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Kinematic Analysis of 3 D.O.F of Robot

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Abstract: ***The study of motion can be divided into kinematics and dynamics. Direct kinematics refers to the calculation of end effectors position, orientation, velocity, and acceleration when the corresponding joint values are known. Inverse refers to the opposite case in which required joint values are calculated for given end effector values, as done in path planning. Some special aspects of kinematics include handling of redundancy collision avoidance, and singularity avoidance. Once all relevant positions, velocities, and accelerations have been calculated using kinematics, this information can be used to improve the control algorithms of a robot. Most of the industrial robots are described geometrically by their Denavit-Hartenberg (DH) parameters, which are also difficult to perceive for students. Students will find the subject easier to learn if they are able to visualize in 3 dimensions. Tools that aid its learning have been developed by universities across the world as referred elsewhere. This project proposes RoboAnalyzer, a 3D model based software that can be used to teach robotics subjects to undergraduate and postgraduate courses in engineering colleges in India and elsewhere. In the present implementation, it can be used to learn DH parameters, forward kinematics of serial robots with revolute joints and allows 3D animation and graph plots as outputs.***

Keywords- (DH), 3D.

ROBOT AND ITS COMPONENTS:

Robot is a mechanical or virtual intelligent agent that can perform tasks automatically or with guidance, typically by remote control. In practice a robot is usually an electro-mechanical machine that is guided by computer and electronic programming.

The components of robot are:

1) End effectors
2) Actuators or Drive
3) Sensors
4) Controller
5) Software.

TYPES OF JOINTS:

REVOLUTE JOINT:

A revolute joint or pin joint or hinge joint is a one degree of freedom kinematic pair used in mechanisms.` Revolute joints provide single-axis rotation function used in many places such as door hinges, folding mechanisms, and other uni-axial rotation devices.

PRISMATIC JOINT:

A prismatic joint provides a linear sliding movement between two bodies, and is often called a slider, as in the slider-crank linkage. A prismatic joint is formed with a polygonal cross-section to resist rotation.

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The relative position of two bodies connected by aprismatic joint is defined by the amount of linear slide of one relative to the other one. This one parameter movement identifies this joint as a one degree of freedom kinematic pair.

CYLINDRICAL JOINT:

A cylindrical joint is two degrees of freedom kinematic pair used in mechanisms. Cylindrical joints provide single-axis sliding function as well as a single axis rotation, providing a way for two rigid bodies to translate and rotate freely. This can be pictured by an unsecured axle mounted on a chassis, as it may freely rotate and translate.

SCREW JOINT:

A screw joint is a one degree of freedom kinematic pair used in mechanisms. Screw joints provide single-axis translation by utilizing the threads of the threaded rod to provide such translation. This type of joint is used primarily on most types of linear actuators and certain types of Cartesian.

SPHERICAL JOINT:

The Spherical Joint class represents a spherical joint node in a world. A spherical joint has three rotational degrees of freedom. When a spherical joint is used toconnect a rigid body to static geometry, it allows rotation about any axis, but maintains a constant distance between the rigid body and the joint position.

DENAVIT-HARTENBERG PARAMETERS

The Denavit-Hartenberg parameters(also called DH parameters) are the four parameters associated with a particular convention for attaching reference frames to the links of a spatial kinematic chain, or robot manipulator

1) Joint offset (b): length of intersections of common normal on joint axis
2) Joint angle (θ): angle between the orthogonal projections of the common normal to the plane normal to the joint axes.
3) Link length (a): measured as the distance between the common normal to the axis.
4) Twist angle (α): the angle between the orthogonal projections of the joint axes onto a plane normal to the common normal.

θis variable if joint is revolute,α is variable if joint is prismatic.

Forward kinematics:

Forward kinematics refers to the use of the kinematic equations of a robot to compute the position of the end-effect or from specified values for the joint parameters. The kinematics equations of the robot are used in robotics, computer games, and animation

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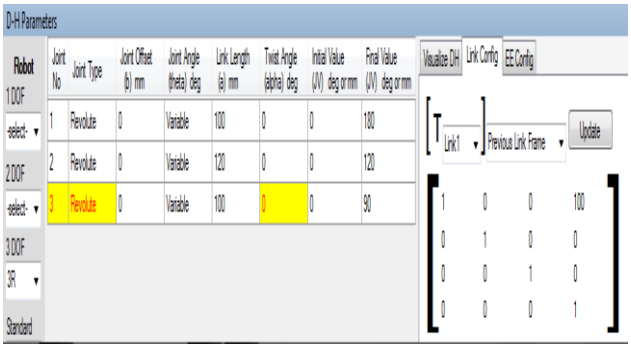
Inverse kinematics:
The reverse process that computes the joint parameters that achieve a specified position of the end-effector is known as inverse kinematics.

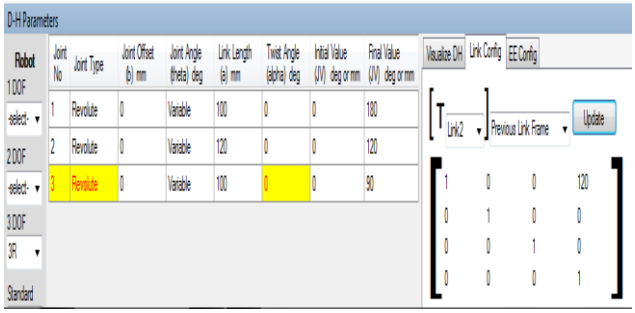
ANALYSIS ON 3DOF (RRR) IN ROBO ANALYZER:

Now to the analysis of the joint is done by selecting RRP in 3 dof The four parameters are to be filled in the DH parameters for the input for the analysis they are joint offset (b), joint angle (θ), link angle (a), twist angle (α)

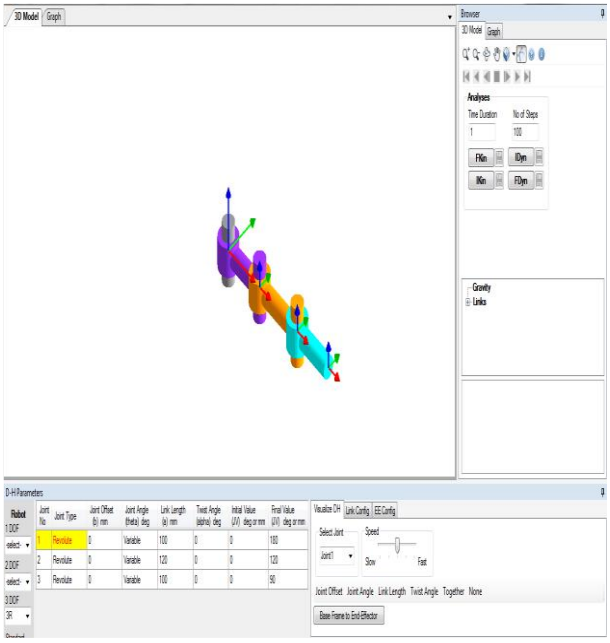
D.H.PARAMETERS LINK 1 MATRIX:



D.H.PARAMETERS LINK 2 MATRIX:

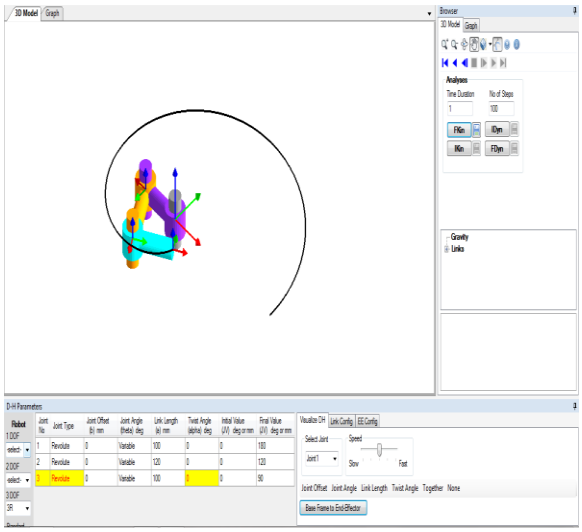


RRR PLANAR ROBOT USING ROBO ANALYZER SOFTWARE:



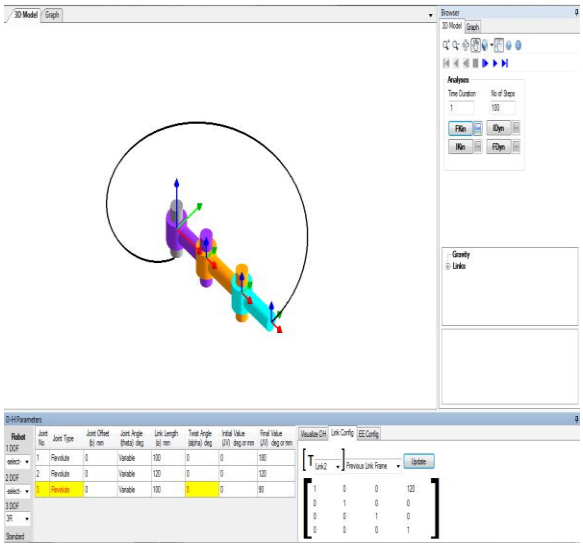
It gives the design that we gave in those parameters in 3D model. The link configuration and end effector configuration is also updated by using input parameters.

Now on the analysis on pressing the forward kinematics option (Fkin) it will analyze the parameters that are given and after completion it shows Analysis is completed.
Now we can simulate the 3D model by using the playing keys as according the figure for the RRP is
Forward Simulation:



It show the simulation of the joint and it also show the path the joint or link revolved.

Backward simulation:



Graph of the links and joints:

For All Links:

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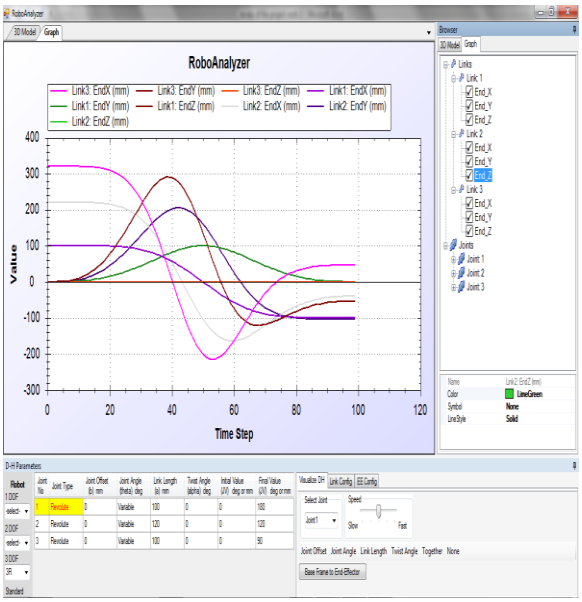
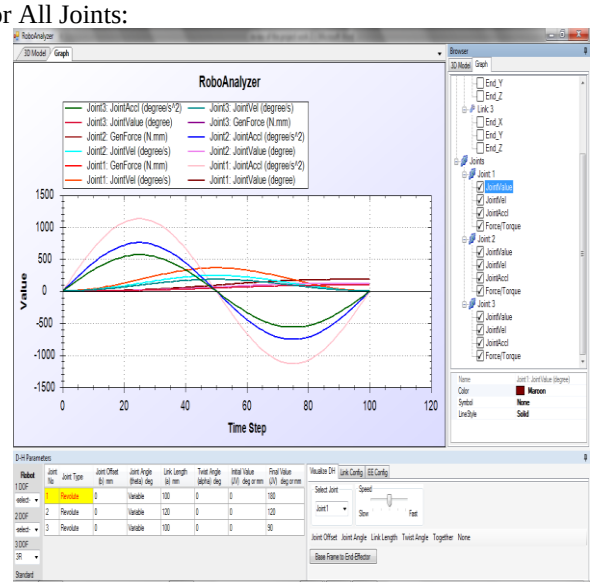
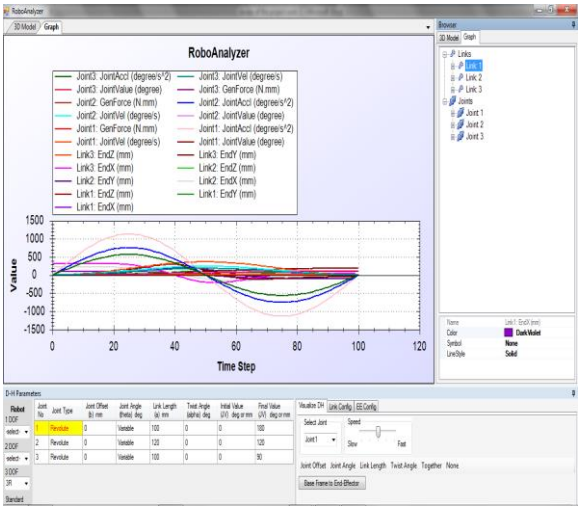


The graph is plotted by selecting the options in the graph tab in that we must select the link or he joint for which we want to know the end effector positions during the forward kinematics.

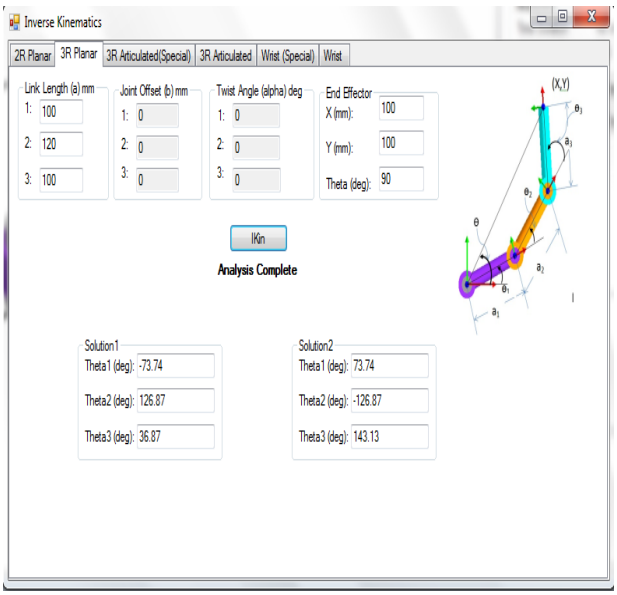
For All Joints:



Graph With All Links And Joints:



INVERSE KINEMATICS SOLUTION:



This is complete analysis that is done usingrobo analyzer software.

THEORTICAL CALCULATIONS:

FRAME NO	ai	Ai	Di	θi
1	L1	0	0	θ1
2	L2	0	0	θ2
3	L3	0	0	θ3

L1=100;θ1=180
L2=120; θ2=120
L3=100;θ3=90

We can find the transformation matrix i-1(T)i for i=3,2,1.

$$^{2}T_3 = \begin{bmatrix} \cos\theta_3 & -\sin\theta_3 & 0 & l_3\cos\theta_3 \\ \sin\theta_3 & \cos\theta_3 & 0 & l_3\sin\theta_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$^{1}T_2 = \begin{bmatrix} \cos\theta_2 & -\sin\theta_2 & 0 & l_2\sin\theta_2 \\ \sin\theta_2 & \cos\theta_2 & 0 & l_2\sin\theta_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$^{0}T_1 = \begin{bmatrix} \cos\theta_1 & -\sin\theta_1 & 0 & l_1\cos\theta_1 \\ \sin\theta_1 & \cos\theta_1 & 0 & l_1\sin\theta_1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

∴ The transformation matrix to relate the end effector from Matrix $^{0}T_1$, $^{1}T_2$, $^{2}T_3$.

$$\begin{bmatrix} \cos(\theta_1+\theta_2+\theta_3) & -\sin(\theta_1+\theta_2+\theta_3) & 0 & r_{14} \\ \sin(\theta_1+\theta_2+\theta_3) & \cos(\theta_1+\theta_2+\theta_3) & 0 & r_{24} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\therefore r_{14} = l_1\cos\theta_1 + l_2\cos(\theta_2+\theta_1) + l_3\cos(\theta_1+\theta_2+\theta_3)$$

$$\therefore r_{24} = l_1\sin\theta_1 + l_2\sin(\theta_1+\theta_2) + l_3\sin(\theta_1+\theta_2+\theta_3)$$

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The position of the origin of the frame which is the tip point of the Robot

$$ {}^{0}T_3 \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} = \begin{bmatrix} l_1\cos\theta_1 + l_2\cos(\theta_1+\theta_2) + l_3\cos(\theta_1+\theta_2+\theta_3) \\ l_2\sin\theta_1 + l_2\sin(\theta_1+\theta_2) + l_3\sin(\theta_1+\theta_2+\theta_3) \\ 0 \\ 1 \end{bmatrix} $$

Co-ordinate of the tip point in the Base coordinate frame if we have the geometry of the robot and all joint Variables

$$ X = l_1\cos\theta_1 + l_2\cos(\theta_1+\theta_2) + l_3\cos(\theta_1+\theta_2+\theta_3) $$

$$ Y = l_1\sin\theta_1 + l_2\sin(\theta_2+\theta_1) + l_3\sin(\theta_1+\theta_2+\theta_3) $$

The real position of the manipulator is lying on the X-axis where $\theta_1 = 0,\ \theta_2 = 0,\ \theta_3 = 0$ become ${}^{0}T_3$

Becomes

$$ {}^{0}T_3 = \begin{bmatrix} 1 & 0 & 0 & l_1+l_2+l_3 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

Transformation matrix ${}^{i-1}T_i$ are enough to determine the Configuration of each link in other links frame

link (2) in 0 is

$$ {}^{0}T_2 = {}^{0}T_1\,{}^{1}T_2 $$

$$ = \begin{bmatrix} \cos(\theta_1+\theta_2) & -\sin(\theta_1+\theta_2) & 0 & f_{14} \\ \sin(\theta_1+\theta_2) & \cos(\theta_1+\theta_2) & 0 & f_{24} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ f_{14} = l_1\cos\theta_1 + l_2\cos(\theta_1+\theta_2) $$

$$ f_{24} = l_1\sin\theta_1 + l_2\sin(\theta_1+\theta_2) \quad \text{and} $$

Configuration of link(3) in (1) is

$$ {}^{1}T_3 = {}^{1}T_2\,{}^{2}T_3 $$

$$ \begin{bmatrix} \cos(\theta_2+\theta_3) & -\sin(\theta_2+\theta_3) & 0 & g_{14} \\ \sin(\theta_2+\theta_3) & \cos(\theta_2+\theta_3) & 0 & g_{24} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ g_{14} = l_3\cos(\theta_2+\theta_3) + l_2\cos\theta_2 $$

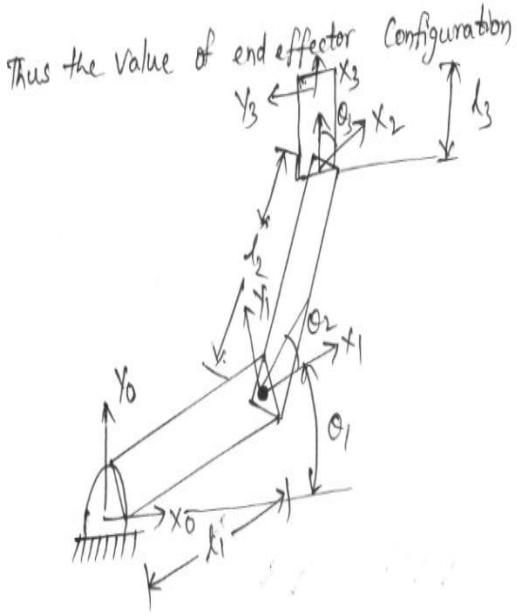
$$ g_{24} = l_2\sin(\theta_2+\theta_3) + l_2\sin\theta_2 $$

As per l_1, l_2, l_3 and $\theta_1, \theta_2, \theta_3$ substitute in above equations

$$ {}^{2}T_3 = \begin{bmatrix} 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 100 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{0}T_3 = \begin{bmatrix} 1 & 0 & 0 & 320 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} $$

Thus the value of end effector Configuration



SIMULATION USING MAT LAB:

In the mat lab required program is generated by using dimensions and DH parameters. The program simulated is Crude Code for 3DOF RRR robot with given DH parameters:

MAT LAB SIMULATION:

PROGRAM FOR 3 LINK ROBOT 3RRR:

Crude code for a 3 link RRR robot given DH params:

```
figure;
h = plot3(0,0,0);p = get(h,'Parent');xlim(p,'manual');
xlim(p,[0 2]);ylim(p,'manual');ylim(p,[0 2]);zlim(p,'manual');
zlim(p,[0 2]);axis vis3d;grid on;
point1.x =0;point1.y = 0;point1.z = 0;
point2.x = 0;point2.y = 0;point2.z = 1;
point3.x = 0;point3.y = 0;point3.z = 1;
point4.x = 2;point4.y = 0;point4.z = 1;
l= line([point1.x, point2.x],[point1.y,point2.y],[point1.z,point2.z],'Color','r','LineWidth',4);
l1 = line([point2.x, point3.x],[point2.y,point3.y],[point2.z,point3.z],'Color','b','LineWidth',4);
l2 = line([point3.x, point4.x],[point3.y,point4.y],[point3.z,point4.z],'Color','g','LineWidth',4);
pause(0.5);
theta2 = 30;
theta3 =0;
for theta1 = 70:-1:0
[point2,point3,point4] = fromDHandTheta(theta1,theta1,theta1); %(each individual theta)
set(l,'ZData',[point1.z,point2.z],'YData',[point1.y,point2.y],'XData',[point1.x,point2.x]);
set(l1,'ZData',[point2.z,point3.z],'YData',[point2.y,point3.y],'XData',[point2.x,point3.x]);
set(l2,'ZData',[point3.z,point4.z],'YData',[point3.y,point4.y],'XData',[point3.x,point4.x]);
hold on;
plot3(point4.x,point4.y,point4.z,'xk');
pause(0.1);
end
```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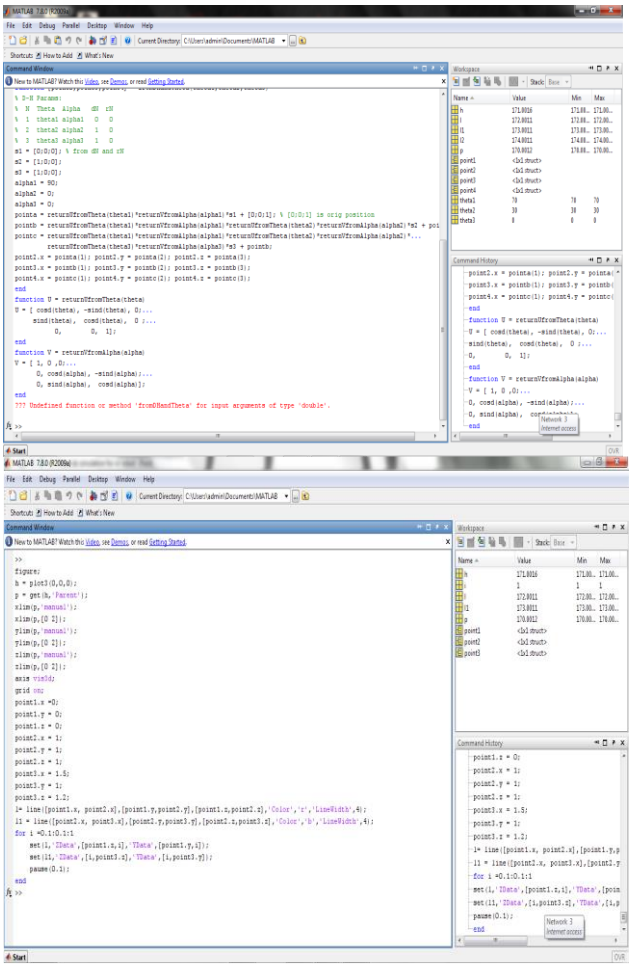
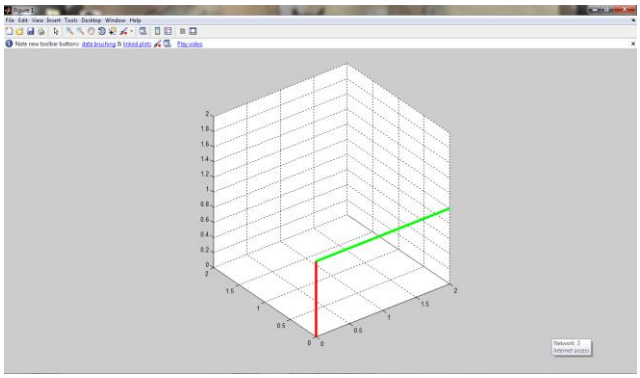
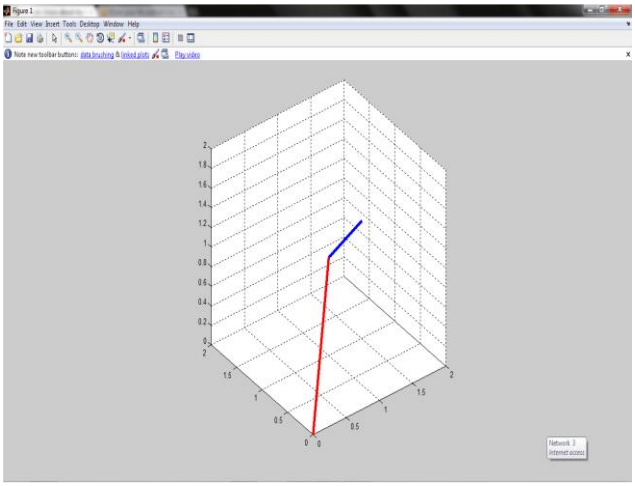
```
end
function [point2,point3,point4] = fromDHandTheta(theta1,theta2,theta3)
% D-H Params:
% N Theta Alpha dN rN
% 1 theta1 alpha1 0 0
% 2 theta2 alpha2 1 0
% 3 theta3 alpha3 1 0
s1 = [0;0;0]; % from dN and rN
s2 = [1;0;0];
s3 = [1;0;0];
alpha1 = 90;
alpha2 = 0;
alpha3 = 0;
pointa = returnUfromTheta(theta1)*returnVfromAlpha(alpha1)*s1 + [0;0;1]; % [0;0;1] is orig position
pointb
returnUfromTheta(theta1)*returnVfromAlpha(alpha1)*returnUfromTheta(theta2)*returnVfromAlpha(alpha2)*s2
pointa;
pointc
returnUfromTheta(theta1)*returnVfromAlpha(alpha1)*returnUfromTheta(theta2)*returnVfromAlpha(alpha2)*...
returnUfromTheta(theta3)*returnVfromAlpha(alpha3)*s3 + pointb;
point2.x = pointa(1); point2.y = pointa(2); point2.z = pointa(3);
point3.x = pointb(1); point3.y = pointb(2); point3.z = pointb(3);
point4.x = pointc(1); point4.y = pointc(2); point4.z = pointc(3);
end
function U = returnUfromTheta(theta)
U = [ cosd(theta), -sind(theta), 0;...
  sind(theta), cosd(theta), 0 ;...
  0,      0,  1];
  end
  function V = returnVfromAlpha(alpha)
  V = [ 1, 0 ,0;...
  0, cosd(alpha), -sind(alpha);...
  0, sind(alpha), cosd(alpha)];
  End
```



SIMULATED AND OBTAINED GRAPHS:





Mat Lab simulation has been completed and the results are obtained in the form of graphs and the graph which plotsare matched with the above graphs and values obtained in theoretical calculations and values using roboanalyzer.

CONCLUSION:

Kinematic analysis of 3DOF 3R robot was simulated using Robo Analyzer software and Mat Works. By using Robo Analyzer we obtained forward kinematics of the end effector of robot and obtained solutions for inverse kinematics and calculated DH parameters theoretically and those obtained matrix of end effector was matched with update matrix of DH parameters in Robo Analyzer and programming using mat works is done and obtained in form of graphwhich is similar to the obtained values in Robo Analyzer. Thus the kinematic analysis of 3DOF 3R robot is completed.

REFERENCES

1. Angles, J, 2003, Fundamentals of Robotics Mechanical Systems, Springer-verlag, NY.
2. Introduction to Robotics, S K Saha, 2009.
3. Denavit and Hartenberg, R.S,1995, A Kinematic Notations for lower pair mechanisms based on matrices
4. Robo Analyzer,(http://www.roboanlyzer.com)
5. Mat Works,(http://www.mathworks.com)
6. International Conference of Multibody Dynamics ICMBD-2011, Vijayawada,India
7. Peter I.corke, Dec.2008, Robotics tool box for matlab.
8. RRR-robot: design of an industrial like test facility for nonlinear robot control, A.M. Van Beek Eindhoven University of Technology(TUE)
9. ROBOT KINEMATICS- Vaclav Hlavac, Czech Technical University, Faculty of Electrical Engineering Department of Cybernetics.

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