# Forward Analysis of 5 DOF Robot Manipulator and Position Placement Problem for Industrial Applications

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## ABSTRACT

In this paper, a forward kinematics problem is concerned with the relationship between the individual joint of robot arm and the position and orientation of the tool or end-effector. The standard Denavit_Hartenberg(D-H) analytical scheme is applied to building mathematical modeling to predict, simulate and recovering the end-effector location (position and orientation) placement of 5DOF R5150 Robot manipulator for different joint variables, the basic challenge associated with the R5150 arm is the limited information available on its governing control model for position placement. Two ways by which control can be effected on R5150 arm, this robot can be programmed by using either a hand-held terminal (teach pendant) or a RoboCIM simulation software. The non-versatility of this control software is seen in the non-availability of a programmable environment by users. The user interface of RoboCIM allows for numeric keyboard inputs such that each input results in the orientation of a specific joint by a margin equivalent to the input. The relationship between the keyboard inputs and joint motion of the arm is not feasible to the users. The proposed D-H scheme as presented herein has successfully reproduced the end-effecter position of the Lab_volt R5150 Robot arm with marginal differences for different experimental trials. The simulation of robot arm forward kinematics is performed through MATLAB. The adopted modeling is validated in the physical behaviors in determine position of robot arm.

**Keywords:** Forward Kinematics; D-H Concept; Lab Volt R5150 Robot Arm.

# التحليل المباشر لذراع روبوت ذو خمس درجات حرية ومشكلة التموضع في التطبيقات الصناعية

**الخلاصة**

في هذا البحث تمت دراسة مشكلة الحركية المباشرة في ذراع الروبوت وعلاقتها مع مفاصل الحركة لذراع الروبوت وموقع واتجاه النهاية المؤثرة لروبوت . ثم تطبيق اسلوب دينيفت-هارتنبيرك(D- H) التحليلي القياسي لبناء موديل رياضي لتنبأ و لمحاكاة وأيجاد موقع واتجاة النهاية المؤثرة لذراع روبوت ذا خمسة درجات حرية نوع



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R5150 لمتغيرات مختلفة من القيم المفصلية.التحدي الرئيسي المتعلق بهذا النوع من الروبوت هو محدودية المعلومات المتوفرة في نموذج السيطرة الخاص بالتموضع. هناك نوعين من السيطرة المؤثرة على ذراع هذا الروبوت , حيث يمكن برمجتة بأستخدام منظومة التحكم اليدوية او بأستخدام برنامج المحاكاة (RoboCIM). عدم تنوع برنامج السيطرة الخاص بهذا الروبوت والذي يمكن ملاحظتة من خلال عدم توفر بيئة برمجية لمبرمج,حيث تسمح واجهة البرنامج (RoboCIM) لمستخدم بأدخال قيم رقمية لزوايا لكل مفصل بأستخدام لوحة المفاتيح ليتم بعدها حركة المفاصل والعلاقة بين مدخلات و الية حساب احداثيات الموقع لنهاية المؤثرة لذراع هي غير ظاهرة للمستخدم. اسلوب دينيفت-هارتنبيرك (D-H) المقترح لحساب احداثيات الموقع لنهاية المؤثرة لذراع روبوت نجح باعادة حساب الموقع النهاية المؤثرة لذراع الروبوت وبفروقات هامشية لعدة تجارب مختلفة مع قيم احداثيات الموقعية لنهاية المؤثرة محسوبة بأ ستخدام برنامج (RoboCIM). تم اعتماد برنامج ( Matlab) للمحاكات والتقييم. اثبتت النتائج الواقعية ولعدة تجارب فعالية الموديل المقترح في أيجاد أحداثيات موقع النهاية المؤثرة لذراع روبوت.

## INTRODUCTION

The kinematical structure of Robot manipulator refers to how to calculate a position of the end-point and to get the manipulator to the desired configuration. Dynamic properties, such as weight, inertia etc., are not considered as part of the kinematics [1]. A robotic manipulator is designed to perform a task in the 3-D space. The tool or end-effector is to follow a planned trajectory to manipulate objects or carry out the task in the workspace. This requires control of position of each link and joint of the manipulator to control both the position and orientation of the tool. To program the tool motion and joint link motions, a mathematical model of the manipulator is required to refer to all geometrical and/or time-based properties of the motion. Kinematic model describes the spatial position of joints and links, and position and orientation of the end-effector [2,3,4].The representation of the robot's end-effector position and orientation through the geometries of robots (joint and link parameters) are called Forward Kinematics. Using Forward Kinematics, the mathematical model is developed to compute the position and orientation of end-effector's based on the given Robot joint position. Each Robot joint is considered as revolute joint. The homogenous transformation of end-effector related to the base frame is formulated using Denavit-Hartenberg (D-H) method [5]. This paper firstly analysis the structure and link parameter, then adopted a forward kinematics model predicated (DH) analytical scheme for robot arm position placement. The developed model aims at predicting and recovering the end-effecter position of R5150 Robot manipulator for different joint variables; finally in the environment of Matlab, the forward kinematics model is built to take kinematics simulation by using of Robotics Toolbox [6]. In simulation process, we can not only directly observe of physical behaviors the robot motion, and get the required data in the graphic form. Therefore, virtual performance of the robot manipulator can be tested in the conceptual design phase so as to improve the design performance, reduce design cost and decrease product development time.

H.S. Lee and S.L. Chang [7] developed a CAD/CAE/CAM integrated system for a robot manipulator. The D–H (Denavit–Hartenberg) coordinate transformation method was used to perform the robot position analysis, according to the transformation matrices, where used Matlab to calculate the robot position analysis. Pro/ENGINEER (Pro/E) was used to construct the robot manipulator parametric solid models, Pro/Mechanica was used to simulate the dynamic simulation and working space, MasterCAM was used to implement the cutting simulation, and the prototype was manufactured using a CNC milling machine. Finally, a CAD/CAE/CAM integrated system for a robot manipulator was developed. A demonstration example is presented to verify the design, analysis, and manufacture results. Jun Zhang and Jie Li [8], established the kinematics model of practical series mechanical arm to act the manipulations with parallel executive mechanism, and solved the problem using (D-H) transformation. The three dimensional model of the arm was created by Pro/E. Baki Koyuncu, and Mehmet Güzel [9], presented mathematical modeling and kinematic analysis of a low Cost Robot arm (Lynx-6). Robot arm was mathematically modeled with (D-H) method. Forward and Inverse Kinematics solutions were generated and implemented by the developed software. Also K. M. Mohanasundaram et al.[10] presented a novel approach used for solving the forward kinematics mathematical model of SCORBOT ER V PLUS in its work space for various set of joint parameters. The obtained results were validated with ROBOCELL 3D graphic software and also using CAD 3D model in AutoCAD 2007. A system based on the theory of computer aided geometric method was proposed. The entire system has been modeled using LabVIEW2011.Tahseen F. Abbas[11], presented a direct kinematics modeling of 5 DOF stationary articulated robot arm which is used for educational tasks, the Denavite – Hartenberg (D-H) model of representation is used to model robot links and joints in this paper. It utilizes Matlab software as the tools for manipulation and testing. The adopted modeling solution was found to be identical with the physical behaviors.

## ROBOT DESCRIPTION

R5150 Robot manipulator used in the work is a 5 DOF robot arm manipulator R5150 by LabVolt Inc. It is a five articulated coordinate robotic manipulator that uses stepper motors for joint actuators, and its motion are controlled by RoboCIM software. R5150 Robot manipulator has a stationary base, shoulder, elbow and wrist in corresponding with human arm joints (no yaw), each of these joints except the wrist has a single DOF. Wrist can move into planes (roll, pitch), this making the end-effector move flexible in terms of object manipulation.

## FORWARD KINEMATICS ANALYSIS OF THE LAB_VOLT R5150 ROBOT MANIPULATOR

The study location placement problem of robot arm in this work involves the analysis and verification of the D-H method as applied to the 5 DOF Lab_Volt Robot R5150 robot manipulator. The application of this method, including the construction of the joint/link parameter table allow to determine the corresponding 4 x 4 homogeneous transformation matrices for the robot arm manipulator. The analysis addressed in the forward kinematics analysis of Lab_Volt R5150 robot arm, while the verification and application of results conducted with the actual robot manipulator to implement end-effector position analysis. The analysis involves three major steps:

1) An assignment of a coordinate frame to each controlled joint axis and to the end-effector.
2) Construction of the joint/link parameter Table.
3) Use the parameters in each row of the parameter table to generate each of the five 4 x 4 coordinate transformation matrices, T(shoulder, base), T(elbow, shoulder), T(pitch, elbow), T(roll, pitch) and T(tool, roll).Then, as an added step, determine T (tool, reference), where, T(tool, reference(base)) =T(shoulder, base) x T(elbow, shoulder) x T(pitch, elbow) x T(roll, pitch) x T(tool, roll).

The direct or forward kinematics problem is to specify a set of values for the joint variables and then calculate the 4 x 4 matrix, T (tool, reference). The fourth column of this matrix defines the coordinates of the origin of the tool frame (point, P) referred to the reference frame. The third column of this matrix defines the projections of the approach vector (z or a axis of the tool frame) onto the x, y, and z axes of the reference frame. The second column of this matrix defines the projections of the orientation vector (y or o axis of the tool frame) onto the x, y and z axes of the reference frame. Finally, the first column of this matrix defines the projections of the normal axis (x or n axis of the tool frame) onto the x, y and z axes of the reference frame.

$$^{0}T_{5} = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

## D-H PROCEDURE ADOPTED

The steps to get the position using D-H procedure are finding the Denavid-Hartenberg (D-H) parameters, building matrices, and calculating T matrix with the coordinate position which is desired. It is a method of assigning coordinate frames to the different joints of a robotic manipulator. The following ten steps denote the systematic derivation of the D-H parameters as follows:

1. Label each axis in the manipulator with a number starting from (0) as the base to (n) as the end-effector. Every joint must have an axis assigned to it.
2. Set up a coordinate frame for each joint. Starting with the base joint, set up a right handed coordinate frame for each joint. For a rotational joint, the axis of motion of the $i^{th}$ joint is always along (Zi−1). If the joint is a prismatic joint, Z( i−1)should point in the direction of translation.
3. The (Xi) axis is normal to (Zi−1) axis, and always point away from it.
4. (Yi) should be directed such that a right-handed orthonormal coordinate frame is created.
5. For the next joint, if it is not the end-effector frame, steps 2–4 should be repeated.
6. For the end-effector, the (Zn) axis should point in the direction of the end-effector approach.
7. Joint angle (θi) is the rotation about (Zi−1) axis to make (X i−1) axis parallel to (Xi) axis.
8. Twist angle ( $\alpha$ i) is the rotation about (Xi) axis to make (Zi−1) axis parallel to (Zi) axis.
9. Link length (ai) is distance measured along (Xi) axis from the point of intersection of (Xi) axis with (Zi−1) axis to the origin of frame (i)
10. Link offset (di) is distance measured along (Zi−1) axis from the origin of frame (i-1) to intersection of (Xi) axis with (Zi-1) axis.

Applying the D-H algorithm, A D-H coordinate system of the robot manipulator is shown in Figure (1). The parameters of links are given in Table (1).

## TRANSFORMATION MATRIX

After establishing (D-H) coordinate system for each link, a homogeneous transformation matrix can easily be developed considering frame {i-1} and frame {i} transformation consisting of four basic transformations as shown in Table (2). There four parameters are respectively joint angle θi, link offset di , link length ai and the twist angle αi ,

So, the link transformation matrix between coordinate fram i-1 and coordinate frame i has the following form;

$$T_i = Rot.(z,\theta_i).Trans(z,d_i).Trans(x,a_i).Rot(x,\alpha_i)$$

$$T_i = \begin{bmatrix} \cos\theta_i & -\sin\theta_i & 0 & 0 \\ \sin\theta_i & \cos\theta_i & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & a_i \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\alpha_i & -\sin\alpha_i & 0 \\ 0 & \sin\alpha_i & \cos\alpha_i & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_i = \begin{bmatrix} \cos\theta_i & -\sin\theta_i.\cos\alpha_i & \sin\theta_i.\sin\alpha_i & a_i.\cos\theta_i \\ \sin\theta_i & \cos\theta_i.\cos\alpha_i & -\cos\theta_i.\sin\alpha_i & a_i.\sin\theta_i \\ 0 & \sin\alpha_i & \cos\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

According to (H-D) method [12], we can get the homogenous transformation matrix of R5150 robot manipulator as follows.

$$^{0}T_1 = \begin{bmatrix} c_{\theta1} & 0 & s_{\theta1} & 0 \\ s_{\theta1} & 0 & -c_{\theta1} & 0 \\ 0 & 0 & 0 & d1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad {}^{1}T_2 = \begin{bmatrix} c_{\theta2} & -s_{\theta2} & 0 & a_2c_{\theta2} \\ s_{\theta2} & c_{\theta2} & 0 & a_2s_{\theta2} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$^{2}T_3 = \begin{bmatrix} c_{\theta3} & -s_{\theta3} & 0 & a_3c_{\theta3} \\ s_{\theta3} & c_{\theta3} & 0 & a_3s_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad {}^{3}T_4 = \begin{bmatrix} c_{\theta4} & 0 & s_{\theta4} & 0 \\ s_{\theta4} & 0 & -c_{\theta4} & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$^{4}T_5 = \begin{bmatrix} c_{\theta5} & -s_{\theta5} & 0 & 0 \\ s_{\theta5} & c_{\theta5} & 0 & 0 \\ 0 & 0 & 1 & d_5 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Therefore the transformation matrix between tool frame and the base frame is obtained as follow:

$$ {}^{0}T_{5} = {}^{0}T_{1} \; {}^{1}T_{2} \; {}^{2}T_{3} \; {}^{3}T_{4} \; {}^{4}T_{5} $$

$$ {}^{0}T_{5} = \begin{bmatrix} c_1c_{234}c_5 + s_1s_5 & s_1c_5 - c_1c_{234}s_5 & c_1s_{234} & c_1(a_3c_{23} + a_2c_2 + d_5s_{234}) \\ s_1s_{234}c_5 - c_1s_5 & -s_1c_{234}s_5 - c_1c_5 & s_1s_{234} & s_1(a_3c_{23} + a_2c_2 + d_5s_{234}) \\ s_{234}c_5 & -s_{234}s_5 & -c_{234} & d_1 + a_3s_{23} + a_2s_2 - d_5c_{234} \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

Where

$C_1 = Cos\theta_1$ , $S_1 = Sin\theta_1$ , $C_{23} = Cos(\theta_2 + \theta_3)$ *and* $S_{23} = Sin(\theta_2 + \theta_3)$

The general position vector (the tool-tip position) of R5150 Robot manipulator is given by

$$ \begin{bmatrix} P_x \\ P_y \\ P_z \end{bmatrix} = \begin{bmatrix} c_1(a_3c_{23} + a_2c_2 + d_5s_{234}) \\ s_1(a_3c_{23} + a_2c_2 + d_5s_{234}) \\ d_1 + a_3s_{23} + a_2s_2 - d_5c_{234} \end{bmatrix} $$

The previous forward kinematics solution can be used for modeling the position of each joint of the manipulator as it moves.

$$ Base = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} , \; Shoulder = \begin{bmatrix} 0 \\ 0 \\ d_1 \\ 1 \end{bmatrix} , \; Elbow = \begin{bmatrix} a_2C_1C_2 \\ a_2C_2S_1 \\ d_1 + a_2S_2 \\ 1 \end{bmatrix} , $$

$$ Wrist = \begin{bmatrix} a_2C_1C_2 + a_3C_1C_{23} \\ a_2S_1C_2 + a_3S_1C_{23} \\ d_1 + a_2S_2 + a_3S_{23} \\ 1 \end{bmatrix} \qquad Tool - tip = \begin{bmatrix} C_1(a_2C_2 + a_3C_{23} + d_5S_{234}) \\ S_1(a_2C_2 + a_3C_{23} + d_5S_{234}) \\ d_1 + a_2S_2 + a_3S_{23} - d_5C_{234} \\ 1 \end{bmatrix} $$

These models have been used to simulate the positional coordinates of each joint of the robot manipulator while it moves to a desired target.

## VERIFICATION OF MATHEMATICAL MODEL USING MATLAB 10.0 PROGRAMM WITH ROBOCIM SOFTWARE

The simulation results as presented are for the forward kinematic analysis of the Lab_volt R5150 Robot as modeled using the (D-H) concept. Simulations were conducted using Matlab Robotics Toolbox on an Intel (R) CPU T2080 @ 0.99GHz, 1.00GB Memory (RAM), 32bit

Operating System. The Matlab Robotics Toolbox was used to represent the graphical simulation of the serial link manipulator. The variables θ1, θ2, θ3, θ4, and θ5 respectively represent the joint axes 0 through 4.Kinematics equations from the overall transformation matrix were developed using the Matlab R 10.0. An algorithm has been developed to generate the forward kinematics equations and calculate the robot Manipulator tool position and orientation in terms of joint angles and its output is compared with Robot software (which is the simulate program supplied with the robot system) for many sets of joint parameters. The result of end-effecter's position from Matlab simulation was then compared with experimental result generated from inbuilt Robot software (RoboCIM). For different keyboard values entered on the RoboCIM software, the corresponding joint angles, simulation and experimental positions for the end-effecter are presented as shown in the Figures (2) through Figure (13).

## A. Experiment No :1

A summing the following values are entered (for the lab_volt R5150 arm joint axes) on the RoboCIM software, the resulting joint angles are as stated in below

Joint 1: axis 0 $\longrightarrow$ θ1= 0 ; Joint 2 : axis 1 $\longrightarrow$ θ2= 130; Joint 3 : axis 2 $\longrightarrow$ θ3= -130; Joint 4 : axis 3 $\longrightarrow$ θ4= 90; axis 4 $\longrightarrow$ θ5= 90;

The analytical values using DH model were given as Px = 182.870, Py = 0, Pz = 401.098 all in millimeters. The forward kinematics matrix from the DH model is given as:

$$
{}^{0}T_{5} = \begin{bmatrix} 0 & 0 & 1 & 182.87 \\ -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 401.48 \\ 0 & 0 & 0 & 1 \end{bmatrix}
$$

The resulting end-effecter's position as plotted on the Matlab Robotics Toolbox is as shown in Figure (2).

while The variable Px,Py,Pz as given by the RoboCIM are Px = 182.55 , Py = 0 , P z = 401.48 all in millimeters and The resulting end-effecter's position as plotted on the RoboCIM is as shown in Figure (3) and Physical Configuration (Real) of the Robot Manipulator for the Case one as shown in Figure (4).

## B. Experiment No :2

A summing the following values are entered (for the lab_volt R5150 arm joint axes) on the RoboCIM software, the resulting joint angles are as stated in below

Joint 1: axis 0 $\longrightarrow$ $\theta_1$= 9 ; Joint 2 : axis 1 $\longrightarrow$ $\theta_2$= 28; Joint 3 : axis 2 $\longrightarrow$ $\theta_3$= -89.59; Joint 4: axis 3 $\longrightarrow$ $\theta_4$= 9.29; axis 4 $\longrightarrow$ $\theta_5$= 0;

The analytical values using DH model were given as Px = 165.109, Py = 26.1507, P z = 107.3065 all in millimeters. The forward kinematics matrix from the DH model is given as:

$$ {}^{0}T_{5} = \begin{bmatrix} 0.6040 & 0.1564 & -0.7815 & 165.109 \\ 0.0957 & -0.9877 & -0.1238 & 26.1507 \\ -0.7912 & 0 & -0.6115 & 107.3065 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

The resulting end-effecter's position as plotted on the Matlab Robotics Toolbox is as shown in Figure (5).

while The variable Px,Py,Pz as given by the RoboCIM are Px = 165.29 , Py = 26.18 , P z = 107.10 all in millimeters and The resulting end-effecter's position as plotted on the RoboCIM is as shown in figure 6 and Physical Configuration (Real) of the Robot Manipulator for the Case two as shown in Figure (7).

C. Experiment No :3

A summing the following values are entered (for the lab_volt R5150 arm joint axes) on the RoboCIM software, the resulting joint angles are as stated in below

Joint 1: axis 0 $\longrightarrow$ θ1= 45 ; Joint 2 : axis 1 θ2= 14.78; $\longrightarrow$ Joint 3 : axis 2 $\longrightarrow$ θ3= 20.48; Joint 4 : axis 3 $\longrightarrow$ θ4= 54.73 axis 4 $\longrightarrow$ θ5= 45.02;

The analytical values using DH model were given as Px = 320.924, Py = 320.924, P z = 413.685 all in millimeters. The forward kinematics matrix from the DH model is given as:

$$ {}^{0}T_{5} = \begin{bmatrix} 0.50031 & 0.4997 & 0.7071 & 320.9247 \\ -0.5001 & -0.4999 & 0.7071 & 320.9247 \\ 0.7069 & -0.7074 & -0.0002 & 413.6852 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

The resulting end-effecter's position as plotted on the Matlab Robotics Toolbox is as shown in Figure (8).

while The variable Px,Py,Pz as given by the RoboCIM are Px = 321.20 , Py = 321.20 , P z = 414.10 all in millimeters and The resulting end-effecter's position as plotted on the RoboCIM is as shown in Figure (9) and Physical Configuration (Real) of the Robot Manipulator for the Case three as shown in Figure (10).

D. Experiment No :4

A summing the following values are entered (for the lab_volt R5150 arm joint axes) on the RoboCIM software, the resulting joint angles are as stated in below

Joint 1: axis 0 $\longrightarrow$ θ1= -24; Joint 2: axis 1 $\longrightarrow$ θ2= 15; Joint 3 : axis 2 $\longrightarrow$ θ3=-60; Joint 4: axis 3 $\longrightarrow$ θ4= 88; axis 4 $\longrightarrow$ θ5= 90;

The analytical values using DH model were given as Px = 362.0436, Py = -161.1922, P z = 86.2697 all in millimeters. The forward kinematics matrix from the DH model is given as:

$$ {}^{0}T_{5} = \begin{bmatrix} -0.4067 & -0.6681 & 0.6230 & 362.0436 \\ -0.9135 & 0.2975 & -0.2774 & -161.1922 \\ 0 & -0.6820 & -0.7314 & 86.2697 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

The resulting end-effecter’s position as plotted on the Matlab Robotics Toolbox is as shown in Figure (11) while The variable Px,Py,Pz as given by the RoboCIM are Px = 362.35 , Py = -161.33 , P z = 86.04 all in millimeters and The resulting end-effecter’s position as plotted on the RoboCIM is as shown in Figure (12) and Physical Configuration (Real) of the Robot Manipulator for the Case four as shown in Figure (13).

## RESULT AND CONCLUSION

The forward kinematics model predicated on Denavit Hardenberg's (D-H) analytical scheme for robot arm position analysis is investigated. The mathematical model is prepared and solved for position and orientation of the end-effector by preparing a forward analysis algorithm programmed in Matlab 10. The developed model aims to predict and recover the end-effecter’s position of “lab_volt R5150” Robot manipulator for different joint variables. The simulation results as presented are for the forward kinematic analysis of the robot manipulator as modeled using the DH concept. Simulations were conducted using Matlab Robotics Toolbox. The variables θ1 θ2 θ3 θ4 and θ5 respectively represent the joint axes 0 through 4. The resulting end effector’s position as plotted on the Matlab simulation as shown in Figures (2, 5, 8, 11), and then compared with experimental results generated from inbuilt R5150 Robot software (RoboCIM) shown in Figures (3, 6, 9, 12). When position of target compared, there is a reasonable correlation between the experimental readings obtained from the R5150 robot manipulator position analysis software and the results obtained from the analytical modeling process. There is a high indication that our utmost goal of building a robot arm with a position placement scheme predicated on the DH concept would be realistic. Using simulation process, it can directly observe of physical behaviors the robot motion and get the required data in the graphic form. Therefore, virtual performance of the robot manipulator can be tested in the conceptual design stage so as to improve the design performance, reduce design cost and decrease product development time.

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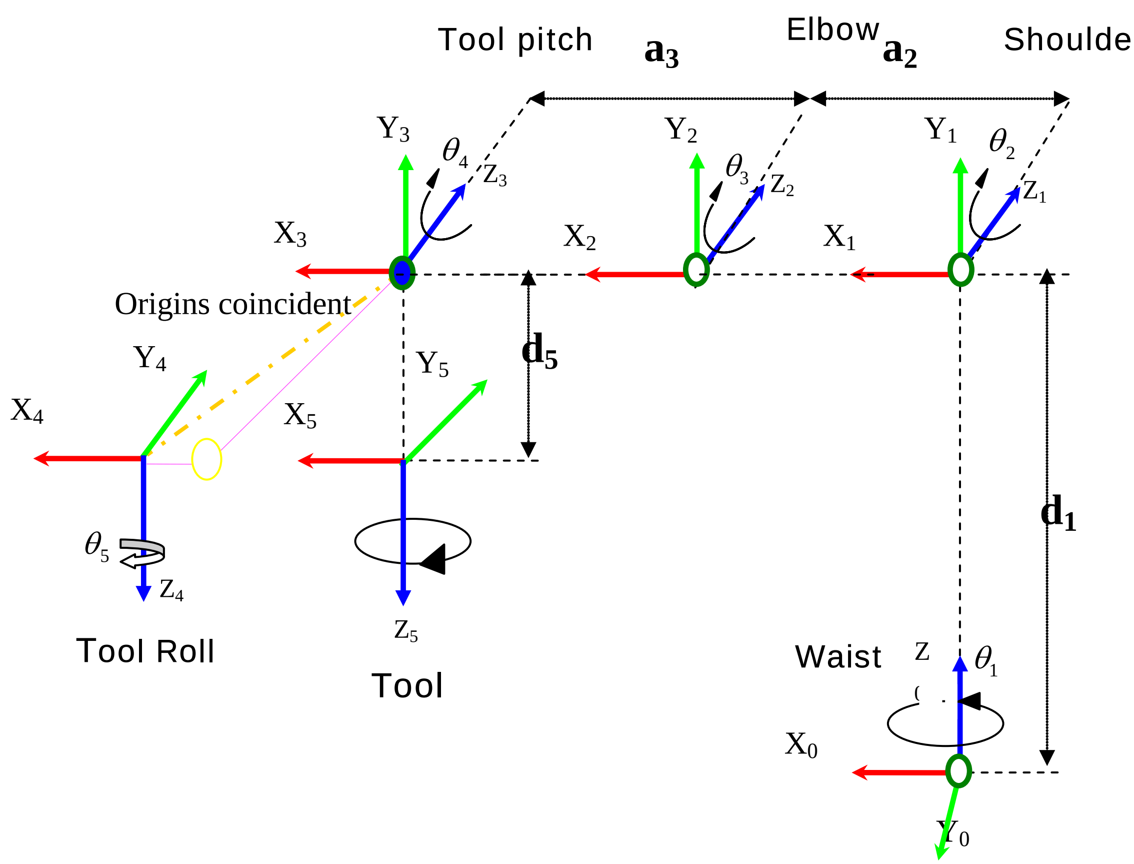
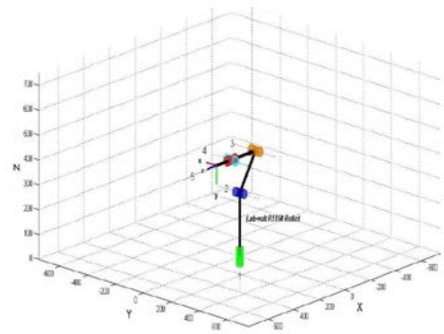



**Figure (1) link coordinates of a 5DOF Robot manipulator [13].**



Figure( 2) Matlab Simulation Plot for Experiment one.

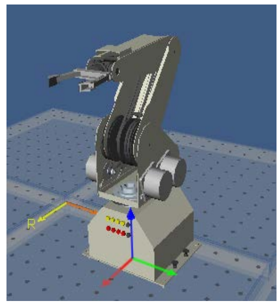


Figure (3) RoboCIM Simulation Plot for Experiment one.

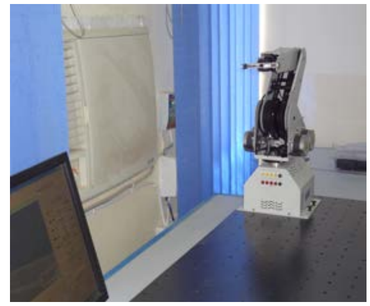
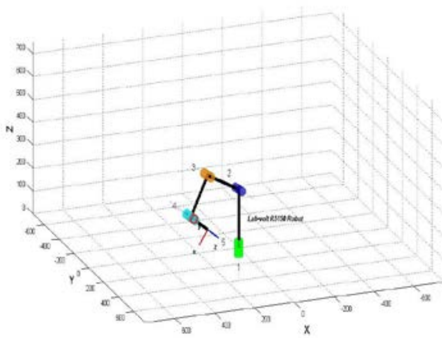
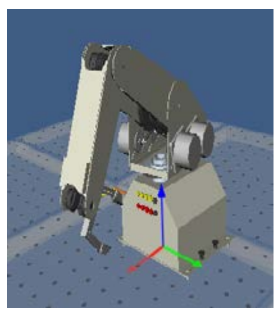


Figure (4): Physical Configuration (Real) of the Robot Manipulator for the Experiment one



Figure(5) Matlab Simulation Plot for Experiment two.



Figure(6) RoboCIM Simulation Plot for Experiment two.

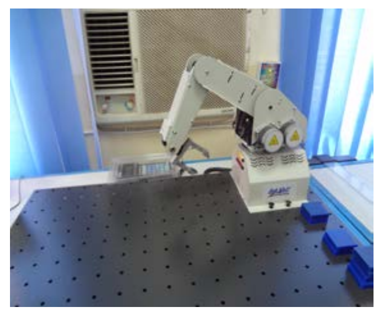


Figure (7) Physical Configuration (Real) of the Robot Manipulator for the Experiment two.

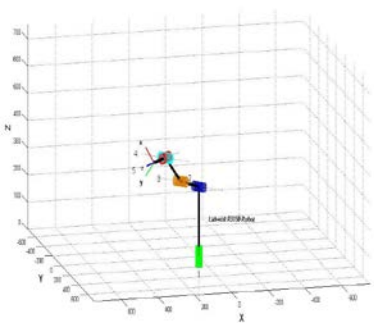


Figure8: Matlab Simulation Plot for Experiment three

Figure 9: RoboCIM Simulation Plot for Experiment three

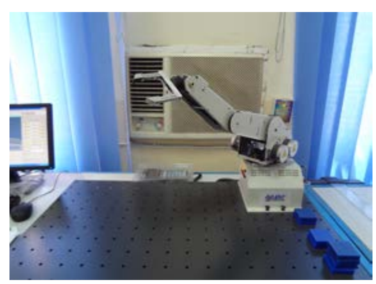
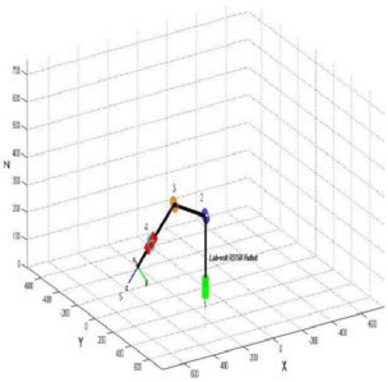


Figure 10: Physical Configuration (Real) of the Robot Manipulator for the Experiment three



Figure(11) Matlab Simulation Plot for Experiment four.

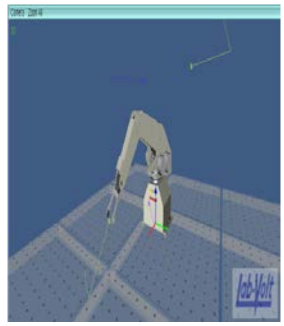


Figure (12) RoboCIM Simulation Plot for Experiment four.

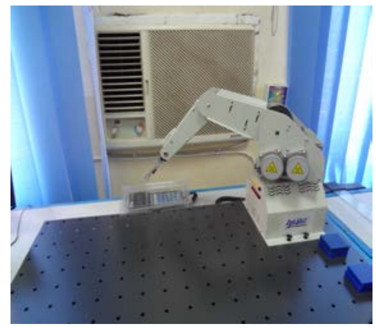


Figure (13) Physical Configuration (Real) of the Robot Manipulator for the Experiment four.

**Table (1) link parameter of the robot manipulator [13].**

| **Joint i** | **joint name** | $\theta_i$ | $d_i$ **(mm)** | $a_i$ **( mm)** | $\alpha_i$ | **range** | **motion** |
|---|---|---|---|---|---|---|---|
| 1 | base | $\theta 1$ | 255.5 | 0 | 90 | -185 to +153 | rotates the body |
| 2 | shoulder | $\theta 2$ | 0 | 190 | 0 | -32 to +149 | raises and lowers (upper arm) |
| 3 | elbow | $\theta 3$ | 0 | 190 | 0 | -147 to +51 | raises and lowers (forearm) |
| 4 | wrist pitch | $\theta 4$ | 0 | 0 | 90 | -5 to 180 | raises and lowers (gripper) |
| 5 | wrist roll | $\theta 5$ | 115 | 0 | 0 | ± 360 | rotates the gripper |

**Table (2) Transferring from frame i-1 to frame i**

| Operation | Description |
|---|---|
| T1 | A rotation about zi-1 axis by an angle θi. |
| T2 | Translation along zi-1 axis by distance di. |
| T3 | Translation by distance ai along xi axis |
| T4 | Rotation by angle αi about xi axis |