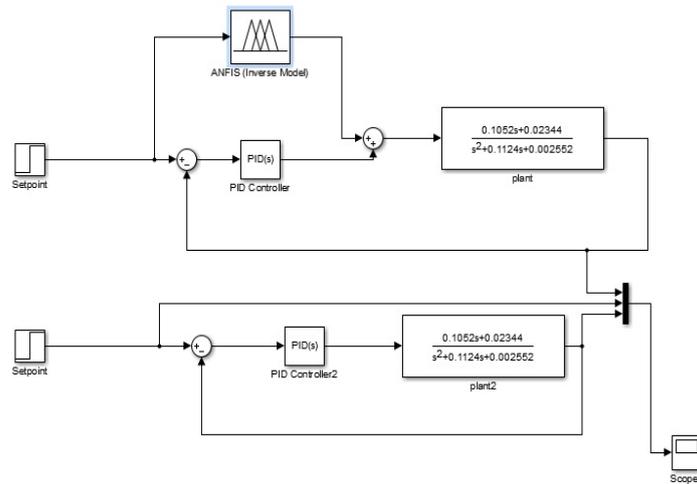


Fig. 6. Configuration of ANFIS-PID and PID control system

The PID controller in the control system is tuned using Auto-tuning method in Matlab where the controller parameters are as shown in Table I while the curve response for the PID controller is shown in Fig. 7. Table II shows the performance of the PID controller.

TABLE I. Controller Parameters

Proportional (P)	0.878302512706282
Integral (I)	0.100881436931177
Derivative (D)	-2.68374281601281

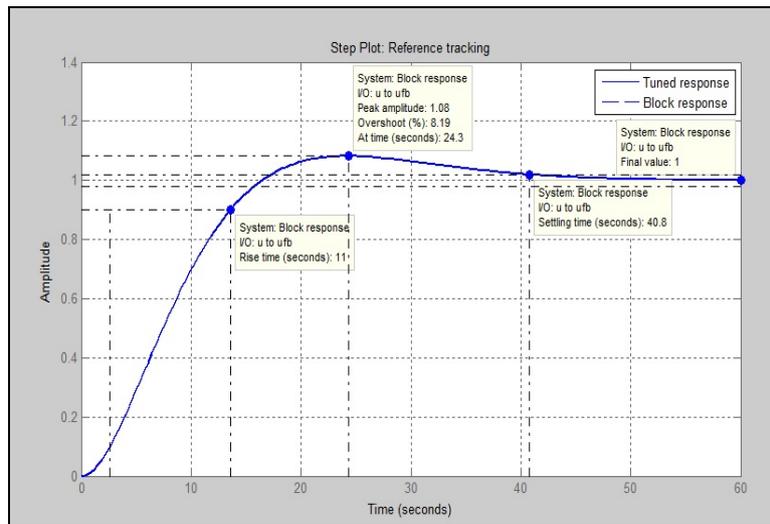


Fig. 7. Step Response for the PID controller

TABLE II. Characteristics of curve response

Rise time (sec)	11
Overshoot (%)	8.19
Settling time (sec)	40.8

Based on Fig. 8, it shows that the performance of ANFIS-PID controller obviously slightly better than PID alone controller. While, the performance of PID alone controller is a bit slower than ANFIS-PID controller because the position trajectory traced the desired set point poorly. This is because, after combining the ANFIS controller with the PID controller to compensate the residual tracking errors, which is caused by disturbance and modeling error it specify that the ANFIS-PID controller improved the response of position tracking.

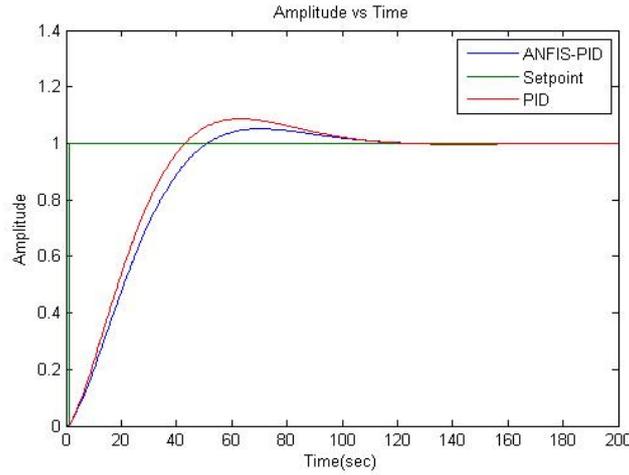


Fig. 8. The simulation results of position control by ANFIS-PID and PID controller

C. Integrate EMG Model with Control System

The EMG is modeled using ANN, and then it is applied into the control system to replace the step input and compare which controller gives the better performance. Fig. 9 illustrates the block diagram of the control system configuration while Fig. 10 is the output response. The performance comparison is tabulated in Table III.

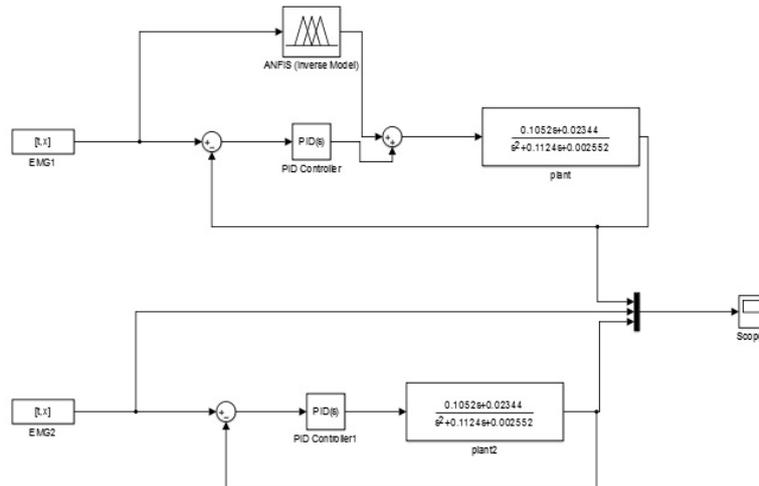


Fig. 9. Block diagram with integrated EMG model

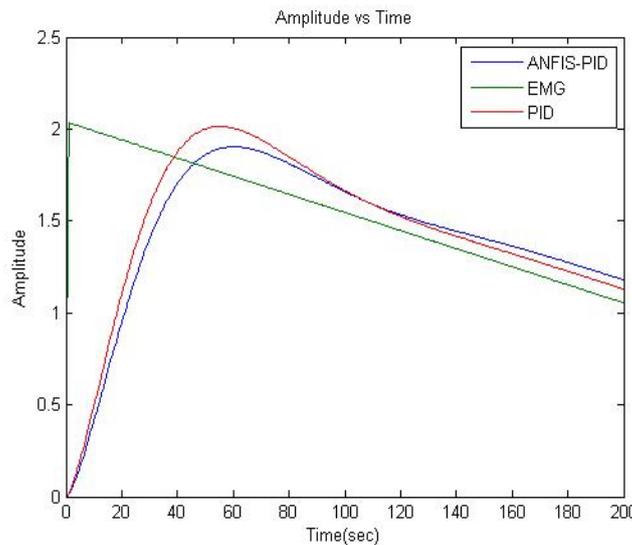


Fig. 10. The simulation results of integrated EMG model by ANFIS-PID and PID controller

TABLE III. Performance of ANFIS-PID and PID controller

Specifications	ANFIS-PID Controller	PID controller
Rise Time (sec)	32.6686	26.4167
Settling Time(sec)	383.8041	384.1554
Overshoot (%)	61.4388	78.3966

Based on the performance of ANFIS-PID controller and PID controller in Table III indicates that the rise time of PID controller is faster than ANFIS-PID controller which is 26.4167s. Whereas ANFIS-PID controller is slightly better than PID controller for the settling time and overshoot percentage. The settling time for ANFIS-PID controller is 383.8041s while PID controller is 384.1554s. So, the time required for the ANFIS-PID controller to settle and remain within final value is faster than PID controller with its percentage overshoot of 61.4388% which is lower than 78.3966% by the PID controller.

ANFIS is nonlinear controller. It has the ability to approximate nonlinear function liked EMG model better than PID controller as PID usually relies on accurate nonlinear model while ANFIS it doesn't need to accurate nonlinear model and don't have to be tuned after training compared to PID controller which have to be tuned again in some conditions [7]. Based on Figure 10, it shows that the best performance integrated EMG model is achieved by ANFIS-PID controller where it is the best approach to regain the adaptiveness for the nonlinear system case.

*D. Robustness of the controller*

To test the robustness or effectiveness between proposed controller ANFIS-PID and PID controller, both controllers are compared with noise rejection. Fig. 11 (a) and (b) show that the control system is applied with Gaussian noise at the input and feedback of the system.

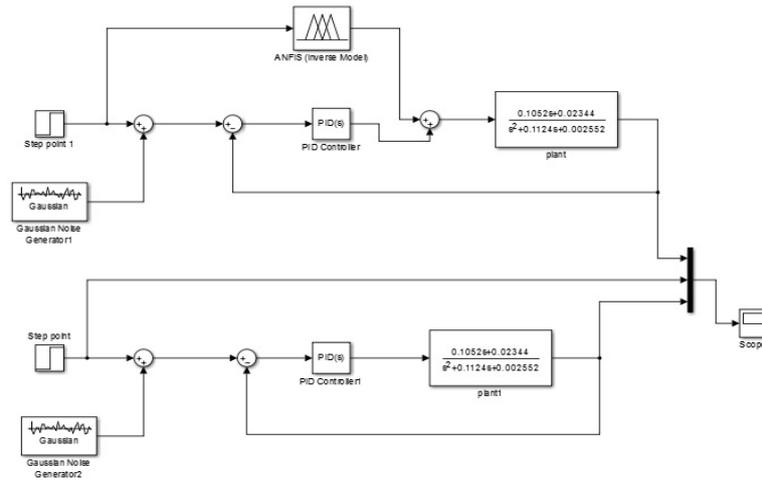


Fig. 11(a). Gaussian noise is applied at the input of the system

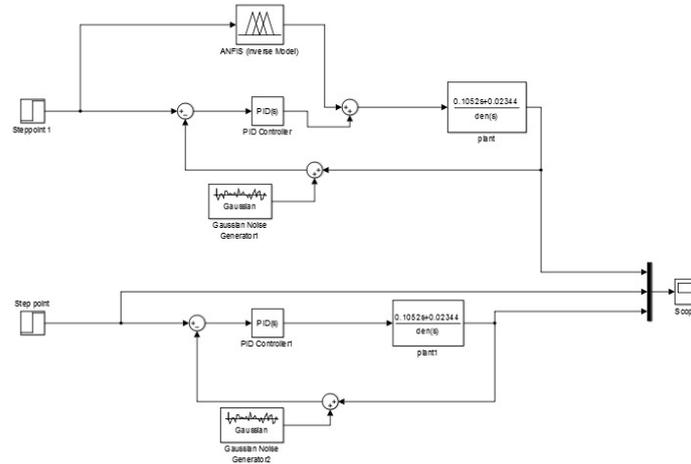


Fig. 11(b). Gaussian noise is applied at the feedback of the system

Based on Fig. 12 and Fig. 13, it shows the comparison of the response by ANFIS-PID controller and PID controller when a Gaussian noise is applied at the input and at the feedback of the system. It indicates that the ANFIS-PID controller response can adapt faster even when there is noise exerted to the system compared to the PID controller. The results can be seen clearly the slightly difference of the response between these two controllers. From the result obtained, ANFIS-PID distinguishes the process variation faster and gives a better performance. Thus, ANFIS-PID controller is more robust compared to PID controller.

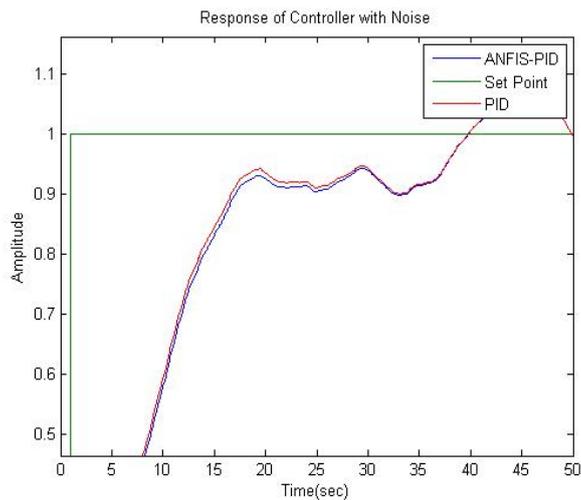


Fig. 12. Zoom In Response of controller with noise at the input of the system

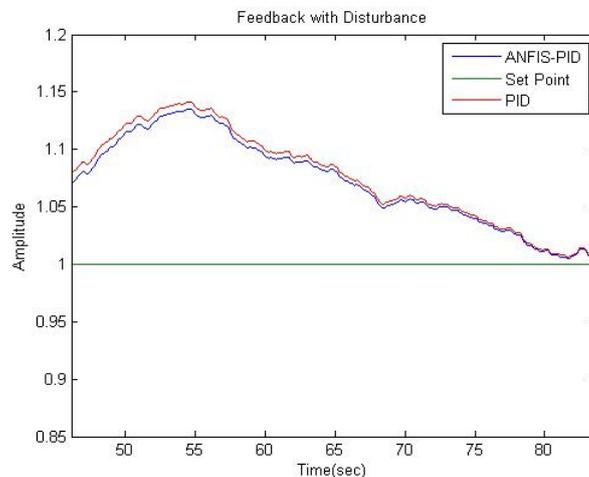


Fig. 13. Zoom In response of controller with noise at the feedback of the system

## V. CONCLUSION

Based on the results, ANFIS-PID controller has the ability to approximate nonlinear function liked EMG model better than PID controller. The best performance integrated EMG model is achieved by ANFIS-PID controller where it is the best approach to regain the adaptiveness for the nonlinear system case. Furthermore, both controllers are tested with implemented of Gaussian noise in the system to compare the effectiveness and robustness between ANFIS-PID controller and PID controller. Gaussian noise is exerted at the input system and at the feedback of the system. Hence, from the system response it indicates that the ANFIS-PID controller is more robust to the system as it can adapt faster even when there is noise exerted to the system compared to the PID controller.

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