Analysis, Design and Implementation of a Robotic Arm with Writing Ability Using Neural Networks

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Abstract: In this paper, multi-segments parametric cartesian space trajectory planning equations based on Neural Network approach is proposed. This work includes using a real two-link robotic arm to be able to write the english words or letters. The proposed algorithm is used to find the positions of the end-effector robotic arm. Neural Network is trained by Back Propagation Algorithm. The two-link robotic has two Degrees Of Freedom. It has two joint angles with three servo motors. A pen is connected to the third servomotor in order to raise and lower the pen. The outputs of this algorithm are: two Pulse Width Modulation motor commands, one Pulse Width Modulation motor command voltage for the first joint angle and the second Pulse Width Modulation motor command voltage for the second joint angle. The results of position errors are acceptable due to servomotors of practical robotic arm. The best training performance error of Mean Square Error for Back Propagation Algorithm equals to (5.3465*10^(-25)). In this work, the maximum positions errors for the end-effector of the robot are computed between theoretical and experimental work. The maximum position error in X axis equals to (-0.0102 m) and the maximum position error in Y axis equals to (-0.0098 m). The writing results of two-link real robotic arm was smooth line segments according to small position errors in X and Y axes.

Keywords: two-link robotic arm, position errors, Automation and Robotics Research Unit, Neural Network, Multi-Layer Perceptron Neural Network.

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1. Introduction

Robotics nowadays has many applications in modern life, from industrial manufacturing to healthcare, transportation, and exploration of the deep space and sea. Skilled and artificial intelligent machines have become part of humanity [1]. Writing is a fundamental part of a child's development. The design of a writing robotic arm will often incorporate principles of mechanical engineering, electronic engineering and computer science (particularly artificial intelligence).

One of robotic fields of design is path planning which is defined as the generation of a geometric path without specified time law [2]. Neural Network (NN) is used to solve the inverse kinematics problem by collecting the training data from a sub joint space. The setting of training data is constrained. Extreme Learning Machine (ELM) method is used in order to train the NN with randomly chosen input weights and analytically evaluates the output weights of the single hidden layer feed forward neural networks. This approach improved the precision [3]. From the forward kinematics equations, A 3-DOF (Degree Of Freedom) robotics arm of inverse kinematics problem is solved in 3-dimension spaces using the NN. This algorithm reduced complexities in computation and increased the speed of convergence [4]. The numerical algorithm study depending on fuzzy logic solved a serial robot manipulator inverse kinematic problem. The algorithm is compared with the classical methods of a SCARA robot. This study encourages using this algorithm in more complex robots [5]. The study of genetic algorithm is presented in order to solve the inverse kinematics for the three degree of freedom robotic problem using real number coding to improve evaluating the efficiency of the algorithm [6]. Proposed multi-neural network structure approach is used to solve the inverse kinematic problem of the Reis robot manipulator end-effector position. Comparison between the inverse kinematic classical solution and the proposed multi-neural network solution is also presented, in order to predict robot joint angles [7].

2. Related Works

2D plotter SCARA robotic arm with 3 DOF was implemented. This SCARA robot is used in graphic applications such as : letters and images. Unfortunately, no simulation results were introduced in their work to give an indication about the quality of drawing or writing [8].

Three DOF real robotic arm is presented by solving the inverse kinematic problem using Neural Network algorithm. Neural Network is trained using Back Propagation Algorithm. The line drawn by this robot practically was is not smooth enough. The robot must receive greater size data file in comparing with other related works in order to reduce the error. Best neural network training performance using Mean Square Error equals to (10^(-5)) for 646 epochs. The writing error was small under 2% in both X and Y coordinates [9].

3. Modeling The Two-link Robotic Arm

The modeling of two-link robotic arm manipulator is presented as shown in Figure 1.

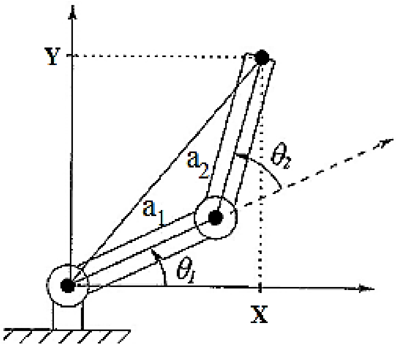


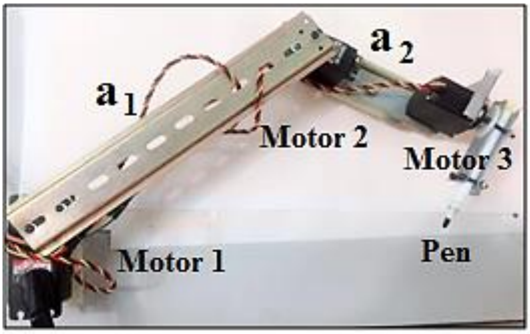
Figure 1: Two-link robotic arm [10].

Forward kinematics problem of the two-link robotic arm is to find the (X,Y) coordinates from two joint variables (θ_1 and θ_2). Forward kinematics of this robot is illustrated in equations (1, 2) [10].

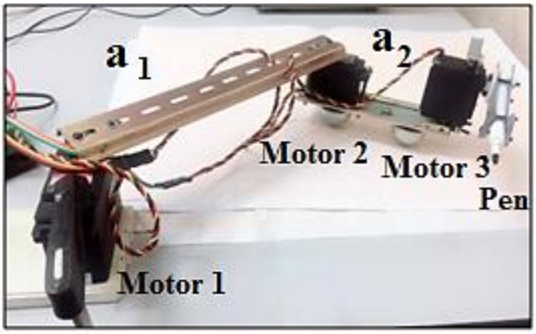
$$X = a_1\cos(\theta_1) + a_2\cos(\theta_1 + \theta_2) \quad (1)$$

$$Y = a_1\sin(\theta_1) + a_2\sin(\theta_1 + \theta_2) \quad (2)$$

In this work, the case study of the practical two-link robotic arm is designed. It consists of three servomotors and two links. The third servomotor is connected to pen in order to move the pen up and down, as shown in Figure 2.



(a)



(b)

Figure 2: Practical two-link robotic arm design in two sides: (a): top view (b): side view.

The link parameter table of the real two-link robotic arm writer is illustrated as in Table 1.

Table 1. Link parameter table of two-link robotic arm.

Link	a_i (m)	α_i (deg.)	d_i (m)	θ_i (deg.)
1	0.2040	0	0	$0 < \theta_1 < 180$
2	0.1460	0	0	$0 < \theta_2 < 180$

Where, a_i = distance along x_i from o_i to the intersection of the x_i and z_{i-1} axes. d_i = distance along z_{i-1} from o_{i-1} to the intersection of the x_i and z_{i-1}

axes. α_i = the angle between z_{i-1} and z_i measured about x_i. θ_i = angle between x_{i-1} and x_i measured about z_{i-1}.

In order the robotic arm to move to any location, It is needed to find the joint variables (θ_1 and θ_2). This is the problem of inverse kinematics.

The analysis equations of inverse kinematics are demonstrated as in the equations (3, 4, 5, 6). Consider the diagram of Figure 1 and using the cosines law that the angle θ_2 is given by [10]:

$$\cos\theta_2 = \frac{X^2+Y^2-a_1^2-a_2^2}{2a_1a_2} = \quad (3)$$

Mathematically θ_2 is determined as $\theta_2 = \cos^{-1}(D)$, but a better way to find θ_2 is by the following equation:

$$\sin\theta_2 = \pm\sqrt{1-D^2} \quad (4)$$

and, hence, θ_2 can be found by:

$$\theta_2 = \tan^{-1}\frac{\pm\sqrt{1-D^2}}{D} \tag{5}$$

Thus, θ_1 can be found by:

$$\theta_1 = \tan^{-1}(Y/X) - \tan^{-1}\frac{a_2\sin\theta_2}{a_1+a_2\cos\theta_2} \tag{6}$$

4. Robotic Arm Writing Analysis using Neural Network

Two-link robotic arm is designed in order to write any letter or word or many words in english language. Constraint workspace of motion the real two-link robotic arm is presented. in Figure 2. Robotic arm is writing using the parametric cartesian space trajectory planning analysis equations (7, 8) as in Figure 3 [11]:

$$X(u) = X_a + u(X_b - X_a) \tag{7}$$
$$Y(u) = Y_a + u(Y_b - Y_a) \tag{8}$$

Where (X_a, Y_a): start point ; (X_b, Y_b): end point (goal point), (u= 0:1). (X, Y): coordinates of end-effector of the robot.

In this paper, the english word or any letter can be designed using equations (7, 8) by several segments of parametric lines equations within the real robot workspace constraints. These ranges are constrainted as: (0.07m$\geq X \geq$0.27m) and (0.1m$\geq Y \geq$0.18m). The constraint workspace is the best region that two-link robotic arm is reached to it.

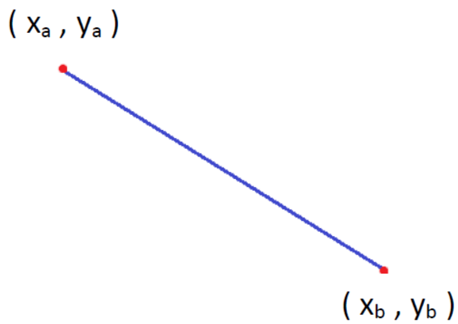


Figure 3: Line trajectory path [11].

The positions of end-effector robotic arm (X, Y) are controlled by Neural Network (NN). Neural Network Toolbox of MATLAB R2017b program is used. Multi-Layer Perceptron Neural Network is used. The training is performed by Back Propagation Algorithm (BPA) [12]. By trial and error NN design approach, the structure consists of two hidden layers:- the number of neurons in the first hidden layer equals to 100 neurons and the number of neurons in the second hidden layer equal to 70 neurons. Two outputs of Pulse Width Modulation (PWM) motor command are computed, where T_1 is PWM command for θ_1 and T_2 is PWM command for θ_2. NN is designed and implemented as in Figure 4. In this algorithm, the inputs data of NN are normalized with (-1, 1). The best design of this work is less complexity in order to ensure the position error is acceptable. The results outputs of NN are needed to demoralize, each result presents the suitable value of PWM motor command.

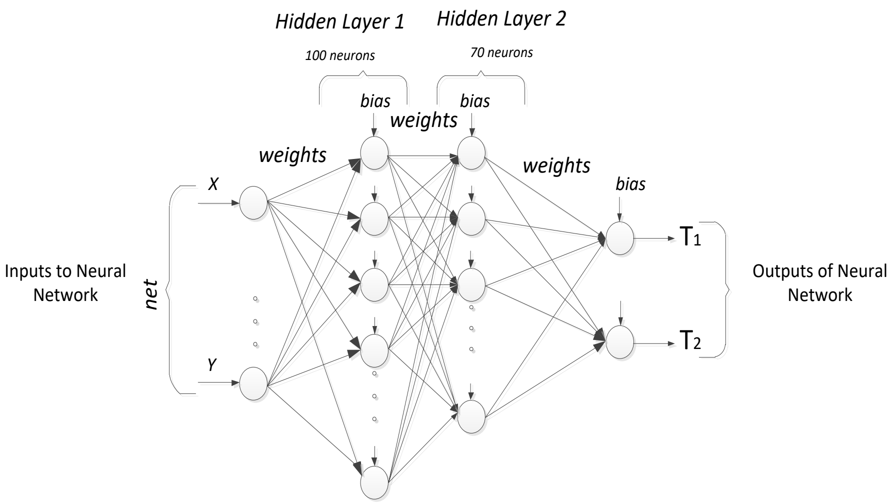


Figure 4: NN algorithm designed and implemented.

In this proposed NN work, tansig is a neural activation function is used in both hidden layers. It is useful for squashing function of the form that maps the input to the interval (-1,1) as shown in Figure 5. Where, n: matrix of net input and a: tansig activation function [13].

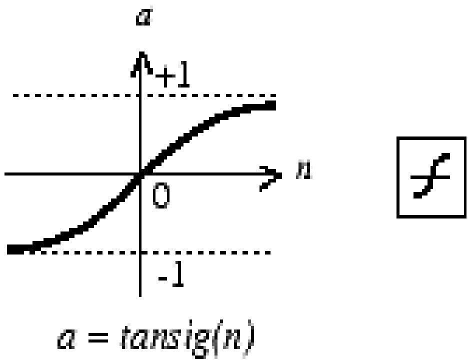


Figure 5: Tansig activation function [13].

5. Implementation of Experimental Robotic Arm for Writing Analysis using Neural Network.

From the previous section, the outputs of PWM command (T_1 and T_2) are computed to derive the robotic end-effector position (X, Y) using NN algorithm. This algorithm is implemented practically to verify the robotic writing ability using our real two-link robotic arm as shown in Figure 6.

It consists of three servo motors with two links and the pen is connected to the third servomotor. The controller is also connected to two-link robotic arm. Robot hardware parts are:

1- Three servomotors: One servo is the base of two-link robotic arm of model No. HS-755MG [14]. This servomotor rotates left and right. The second and third servos of model No. HS-645MG. The main feature of this servo has high torque metal gear servo [15]. The second servo moves left and right. Finally, the third servomotor is moving up and down. The pen is connected with the third servomotor. The pen is useful for writing on the paper.

2- SSC-32 Servo Controller: The SSC-32 (Serial Servo Controller). It has high resolution for accurate positioning, and extremely smooth moves. The motion control can be immediately gives response, speed controlled, timed motion from 32 controller channels. It has bidirectional communication [16].

MATLAB software code is written. This code is sent to the SSC-32 Servo controller using USB to serial convertor. The values of (T_1 ,T_2) are driving the servomotors in order to move the end-effector according to the desired letters and words. Power supply is attached to the hardware connection with 5 volt in order to drive the motors and SSC-32 Servo controller. The design of experimental work of the two-link robotic arm hardware is implemented at Automation and Robotics Research Unit in Control and Systems Engineering Department at University Of Technology (ARRU-CSED-UOT), as shown in the Figure 6.

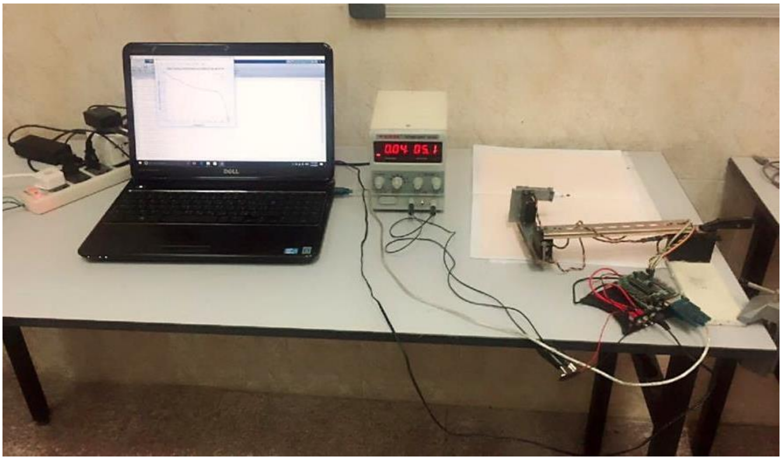


Figure 6: Experimental work of the two-link robotic arm with three servomotors and SSC-32 Servo controller at ARRU-CSED-UOT.

The errors equations between the theoretical and experimental work are:

$$e_x(i) = X_{th}(i) - X_{exp}(i) \quad (9)$$

$$e_y(i) = Y_{th}(i) - Y_{exp}(i) \quad (10)$$

where, X_{th}, Y_{th}: theoretical position of end-effector robotic arm.

X_{exp}, Y_{exp}: experimental position of end-effector robotic arm.

e_x: position error in x axis.

e_y: position error in y axis.

i =1:m, m is the number of iterations. The simulation results are explained in the next section.

6. Simulations and Experimental Work

According to the forward kinematics equations (1,2) and the parametric cartesian space trajectory equations (7, 8) of the two-link robotic arm writing analysis using NN algorithm. The two-link robotic arm writes any english letter or word in its constraint workspace. The real two-link robotic arm writes the word (ARRU). ARRU word is derived from the beginning of each the word: Automation and Robotics Research Unit. The simulation result of this word is shown in Figure 7:

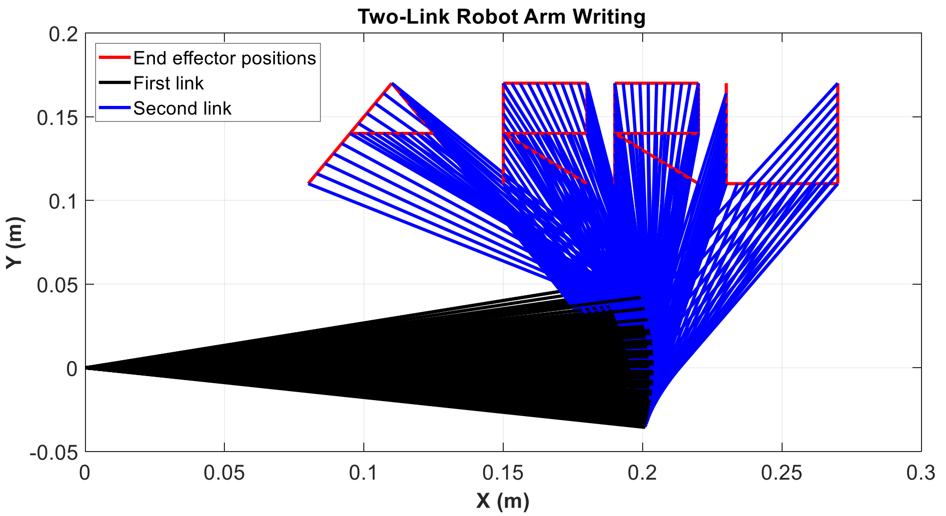


Figure 7: Simulation of two-link robotic arm motion using designed NN.

Where, the start point of the end-effector position robot is (0.08, 0.11) m and the goal point of end-effector position is (0.27, 0.17) m. Positions of the end-effector two-link robotic arm are computed for the theoretical and the experimental work trajectory for (ARRU) word. The experimental results of real two-link robotic arm are shown in Figure 8.

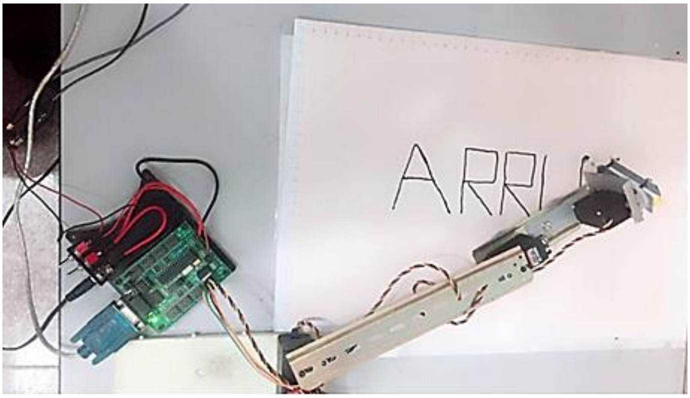


Figure 8: Experimental two-link robotic arm motion using designed NN.

From Figure 7, the ARRU is simulated using end-effector positions (X, Y), so that, the changes of X axis and Y axis end-effector positions are also simulated with the 217 iterations in the following Figures 9,10 respectively.

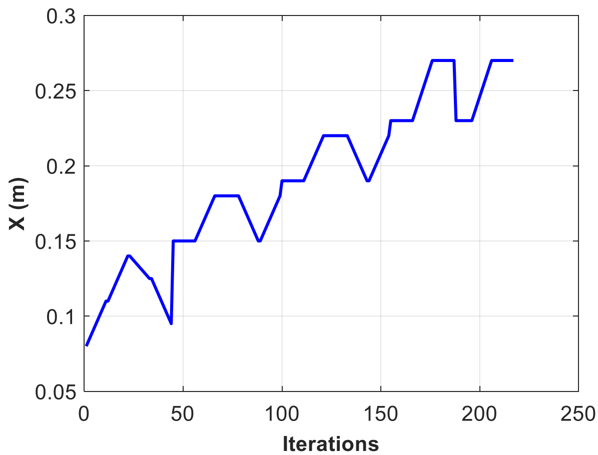


Figure 9: Changes of X axis positions with the iterations.

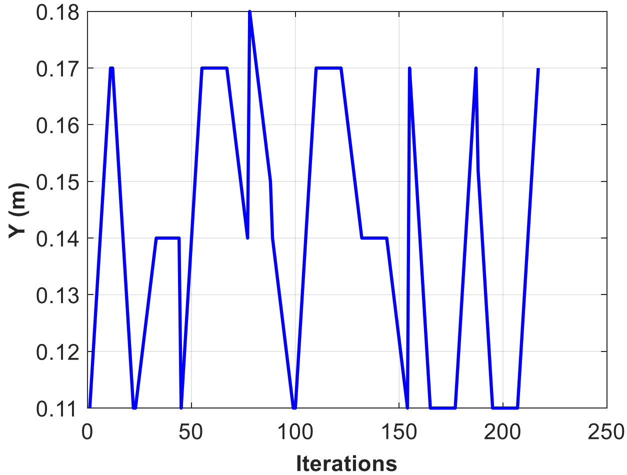


Figure 10: Changes of Y axis positions with the iterations.

The best training performance equals to (5.3465*10^(-25)) of the BPA algorithm for MATLAB NN toolbox as in Figure 11. The figure below shows that the Mean Square Error with 18 Epochs.

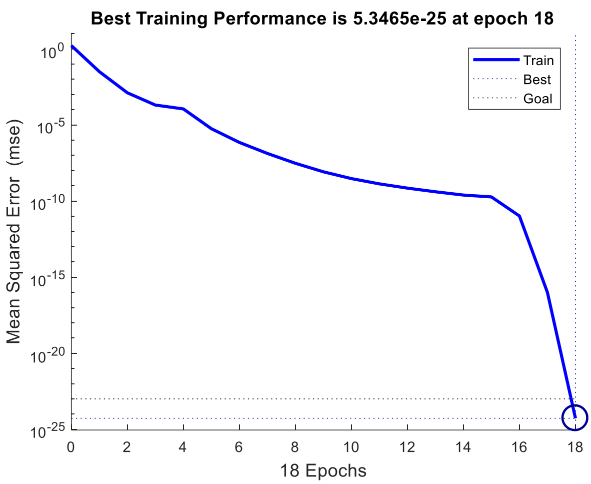


Figure 11: Performance training of Mean Square Error with 18 Epochs.

The end-effector positions errors are evaluated and simulated from equations (9, 10) between theoretical and experimental errors as in figures (12, 13).

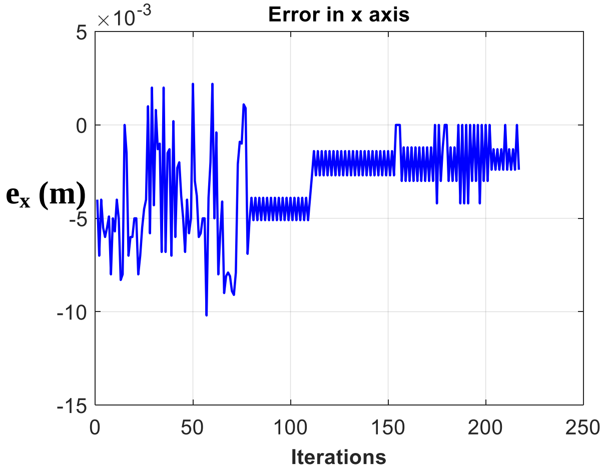


Figure 12: Error in X axis (e_x) with iterations.

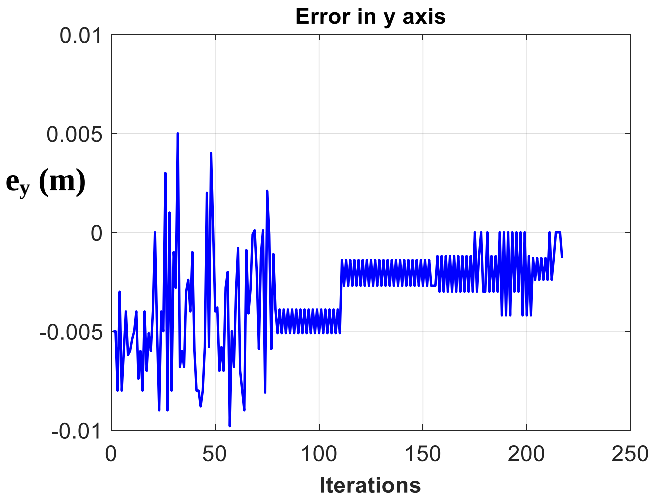


Figure 13: Error in Y axis (e_y) with iterations.

Figures 12, 13 showed that the errors of end-effector in X and Y axes between theoretical and experimental work. The maximum error of e_x equals to (-0.0102 m) and the maximum error of e_y equals to (-0.0098 m) in 57 iterations. The changes of errors are occurred in this point, because of the mechanical sudden movement of the first and the second servomotors at this moment.

7. Conclusions

The two-link robotic arm writing the (ARRU) word is presented using multi-segments parametric cartesian space trajectory planning equations based on Neural Network (NN). This proposed approach is implemented theoretically and experimentally for real two-link robotic arm. Inputs of NN are position of end-effector robotic arm (X, Y). Two outputs of PWM motor commands (T_1,T_2). T_1 is the output voltage for first joint angle and T_2 is the output voltage for second joint angle with two NN hidden layers. The tarinning is implemented by BPA. Changes of (X, Y) positions are simulated with iterations. The best performance error of Mean Square Error for NN algorithm equals to (5.3465*10^ (-25)). The end-effector position errors e_x and e_y are evaluated for practical and theoretical work. These position errors are acceptable according to the servomotors practical robotic arm.

The maximum errors are: (e_x= -0.0102 m) and (e_y= -0.0098 m). The changes of errors in this point, because of the mechanical sudden movement of the first and the second servomotors at this moment.

Acknowledgements

Authors are deeply indebted to Iraq Automation and Robotics Research Unit in Control and Systems Engineering Department at University Of Technology (ARRU-CSED-UOT).

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تحليل، تصميم و تنفيذ قدرة ذراع روبوت للكتابة باستخدام الشبكات العصبية

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المستخلص: في هذا البحث، تم اقتراح المعادلات التخطيطية لمسار المسافات الحيزية الديكارتية المتعددة القطاعات استنادا إلى نهج الشبكة العصبية .هذا العمل يتضمن استخدام ذراع روبوت ثنائي الاطراف حقيقي قادر على كتابة الكلمات الإنجليزية أو الحروف. تم اقتراح الخوارزمية التي تستخدم لإيجاد مواقع ذراع الروبوت المؤثر النهائي. يتم تدريب الشبكة العصبية بواسطة خوارزمية الانتشار العكسي. ذراع الروبوت الثنائي الاطراف لديه درجتين للحرية. له اثنين من زوايا المفاصل مع ثلاث محركات سيرفو. يتم توصيل القلم إلى محرك سيرفو ثالث لرفع وخفض القلم. مخرجات هذه الخوارزمية هي: اثنان من نبض العرض التحويري لمحرك الايعازات، محرك ايعاز الجهد لزاوية المفصل الأولى و محرك ايعاز الجهد لزاوية المفصل الثانية. نتائج اخطاء المواقع مقبولة حسب محركات السيرفو للروبوت العملي. اقصى خطأ لاداء التدريب الافضل لمتوسط مربع الخطأ لخوارزمية الانتشار العكسي تساوي (5.3465*10^(-25)). في هذا العمل, اقصى اخطاء المواقع للروبوت المؤثر النهائي تم حسابها بين العمل النظري و التجريبي. في هذا العمل, اقصى موقع خطأ لمحور X يساوي (0.0102 - متر) و اقصى موقع خطأ لمحور Y يساوي (0.0098 - متر). نتيجة كتابة ذراع الروبوت الثنائي الاطراف الحقيقي تكون ذات مقاطع لخطوط ناعمة وفقاً لأخطاء المواقع الصغيرة في محاور X و Y.

الكلمات المفتاحية: ذراع الروبوت الثنائي الاطراف، أخطاء الموقع، وحدة بحوث الاتمتة و الروبوتات، الشبكة العصبية, متعدد طبقات الشبكة العصبية الإدراكية.

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