Future Generation of Communication and Internet of Things (FGCIOT)

Journal homepage: http://fgciot.semnaniau.ac.ir/

Paper type (Research paper)

Design a robot arm to write English word

Amin Akhlaghi

Bachelor, Medical Engineering, Islamic Azad University of Semnan, Semnan

Article Info

Article History:
Received July 08, 2022
Revised August 02, 2022
Accepted August 15, 2022

Keywords:
simulation
robotic
Author
Optimization
automatically

*Corresponding Author's Email Address:
amin.akhlaghi.1999@gmail.com

Abstract

In this article, the pen tip angles of a robotic arm taken from a human hand with the ability to write Latin words in upper and lower case with axes and degrees of freedom that are in accordance with the anatomy of the human hand are simulated and designed. This robotic arm is simulated along with the code that is implemented in MATLAB and the output of the designed system is reported in this article and its errors are also investigated. There is the issue of replacing robotic equipment instead of humans in high-precision industrial work, which is sometimes in difficult conditions that are beyond the ability and endurance of humans, but with the help of robots, these activities can be performed completely. And energy resources, time and raw materials are also saved because the use of the robot keeps the accuracy of the repetition activity the same in all stages of the work and the speed of the work can be controlled.

Introduction

A robot is a machine that can usually be programmed by a computer and is able to automatically perform a number of complex actions [1,2]. Robotics is a branch between engineering and science that includes mechanical engineering, electrical engineering and computer science. Robotics includes the design, construction, operation and application of robots [3].
A robotic arm is a type of mechanical arm, generally programmable, that has similar uses to a human arm. The robotic arm may be a robot itself or part of a more complex robot. Static robotic arms have been of interest in the industry due to their high capabilities. They can perform repetitive tasks with high accuracy [4,5].
In the last few decades, a lot of attention has been paid to the control of the robot arm and many works have been done on the control of the robot arm. Various control methods and many controllers have been implemented on robotic arms, each of which has its own merits and demerits. Among them, the following control methods can be mentioned:
Robust control [6,7], optimal control [8,9], adaptive control [10,11], predictive control [12], linear control [13,14] PID, nonlinear sliding mode control [15,16] and intelligent control including neural networks and fuzzy type control First and second and so on.

Meanwhile, the use of PD and PID linear controls are one of the common control methods in the control of mechanical arms and are widely used in the industry. But as we know, linear controllers are subject to uncertainties and inefficient system disturbances. In recent researches, intelligent control techniques have been considered as a suitable alternative to classical control techniques (including: linear control, non-linear and sliding mode control, resistant control, etc.). The advantage of fuzzy and neural intelligent methods compared to The classical methods are that in intelligent methods, accurate knowledge of the mathematical model and dynamics of the system, which are often difficult to obtain, is not required. Fuzzy control is very easy to use because it usually does not require a mathematical model of the system under control. And it works very well in systems that are complex, ill-defined, non-linear and change with

Doi:

time. In general, the superiority of fuzzy control is the use of human knowledge (the knowledge and experiences of an expert) in the control process [17]. The problem that can be taken with fuzzy controllers is that, compared to classical controllers such as PID linear controllers or non-linear controllers, etc., it is more difficult and complicated to check and prove their stability, because the analysis Their stability is discrete-time and requires its own mathematics-Fuzzy control methods successfully in control Complex non-linear and multi-variable systems such as robotic arms and decision-making systems are used to overcome various complications. As an example in references [18,19], the fuzzy controller is used to control a PUMA and SCARA robot arm, respectively. Also, in [20], a fuzzy controller is designed using an innovative algorithm to control the robot arm.

Neural networks have the inherent ability to learn and estimate a nonlinear function with desired accuracy. This feature is used in control in order to model complex processes and compensate unstructured uncertainties [21]. However, its inevitable training process reduces its transient performance in the face of disturbances and uncertainties, and for some systems such as a robot arm, which are subject to uncertainties and the model information is insufficient It is not used, it degrades the performance of the transient state of the system. Controlling the position of the mechanical arm using neural networks is given as an example in references [22,23,24]. Also, in references [25, 26] adaptive neural network control on robotic arms is presented.

In [27,28,29] adaptive neural-fuzzy network control and in [30,31] adaptive neuro-fuzzy control have been applied to industrial and laboratory robotic arms. Also, in reference [32], a new robust adaptive control method is presented to control the position of the SCARA robot arm, and recently, in the research [33], a robust neuro-adaptive controller was designed to control parallel cable robots.
Fuzzy-neural inference system based on adaptive network (ANFIS), [35,34] is a neural network realization of Takagi-Sugno fuzzy inference system. In neural-fuzzy models such as ANFIS, neural network and fuzzy system work in a coordinated structure and have a complementary relationship with each other. In fact, the ANFIS model can be considered a fuzzy system with distributed learning that uses the training methods that are common in neural networks. The ANFIS network simultaneously uses the advantages of neural networks (that is, learning and adaptability) and the advantages of fuzzy logic (that is, the use of expert knowledge) to achieve the goal of robust control in dynamic systems. ANFIS network, in addition to It is able to estimate any non-linear function with desired accuracy, but it has high convergence speed and low error. It also needs less training data. Therefore, it seems to be a suitable choice as a controller for the mechanical robot arm. In the researches [36,37,38] ANFIS controller has been used to control a robotic arm. In reference [39], a comparison between ANFIS controller and conventional PID controller for a 3-link rigid robot arm has been made, in which it is clearly It can be seen that the step response of ANFIS controller is more suitable and better than the step response of PID controller. Also, in reference [40], ANFIS controller with Sugno fuzzy controller of the second type and PID controller, for a 2-link arm mounted on a base Oscillation has been compared which shows the superiority of the ANFIS controller over the other two controllers.

I. Forward kinematic:

We place the coordinate axes of the mentioned robot in the places of Joints and End Effector as below and considering that all 3 Joints are of Revolute type according to the direction of their rotation while using the right hand rule, the direction of the thumb is aligned We consider the positive Z axis of each joint.

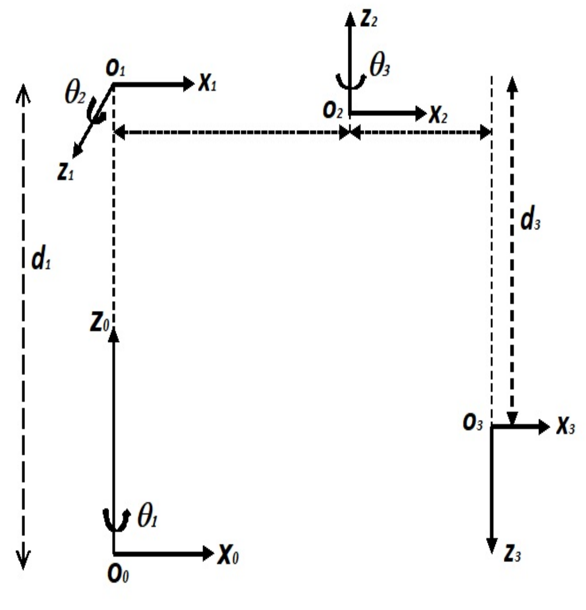


Figure 1: Coordinate system at the location of joints and end effector of the robot

With the transformation matrices, we will be able to obtain the rotation and position matrix at the final location of the robot (the tip of the pen placed on the paper page).
To achieve this, we use the Hartenberg (D-H) Denavit method and form the D-H parameter table, which is as follows:

Table 1: Table of D-H parameters

	θ	d	a	α
Link1	θ_1*	d_1	0	90°
Link2	θ_2*	0	a_1	-90°
Link3	θ_3*	d_3	a_2	180°

Now, according to the table of D-H parameters, we obtain the transformation matrices of both consecutive frames (from the first frame to the frame on the end effector), the result of which is shown below:

Transformation matrices

$$A_1=\begin{bmatrix}\cos\theta_1 & 0 & \sin\theta_1 & 0\\ \sin\theta_1 & 0 & -\cos\theta_1 & 0\\ 0 & 1 & 0 & d_1\\ 0 & 0 & 0 & 1\end{bmatrix}$$

$$A_2=\begin{bmatrix}\cos\theta_2 & 0 & -\sin\theta_2 & a_2\cos\theta_2\\ \sin\theta_2 & 0 & \cos\theta_2 & a_2\sin\theta_2\\ 0 & -1 & 0 & 0\\ 0 & 0 & 0 & 1\end{bmatrix}$$

$$A_3=\begin{bmatrix}\cos\theta_3 & \sin\theta_3 & 0 & a_3\cos\theta_3\\ \sin\theta_3 & -\cos\theta_3 & 0 & a_3\sin\theta_3\\ 0 & 0 & -1 & d_3\\ 0 & 0 & 0 & 1\end{bmatrix}$$

By multiplying these matrices together, a matrix called Homogenous matrix is formed, which has both position and rotation.

$$\cos\theta_i = c_i$$
$$\sin\theta_i = s_i$$

Homogeneous matrix

$$H: A_1A_2A_3=\begin{bmatrix}c_1c_2c_3 - s_1s_3 & c_1c_2s_3 - s_1c_3 & c_1s_2 & a_3c_1c_2c_3 - a_3s_1s_2 + a_2c_1c_2\\ s_1c_2c_3 + c_1s_3 & s_1c_1s_3 - c_1c_3 & s_1s_2 & a_3s_1c_2c_3 + a_3c_1s_2 - d_3s_1s_2 + a_2s_1c_2\\ s_2c_3 & s_2s_3 & -c_2 & a_3s_2c_3 + d_3c_2 + a_2s_2 + d_1\\ 0 & 0 & 0 & 1\end{bmatrix}$$

II. Velocity kinematic:

By deriving the elements of the position matrix (as described below), a Jacobian matrix is obtained.

Jacobian matrix formula display

$$J=\begin{bmatrix}\frac{\partial p_x}{\partial\theta_1} & \frac{\partial p_x}{\partial\theta_2} & \frac{\partial p_x}{\partial\theta_3}\\ \frac{\partial p_y}{\partial\theta_1} & \frac{\partial p_y}{\partial\theta_2} & \frac{\partial p_y}{\partial\theta_3}\\ \frac{\partial p_z}{\partial\theta_1} & \frac{\partial p_z}{\partial\theta_2} & \frac{\partial p_z}{\partial\theta_3}\end{bmatrix}$$

$$P=\begin{bmatrix}p_x\\ p_y\\ p_z\end{bmatrix}$$

The final Jacobian matrix

$J=$

$$\begin{bmatrix}-L_3s_1c_2c_3 - L_3c_1s_3 + L_4s_1s_2 - L_3s_1c_2 & -L_3c_1s_2c_3 - L_4c_1c_2 - L_2c_1s_2 & -L_3c_1c_2s_3 - L_3s_1c_3\\ L_3c_1c_2c_3 - L_3s_1s_3 - L_4c_1s_2 + L_2s_1c_2 & -L_3s_1s_2c_3 - L_4s_1c_2 - L_2s_1s_2 & -L_3s_1c_2s_3 + L_3c_1c_3\\ 0 & L_3c_2c_3 - L_4s_2 + L_2c_2 & -L_3s_2s_3\end{bmatrix}\begin{bmatrix}L_1\\ L_2\\ L_3\\ L_4\end{bmatrix}=$$

$$\begin{bmatrix}d_1\\ a_2\\ a_3\\ d_3\end{bmatrix}$$

Considering that the writer's robot in this project is of serial type, therefore, if the speed we are considering is a specific speed at the tip of the pen and in the direction of X, Y and Z.

So we can have:

$$\begin{bmatrix} d\theta_1/dt \\ d\theta_2/dt \\ d\theta_3/dt \end{bmatrix} = J^{-1} \times \begin{bmatrix} dx_{end\_effector}/dt \\ dy_{end\_effector}/dt \\ dz_{end\_effector}/dt \end{bmatrix}$$

III. Inverse kinematics:

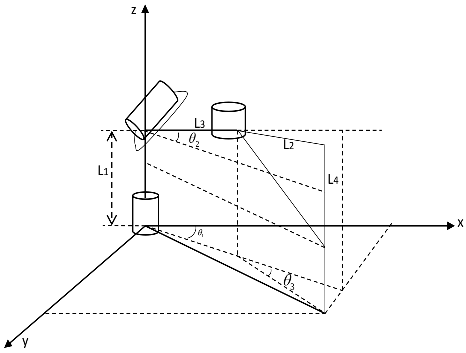


Figure 2: view of the general coordinate system of the robot 3D

In order to be able to write the value of the angles of the robot's joints for the location of the tip of the pen on the robot (end effector location), it is necessary to use the inverse kinematics of the robot:

Now, if we look at the three-dimensional view from the side view (X-Z plane), the angle of Joint No. 2 is obtained, and if from the top view (X-Y page) Let's see the angle of Joints No. 2 and 3 will be obtained, which is as follows:

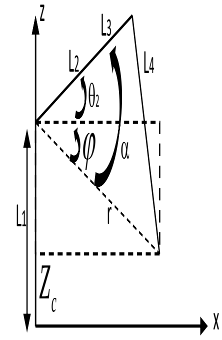


Figure 3: Calculating the angles of joints according to the location of the tip of the pen

$$r = \sqrt{(L_1 + L_2)^2 + L_4^2}$$

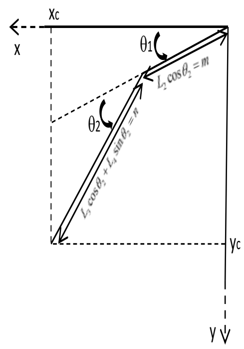
$$\sin\varphi = \frac{L_1 - Z_c}{r}$$

$$\varphi = a\tan 2\left[\left(\frac{L_1 - Z_c}{r}\right), \sqrt{1 - \left(\frac{L_1 - Z_c}{r}\right)^2} \right]$$

$$\alpha = a\tan 2(L_4, L_2 + L_3)$$

$$\theta_2 = \alpha - \varphi$$

$$\theta_2 = a\tan 2(L_4, L_2 + L_3) - a\tan 2\left(\left(\frac{L_1 - Z_c}{\sqrt{(L_1 + L_2)^2 + L_4^2}}\right), \sqrt{1 - \left(\frac{L_1 - Z_c}{(L_1 + L_2)^2 + L_4^2}\right)^2} \right)$$



Future Generation of Communication and Internet of Things (FGCIOT)

Journal homepage: http://fgciot.semnaniau.ac.ir/

$$m^2 + n^2 + 2mn\cos\theta_3 = x_c^2 + y_c^2$$

$$\Rightarrow \cos\theta_3 = \frac{x_c^2 + y_c^2 - m^2 - n^2}{2mn}$$

$$\Rightarrow \cos\theta_3 = \frac{x_c^2 + y_c^2 - L_2^2\cos^2\theta_2 - (L_3\cos\theta_2 + L_4\sin\theta_2)^2}{2L_2\cos\theta_2(L_3\cos\theta_2 + L_4\sin\theta_2)}$$

$$\theta_3 = a\tan 2\left(\sqrt{1-(\frac{x_c^2 + y_c^2 - L_2^2\cos^2\theta_2 - (L_3\cos\theta_2 + L_4\sin\theta_2)^2}{2L_2\cos\theta_2(L_3\cos\theta_2 + L_4\sin\theta_2)}}, \frac{x_c^2 + y_c^2 - L_2^2\cos^2\theta_2 - (L_3\cos\theta_2 + L_4\sin\theta_2)^2}{2L_2\cos\theta_2(L_3\cos\theta_2 + L_4\sin\theta_2)}\right)$$

$$\theta_1 = a\tan 2(y_c, x_c) - a\tan 2\left[(L_3\cos\theta_2 + L_4\sin\theta_2)\sin\theta_3, L_2\cos\theta_2 + (L_3\cos\theta_2 + L_4\sin\theta_2)\cos\theta_3\right]$$

IV. Work Space:

The space that can be covered by the movement of the tip of the pen on the paper can be displayed as the working space of the writer's robot. Here, we have assumed that the physical and structural system of the robot we are considering is made so that the limits of angle changes are as shown in the figure below.

$$\sqrt{L_2^2 + L_3^2 - L_2 L_3\sqrt{2}} = r$$

θ_3	closed	open	open	closed
θ_1	closed	closed	open	open

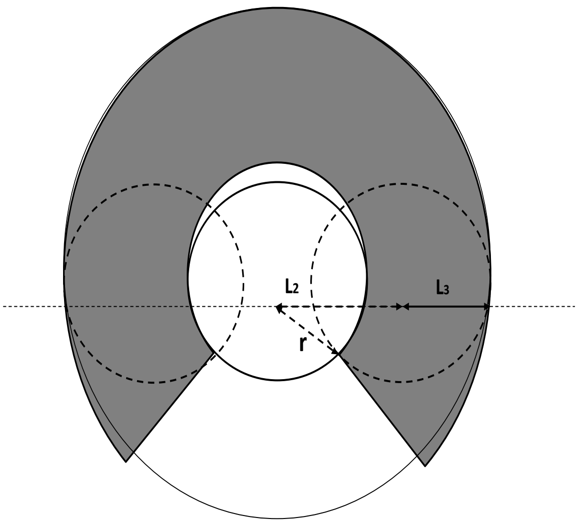


Figure 4: Robot workspace (view from above)

The required working space is the working space that we look at the robot from above, because only the space that the pen tip draws on the paper page is relevant to us, and any space that the pen tip travels while removing it from the paper page. It was not considered by us and we have not checked it.

Designing the movement path for drawing letters

Since Latin letters are a combination of circular paths or broken lines, we decided to:

• Write a polynomial equation for one of the parameters X or Y in the parts of the letters that are part of a line, and

Doi:

express a line equation in terms of the other one.

• In the parts of the letters that are in the form of a circle, write a polynomial equation for one of the X or Y parameters and express a circle equation in terms of that one for the other (of course, we must be careful depending on Which quadrant of the circle is considered, let's get the equation according to that area of the circle).

For each line segment navigation, we have the location of the start and end points of that line segment (according to the corresponding letter). As a designer, we can design and choose the speed of the beginning and the end. The start time and the end time are also available. Now we can obtain the coefficients of the polynomial with four unknowns for each line segment and rewrite the corresponding polynomial as shown below:

Calculation of polynomial coefficients and rewriting X as a function of time

$$x = a_0 + a_1 t + a_2 t^2 + a_3 t^3$$

$$\dot{x} = a_1 + 2a_2 t + 3a_3 t^2$$

$$x(t_0) = x_0 \rightarrow a_0 + a_1 t_0 + a_2 t_0^2 + a_3 t_0^3 = x_0$$

$$x(t_f) = x_f \rightarrow a_0 + a_1 t_f + a_2 t_f^2 + a_3 t_f^3 = x_f$$

$$\dot{x}(t_0) = \dot{x}_0 \rightarrow a_1 + 2a_2 t_0 + 3a_3 t_0^2 = \dot{x}_0$$

$$\dot{x}(t_f) = \dot{x}_f \rightarrow a_1 + 2a_2 t_f + 3a_3 t_f^2 = \dot{x}_f$$

$$\begin{bmatrix} 0 & 1 & 2t_0 & 3t_0^2 \\ 0 & 1 & 2t_f & 3t_f^2 \\ 1 & t_0 & t_0^2 & t_0^3 \\ 1 & t_f & t_f^2 & t_f^3 \end{bmatrix}_T \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \end{bmatrix}_A = \begin{bmatrix} \dot{x} \\ \dot{x}_f \\ x_0 \\ x_f \end{bmatrix}_X$$

$$A = T^{-1} X$$

$$\begin{Bmatrix} X = A(1) + A(2)t + A(3)t^2 + A(4)t^3 \\ A(1) = a_0, A(2) = a_1, A(3) = a_2, A(4) = a_3 \end{Bmatrix}$$

To navigate the circular paths, assuming for example for Y, we obtain the polynomial equation exactly similar to the previous part. For circular paths, according to the start and end points, for each circular part in the representation of each letter, we have:

Circle equations for letter-shaped circular paths

$$(x - x_0)^2 + (y - y_0)^2 = R^2$$

$$x = \pm\sqrt{R^2 - (y - y_0)^2} + x_0$$

$$x_0 = \frac{(end)x + (start)x}{2}$$

$$y_0 = \frac{(end)y + (start)y}{2}$$

$$R = \sqrt{((end)x - (start)x)^2 + ((end)y - (start)y)^2}$$

Now, when the path of the circle is in the first or fourth quadrant, we use the positive sign in the formula related to X, and when the path of the circle is in the second or third quadrant, we use the negative sign in the formula.

For example, we have:

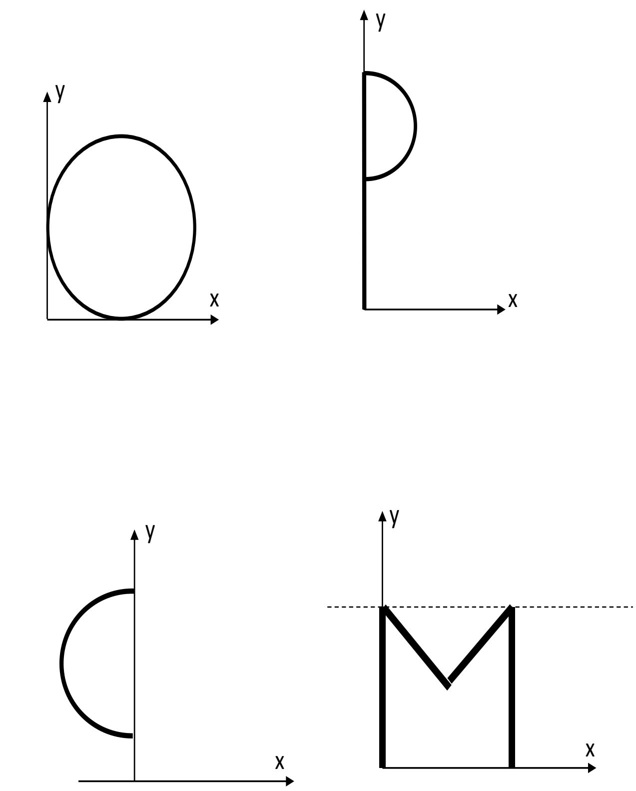


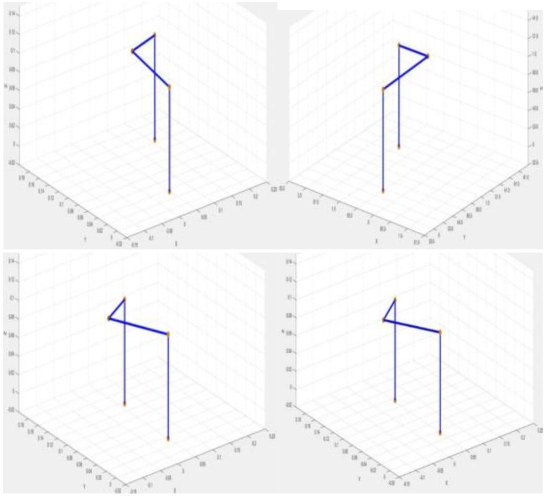
Figure 5: Sample placement of letters on the coordinate plane

V. Results

For example, some Latin words are given to the robot, and its movement along the path is shown below in the form of several photos, and the first and last thetas calculated from the angles of the joints are also presented to you according to the location of the pen tip.

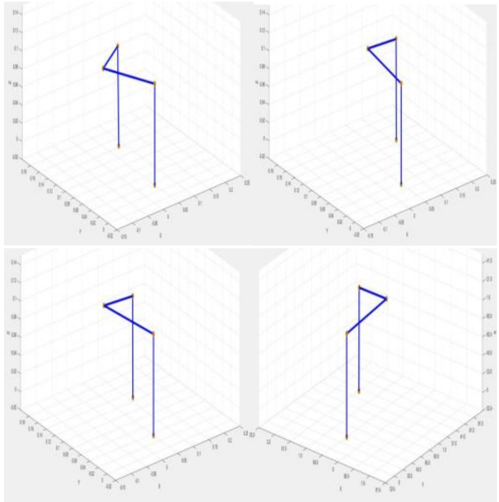
Please enter a word: amin

{ theta1 = 141.4767 & theta3 = 121.9688 } start
{ theta1 = 74.0319 & theta3 = 65.2424 } end



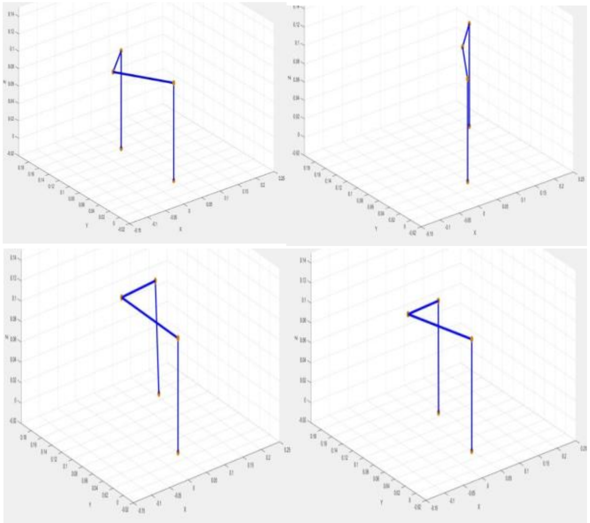
Please enter a word: book

{ theta1 = 141.4767 & theta3 = 121.9688 } start
{ theta1 = 74.7381 & theta3 = 79.1062 } end



Please enter a word: Flower

{ theta1 = 141.4767 & theta3 = 121.9688 } start
{ theta3 = 25.3972 & theta1 = 40.1253 } end



Conclusion:

Today, robots form a major part of the industry and it will be much more economical for employers to use robots instead of humans, and these major advantages that robots have over human labor can be minimally stated: The robot does not need to rest, and as much as a production line worker, it can work all hours of the day without interruption, without hunger or the need to rest, or in another example, a robotic arm has the condition that the coordinates are very precise and detailed. receive it for cutting or welding, and the robot can perform the specified activity precisely and calculated with the possibility of having less energy and wasted materials than human labor, or to work in the parts that require human labor They have safety devices and expensive equipment, but the robot does not include any of these costs

Now, according to the investigations carried out and the results that were displayed, the robotic arm can be correctly managed by considering the arm's movement angles from the start point to the end point, which will lead to optimization in the use of time and force, for optimization, if this method is considered, by choosing the right angle and exact location, cutting or welding can be done by the robot in a short period of time.

Reference

[1] robot noun - Definition, pictures, pronunciation and usage notes | Oxford

[2] "Robot | technology". Retrieved 2018-07-01

[3]"robotics". Oxford Dictionaries. Retrieved 4 February 2011.

[4] White GD, Bhatt RM, Krovi VN (2007) Dynamic redundancy resolution in a nonholonomic wheeled mobile manipulator. Robotica 25(2): 147–156.

[5] Boukattaya M, Jallouli M, Damak T (2012) On trajectory tracking control for a nonholonomic mobile manipulators with dynamic uncertainties and external torque disturbances. Robot Auton Syst 60(12): 1640–1647.

[6] J. P. Kolhe, M. Shaheed, T. Chandar, and S. Talole, "Robust control of robot manipulators based on uncertainty and disturbance estimation," International Journal of Robust and Nonlinear Control, vol. 23, pp. 104 -122, 2013.

[7] A. Mishkat and N. Verma, "ROBUST CONTROL OF ROBOTIC MANIPULATOR," 2014.

[8] M. Mehdi Fateh and M. Baluchzadeh, "Discrete optimal control for robot manipulators," COMPEL: The International Journal for Computation and Mathematics in Electrical and Electronic Engineering, vol. 33, pp. 423 -444, 2013.

[9] A. Olivares and E. Staffetti, "Embedded optimal control of robot manipulators with passive joints," Mathematical Problems in Engineering, vol. 2015, 2015.

[10] Y. Yanling, "Model free adaptive control for robotic manipulator trajectory tracking," Open Automation and Control Systems Journal, vol. 7, pp. 358 -365, 2015.

[11] H. Wang, "Adaptive control of robot manipulators with uncertain kinematics and dynamics," IEEE Transactions on Automatic Control, vol. 62, pp. 948 - 954, 2017.

[12] Y. Zhao, "Study on Predictive Control for Trajectory Tracking of Robotic Manipulator," Journal of Engineering Science & Technology Review, vol. 7, 2014.

[13] I. Cervantes and J. Alvarez -Ramirez, "On the PID tracking control of robot manipulators," Systems & control letters, vol. 42, pp. 37 -46, 2001.

[14] V. Hernández -Guzmán and J. Orrante -Sakanassi, "Global PID Control of Robot Manipulators Equipped with PMSMs," Asian Journal of Control, 2018.

[15] F. Piltan, S. Emamzadeh, Z. Hivand, F. Shahriyari, and M. Mirazaei, "PUMA -560 Robot Manipulator Position Sliding Mode Control Methods Using MATLAB/SIMULINK and Their Integration into Graduate/Undergraduate Nonlinear Control, Robotics and MATLAB Courses,"

International Journal of Robotics and Automation, vol. 3, pp. 106 -150, 2012.

[16] F. Moldoveanu, "SLIDING MODE CONTROLLER DESIGN FOR ROBOT MANIPULATORS," Bulletin of the Transilvania University of Brasov. Engineering Sciences. Series I, vol. 7, p. 97, 2014.

[17] L. -X. Wang, A course in fuzzy systems: Prentice - Hall press, USA, 1999.

[18] F. Piltan, S. T. Haghighi, N. Sulaiman, I. Nazari, and S. Siamak, "Artificial control of PUMA robot manipulator: A -review of fuzzy inference engine and application to classical controller," International Journal of Robotics and Automation, vol. 2, pp. 401 - 425, 2011.

[19] D. W. Bertol, V. Barasuol, E. R. De Pieri, and N. A. Martins, "FUZZY MAPPING OF DYNAMIC FUNCTIONS TO CONTROL ROBOT MANIPULATORS IN THE OPERATIONAL SPACE," 2012.

[20] M. Aghajarian, K. Kiani, and M. M. Fateh, "Design of Fuzzy Controller for Robot Manipulators Using Bacterial Foraging Optimization Algorithm," Journal of Intelligent Learning Systems and Applications, vol. 4, p. 53, 2012.

[21] L. Fausett, Fundamentals of neural networks: architectures, algorithms, and applications: Prentice - Hall, Inc., 1994.

[22] L. Wang, T. Chai, and C. Yang, "Neural -network - based contouring control for robotic manipulators in operational space," IEEE Transactions on Control Systems Technology, vol. 20, pp. 1073 -1080, 2012.

[23] L. Yu, S. Fei, J. Huang, and Y. Gao, "Trajectory switching control of robotic manipulators based on RBF neural networks," Circuits, Systems, and Signal Processing, vol. 33, pp. 1119 -1133, 2014.

[24] L. Yu, S. Fei, J. Huang, Y. Li, G. Yang, and L. Sun, "Robust neural network control of robotic manipulators via switching strategy," Kybernetika, vol. 51, pp. 309 -320, 2015.

[25] M. M. Fateh, S. M. Ahmadi, and S. Khorashadizadeh, "Adaptive RBF network control for robot manipulators," Journal of AI and Data Mining, vol. 2, pp. 159 -166, 2014.

[26] P. Van Cuong and W. Y. Nan, "Adaptive trajectory tracking neural network control with robust compensator for robot manipulators," Neural Computing and Applications, vol. 27, pp. 525 -536, 2016.

[27] R. -J. Wai, Y. -C. Huang, Z. -W. Yang, and C. -Y. Shih, "Adaptive fuzzy -neural -network velocity sensorless control for robot manipulator position tracking," IET control theory & applications, vol. 4, pp. 1079 -1093, 2010.

[28] B. O. Mushage, J. C. Chedjou, and K. Kyamakya, "Fuzzy neural network and observer -based fault - tolerant adaptive nonlinear control of uncertain 5 - DOF upper -limb exoskeleton robot for passive rehabilitation," Nonlinear Dynamics, vol. 87, pp. 2021 -2037, 2017.

[29] W. He and Y. Dong, "Adaptive fuzzy neural network control for a constrained robot using impedance learning," IEEE Transactions on Neural Networks and Learning Systems, 2017.

[30] D. C. Theodoridis, Y. S. Boutalis, and M. A. Christodoulou, "A new adaptive neuro -fuzzy controller for trajectory tracking of robot manipulators," International Journal of Robotics and Automation, vol. 26, p. 64, 2011.

[31] A. Farrage and A. B. Sharkawy, "Experimental Investigation of an Adaptive Neuro -Fuzzy Control Scheme for Industrial Robots," J. Eng. Sci. Fac. Eng. Univ, vol. 42, pp. 703 -721, 2014.

[32] S. M. Ahmadi and M. M. Fateh, "Robust control of electrically driven robots using adaptive uncertainty estimation," Computers & Electrical Engineering, vol. 56, pp. 674 -687, 2016.

[33] M. H. Barhaghtalab, H. Bayani, A. Nabaei, H. Zarrabi, and A. Amiri, "On The Design of The Robust Neuro - Adaptive Controller for Cable -driven Parallel Robots," Automatika: časopis za automatiku, mjerenje, elektroniku, računarstvo i komunikacije, vol. 57, pp. 724 - 735, 2017.

[34]] J. -S. Jang, "ANFIS: adaptive -network -based fuzzy inference system," IEEE transactions on systems, man, and cybernetics, vol. 23, pp. 665 -685, 1993.

[35] J. -S. Jang and C. -T. Sun, "Neuro -fuzzy modeling and control," Proceedings of the IEEE, vol. 83, pp. 378 - 406, 1995.

[36]] O. Bachir and A. -F. Zoubir, "Adaptive neuro -fuzzy inference system based control of puma 600 robot manipulator," International Journal of Electrical and Computer Engineering, vol. 2, p. 90, 2012.

[37] F. Z. Baghli, Y. Lakhal, L. El Bakkali, and O. Hamdoun,

"Design and simulation of Adaptive Neuro Fuzzy Inference System (ANFIS) controller for a robot manipulator," in Complex Systems (WCCS), 2014 Second World Conference on, 2014, pp. 298 -303.

[38] P. Agnihotri, V. Banga, and E. G. Singh, "ANFIS Based Forward and inverse Kinematics of Robot Manipulator with five Degree of Freedom," 2015.

[39] R. K. Gupta and S. Chauhan, "Comparision of PID controller & adaptive neuro fuzzy controller for robot manipulator," in Computational Intelligence and Computing Research (ICCIC), 2015 IEEE International Conference on, 2015, pp. 1 -4.

[40]] J. Lin and C. -C. Lin, "Hybrid fuzzy position/force control by adaptive network -based fuzzy inference system for robot manipulator mounted on oscillatory base," Journal of Vibration and Control, vol. 21, pp. 1930 -1945, 2015.