KINEMATIC MODELING OF A SERIAL ROBOT USING DENAVIT-HARTENBERG METHOD IN MATLAB

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***ABSTRACT*-This paper discusses on denavit-hartenberg method in kinematic modeling of a serial robot using matlab. Denavit-Hartenberg (D-H) representation is used to define the configuration of a link of a robot with respect to another link. All the four D-H parameters are discussed in details with graphical representations. This paper also explains the importance of using matlab for simulation in robotics and the simmechanics environment. Actuators are used to move revolute joints and sensors get the feedback from these joints. Image captured during the simulation helps to understand the degrees of freedom of the robot manipulator.**

Keywords: Links, Revolute Joints, Serial robot, manipulator and kinematics

1. INTRODUCTION

Kinematics deals with the study of relative motion between various links of a robot manipulator without the consideration of forces acting on it. Robots are classified into three types based on their kinematic structural topologies namely, serial robot or open-loop manipulator, if its kinematic structure takes the form of an open-loop chain, secondly a parallel manipulator, if it is made up of a closed-loop chain and finally a hybrid manipulator, if it consists of both open and closed-loop chain [1].

A robot for performing a specific task, the location of the end-effectors relative to the base should be established first. This is known as position analysis problem. There are two types of position analysis problem: direct position or direct kinematics and inverse position or inverse kinematics problems. The direct kinematics analysis is the process of calculating the end effector position from the joint positions given, while the inverse kinematics analysis is the process of obtaining the joint positions from the given end effector position. Both analyses are important in motion study [2]. Denavit-Hartenberg (D-H) representation is used to define the configuration of a link of a robot with respect to another link [3] [4].. Richard Paul demonstrated its value for the kinematic analysis of robotic systems in

1981, which remains as one of the standard approaches for attaching the reference frame [5]. D-H parameters describe the motion of series of rigid joints. This is useful for official calculation of forward and inverse kinematics.

Simulation is a powerful tool supporting the design, planning, analysis, and decisions in different areas of robotics. You can investigate, visualize and test an object even if it does not exist and can see the results of a system yet to be built and also learn about in a very effective way. MATLAB/Simulink is a general simulation tool used for simulation of robot system [6].

In this paper, kinematic modeling of a serial robot using denavit-hartenberg representation is being studied and a 3 DOF robot is modeled in MATLAB.

2. GRAPHICAL REPRESENTATION USING DENAVIT-HARTENBERG METHOD

Transformation means changing or moving the original size, shape or position to create a new image. There are two rules to be followed while using D-H method. First rule states that all z-axis should be parallel to the axis of rotation. Zi axis couples ith body with i+1th body. Secondly, the common perpendicular to Zi from Zi-1 would be defined as Xi. Yi should be such that it follows right hand rule and mark Oi as origin.

The process begins by defining the z-axis, along the axis of rotation for revolute joint or the axis of translation for prismatic joint. For the first joint x-axis is a free choice. For later joints each x-axis will point away from the previous joints. The y-axis simply completes the right handed reference frame. If we add another joint we can determine the transformation between them as before, the z-axis points along the axis of rotation. The D-H parameters will be derived from the common normal between the z-axis. The new x-axis points along the common normal and has its origin at the intersection of new z-axis. Notice the origin is not within the physical actuator because the D-H parameters are only concerned with the motion of the link and not with the physical placements of components. The origin may be in "open space". Using this protocol, for laying out the reference frame, only four parameters are needed. First is the joint offset (d) which is the depth along the previous joint's z-axis from the origin to the common normal. Second is joint angle (θ) rotates about the previous z-axis to align its x-axis with the new origin. Third parameter is the link length (r) which is the length of the common normal itself. Link length is the distance along the rotated x- axis, alternatively, radius of rotation about previous z-axis. Finally, twist angle (α) rotates about the new x-axis to put z-axis in its desired orientation [7].

There is one special case when the z-axis are parallel, is to take the first parameter that is joint offset as a free parameter because parallel z-axis have infinite number of common normal. Other parameters are determined as before. Twist angle is already known to be zero because the z-axis was parallel in this case. Hence no rotation is needed [7].

In a revolute joint, link length, twist angle and joint offset are constant, and joint angle is a variable that measures the relative location of link i with respect to link i-1. For a prismatic joint, link length, twist angle and joint angle are constant, and joint offset is a variable that measures the relative location of link i with respect to link i-1. We refer joint angle for a revolute joint and joint offset for a prismatic joint as *joint variables* and the constant parameters as the *link parameters*.

There are four DH parameters that are used for the design of a serial robot and they are joint offset, joint angle, link length and twist angle .Two links with two revolute joints connected in series is shown in figure 1. Both joints are offset by some distance. Blue colour axis is denoted as z-axis which is along the axis of rotation for revolute joints.

Red colour axis is x-axis and green color axis is y-axis which simply completes the right handed reference frame. In figure 1 (a), there is a base reference frame and moving reference frame. Moving reference frame will move away from the base reference frame which indicates the joint offset distance. Joint offset can be calculated by measuring the distance between the origins of base and moving reference frame. First joint and second joint is offset by measurement.

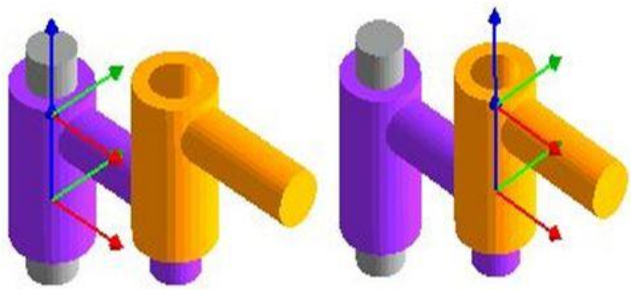
(a) (b)

Figure 1: Joint offset

Figure 2 explains graphically the joint angle. To show joint angle, we have taken a prismatic joint instead of revolute joint because joint angle is a joint variable for revolute joints. In figure 2 (a), there is a base and moving reference frame. Figure 2 (b), (c), and (d) shows joint angles varying from 0^0 to 90^0, by moving the moving reference frame to coincide with the base reference frame. The movement is shown in a step by step procedure with total movement of 90^0.

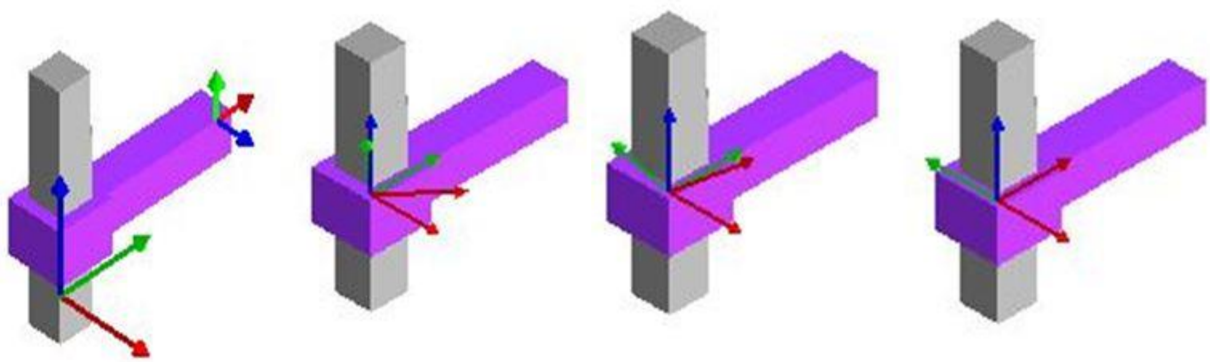
(a) **(b)** **(c)** **(d)**

Figure 2: Joint angle

Link length is measured from the origin of base reference frame to the origin of moving reference frame. In figure 3, there are two links with two revolute joints. Base reference frame is located on the first joint which is always fixed. Moving reference frame will first move from the base reference frame to the origin of the second joint to measure the length of first link. Then it will move from the second joint to the end position of the second link to measure the link length of second link as shown in figure 3 (a), (b), (c) and (d).

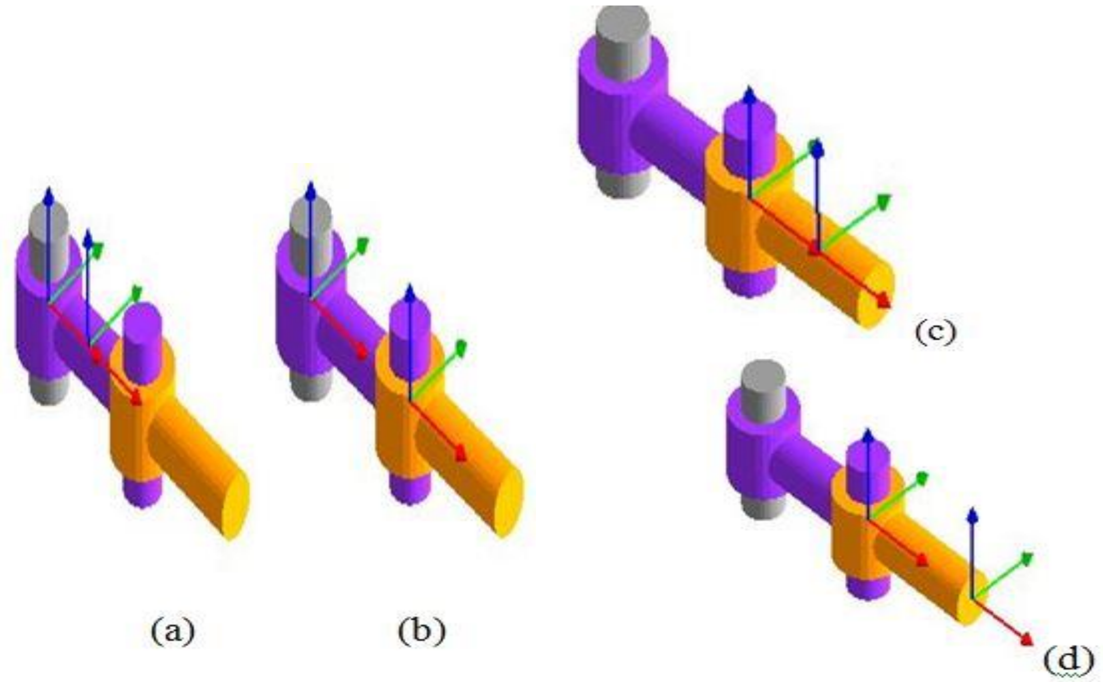

Figure 3: Link length

Two links with two revolute joints are shown in figure 4 to represent the parameter "twist angle". Second revolute joint is twisted by 90^0 which can be very well understood from figure 4 (a). From figure 4 (b), (c), and (d) we can see the moving reference frame moving from the base reference frame to the origin of the second revolute joint and then twist by 90^0 about the base reference frame to denote the twist angle.

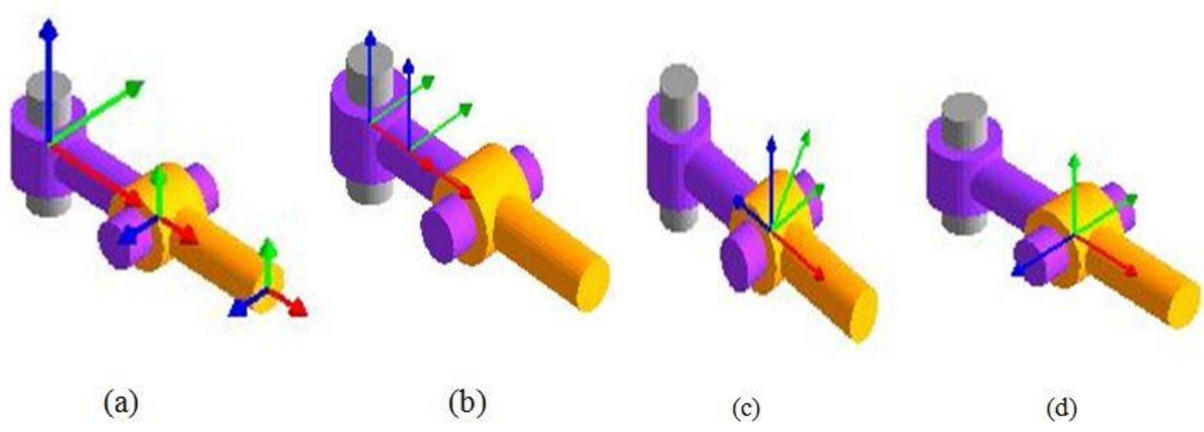

Figure. 4: Twist Angle

3. IMPLEMENTING D-H REPRESENTATION FOR MODELING A 3 DOF SERIAL ROBOT IN MATLAB

MATLAB has the capability of solving problems using matrix formulations and easy extensibility and therefore it is used intensively for the simulation of robotic system. We have selected “SimMechanics toolbox” developed by MATLAB for simulation of serial robot using D-H parameters. SimMechanics software is a block diagram modeling environment for the engineering design and simulation of rigid multibody machines and their motions, using the standard Newtonian dynamics of forces and torques [7]. (TheMathworks, SimMechanics, User’s Guide, , 2005) Block diagram modeling of a serial robot is shown in figure 5.

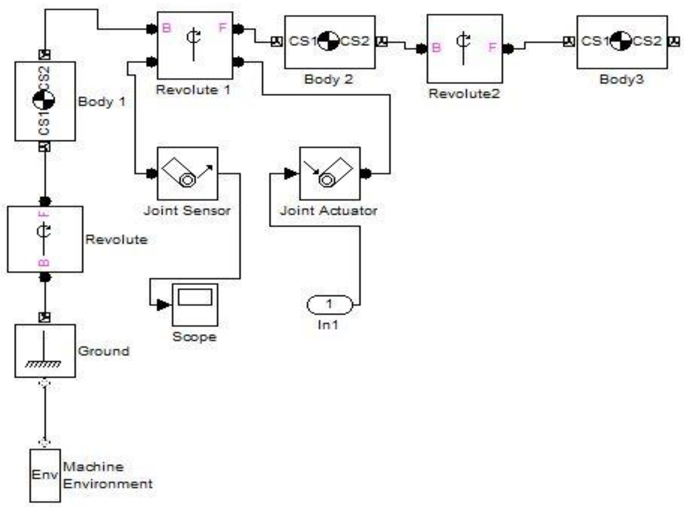

Figure 5: Model of three links (SimMechanics toolbox)

Open-loop manipulator model shown in figure 5 has three links connected in series. First link is fixed on the ground and other links are moving with the help of a stepper motor. The stepper motor used is of 10rpm and DC 12V. The Machine Environment block allows you to view and change the mechanical environment settings for one machine in your model [7].Each links are connected by revolute joints. Revolute joints are actuated by using joint actuator or motor. Parameters that were given as input to model the machine environment, ground, revolute joint, body and joint actuators are shown below in their respective block parameter box. As you can see a description for each block is given at the top of each box.

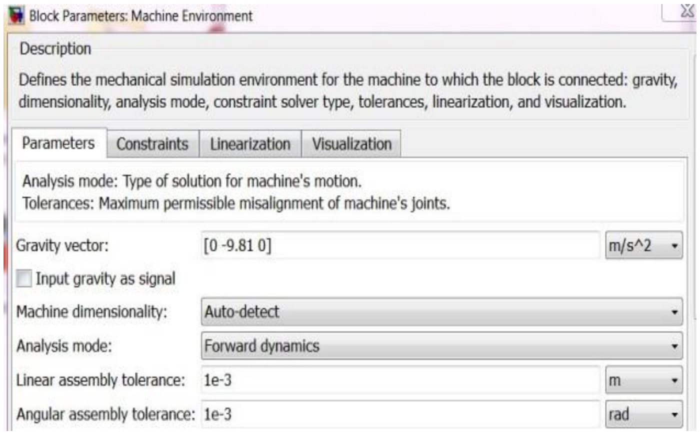

Figure 6: Machine environment block parameter

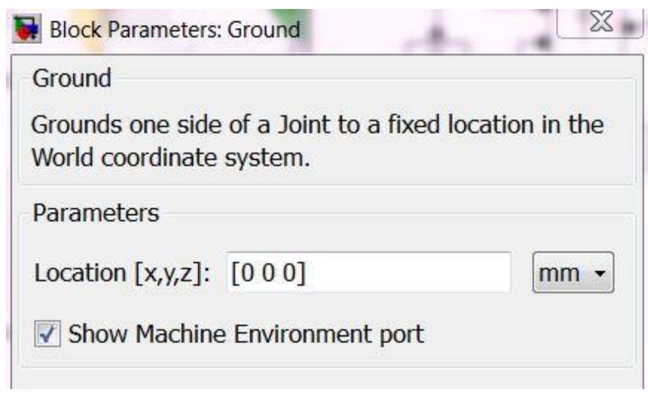

Figure 7: Ground block parameter

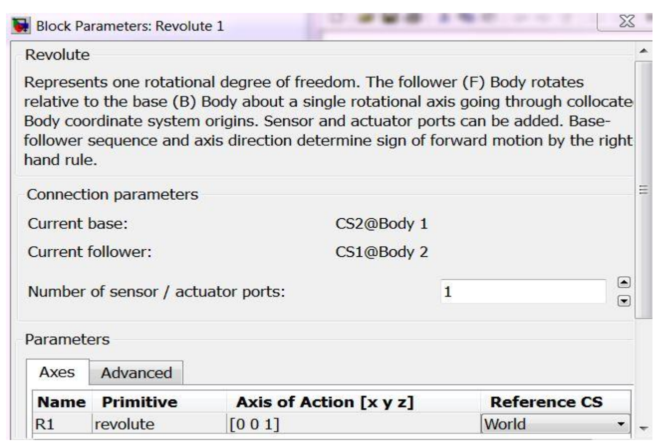

Figure 8: revolute joint block parameter

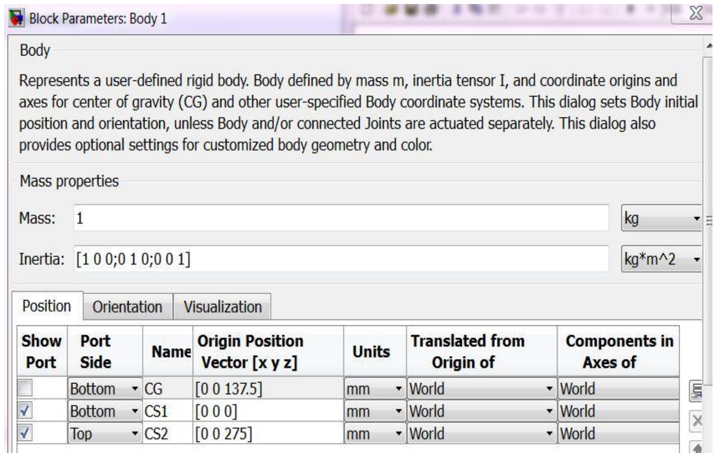

Figure 9: Body 1 block parameter

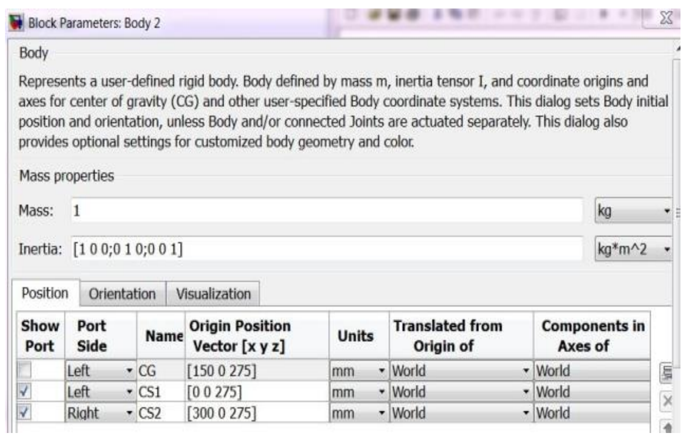

Figure 10: Body 2 block parameter

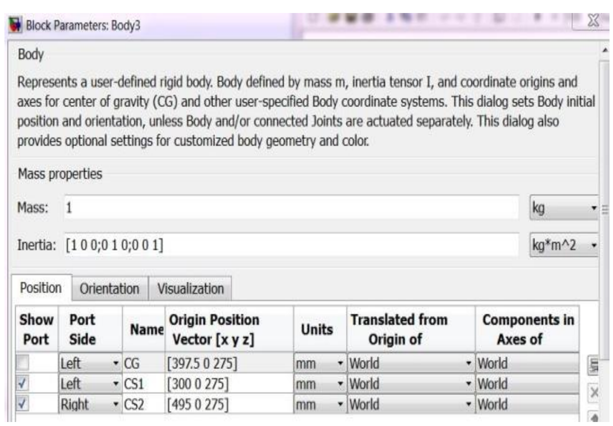

Figure 11: Body 3 block parameter

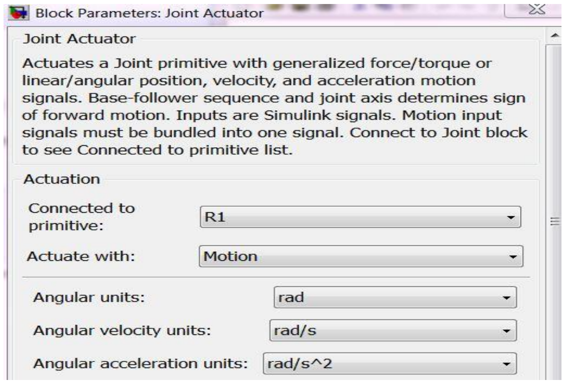

Figure 12: Joint actuator block parameter

While start of simulation we obtained the results and an image that was captured during simulation is shown in figure 13.

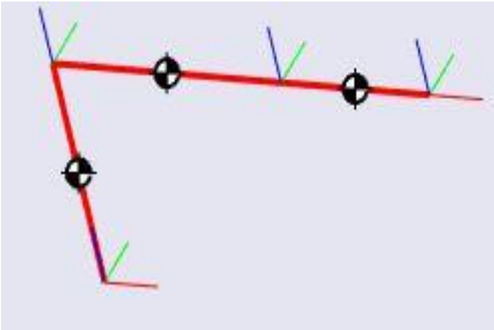

Figure 13: Image captured during simulation

4.CONCLUSION

Kinematic modeling of a serial robot is done in matlab using denavit-hartenberg representation. Image captured during the simulation helps to identify the degrees of freedom of a robot. This paper shows the importance of this software in the modeling of a serial robot for specific task. All the four D-H parameters are to be considered in the design of a serial robot. This method can be implemented without any difficulty in matlab. This method can be used only for modeling a serial robot and it cannot be used for parallel robots.

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