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Polarity assignment method (PAM), ANN, Neural networks strategy for the data of PAM for the single degree of freedom flexible joint robot

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Abstract

This paper "describes" the investigation of the stability of Degree of Freedom (DOF) flexible robotic arm by the diagrams shown below. The derived model is based on Euler- Lagrange approach. Exploration of a flexible robotic arm with using state-of-the-art controllers is essential for intelligent applications. These robot arms have joints that work independently of each other in order to create a smooth connection between joints. They still ensures the natural properties like a real human arm. The use of polarity assignment method "helps" the system to achieve desired output signals which has not been thoroughtly studied before for this system. The author can also compare the effectiveness of control methods for this system to find the most effective method for control strategies. In particular, ANN (artificial neural network) is the most modern technique currently applied to this system to investigate the security and stability of the system through this program. This is new and it has never been used before for a system of this type. Neural networks strategy has been implemented in this paper as an application of artificial intelligence. It has successfully performed a mission in re-simulating functions of another control method: Polarity assignment method. Simulation results are done by Matlab.

Keywords: Flexible joint, stability, arm robot, poles, ANN.

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1. Introduction

The use of robots to replace human manual labor arises from laborious work, especially natural factors can affect progress towards completing a worker's mission. The formation and development of modern controllers have made robotics more flexible [1]. Thanks to works [2], the emotions through the robot's voice and gestures become more vivid. The robot's behavior is more tightly controlled [3]. Electrical engineering is a powerful factor in determining the operation of a robotic arm [4]. The use of control algorithms to execute automated applications for websites will not be strange in the future [5]. The ability of the human brain to control the operation of a pointer on a computer is always a new topic [6]. The feelings of the robots can be sincere to humans when they perceive situations of human gestures and voices [7]. Industrial robotic arms can 'detect' product failures using sensors [8]. Robotic exercise machines can 'count' the fitness indicators of exercisers [9]. The establishment of multi-arm robots based on references [10] is always new. Light weight for the robots is essential according to the paper [11]. Robots for dangerous jobs are future prospects [12]. Surveying the behavior of robots on the Martian surface according to laboratory simulations [13], [14] is of interest to scholars. A flying robot is always an interesting subject according to the paper [15]. Robotic radar screens for locating objects [16] are the work of the future. Human resource work in factories can be robotized [17], [18]. It is entirely possible to research robots that know how to save drowning people [20], [21].Tethered robotic systems [22] in the future can be surveyed the structure of surfaces in the deep sea. Physiotherapy robots can 'help' patients recover [23], [24], [25], [26], [27]. The links in the joints of the robot arms operate flexibly according to requirements [28]. The feet of the flying robot can be secured against vibration while it lands on the ground according to references [29]. The wheels of planetary robots need to be thoroughly investigated in a zero-gravity environment [30-33]. High-rise building robots are a combination of various types of links [29, 30-33] integrated into these robots [34]. Active control of links [35] of flying robots can be implemented in the future. For the following structures, both linear [36, 37] as well as non-linear control approaches [38, 39] has been realized in practice. Modeling parachute grips for parachute robots based on [40] is always new. The focus of this paper is on the stability investigation of a working mechanism of a flexible joint controller. The status of this research subject is that there have been very few surveys on it before with the use of controllers to form the data, specifically these objects are the single degree of freedom flexible joint robot in particular and the single degree of freedom in general. These data generated in surveys are an important data for future comments on the effectiveness of control methods. The advantage of polarity assignment method is that it is easy to implement and the success rate for implementation is relatively high. In particular, this method is suitable for models of this type. The innovation of this method under the influence of noise signals is in the process of the author's research. This control method is an interesting research work for robots of this type because of the flexibility and robustness of the robot's operation. ANN (artificial neural network) applied to this model has proven its effectiveness in the following issues: information security, stable system operation, ANN's ability to track targets is always at a good level. Neural Networks strategy has shown it. In the description below of the operating mechanisms of the system, there is a rigid arm that is padded with springs to give elasticity in the way of movement and flexibility in the operation of the system. This device can be integrated with multiple robotic arms into one base depending on the area of the base plate. Figure 1 is a depicted model for a robotic arm (below). It was developed by Quanser [41] on the basis of: initially a static period for rotational platform to perform its operation with a flexible control unit mounted in it. Sliding mode control design for models [42, 43, 44] is a refreshing experience. The use of the pole assignment method for [45] to increase diversity in the approach to control methods.

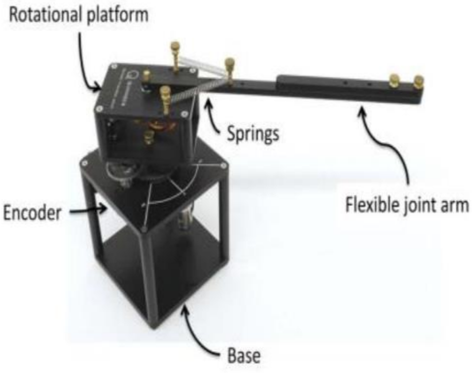


Figure 1. Flexible joint robot arm by Quanser [41].

2. Modelling of flexible joint robot

The arm used in this model is a rotary joint limited by an angle of about 90 degrees and has two Degree Of Freedom (DOF). The base is combined with a set of springs that help balance the movements of the joints. This type of arm is a premise for research for the development of other types of arms. So it is very useful for automation industry. Figure 2 'depicts' the arm in action on a plane with its base. The Euler-Lagrange equation of motion is applied to this system to obtain the mathematical models of the arm described below. In the paper, the theoretical part and the simulation part of polarity assignment method are carried out at the same time. This approach is effective for most robotic systems as well as flexible link systems. So, it is very useful for the above model. In addition, the adjustment of parameters to suit requirements is also relatively simple compared to other methods. This mathematical equation is also used in the flexible linkage model of the MIMO system. The parameters of this system are used to create the model shown in Table 1.The coordinates contained in the platform according to the model [41] are described as follows: the movement of the rotating platform 'forms' an angular (θ) between a vertical axis determined from the beginning, another angular (α) is formed due to the displacement of the flexible joints. This is detailed in Figure 2.

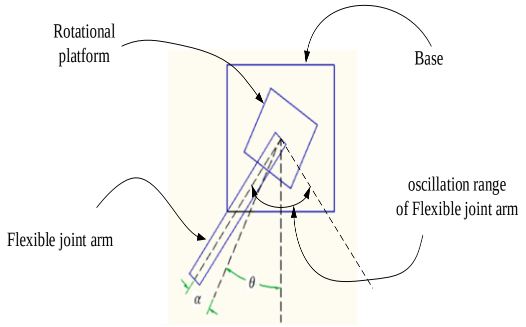


Figure 2. Schematic diagram of flexible joint robotic arm.

The Euler-Lagrange's equation (3) 'L' requires the total kinetic and potential energies. The total potential energy 'P_{Total}' is the sum of the spring's stored energy at the joint and gravity given by (1). The sum of kinetic energies of rotational platform and flexible link manipulator constitutes 'K_{Total}', which is given by (2).

$$P_{Total} = \frac{1}{2} K_s \alpha^2 + mgh\cos(\theta + \alpha) \tag{1}$$

$$K_{Total} = \frac{1}{2} J_h(\dot{\theta}_2) + \frac{1}{2} J_l(\dot{\theta} + \dot{\alpha})^2 \tag{2}$$

$$L = K_{Total} + P_{Total} \tag{3}$$

The Euler-Lagrange equation of motion (4) is used to get the mathematical equations for the rotational acceleration of rotational platform and flexible joint are given by (5) and (6) to form the corresponding motion mechanisms. In (4) the torque is represented by 'τ' and 'q_i' is the variable of differentiation i.e. 'θ' or 'α'. Schematic diagram of flexible joint robotic arm (Fig. 2) is shown above.

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_l}\right)-\frac{\partial L}{\partial \dot{q}_i}=\tau \tag{4}$$

$$\ddot{\theta}=\frac{1}{J_h}\left(\tau+K_s\alpha\right) \tag{5}$$

$$\ddot{\alpha}=-K_s\alpha\left(\frac{1}{J_h}+\frac{1}{J_l}\right)+\frac{1}{J_l}mgh\sin\left(\theta+\alpha\right)-\tau \tag{6}$$

$$\begin{cases}\ddot{\theta}=\frac{1}{J_h}\left(\tau+K_s\alpha\right)\\ \ddot{\alpha}=-K_s\alpha\left(\frac{1}{J_h}+\frac{1}{J_l}\right)+\frac{1}{J_l}mgh\sin\left(\theta+\alpha\right)-\tau\end{cases} \tag{7}$$

Table 1. Parameters of flexible joint robot

Symbol	Description	Value	Units
K_s	Spring stiffness	5.468	N/m
m	Link mass	0.1	kg
J_h	Inertia of rotaltional platform	0.00035	Kgm^2
J_l	Inertia of flexible manipulator	0.003882	Kgm^2
h	Distance of center of gravity of rotational platform	0.06	m
g	Gravitational acceleration	-9.81	N/m
τ	Torque applied to Active joint	0.0134	N-m/A

The author had set state and output variables for the system as follows:

$$\begin{cases}x_1=\theta, x_2=\alpha, x_3=\dot{\theta}, x_4=\dot{\alpha}, x_5=\arcsin z\\ y_1=x_1, y_2=x_2\end{cases} \tag{8}$$

The author combined (7) and (8) to obtain the system of state equations describing the system:

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\\ \dot{x}_3\\ \dot{x}_4\\ \dot{x}_5\end{bmatrix}=\begin{bmatrix}0 & 0 & 1 & 0 & 0\\ 0 & 0 & 0 & 1 & 0\\ 0 & \frac{K_s}{J_h} & 0 & 0 & 0\\ 0 & -K_s\left(\frac{1}{J_h}+\frac{1}{J_L}\right) & 0 & 0 & \frac{1}{J_L}mgh(\arcsin z)\\ 0 & 0 & 0 & 0 & 0\end{bmatrix}\begin{bmatrix}x_1\\ x_2\\ x_3\\ x_4\\ x_5\end{bmatrix}+\begin{bmatrix}0\\ 0\\ \frac{\tau}{J_h}\\ -\tau\\ 0\end{bmatrix} \tag{9}$$

Substituting the values from table 1 into (8), (9) is shown above. 'z' =0.866 has been selected:

$$\begin{cases}\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\\ \dot{x}_3\\ \dot{x}_4\\ \dot{x}_5\end{bmatrix}=\begin{bmatrix}0 & 0 & 1 & 0 & 0\\ 0 & 0 & 0 & 1 & 0\\ 0 & 15622.85 & 0 & 0 & 0\\ 0 & -17031.4 & 0 & 0 & -2.39\times10^{-4}\\ 0 & 0 & 0 & 0 & 0\end{bmatrix}\begin{bmatrix}x_1\\ x_2\\ x_3\\ x_4\\ x_5\end{bmatrix}+\begin{bmatrix}0\\ 0\\ 38.28\\ -0.0134\\ 0\end{bmatrix}\\ \begin{bmatrix}y_1\\ y_2\end{bmatrix}=\begin{bmatrix}1 & 0 & 0 & 0 & 0\\ 0 & 1 & 0 & 0 & 0\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix}\end{cases}$$

The transfer function of the system:

$$G(s)=\frac{38.28s^2-2.167\times10^{-13}s+6.518\times10^5}{s^4+1.703\times10^4s^2} \tag{10}$$

3. The survey of the system with using polarity assignment method

The author considered the control system in terms of state variables as follows:

$$\begin{cases}\dot{x}(t)=Ax+Bu(t)\\ y(t)=C(x)\end{cases} \tag{11}$$

The author also considered the block diagram of the system with the following state feedback mechanism:

$$u(t)=-Kx(t) \tag{12}$$

where 'K' is a constant feedback gain vector. The input to the control system is assumed to be 0. The purpose of this system is to return all states to zero when the states are perturbed. The author substituted (11) into (12), the closed system state is represented as follows:

$$\dot{x}(t)=(A-BK)x(t)=A_f x(t) \tag{13}$$

The characteristic equation for the closed system is:

$$|sI-A+BK|=0 \tag{14}$$

The author assumed that the system can be represented as a phase variable normal form as follows:

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\\ \dots\\ \dot{x}_{n-1}\\ \dot{x}_n\end{bmatrix}=\begin{bmatrix}0 & 1 & 0 & \dots & 0\\ 0 & 0 & 1 & \dots & 0\\ \dots & \dots & \dots & \dots & \dots\\ 0 & 0 & 0 & \dots & 1\\ -a_0 & -a_1 & -a_3 & \dots & -a_{n-1}\end{bmatrix}\begin{bmatrix}x_1\\ x_2\\ \dots\\ x_{n-1}\\ x_n\end{bmatrix}+\begin{bmatrix}0\\ 0\\ \dots\\ 0\\ 1\end{bmatrix}u(t) \tag{15}$$

The author substituted 'A' and 'B' in (15), the closed-loop characteristic equation for the control system is given by:

$$|sI-A+BK|=S^n+(a_{n-1}+k_n)s^{n-1}+....+(a_1+k_2)s+(a_0+k_1)=0 \tag{16}$$

For closed-loop pole positions defined by: $\lambda_1,\lambda_{-2},.....,\lambda_{-n}$, the desired characteristic equation would be:

$$\alpha_c(s)=(s+\lambda_1)....(s+\lambda_n)=s^n+\alpha_{n-1}s^{n-1}+...+\alpha_1 s+\alpha_0=0 \tag{17}$$

The purpose of the design is to find 'K' so that the characteristic equation for the control system is identical to the desired characteristic equation. Therefore, the value of the vector ‘K’ is obtained by homogenizing the coefficients of equations (16) and (17):

$$k_i = \alpha_{i-1} - \alpha_{i-1} \qquad (18)$$

If the state model is not in the phase variable normal form, the author can use the transformation technique to transform the given state model into the phase variable normal form. The coefficient ‘K’ is obtained for this model and then transformed back to confirm with the original model. This procedure leads to the following formula, known as the Ackermann formula:

$$K = \begin{bmatrix} 0 & 0 & \ldots & 0 & 1 \end{bmatrix} S^{-1} \alpha_c(A) \qquad (19)$$

Here, the matrix S is given by:

$$S = \begin{bmatrix} B & AB & A^2B & \ldots. & A^{n-1}B \end{bmatrix} \qquad (20)$$

and the notation is given by the following formula:

$$\alpha_c(A) = A^n + \alpha_{n-1}A^{n-1} + \ldots. + \alpha_1 A + \alpha_0 I \qquad (21)$$

4. Simulation results and discussions

This model is set up to serve control algorithms and this model does not cover other degrees of freedom. The determination of control parameters is based on the adjustment of simulation data that are generated during the initialization of the algorithms described earlier. Simulation results with using the polarity assignment method, PID controller, optimal controller, Neural Networks Application is shown Figures 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16. Figure 3 below shows that using the polarity assignment method ‘helps’ the system's operation gradually become more stable.

Part 1: Model with using Polarity assignment method The survey of the system with using polarity assignment method: The author used a command: eig (A) in Matlab software to find the following result: eig (A)=[10^2*(0; 0; 1.3*i; -1.3*i)]. Now, the author have to choose the polarity of the closed system based on the set time criteria <0.5s and overshoot <5%. The author relies on the following comments: The kinetics of a closed system depends mainly on the poles located near the virtual axis, for fast response, the pole can be the complex union pair, the real part of the polar pair determines the buffer coefficient and the virtual part determines the frequency of oscillation. The author chooses 5 poles: p_1=-10+10*i, p_2=-10-10*i, p_3= -50, p_4=-52, p_5=-54. K = place (A, B, [p_1 p_2 p_3 p_4 p_5]) = [0 0 0 0 3.1502 *10^{11}].

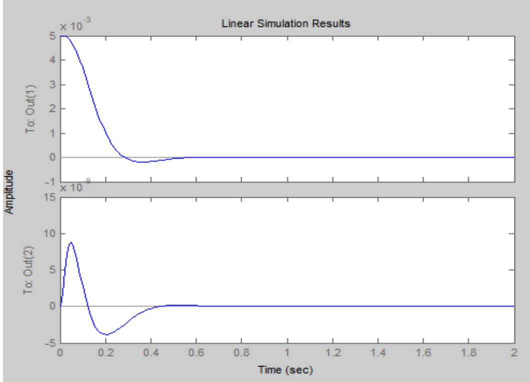


Figure 3. The response of the system to non zero input conditions of the system.

The response of $c\Delta = x$ around the value of x_0 is recognized. The output has the amplitude of variation in two values: the positive value and the negative value before it return to the equilibrium/steady state (0.6 sec).

Part 2: Model with using PID controller

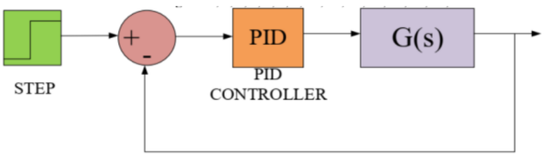


Figure 4. Simulink model of PID controller.

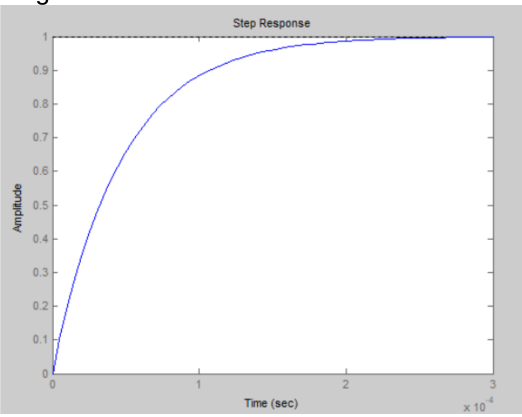


Figure 5. step response of the closed system for PID controller G(s)

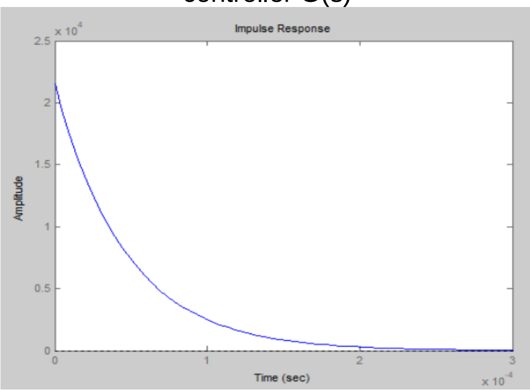


Figure 6. impulse response of the closed system for PID controller G(s)

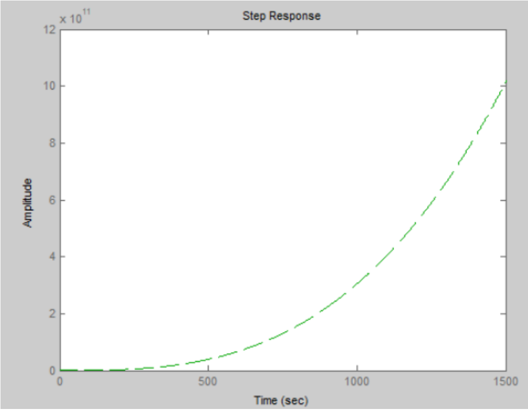


Figure 7. step response of the open system for PID controller G(s).

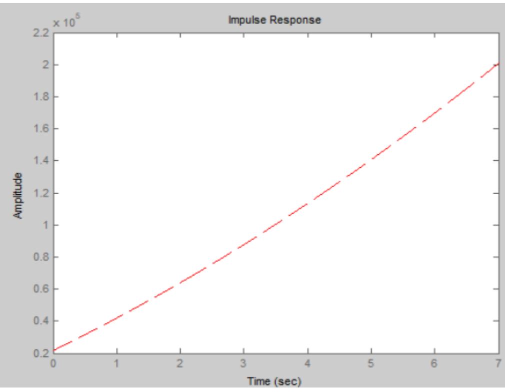


Figure 8. impulse response of the open system for PID controller G(s)

Part 3: Model with using optimal controller

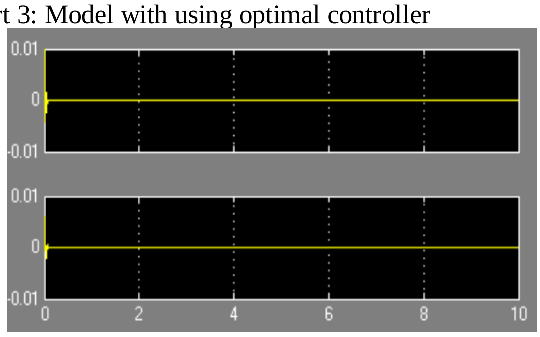
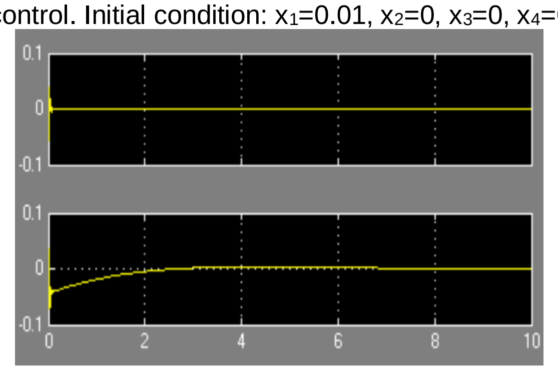


Figure 9. The simulation result with using optimal control. Initial condition: $x_1=0.01$, $x_2=0$, $x_3=0$, $x_4=0$



Figigure 10. The simulation result with using optimal control. Initial condition: $x_1=0.04$, $x_2=0.03$, $x_3=0.03$, $x_4=0.03$.

Part 4: Model without any control algorithm

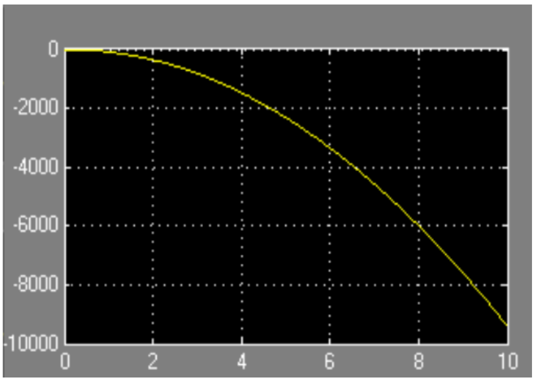


Figure 11.The simulation result without using any control algorithm G(s).

Part 5: Model with using ANN

Procedures for carrying out this research work:

Step 1: Set up the model

Step 2: mathematically represent this model in terms of a function or a transfer function

Step 3: build an artificial intelligence algorithm (ANN)

Step 4: simulate the built-in artificial intelligence algorithms according to the function of the model

Step 5: Identify and evaluate this program

Model with using Artificial neural network (ANN).

Diagrams of the system using ANN and simulation results are shown Figures 12, 13, 14, 15.

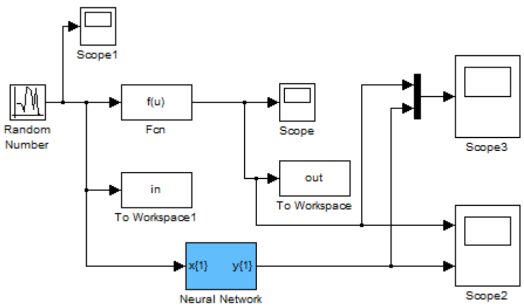


Figure 12. Simulink of model with using ANN

Figure 12 : the value of f(u)= G(u): the tranfer function of the system

The calculation process of the program is carried out as shown in Figure 12

Step 1: The author has assembled the components together as shown in Figure 12

Step 2: The author has loaded the data for the components according to the requirements of the problem.

Step 3: The author has written a program to display a Blue Box.

Step 4: The author has pressed "play" on the control bar to produce the results as shown below.

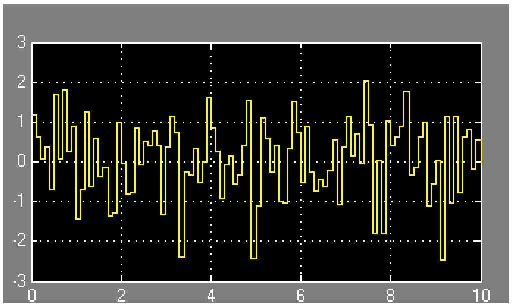


Figure 13. model with using ANN of Scope 1

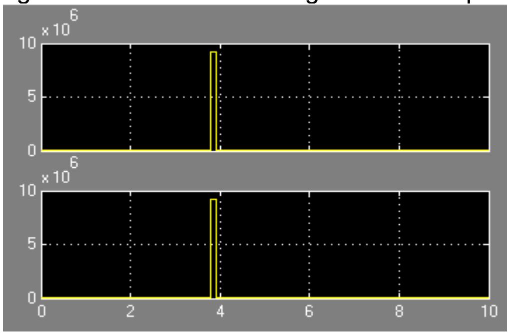


Figure 14. model with using ANN of Scope 2

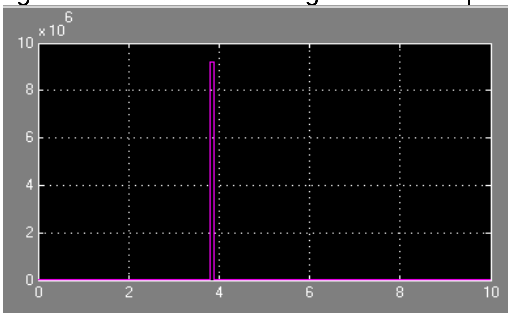


Figure 15. model with using ANN of Scope 3

Figure 13 is the result of given input values. Figures 14, 15 are results of the output values. Figure 14 is the result of the value of the output without using ANN (above image) and Figure 14 also is the result of the output with using ANN (bottom image). Figure 15 is a composite image of the value of the output without using ANN and the value of the output with using ANN. This result has an almost absolute match between the two values above. Therefore, this is considered a successful survey in training the network to achieve desired results.

Part 5: Model with using Neural Networks application for the data of polarity assignment method

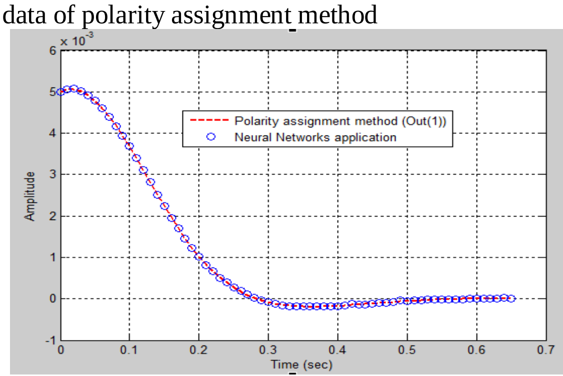


Fig 16. Neural Networks application for Out (1).

Figures 16 show that ANN is the best choice for training the network according to a given control method. Results show that values of control methods are relatively consistent with each other and results have achieved desired problem requirements. Neural Networks application has made remarkable achievements in replacing structures of given signals with a certain value. This value is not too small or too large for the working framework of the given signal stream. The effectiveness of the methods is sorted in descending order below. This is based on states that are determined to be stable through simulation results. The number of simulation results reaching steady state is the criterion to evaluate the effectiveness of ANN, PID controller, Polarity assignment method, and optimal controller applied to the above model:

A. ANN
B. PID controller ($2*10^{-4}$ sec)
C. Optimal controller (~0.1 sec) [46]
D. Polarity assignment method (0.6 sec)
E. The system without using any control algorithm [46].

5. Conclusions

The effectiveness of using modern controls for the robotic arm was mentioned above. Control methods have shown their role well, especially ANN in the above model: ANN has been used to 'perform' tasks set out before. Neural Networks strategy has been included in this paper for the purpose of exploiting its security features as well as re-simulation features of applications of given structures. In the future, the use of other powerful control algorithms can be applied to the above model. Comparing the efficiency of controllers above 'helped' readers understand the essence of the problem for robotic arm models in particular and other automatic models in general.

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