Modeling and Simulation of 3DOF Parallel Manipulator Using Artificial Neural Network

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Abstract— Parallel Robot (PR) has shown its ability to be precise in its movement. Actuators move simultaneously to achieve the required target, on top of that its payload is much greater than what a serial robot can withstand. To determine workspace of the robot with known angles Forward kinematics has to be introduced which, bring a lot of difficulty as it requires the solution of multiple coupled nonlinear algebraic equations. Those equations bring multiple valid solutions. Those solutions could lead to different locations. As it is not going to make the pick and place for PR will be easier. This paper will discuss a numerical method that calculates the Forward Kinematics for PR. This method uses Artificial Neural Network which relay on training with a certain number of iterations. The set of data to be used in the training can be obtained from PR simulation. This method will serve to know workspace around PR as it will help it to pick the target object.

Keyword—Parallel Robot, Delta Robot, Neural Networks, Artificial Intelligence, Pick and place, Forward Kinematics, Inverse Kinematics

I. Introduction

Parallel robot witnessed an extensive development among the years due to its high accuracy and speed, PR is mainly used in precision positioning, medical application and Ultra speed pick and Place. Pradya Prempraneerach proved that Singularity of the Parallel Robot can be avoided by the usage of the Inverse Kinematics and workspace could be easy identified, for more accuracy in pick and place and accurate Trajectory, a combination between inverse and forward Kinematics should be developed [1]. O¨ zkan Bebek developed a 5 degree of freedom parallel robot for needle injection for small animal, He did use an optical tracker to perform a kinematic calibration. This method enhanced the accuracy of the needle tip, the accuracy of the system was tested before calibration and it was about 5 mm as tested, after the calibration the error of the system has dropped to 0.4mm [2]. Abdul Muis suggested the hybrid techniques for visual servoing between eyes to hand and eye in hand to overcome the drawback of each technique alone, which will increase the precision and the global view of the workspace. [3] Ren C. Luo Managed to develop a conveyor object tracking system and picking system by the Hybrid techniques of Eye in hand and Yet to hand, that result not only the maximization of the efficiency but also the accuracy, the suggested system constructed with 2 camera, the 1st on is low resolution camera that only for the estimation for the velocity and orientation of the object, this information is fed to the 2nd camera with high resolution and it can track the object frame by frame. He did prove that that stand-alone Eye to hand system have successful detect about 39 of 100 objects, and when he used the hybrid one the accuracy of the suggested system was dramatically increased about 40% [4].

Daniel Chaparro-Altamirano proposed a method for obtaining Forward kinematics with a geometrical approach and he used the Neural Networks and Newton Raphson to describe workspace of the parallel robot [5]

With this kind of robotics it may be confronted with a lot of limitations as Jean-Pierre [6] which could introduce some errors could keep PR to move to its correct position one of these limitations as he suggested is calibration , as if the usage of error combination techniques for serial robots could lead to a catastrophic behavior for the delta robot , that’s why he refers that another technique should be introduced to Calibrate PR, one of those methods is the usage of auto-calibration which state an extra sensor should be used or a mechanical constrain should be add .

Mahfuzah Mustafa has proposed a method that solve Forward Kinematics by using method called Spherical- Spherical join pair and compare the results with the actual position[7]

M. Dehghani also states that it is very difficult to obtain forward kinematics as it is not the same as the forward kinematics for serial robot. therefore, other techniques should be applied and she stated the Numerical method is suitable for determining Forward kinematics for her Hex robot, also she hinted this method can withdraw setbacks as it is a relay on the convergence. that’s why she suggested the usage of the Neural Networks to solve this matter, which provides a very small modeling error.[8]

Chi-Sheng Tsai obtain the kinematics model for the PR which helps a lot to calculate the inverse kinematics of any parallel robot have the share the same base by using spherical method [9]

The problem that this paper will discuss is how to solve Forward Kinematics without solving the nonlinear equations for FK as it is very difficult to obtain because it will bring more than one results for the same input angles , and this method will not be helpful for the pick and place for any object or movement or PR in a certain workspace, a certain movement will be performed to measure the cartisean coordinated of a fixed point on top of the end-effector and then those data will be fed to system as training data .

II. Methodology

For each robot to move around in its workspace the mathematical model should be obtained, and there are two methods to identify their mathematical model either by Forward kinematics or inverse kinematics. The proposed model is to calculate Forward Kinematics. Therefore, this paper shows an easier way to obtain the workspace of Parallel Robot (PR) to move it with a minimal error.

a. Structure design of the proposed parallel robot manipulator

The proposed consist of a set of three actuators which are connected to single manipulator. This manipulator has the capability to carry out the pick-place task. to know the number of degrees of freedom, the mobility of the robot should be calculated as shown below:

Starting from Kutzbach mobility equation

$$M = 6(N-1) - 5J_1 - 4J_2 - 3J_3 \quad (1)$$

Where:

M is the Mobility or number of degrees of freedom

N is the total number of links

J_1 is the number of revolute and prismatic degrees of freedom joints

J_2 is the number of Universal degrees of freedom joints

J_3 is the number of Spherical degrees of freedom joints

And for the proposed design there is no spherical nor universal joints therefore the values of J_2, J_3 are equal to zeros

So,

$$N = 14$$
$$J1 = 15$$
$$M = 6(14-1) - 5(15) - 4(0) - 3(0)$$
$$M = 3 \text{ DOF}$$

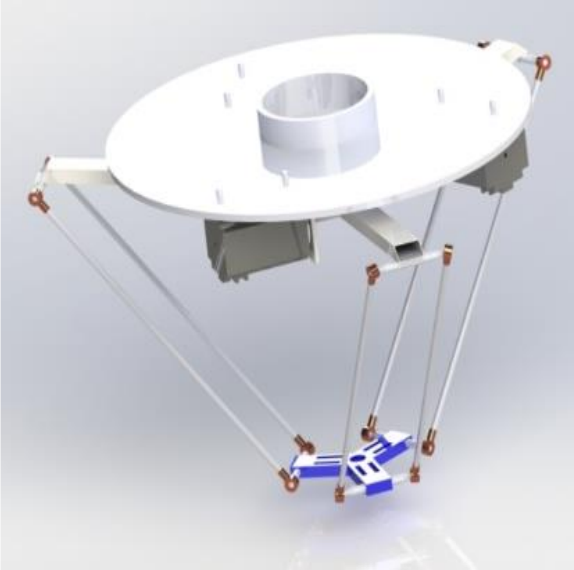

Figure 1-PR Mechanical Design

b. Inverse Kinematics

To start the calculation of the inverse kinematics of the given PR , a simplified model and parameters should be introduced [10]. Therefore, the next 3 figures (Figure 2 - 4) show how to assign the coordinates system and reference for each part. Where i = 1, 2, 3, Figure 2 shows the hips of PR as B_i, A_i work as the knees, finally P_i are the ankles. S_B is the side length of the fixed triangle and S_p is the side length of the moving end effector (manipulator)

the coordinates system will be measured from point P_E with the respect to point O.

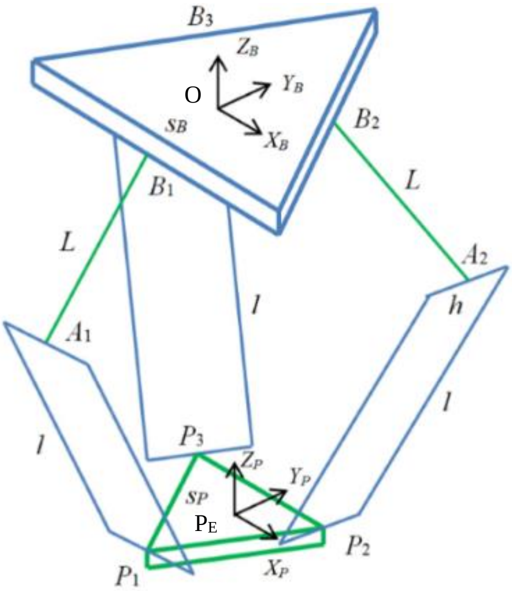

Figure 2- PR Kinematics Diagram

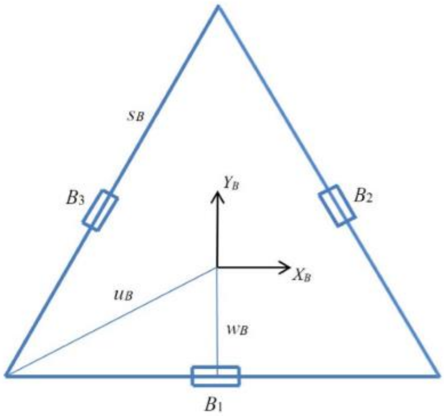

Figure 3- PR Fixed Base Details

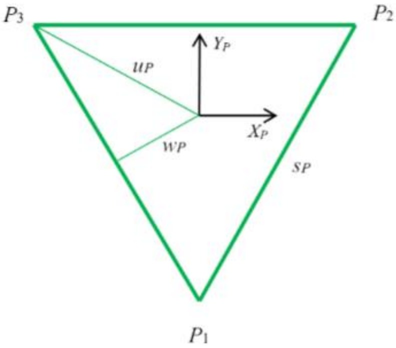

Figure 4- PR Moving Platform

Those parameters can be simplified as shown in the following table

Name	Meaning	Value (mm)
S_B	Base equilateral triangle side	277.13
S_P	platform equilateral triangle side	173.21
L	upper legs length	150
I	lower legs parallelogram length	262.57
H	lower legs parallelogram width	53
W_B	planar distance from {0} to near base side	80
U_B	planar distance from {0} to a base vertex	160
W_P	planar distance from {P} to near platform side	50
U_P	planar distance from {P} to a platform vertex	100

Table 1- PR Parameters

The base of the PR is considered fixed all the time $\{B_i\}$,and the revolute joints for the end-effector could be assumed also $\{P_i\}$.

$$ {}^{B}B_1 = \begin{Bmatrix} 0 \\ -w_B \\ 0 \end{Bmatrix} \quad {}^{B}B_2 = \begin{Bmatrix} \frac{\sqrt{3}}{2} w_B \\ \frac{1}{2} w_B \\ 0 \end{Bmatrix} \quad {}^{B}B_3 = \begin{Bmatrix} \frac{-\sqrt{3}}{2} w_B \\ \frac{1}{2} w_B \\ 0 \end{Bmatrix} \tag{2} $$

$$ {}^{P}P_1 = \begin{Bmatrix} 0 \\ -u_p \\ 0 \end{Bmatrix} \quad {}^{P}P_2 = \begin{Bmatrix} \frac{S_p}{2} \\ w_p \\ 0 \end{Bmatrix} \quad {}^{P}P_3 = \begin{Bmatrix} \frac{-S_p}{2} \\ w_p \\ 0 \end{Bmatrix} \tag{3} $$

Where vertices of the fixed-based equilateral triangle are:

$$ {}^{B}b_1 = \begin{Bmatrix} \frac{s_B}{2} \\ -w_B \\ 0 \end{Bmatrix} \quad {}^{B}b_2 = \begin{Bmatrix} 0 \\ u_B \\ 0 \end{Bmatrix} \quad {}^{B}b_3 = \begin{Bmatrix} -\frac{S_B}{2} \\ -w_B \\ 0 \end{Bmatrix} \tag{4} $$

Therefore:

$$ w_B = \frac{\sqrt{3}}{6} s_B \;, u_B = \frac{\sqrt{3}}{3} s_B \;, w_P = \frac{\sqrt{3}}{6} s_P \;, u_P = \frac{\sqrt{3}}{3} s_P \tag{5} $$

The inverse position kinematics is to solve the problem of how joints is going to be moved. Giving the Cartesian position of the floating End-effector central point ${}^{B}P_P = \{x, y, z\}^T$ and from that the angles can be obtained $\theta = \{\theta_1, \theta_2, \theta_3\}$ this could be achieved by applying IPK equations:

$$ E_i \cos\theta_i + F_i \sin\theta_i + G_i = 0 \qquad i=1,2,3 \tag{6} $$

Where

$$ \begin{aligned} E_1 &= 2L(y+a) \\ F1 &= 2zl \\ G1 &= x^2 + y^2 + z^2 + a^2 + L^2 + 2ya - l^2 \end{aligned} \tag{7} $$

$$ \begin{aligned} E_2 &= -L(\sqrt{3}(x+b) + y + c) \\ F_2 &= 2zL \\ G_2 &= x^2 + y^2 + z^2 + b^2 + c^2 + L^2 + 2(xb + yc) - l^2 \end{aligned} \tag{8} $$

$$ \begin{aligned} E_3 &= L(\sqrt{3}(x-b) - y - c) \\ F_3 &= 2zL \\ G_3 &= x^2 + y^2 + z^2 + b^2 + c^2 + L^2 + 2(-xb + yc) - l^2 \end{aligned} \tag{9} $$

$$ t_{i_{1,2}} = \frac{-F_i \pm \sqrt{E^2{}_i + F^2{}_i - G^2{}_i}}{G_i - E_i} \tag{10} $$

After that joint angles could be obtained with arctan2 function to get θ_i :

$$ \theta_i = 2\tan^{-1}(t_i) \tag{11} $$

c. Forward kinematics

Forward Kinematics could provide the answer of the question of where the end-effector is in the workspace. By moving joints with known angles which is going to move end-effector to required location, FK is hard to obtain therefore a numerical method should be introduced. For the proposed PR Solid works provide the tool called motion analysis which provide the training set for the movement of any mechanical systems, as in the design it will be moved in a known set of movement. After this movement we could measure the position (X, Y, Z) of the end-effector with the respect to point O.

d. Artificial Neural Networks

This method of the ANN is based on the Biological neural networks which relays on neuron training, where data is divided into two categories: training and validation testing, also performance is divided to training procedure and recall procedure.

ANN consist of Neurons (nodes) and links (synaptic), the network consist of input layers, output layer, and hidden layers [11] as show in Figure 5

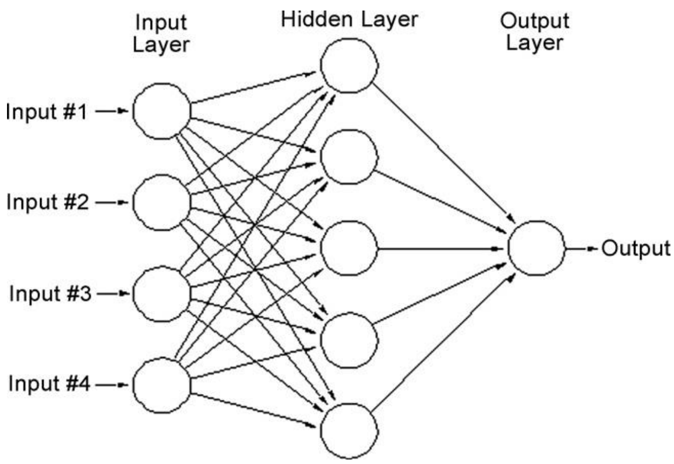

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Figure 5 - ANN construction

There are two modes of Neural Networks: one called feed forward calculation of Neural networks and in this kind of technique the information or input vector flow in only one direction which means that the information flow from the input layer to the output layer crossing hidden layer without changing the weight. The other mod is Back-Propagating and in this technique the information flow from the input layer to the output layer and the weight of the hidden layer is adjusted by measuring error from the target values and go back to fix each weight to gain a better learning and minimizing the error from trained value.

III. Simulation and results

After finishing the design of the proposed PR, a major thing is to make robot move in correct way is to be mated correctly as it will affect its motion in motion study.

Figure 6 Flow chart for the motion sequence

A set of fixed motion introduced to the design to study behavior of system this sequence as in Figure 6.

Solid works have this tool which called motion study [12] it helps to study behavior of the system movement. The path could be generated by a lot of profiles like linear movement or constant acceleration in this proposed model the path that was selected is the cubic one, After movement is calculated and generated as a.CSV file with the position of the end effector relative to the origin point which is mounted on the base of the PR. angles of motion can be obtained too in figure 7.

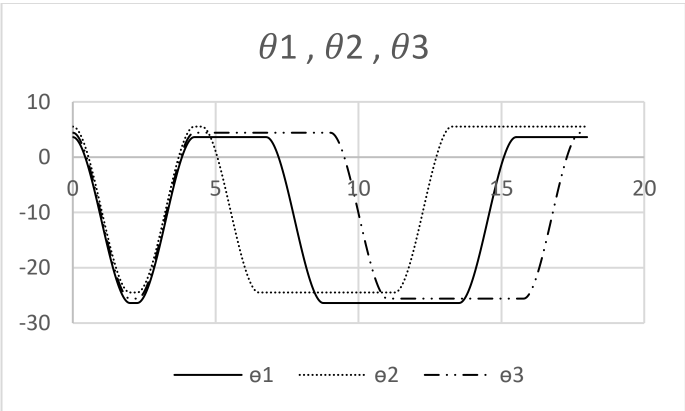

Figure 7-Actuators Angles

On top of that the end-effector position also can be plotted as it is shown in Figure 8 these data set will be the input for the training model.

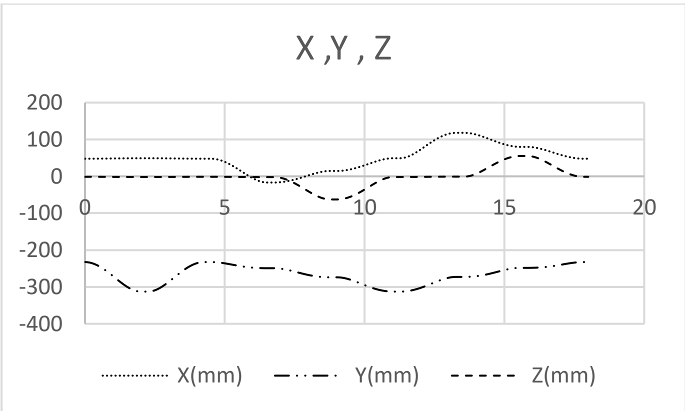

Figure 8-End-effector position along X, Y, Z

The actual Path from the simulation can be plotted from solid works which can be obtained from motion analysis. Figure 9

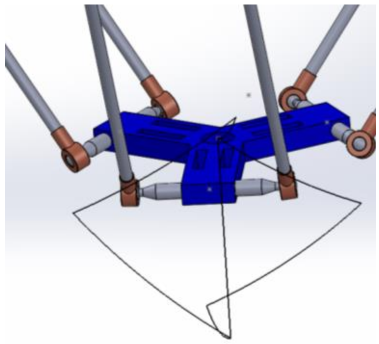

Figure 9 - Motion Study Path

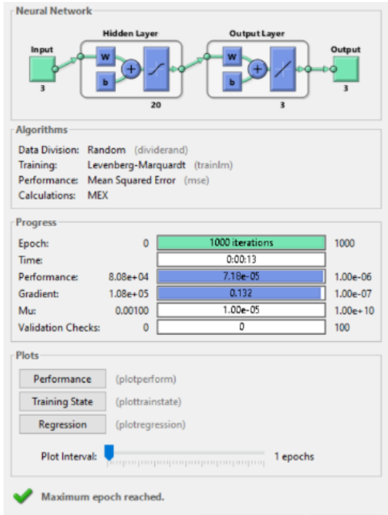

Figure 10-Model Architecture

The proposed model Architecture consist of one input layer with 3 nodes, one output layer with 3 nodes, and one hidden layer with 20 nodes. This model trained by 1000 iterations as shown in Figure 10.

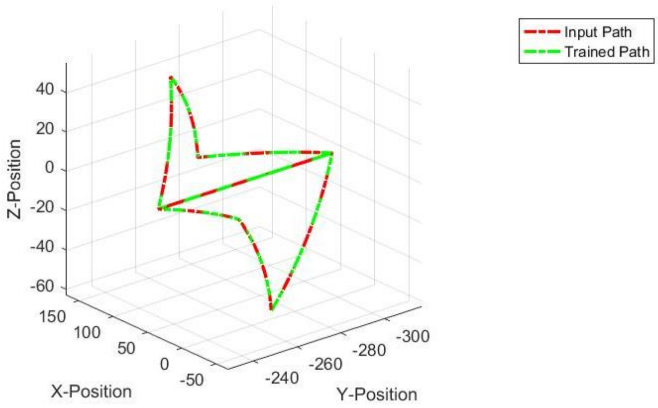

Figure 11 -Generated Path

After the model is trained, Figure (11-12) can conclude the behavior of the trained model. Figure 11 indicate that X, Y, Z position of the end effector which was obtained from the Neural training have a high match with the Trained data itself.

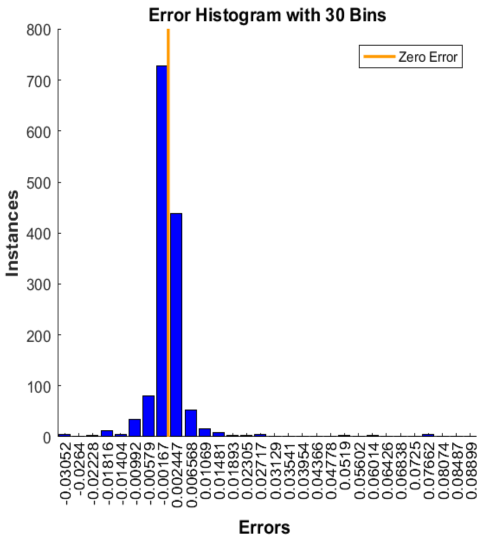

Figure 12- Error Histogram

In Figure 12 Histogram error are composed of 30 bins which show the errors are normally distributed. On top of that what is the value of repeated error. Therefore, the trained process can indicate a high matching to actual value that is measured by Solid works. As shown Figure 13

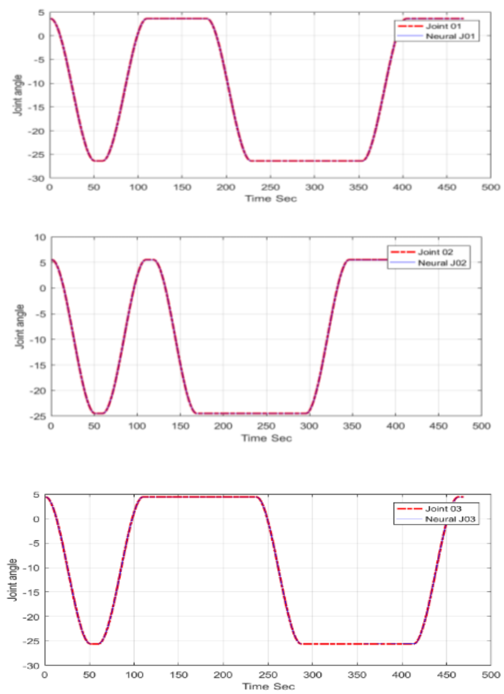

Figure 13 - Joint action With Neural Training comparison

IV. Conclusion

Forward kinematics calculation with nonlinear equation is very difficult as it could lead to several different solutions, on top of that it will be hard to perform the pick and place with this method. This paper focus on solving the problem of generating Forward Kinematics for the Parallel (PR), and its movement in its workspace. With the simulation by using Solid works PR workspace can be obtained. With SolidWorks motion analysis, a certain movement can be introduced to make PR move in its workspace. those movement with the help of Artificial Neural Network (ANN) training algorithm, Actuator movement can be obtained to move end-effector to the target position. With this method Forward kinematics is going to be predicted to help PR for pick and place task.

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