Simulation design of trajectory planning robot manipulator

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ABSTRACT

Robots can be mathematically modeled with computer programs where the results can be displayed visually, so it can be used to determine the input, gain, attenuate and error parameters of the control system. In addition to the robot motion control system, to achieve the target points should need a research to get the best trajectory, so the movement of robots can be more efficient. One method that can be used to get the best path is the SOM (Self Organizing Maps) neural network. This research proposes the usage of SOM in combination with PID and Fuzzy-PD control for finding an optimal path between source and destination. SOM Neural network process is able to guide the robot manipulator through the target points. The results presented emphasize that a satisfactory trajectory tracking precision and stability could be achieved using SOM Neural networking combination with PID and Fuzzy-PD controller.The obtained average error to reach the target point when using Fuzzy-PD=2.225% and when using PID=1.965%.

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1. INTRODUCTION

Optimal manipulator robot control to achieve the desired trajectory points requires sustainable research. Optimal control in this research is the handling of objects or workpieces in specified positions, where the robot manipulator can determine the angle with a small error to achieve the targets that have been determined [1, 2]. The addition of fuzzy control system to robot manipulatoris able to move the robot to reach one target point but it still have an error. During the process of movement of the robot manipulator by using forward and inverse kinematic, so it can be transformed from the angle of the arm to the coordinate position in two-dimensional plane or vice versa [2-4]. In the realization of robot manipulators to solve a problem or just applyinga method, it requires a number of hardware with expensive cost. Simulation is one of the solutions to represent robot performance research without using hardware. Problems about robots can be modeled mathematically with computer programs where the results can be displayed visually, so it can be used to determine the input, gain, attenuate and error parameters of the control system. Manipulator robot simulation can be included force element by using dynamic equation, so the effect of load change has influence the movement of robot manipulator [1-5].

The use of this simulation can help researchers in the field of robot movement technology, so it can approach the problems to be solved [6, 7]. In addition to the robot motion control system, to achieve the target position and get the best trajectory/track the robots needs to be controlled, so the movement of robots can be more efficient. One method that can be used to get the best path is using Genetic Algorithm (GA), where GA is an optimization method of a mathematical function [7]. Another method that can be used to get the best path is one of the types of neural network that usually called SOM (Self Organizing Maps) [8-11].

This paper is organized as follows, applied SOM neural network to get the best path from the point that spread randomly on the robot manipulator. This robot manipulator is also given a control using Proportional Integral Derivative (PID) and Fuzzy Proportional Derivative (Fuzzy-PD) [12-16]. The reason to combineboth of SOM neural network and Fuzzy-PD control to simulate robot manipulator in this research because it is still rarely used. The advantage of SOM's neural network for trajectory planning robot arm manipulator is the learning process without guidance, unlike the neural network back propagation that should always be guided to learn trajectory planning [17-21]. This robot manipulator simulation is usingMatlab Robotics Toolbox, where the simulation is not built from beginning [5, 6]. The simulation was made by using C# programming languages and the results are displayed with images in 2 dimensional fields. The purpose of this joint implementation research between SOM neural network and Fuzzy-PDcontrol can be the basic research in the realization process later.

2. RESEARCH METHOD

2.1. SOM training algorithm

Stages for the SOM training algorithm is described below [18]:

a. Initialize all we weight, learning rate parameter μ (0), set iteration value (epoch) k=0 and determine the topology of the neighbourhood function.
b. Check the conditions that meet to stop the iteration.
c. For each training value of vector xi, do steps a through c
   1) Calculate the best pair of weights and input values.

$$q(x) = \min_{\forall i} \| x - w_i \|_2 \tag{1}$$

   2) Update the weighted value by using the function as in (2):

$$w_i(k+1) = \begin{cases} w_i + \mu(k)[x - w_i(k)] & \text{if } i \in N_q(k) \\ w_i(k) & \text{if } i \notin N_q(k) \end{cases} \tag{2}$$

where the learning rate value : $0 < \mu(k) < 1$

   3) Set the learning rate parameter.
d. Set k=k+1, then subtract the value of learning rate and proceed to step no. 3.

2.2. Simulation of 3 DOF robot manipulator

Figure 1 shows the 3 DOF *three-link planar* physical structure, its consists of link 1 (shoulder), link 2 (elbow) and link 3 (end of effector (EE)), which in this study link 3 is designed passive. EE is the end of the robot manipulator which had a special device. This device has a function like human-hand that directly relate with the object and the environment. This simulation is using a computer program where the movement of this robot manipulator as visually. Things that need to be understood during the making of this simulation program are programming, mathematical concepts about geometry, kinematic and dynamics of robot manipulator.

The control system in this research is using proportional integral derivative (PID) and Fuzzy-PD as in Figure 2, where for Fuzzy-PD input variables are using error θ_1, error θ_2, Δerror θ_1 and Δerror θ_2 while the output variables are tho_1 and tho_2 [12-16]. The distribution of membership function for each input error and Δerror is represented in Figure 3(a) and 3(b), for the output as in Figure 4, while for rule evaluation is described in Table 1. This tho output is included in dynamic equation, so the kinetic and potential energy can be entered. The result of this dynamic process were produce an angular acceleration of θ_1 and θ_2. Both angular accelerations are incorporated in the kinematic forward and the integral of this kinematic forward is used to obtain the angle of each arm.Center of Area (COA) is chosen as defuzzification method, which calculates the area center ofthe fuzzy set membership function curve surrounded by the horizontal coordinate.

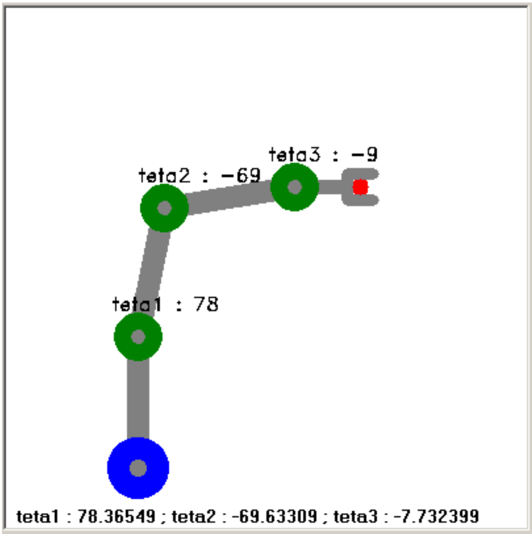


Figure 1. 3 DOF*three-link planar* physical structure [2]

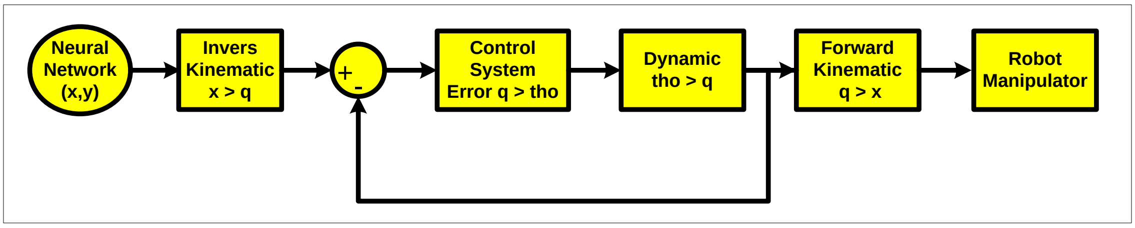
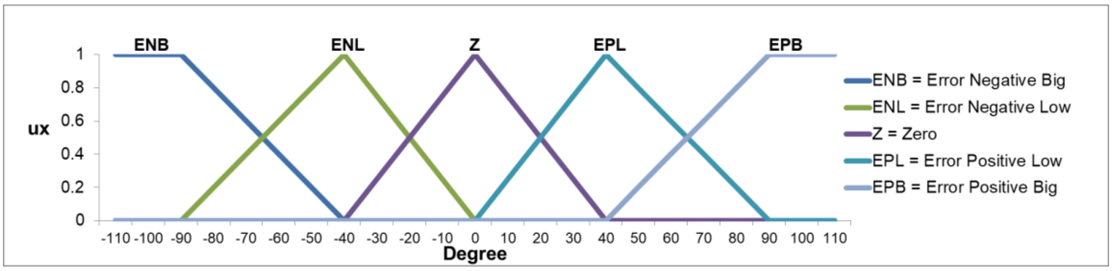
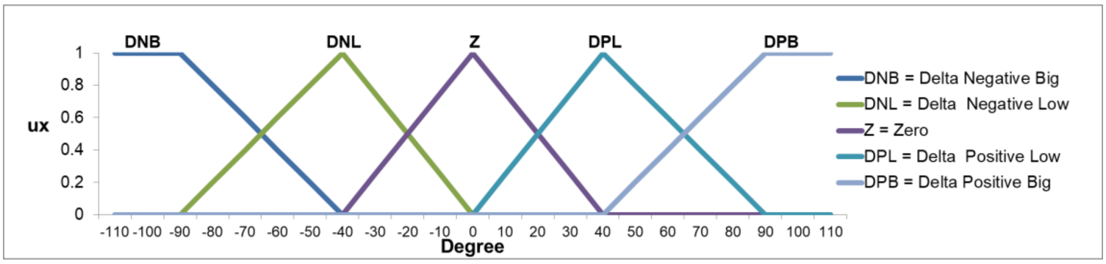


Figure 2. Block diagram control system on simulation of 3 DOF robot manipulator.



(a)



(b)

Figure 3. Fuzzification of input variable (a) error input (b) delta error inputx

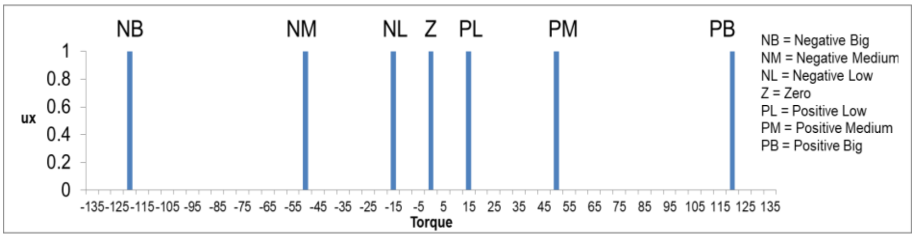


Figure 4. Fuzzification of output variable

Table 1. Rule evaluation of fuzzy-PD inference system

		Delta Error				
		Neg Big	Neg Small	Z	Pos Small	Pos Big
Error	Neg Big	PB	PB	PL	PB	PB
	Neg Small	PB	PL	PL	PL	PB
	Z	PL	PL	Z	PL	PL
	Pos Small	NB	NL	NL	NL	NB
	Pos Big	NB	NB	NL	NB	NB

The working principles of this system are; at the beginningwill be given some input target coordinate point (x, y) which created randomly, and then SOM will conduct trainingautomatically until a certain epoch to get the best trajectory points. After the trajectory points obtained then it will be converted into angular form for link 1 and link 2by using kinematic inverse. The Fuzzy-PD control system will evaluate the given angle error, the Fuzzy-PD control system is selected due to the robust excess and it is more resistant to the noise with different object conditions when it compared to PID [15]. Flowchart of the simulation program is created in Figure 5, the program results as in Figure 6. The initial process in this simulation program will put the target position points, then runs the SOM neural network program to generate trajectory. The trajectory result is converted into an angle with the inverse kinematic of robot manipulator. The output of the kinematic inverse is made as a setpoint for the Fuzzy-PDcontrol; its output will be processed to dynamic, so the present output is angular. This angle always is corrected by Fuzzy-PDtill the result is close to the set point. In addition the angle of the dynamic process is processed again to the kinematic forward to become the robot manipulator position.

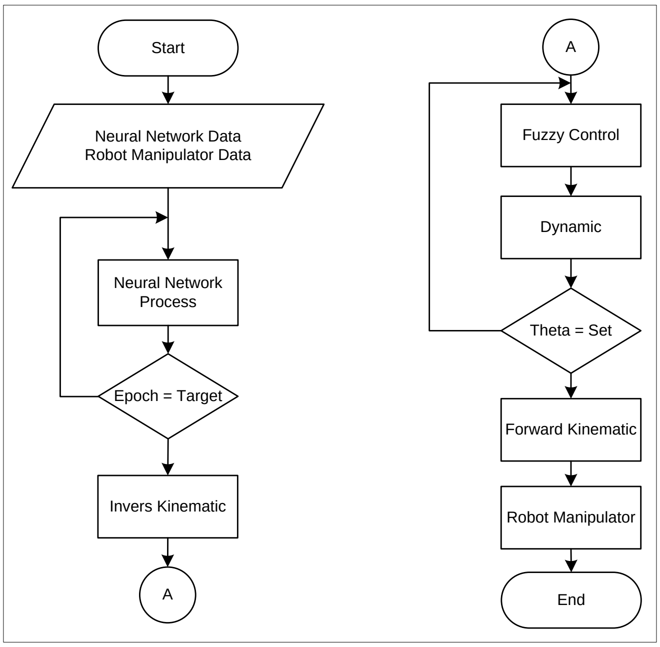


Figure 5. Flowchart of simulation program

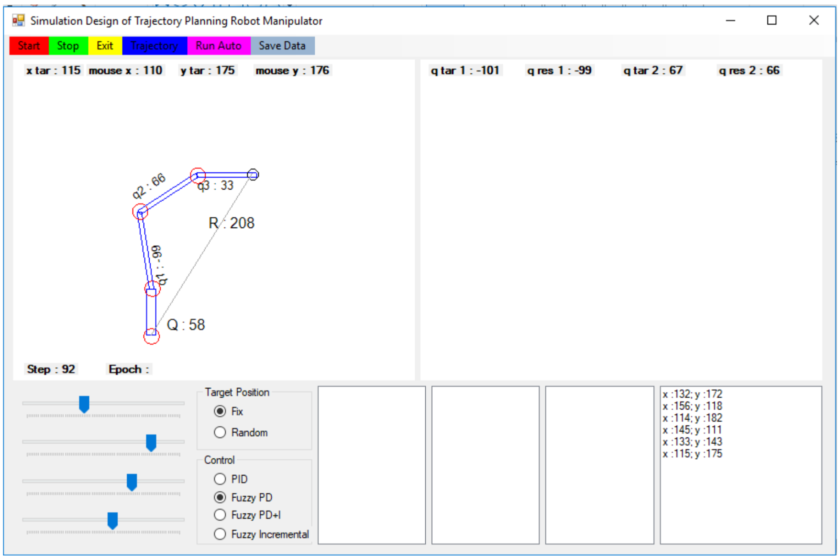
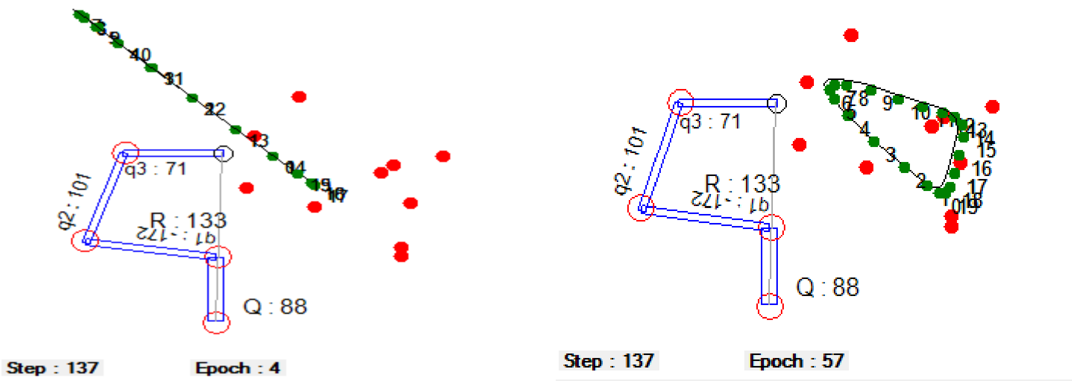


Figure 6. Manipulator robot simulation program

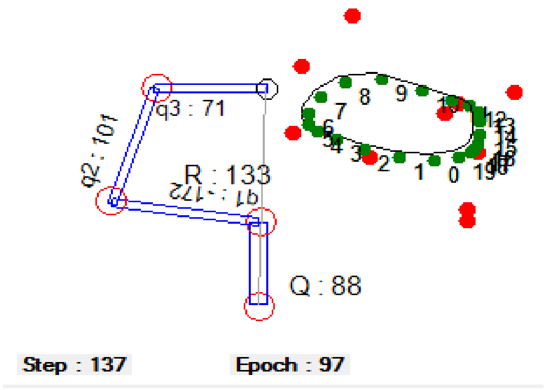
3. RESULTS AND ANALYSIS

Simulation was performed in Visual Studio C# software to investigate the performance of Fuzzy-PD and PID controller for finding an optimal path between source and destination. The simulation results are demonstrated in thissection. Travelling salesman problem (TSP) implementation program with SOM on simulation of robot manipulator is using Fuzzy-PD control system and follows the block diagram in Figure 2. The used scale for this simulation is 1 pixel=1 cm, while speed in robot motion unit is 10 cm/sec. The gravity value is equal to 9.8 cm/s^2, shoulder length of 0.75 m and elbow of 0.85 m. At the first run, the point distributed randomly around the EE, the number of points is 10, the plot results from this point as in Figure 7(a) when it was executed by using SOM algorithm then the result as shown in Figure 7(b)-(d). Based on Figure 7(b)-(d) it can be described that during SOM process, the network were formed following the specified target point. This network is created as a trajectory robot manipulator. The next testing stage is to provide new target points, the result can be seen in Figure 8(a)-(h), where the red (large) point is the target and the green dot (small) is the SOM process. SOM was used in the study because it was better than back propagation in the previous studies [17], this is due to the learning process of SOM that doesn't need to be guided to make trajectory. Trajectory Planning Robot Manipulator simulation test in this research is using 20 target points where in the previous research is less than 20 target points [19].

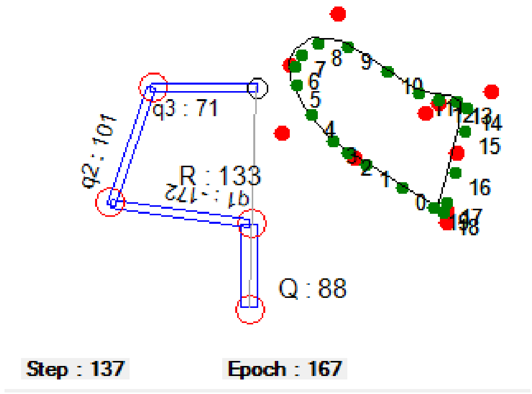


(a) the initial process

(b) SOM process on the 57th*epoch*

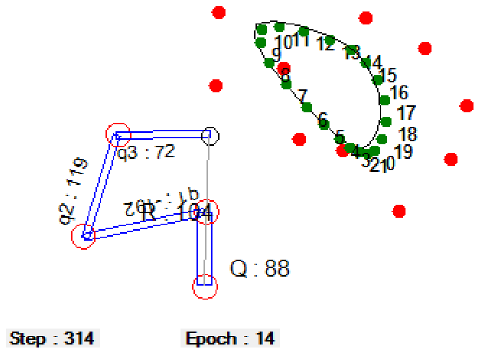


(c) SOM on the 97th epoch

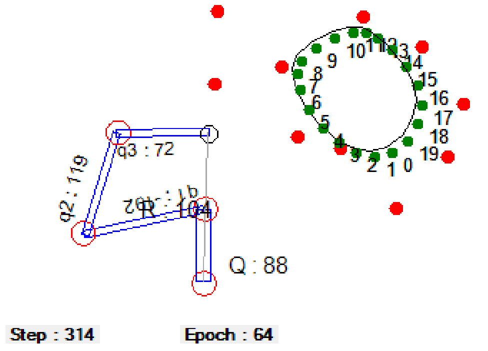


(d) SOM processon the 167th epoch

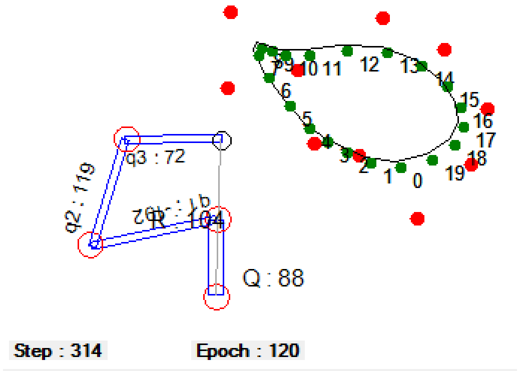
Figure 7. First simulation



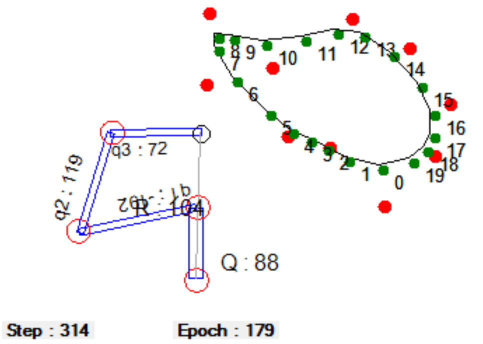
(a) SOM process on the 14th epoch



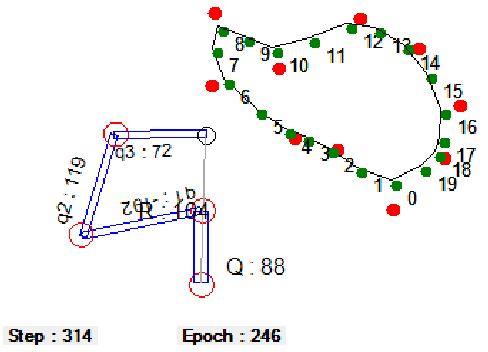
(b) SOM process on the 64th epoch



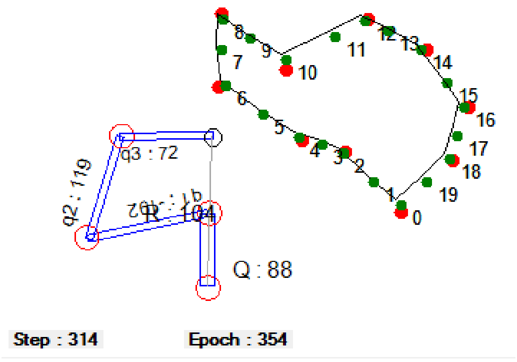
(c) SOM process on the 120th epoch



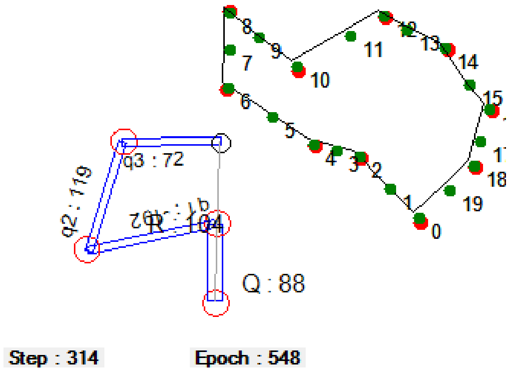
(d) SOM process on the179th epoch



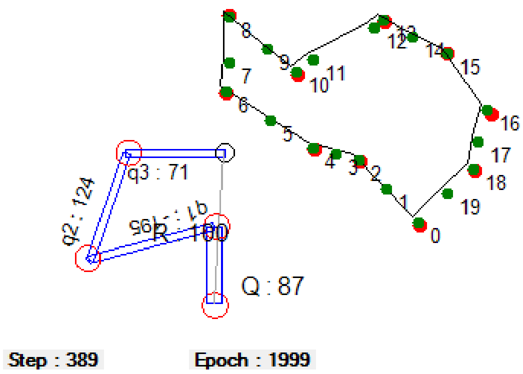
(e) SOM process on the 246th epoch



(f) SOM process on the 354th epoch



(g) SOM process on the 548th epoch



(h) SOM process on the 1999th epoch

Figure 8. Second simulation

Based on the Figure 8(a)-8(h), when epoch isless than 246 SOM the process has not achieved the target points optimally. After entering epoch above 354, SOM process has achieved the target points and kept stable until 1999th epoch. Result of trajectory planningcan be seenin Figure 9, where the result of trajectory robot manipulator is able to follow trajectory that formed by neural network. Figure 10 and Figure 11, represents a change in angle q1 and q2 during the arm manipulator process along the planned targets using the Fuzzy-PD control, while Figure 11 when using PID controls. The testing process of arm manipulator is using random points between 9 to 182 on x-axis and 52-186 on y-axis. The result of this arm manipulator simulation test has an average error of 3.57% on x-axis and 0.88% on y-axis for PID control, whereas The Fuzzy-PD has an average error of 2.62% on x-axis and 1.31% in y-axis. The average error on x-axis and y-axis for the Fuzzy-PD control is 2.225%, when using the PID control the error is 1.965%. This result is better than previous studies that have an average error of 3% [20]. The complete result during the process of movement of this manipulator arm is represented in Table 2 and Table 3.

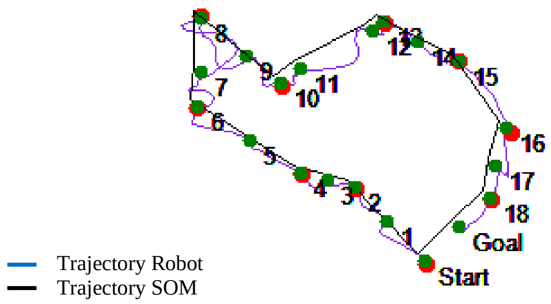


Figure 9. Trajectory robot manipulator during the simulation process

Table 2. Target vs SOM results for (x,y) coordinates using fuzzy-PD

Target x	*SOM result x*	*Error (%)*	*Target y*	*SOM result y*	*Error (%)*
175	175	0.00%	103	103	0.00%
182	181	0.55%	124	124	0.00%
167	169	1.20%	142	140	1.41%
153	154	0.65%	163	161	1.23%
147	148	0.68%	167	166	0.60%
118	120	1.69%	181	180	0.55%
112	112	0.00%	185	183	1.08%
96	94	2.08%	185	187	1.08%
26	27	3.85%	184	184	0.00%
10	12	20.00%	186	185	0.54%
9	7	22.22%	142	143	0.70%
33	31	6.06%	148	146	1.35%
55	54	1.82%	149	149	0.00%
62	61	1.61%	123	125	1.63%
66	66	0.00%	101	102	0.99%
82	80	2.44%	97	95	2.06%
96	94	2.08%	93	95	2.15%
116	114	1.72%	75	75	0.00%
137	135	1.46%	54	54	0.00%
170	168	1.18%	86	84	2.33%
Average		3.57%	Average		0.88%

Table 3. Target vs SOM results for (x,y) coordinates using PID

Target x	*SOM result x*	*Error (%)*	*Target y*	*SOM result y*	*Error (%)*
152	151	0.66%	69	67	2.90%
135	136	0.74%	52	54	3.85%
112	111	0.89%	76	74	2.63%
96	96	0.00%	93	91	2.15%
83	84	1.20%	96	94	2.08%
66	68	3.03%	101	100	0.99%
39	40	2.56%	119	117	1.68%
9	8	11.11%	138	136	1.45%
10	9	10.00%	160	158	1.25%
11	12	9.09%	187	186	0.53%
35	34	2.86%	167	166	0.60%
55	53	3.64%	151	151	0.00%
79	79	0.00%	165	163	1.21%
112	111	0.89%	184	182	1.09%
133	131	1.50%	173	174	0.58%
153	151	1.31%	164	164	0.00%
164	165	0.61%	147	149	1.36%
181	181	0.00%	124	125	0.81%
175	177	1.14%	103	102	0.97%
171	173	1.17%	87	87	0.00%
Average		2.62%	Average		1.31%

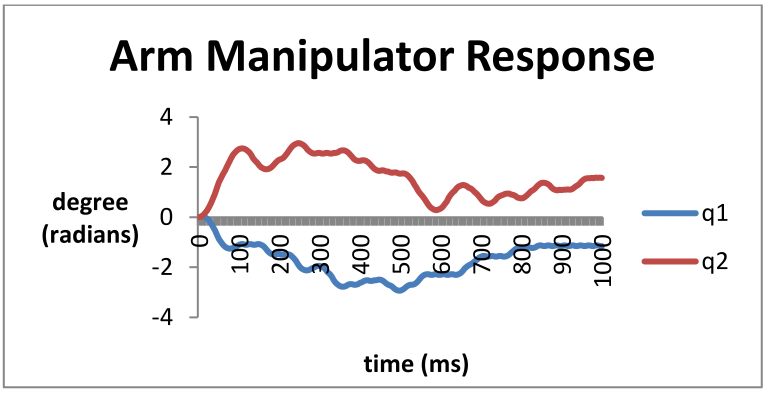


Figure 10. The angle changes of the arm manipulator using Fuzzy-PD

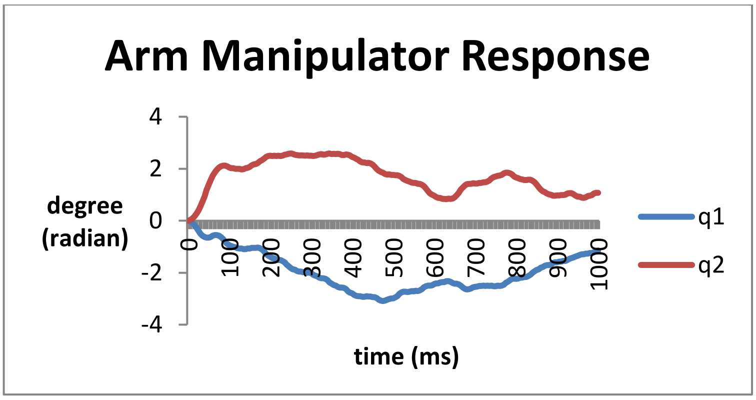


Figure 11. The angle changes of the arm manipulator using PID

The novel of this research is the use of Fuzzy-PD on SOM application. In most cases, SOM applications are using heuristic-based methods such as Back Propagation Neural Network and Extreme Learning Machine [21] to model the movement of robotic arms, this heuristic method has limitations to the generated response if the used dataset and sensor readings are not suitable with the field conditions. Therefore this research concludes that kinematic inverse modeling will be more efficient by using an error-based method through the use of PID and with a little additional logic rule (Fuzzy-PD). The result shows the error-based method by using either PID or Fuzzy-PD has been able to produce a smaller error deviation than the ANN and Genetic Algorithm methods [20].

4. CONCLUSION

Trajectory planning on robot manipulator by using SOM neural network and Fuzzy logic control is able to guide robot manipulator to reach the target points. The obtained results from this simulation to reach the target point is when using the Fuzzy-PD control, errors are in x coordinates is 3.57% and y coordinates is 0.88% or the average of both is 2.225%. When using PID, errors are in x coordinates is 2.62% and y coordinates is 1.31% or the average is 1.965%.

REFERENCES

[1] HalaBezine, NabilDerbel, Adel M Alimi.Fuzzy control of robot manipulators: some issues on design and rule base size reduction. *Science Direct Engineering Applications of Artificial Intelligence*. 2002; 15(5): 401–416.

[2] W S Pambudi, N M A Sumanang. Implementation of FuzzyPD to Determine Object Position on Simulation Model of Robot Arm Manipulator 3 DOF (Degree of Freedom) in 2D. *Mikrotek Journal*, Universitas Trunojoyo Madura. 2014; 1(2): 19-29 (original version in Bahasa Indonesia).

[3] Jinho K, Andrew S. Lee, Kevin C, Brian S, S A Gadsden. M Al-Shabi. *Dynamic Modeling and Motion Control of a Three-Link Robotic Manipulator.* The 2017 International Conference on Artificial Life and Robotics (ICAROB 2017). Miyazaki. 2017; P-380 – P-381.
[4] I. Pajak, "Trajectory planning of cooperative mobile manipulators subject to control constraints," *2017 11th International Workshop on Robot Motion and Control (RoMoCo)*, Wasowo, 2017, pp. 123-128.
[5] Adri`a Colom´e. Smooth Inverse Kinematics Algorithms for Serial Redundant Robots. Master Thesis. Barcelona: Institute de Rob`oticai Inform`atica Industrial (IRI). 2011.
[6] Li Jingwei, Tong Yifei, Wu Shaofeng, Tan Qingmeng, Li Dongbo. Welding Robot Kinematics Analysis and TrajectoryPlanning. *TELKOMNIKA (Telecommunication, Computing, Electronics and Control) Indonesian Journal of Electrical Engineering*. 2016; 14(2A): 92-100.
[7] V. K. Banga, Y. Singh, and R. Kumar. Simulation of Robotic Arm using Genetic Algorithm & AHP. *World Academy of Science, Engineering and Technology* 25 2007. 2007; 25: 95-101.
[8] YanpingBai, Wendong Zhang, Zhen Jin. An new self-organizing maps strategy for solvingthe traveling salesman problem. *Science Direct Elsevier, Chaos, Solitons and Fractals 28 (2006)*. 2006; 1082–1089.
[9] Kwong-SakLeunga, Hui-Dong Jinb, Zong-Ben Xu. An expanding self-organizing neural networkfor the traveling salesman problem.*Science Direct Elsevier Neurocomputing 62 (2004)*.2004; 267-292.
[10] Boumediene Selma, Samira Chouraqui. Neural Network Navigation Technique for UnmannedVehicle. *Bulletin of Electrical Engineering and Informatics (BEEI)*. 2014; 3(3): 195-200.
[11] MeenakshiMoza, Suresh Kumar. Routing in Networks using Genetic Algorithm. *Bulletin of Electrical Engineering and Informatics (BEEI)*. 2017; 6(1): 88-98.
[12] ManafeddinNamazov and OnurBasturk.DC motor position control using fuzzy proportional-derivative controllers with different defuzzification methods. *Turkish Journal of Fuzzy Systems.* 2010; 1(1): 36-54.
[13] W M N WLezaini, A Irawan, S N S Ali.Forkloader Position Control for A Mini Heavy LoadedVehicle using Fuzzy Logic-Antiwindup Control. *TELKOMNIKA (Telecommunication, Computing, Electronics and Control) Indonesian Journal of Electrical Engineering*. 2017; 15(2): 739-745.
[14] SM Rakhtala, E ShafieeRoudbari. Application of PEM Fuel Cell for Stand-alone Based ona Fuzzy PID Control. *Bulletin of Electrical Engineering and Informatics (BEEI)*. 2016; 5(1): 45-61.
[15] AliGhareaghaji. A Comparison between Fuzzy-PSO Controller and PIDPSO Controller for Controlling a DC Motor.*Bulletin of Electrical Engineering and Informatics*. 2015; 4(2): 130-135.
[16] W S Pambudi. T Suheta. Implementation of Fuzzy-PD for Folding MachinePrototype Using LEGO EV3. *TELKOMNIKA Telecommunication, Computing, Electronics and Control) Indonesian Journal of Electrical Engineering*. 2018; 16(4): 1625-1632.
[17] Y Bassil. Neural Network Model for Path-PlanningOf Robotic Rover Systems. *International Journal of Science and Technology (IJST)*.2012; 2(2).
[18] Fausett. Fundamentals of Neural Networks: Architectures, Algorithms And Applications", Pearson, 1 edition (December 19, 1993). 1993: 169 -175.
[19] A Prasad, B Sharma.J Vanualailai. Motion Control of a 2-link Revolute Manipulator in an Obstacle-Ridden Workspace. *World Academy of Science, Engineering and Technology International Journal of Mathematical and Computational Sciences.* 2012; 6(12): 1751-1756.
[20] Akash Dutt Dubey, R. B. Mishra, A. K. Jha. Task Time Optimization of a Robot Manipulator using Artificial Neural Network and Genetic Algorithm. *International Journal of Computer Applications*. 2012; 51(13):26-33.
[21] RY Putra, *Neural Network Implementation for Invers Kinematic Model of Arm Drawing Robot.* International Symposium on Electronics and Smart Devices (ISESD).153-157. 2016.