ROBOT KINEMATICS USING ROBOANALYZER SOFTWARE

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OBJECTIVE

- RoboAnalyzer is a software based on 3D model of robots. It was developed primarily for teaching and learning of robot mechanics, although it is robust enough for the use by researchers as well.
- The motive behind the development of RoboAnalyzer was mainly to help teachers and students get started with teaching/learning of robotics using template-based skeleton models or CAD models of serial robots.
- This minimizes the time otherwise spent on modelling, programming, and simulating the robots from scratch. In this article, we focus on the visualization of the **Denavit Hartenberg (DH)** parameters used to define a robot's architecture, and the modelling of the robot's input-output motion characteristics, that is, robot kinematics, using them.
- The advantages of using RoboAnalyzer to overcome several challenges of learning robotics in a classroom environment are also discussed.

PROBLEM STATEMENT

- After obtaining all the concepts and theoretical knowledge about basic robotics and the DH parameters, we have implemented the same using the Roboanalyzer software.
- We have worked on three topics in this minor project which are as follows: -

    1. Joint Control of 3R robot manipulator
    2. Forward dynamics
    3. Inverse dynamics

- Finally we have extended our project to trying out the Virtual Robot Module from the Roboanalyzer software.

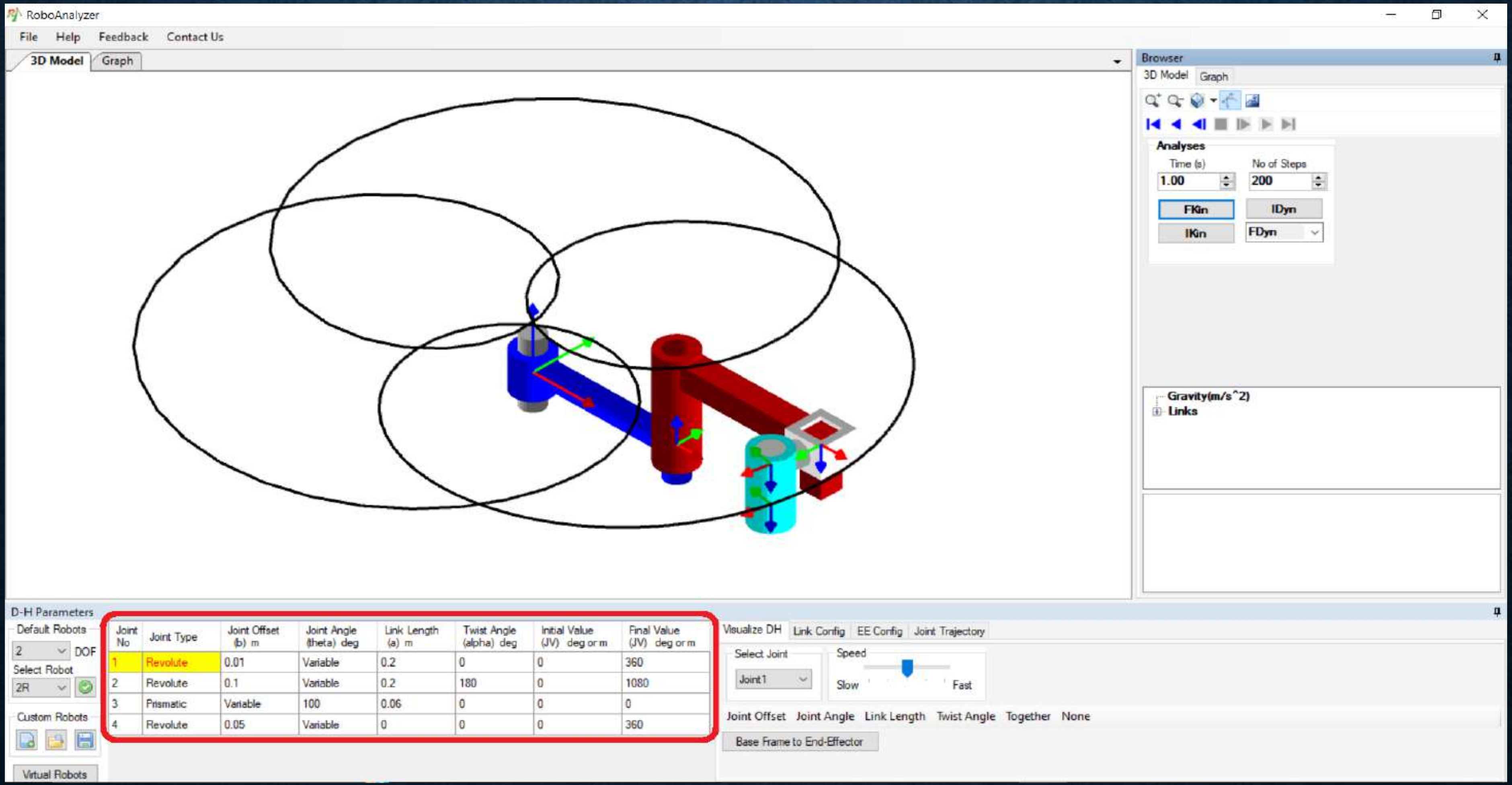
INTRODUCTION

- The design philosophy behind RoboAnalyzer was as follows: While learning robot mechanics, its physics must not be obscured by the underlying mathematics.
- It has been developed with an objective of teaching and learning robotics using few regular shapes of the links. That way a we got started with the kinematic and dynamic analyses of the robots without spending too much time in learning CAD modelling and/or programming a real robot if it exists.
- The emphasis is given on the visualization of the DH parameters used to define a robot's architecture, and the problems.

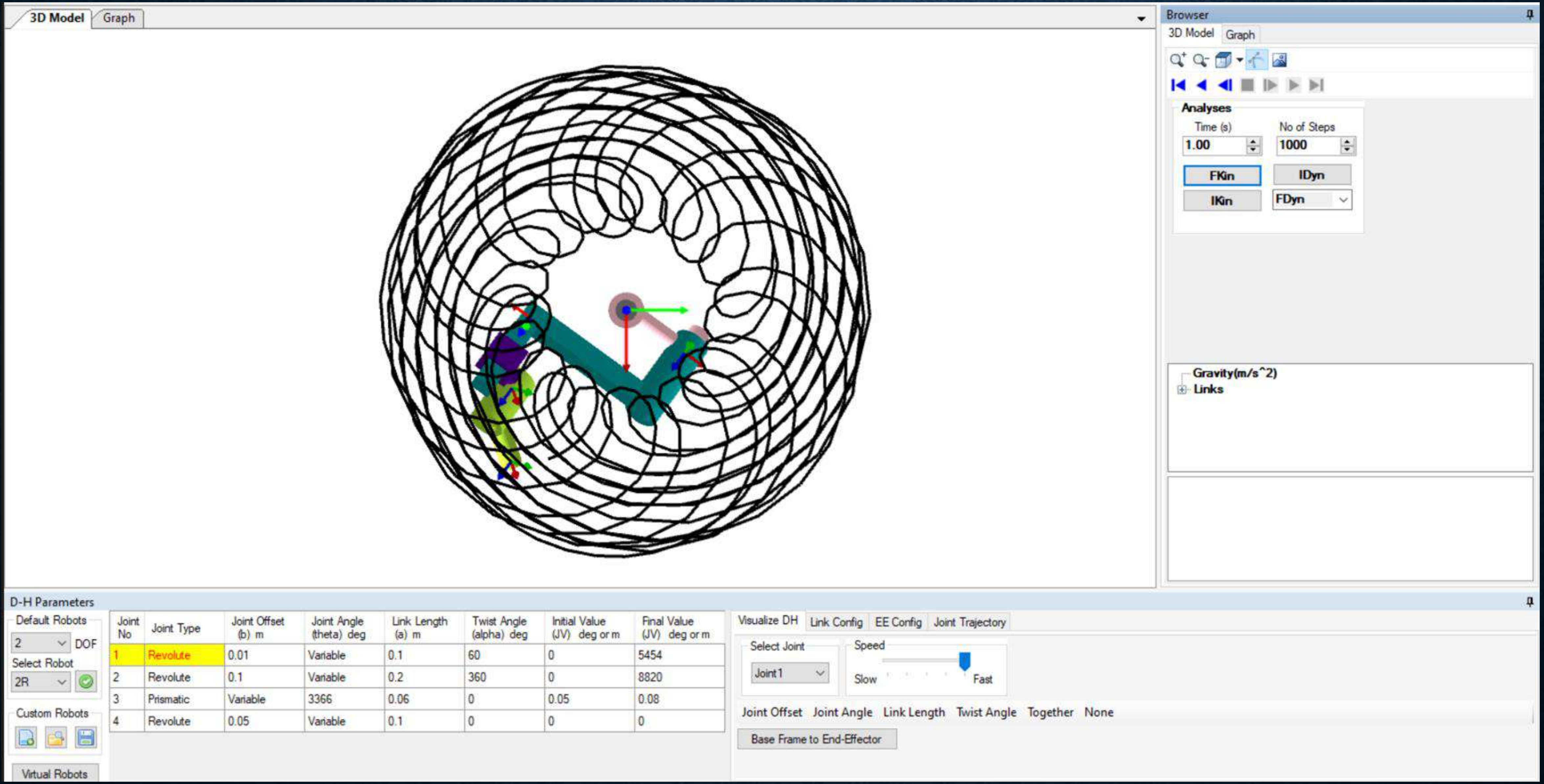
WORKFLOW

- In its present implementation RoboAnalyzer takes DH parameters of a serial robot (manipulator) with revolute joints as input.
- It then generates a 3D model of the robot as per the DH parameters. The 3D viewing window has zoom, pan and tilt capabilities using which 3D model can be viewed from various angles.
- Simulation parameters can be set and forward kinematics analysis can be performed. The results can then be viewed in the form of animation of all the links and the trace of end-effector position.
- The plots of the end-effector positions and the joint variables can be drawn and exported as comma separated value (CSV) files.

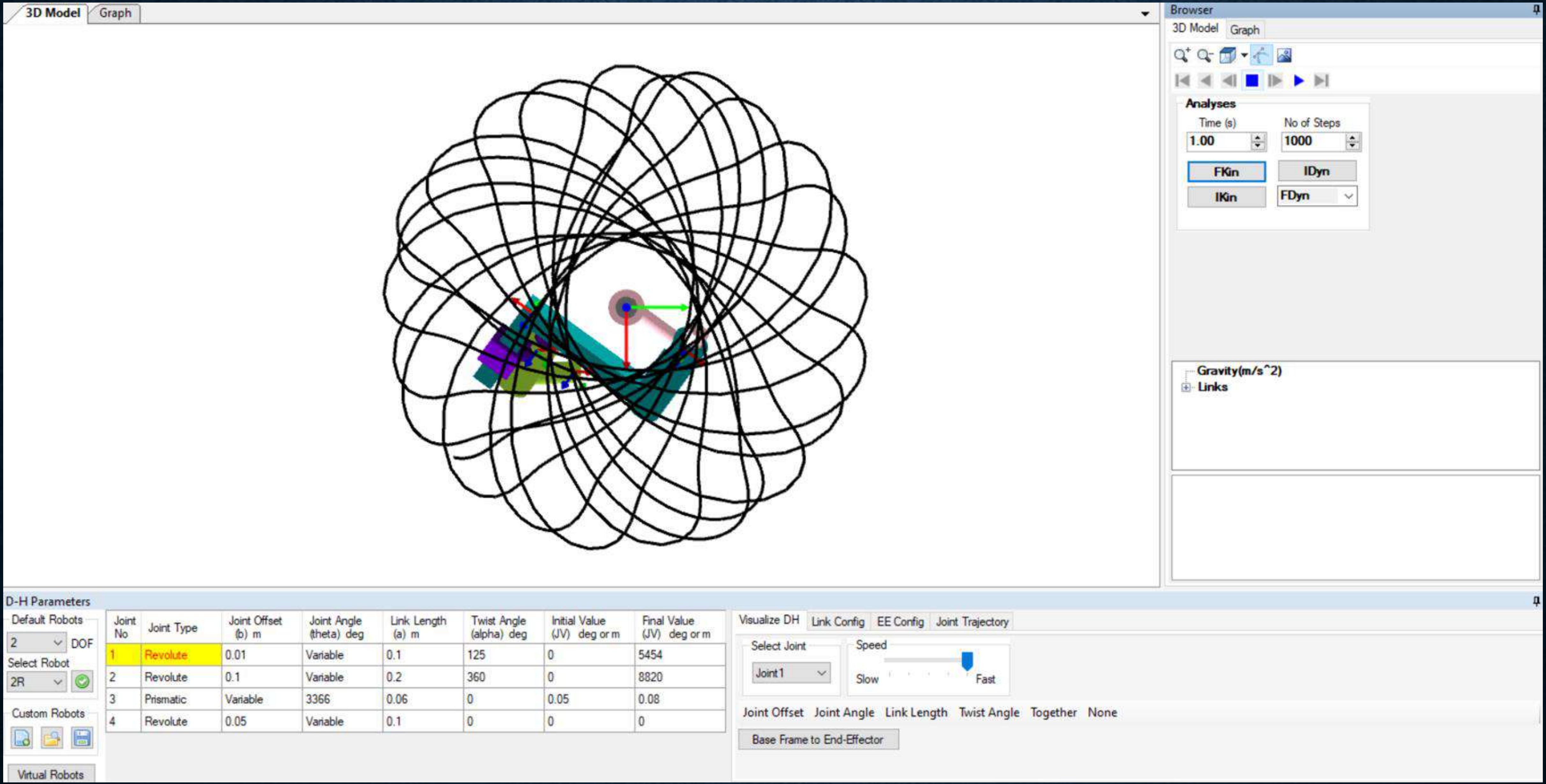
DH PARAMETERS



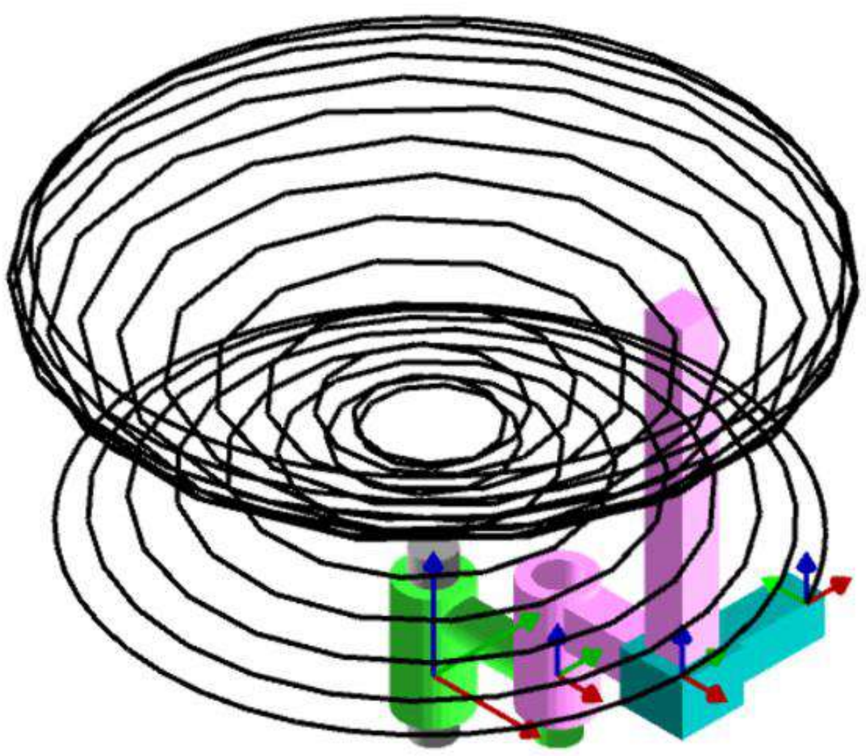
Some robot arms with different trajectory :



Joint No	Joint Type	Joint Offset (b) m	Joint Angle (theta) deg	Link Length (a) m	Twist Angle (alpha) deg	Initial Value (JV) deg or m	Final Value (JV) deg or m
1	Revolute	0.01	Variable	0.1	60	0	5454
2	Revolute	0.1	Variable	0.2	360	0	8820
3	Prismatic	Variable	3366	0.06	0	0.05	0.08
4	Revolute	0.05	Variable	0.1	0	0	0


3D Model
Graph
Browser
3D Model
Graph
Analyses
Time (s)
1.00
No of Steps
1000
FKin
IDyn
IKin
FDyn
Gravity(m/s^2)
Links
D-H Parameters
Default Robots
2
DOF
Select Robot
2R
Custom Robots
Virtual Robots
Joint No
Joint Type
Joint Offset (b) m
Joint Angle (theta) deg
Link Length (a) m
Twist Angle (alpha) deg
Initial Value (JV) deg or m
Final Value (JV) deg or m
1 Revolute 0.01 Variable 0.1 125 0 5454
2 Revolute 0.1 Variable 0.2 360 0 8820
3 Prismatic Variable 3366 0.06 0 0.05 0.08
4 Revolute 0.05 Variable 0.1 0 0 0
Visualize DH
Link Config
EE Config
Joint Trajectory
Select Joint
Joint 1
Speed
Slow
Fast
Joint Offset
Joint Angle
Link Length
Twist Angle
Together
None
Base Frame to End-Effector

3D Model | Graph



D-H Parameters

Default Robots

3 DOF

Select Robot

RRP

Joint No	Joint Type	Joint Offset (b) m	Joint Angle (theta) deg	Link Length (a) m	Twist Angle (alpha) deg	Initial Value (JV) deg or m	Final Value (JV) deg or m
1	Revolute	0.05	Variable	0.1	0	0	7200
2	Revolute	0.05	Variable	0.1	0	0	360
3	Prismatic	Variable	90	0.1	0	0	0.2

Custom Robots

Virtual Robots

Visualize DH | Link Config | EE Config | Joint Trajectory

Select Joint: Joint1

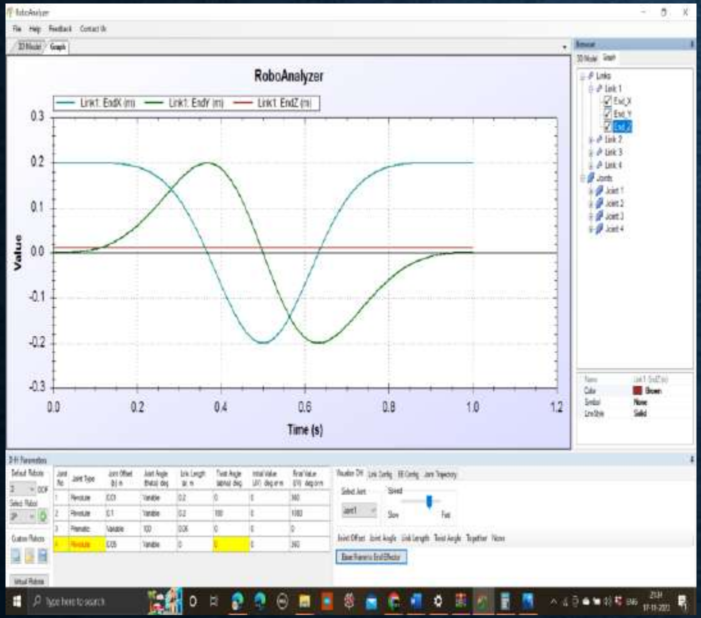
Speed: Slow — Fast

Joint Offset | Joint Angle | Link Length | Twist Angle | Together | None

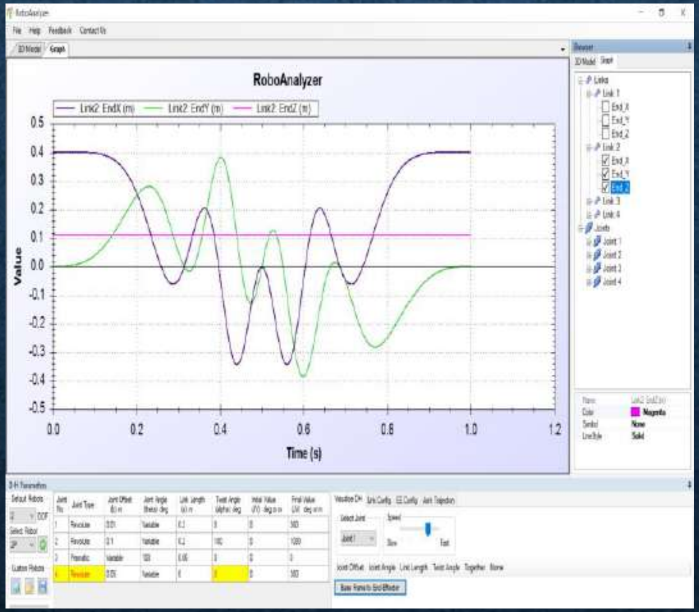
Base Frame to End-Effector

MODEL GRAPH FOR THE DIFFERENT LINKS OF ROBOS :

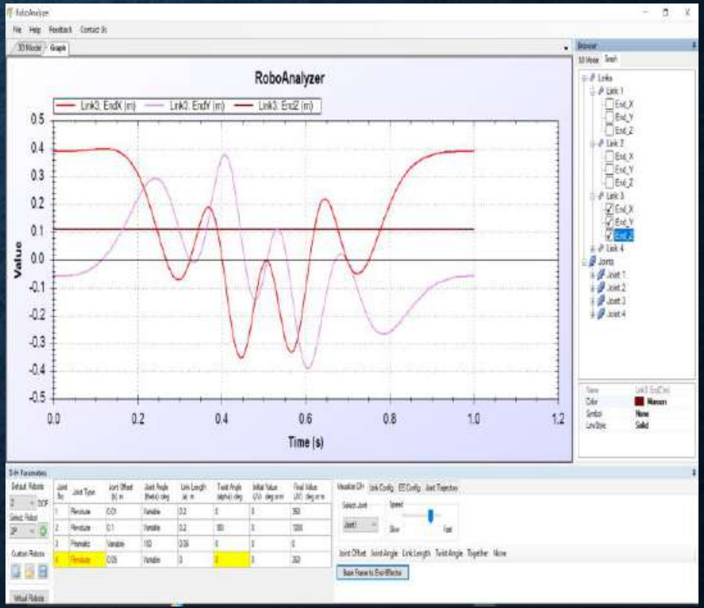
LINK 1



LINK 2



LINK 3



FORWARD DYNAMICS

- A study of forward kinematics of the 2-R robot shown in Figure 7(a) will be carried and that will be validated against the forward kinematics relations.
- The configuration of its end-effector (EE) in terms of the Cartesian coordinates of the EE and the orientation of the EE should be known in the fixed frame of reference located at the base.
- A relation between the configuration of the end-effector and the joint angles (in case of a revolute joint) can be obtained as follows:

  The ith set of DH parameters relate the coordinate frame Xi+1Yi+1Zi+1 attached to the ith link with the frame XiYiZi attached to (i -1) link.

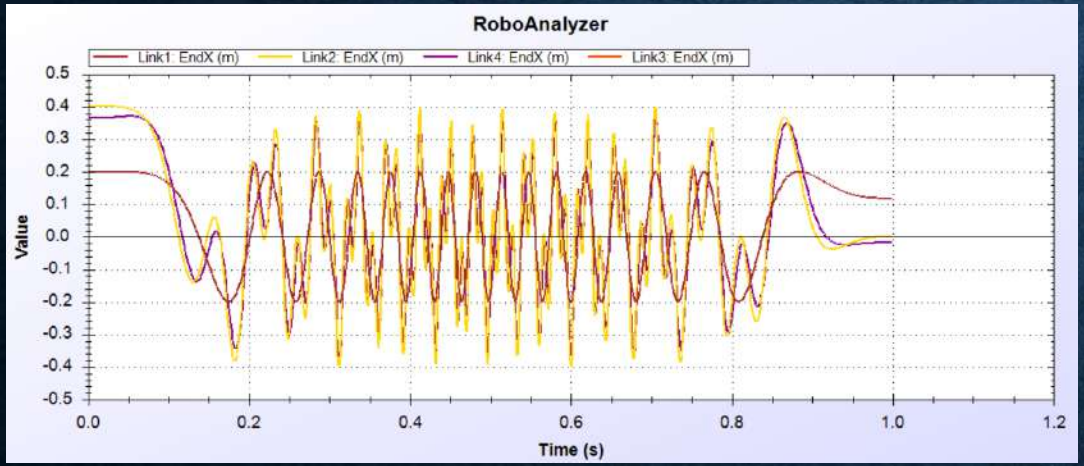
- The relationship can be expressed as the transformation matrix Ti, comprising of both position and orientation information of the (i + 1)st frame with respect to the ith frame terms.

INVERSE DYNAMICS

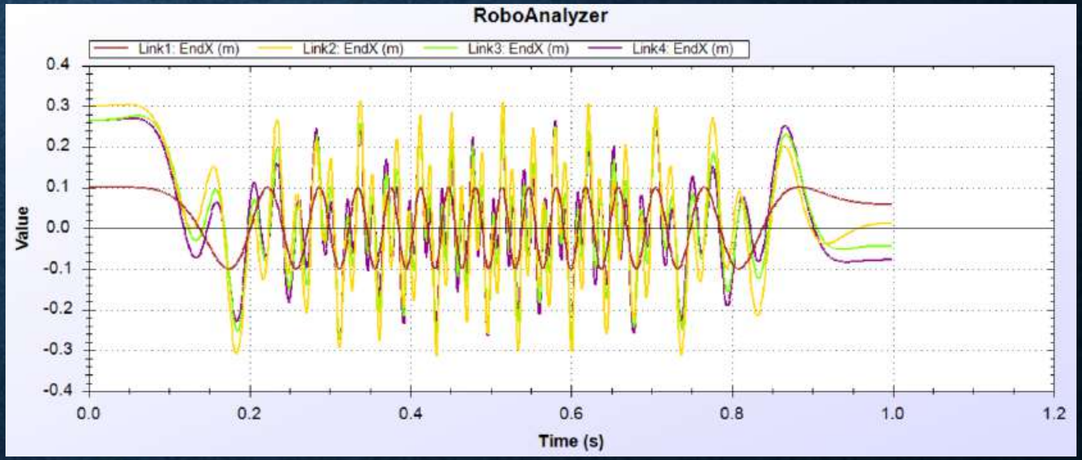
- Inverse kinematics problem of a typical industrial robot is not straight forward, mainly, owing to the existence of multiple solutions of the highly non-linear trigonometric functions. While the forward kinematics has a generic procedure for all robot architectures, there is no generic inverse kinematics solution possible that can accommodate all robot architectures.
- To obtain solutions to the inverse kinematics problem, one is required to solve multiple multivariate transcendental equations. Sometimes no solution may exist for a given input pose. The inverse kinematics module of RoboAnalyzer was designed to tackle the above issues.
- The closed-form solutions of the inverse kinematics problem of several commonly discussed robots in a textbook were implemented. We can supply the position and orientation of the EE in the form of the Homogeneous Transformation Matrix (HTM) containing 3×3 rotation matrix and the 3-dimensional end-effector position, and then obtain all possible solutions, if they exist.
- This would help the user in appreciating various solutions for a single EE pose. The focus here is not the computational efficiency of the inverse kinematics solution, but the ease with which the solutions can be obtained and visualized. Using these, we were able to verify our results.

RESULTS OF FORWARD AND INVERSE DYNAMICS (FROM REPORT)

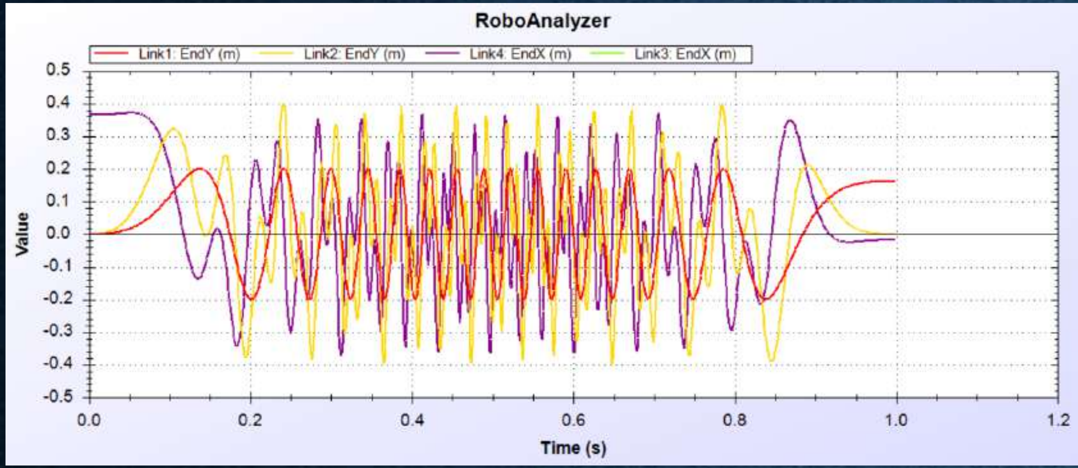
FORWARD KINEMATICS-2D

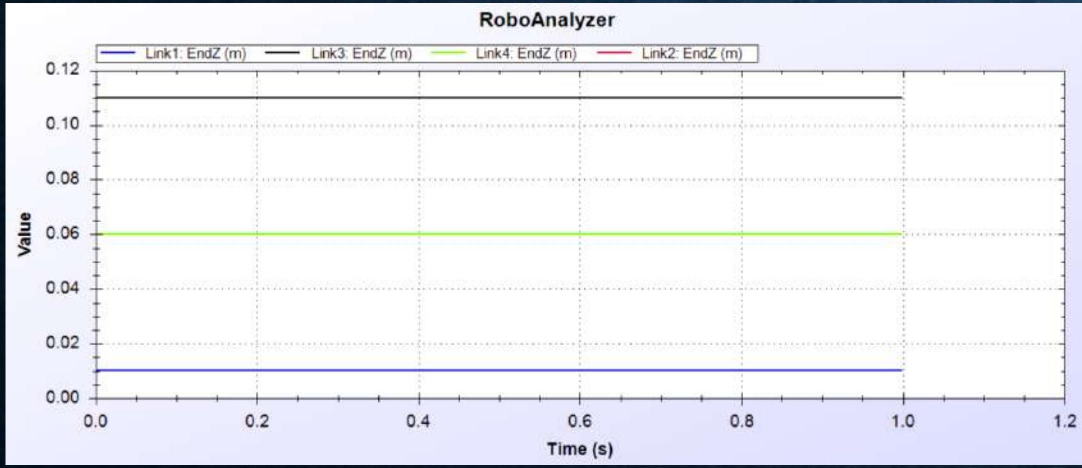


REVERSE DYNAMICS-3D

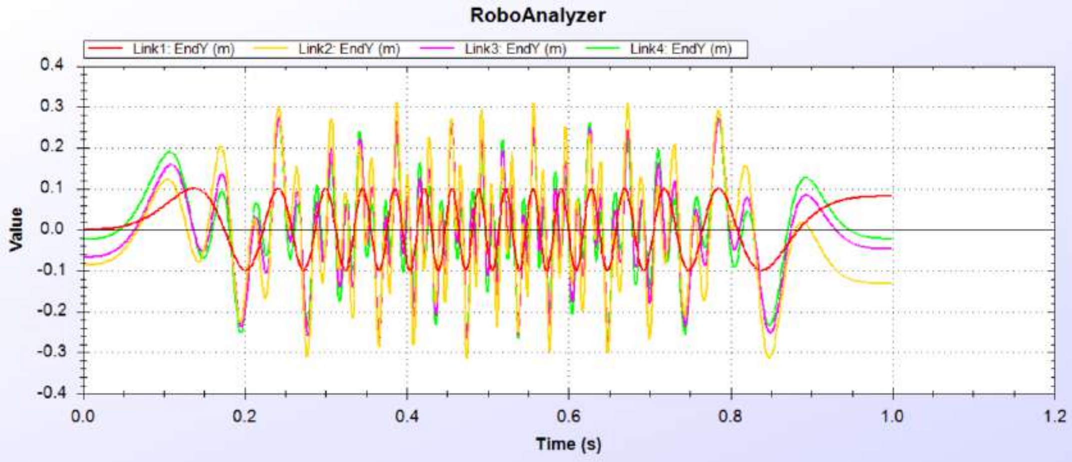


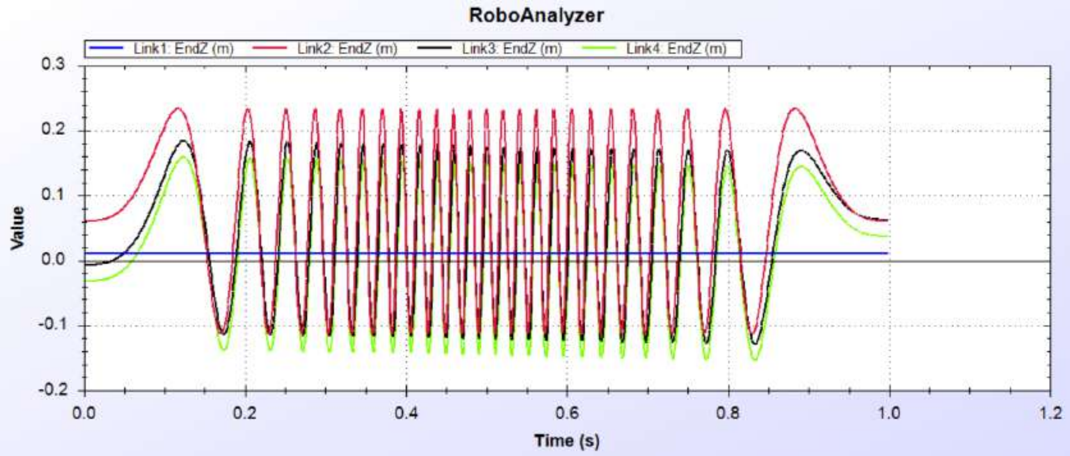
FORWARD KINEMATICS-2D



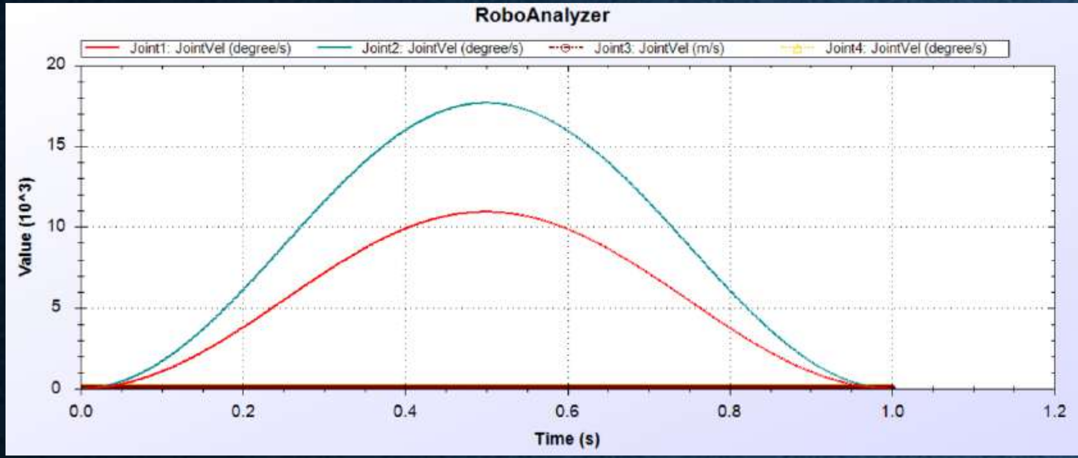


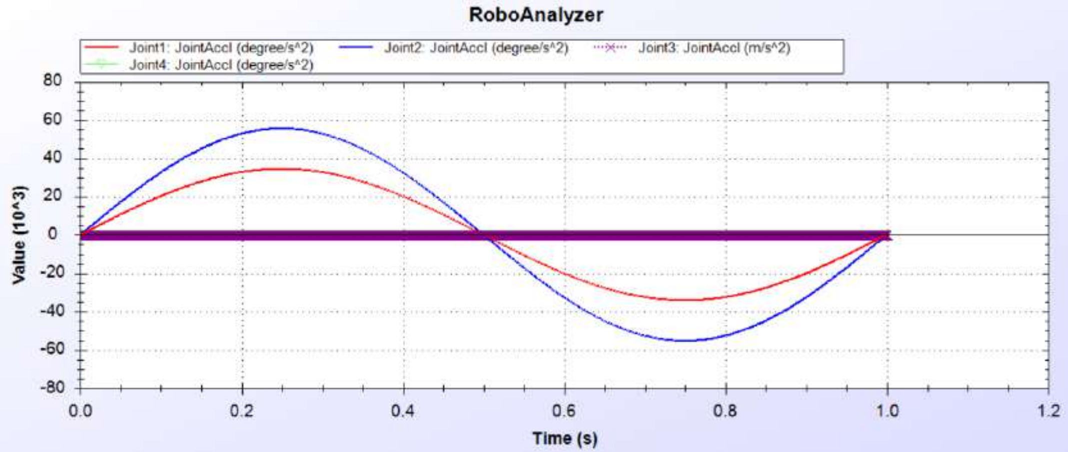
REVERSE DYNAMICS-3D



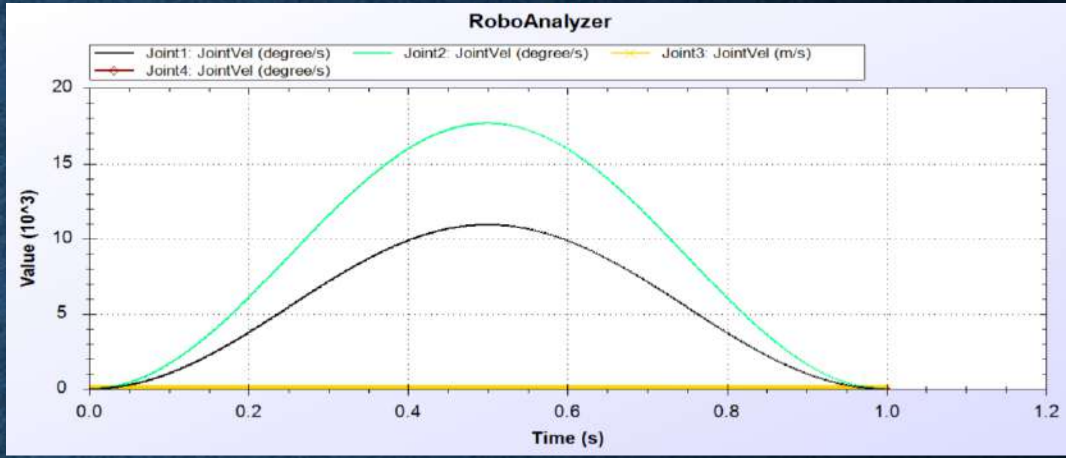


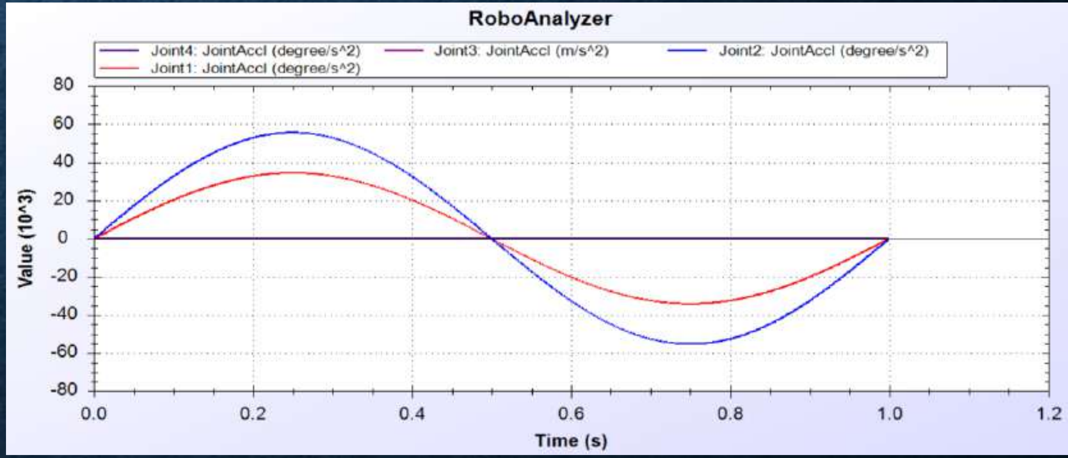
FORWARD KINEMATICS-2D





REVERSE DYNAMICS-3D

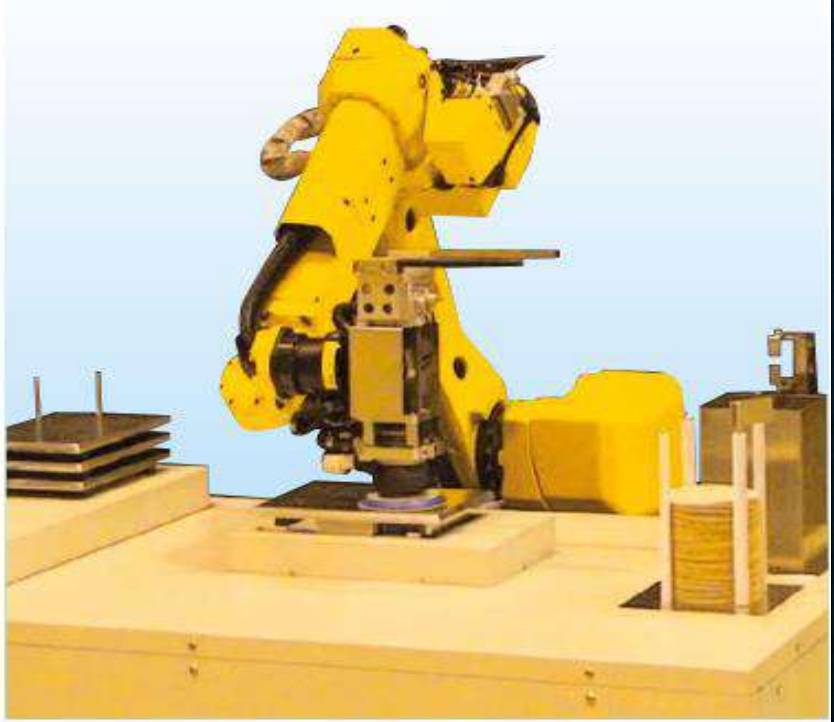




JOINT CONTROL OF VIRTUAL ROBOTS

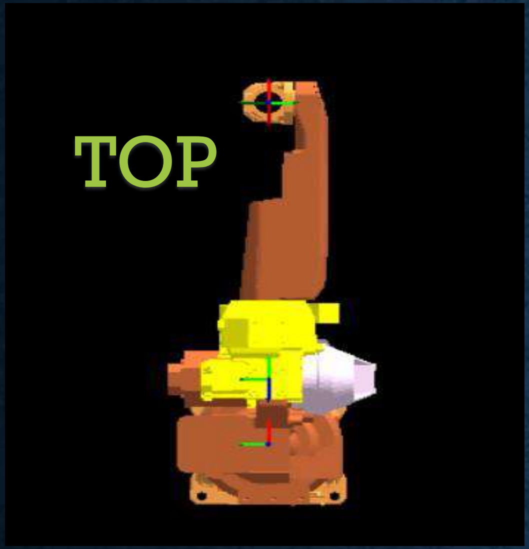
We have taken “Fanuc M10 iA” for our simulation purpose. FANUC Robot M-10iA is the cables integrated small payload handling robot whose payload is 7 to 12kg . Some of the industrial application of this robots are :

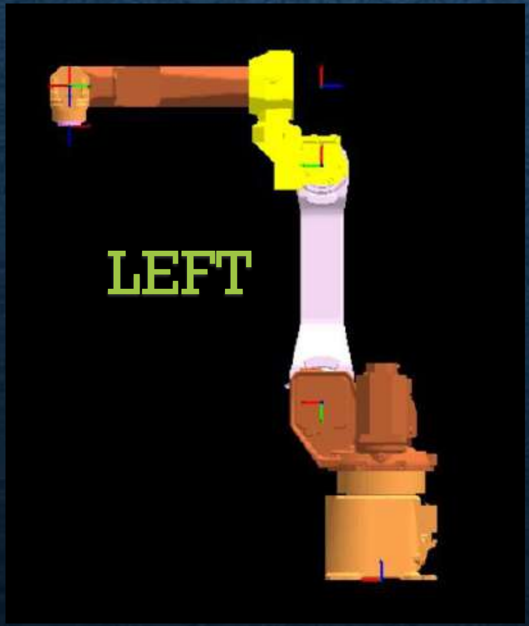
Small parts bin picking

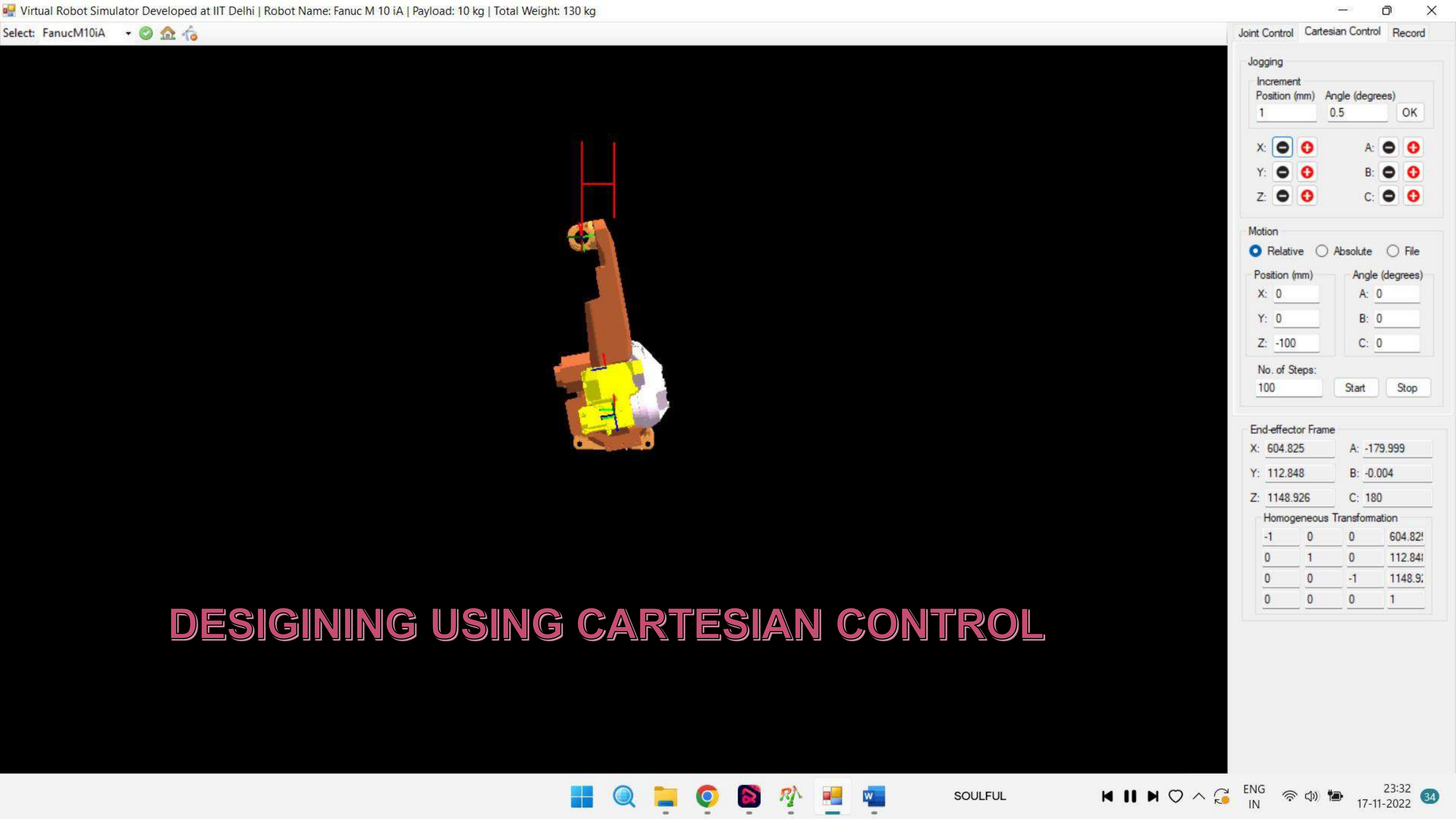


Case parts polishing

Diiferent view of "Fanuc M10 iA" in robo analyzer software :






Virtual Robot Simulator Developed at IIT Delhi | Robot Name: Fanuc M 10 iA | Payload: 10 kg | Total Weight: 130 kg
Select: FanucM10iA
Joint Control
Cartesian Control
Record
Jogging
Increment
Position (mm)
Angle (degrees)
1
0.5
OK
X:
Y:
Z:
A:
B:
C:
Motion
Relative
Absolute
File
Position (mm)
Angle (degrees)
X: 0
Y: 0
Z: -100
A: 0
B: 0
C: 0
No. of Steps:
100
Start
Stop
End-effector Frame
X: 604.825
Y: 112.848
Z: 1148.926
A: -179.999
B: -0.004
C: 180
Homogeneous Transformation
-1 0 0 604.82!
0 1 0 112.84!
0 0 -1 1148.9:
0 0 0 1
DESIGIGINING USING CARTESIAN CONTROL
SOULFUL
ENG
IN
23:32
17-11-2022
34

JOINT CONTROL OF VIRTUAL ROBOT

REFERENCES

I. Rajeevlochana, C. G., and S. K. Saha. "RoboAnalyzer: 3D model based robotic learning software." In International Conference on Multi Body Dynamics, pp. 3-13. 2011.

II. Othayoth, Ratan S., Rajeevlochana G. Chittawadigi, Ravi P. Joshi, and Subir K. Saha. "Robot kinematics made easy using RoboAnalyzer software." Computer Applications in Engineering Education 25, no. 5 (2017): 669-680.

III. Gupta, Vaibhav, Rajeevlochana G. Chittawadigi, and Subir Kumar Saha. "RoboAnalyzer: robot visualization software for robot technicians." In Proceedings of the Advances in Robotics, pp. 1-5. 2017.

IV. Sadanand, Ratan, Ravi Prakash Joshi, Rajeevlochana G. Chittawadigi, and Subir Kumar Saha. "Virtual experiments for integrated teaching and learning of robot mechanics using roboanalyzer", pp. 59-68. Springer, New Delhi, 2016.

V. Singh, Ambuja, Ratna Priya Kanchan, and Saakshi Singh. "A review paper on analysis and simulation of kinematics of 3r robot with the help of roboanalyzer." International Journal of Engineering Research 5, no. 04 (2016).

ROBOTICS AND CONTROL

- Prof. Rashmi Ranjan Das

Robot kinematics using RoboAnalyzer software

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OBJECTIVE: -

- RoboAnalyzer is a software based on 3D models of robots. It was developed primarily for teaching and learning robot mechanics, although it is robust enough for use by researchers as well.
- The motive behind the development of RoboAnalyzer was mainly to help teachers and students get started with teaching/learning robotics using template-based skeleton models or CAD models of serial robots.
- This minimizes the time otherwise spent on modelling, programming, and simulating the robots from scratch. In this article, we focus on the visualization of the **Denavit Hartenberg (DH)** parameters used to define a robot's architecture, and the modelling of the robot's input-output motion characteristics, that is, robot kinematics, using them.
- The advantages of using RoboAnalyzer to overcome several challenges of learning robotics in a classroom environment are also discussed.

PROBLEM STATEMENT: -

- After obtaining all the concepts and theoretical knowledge about basic robotics and the DH parameters, we implemented the same using the Roboanalyzer software.
- We have worked on three topics in this minor project which are as follows: -

  1. Joint Control of 3R robot Manipulator

  2. Forward dynamics of 4 Joint Manipulator

  3. Inverse dynamics of 4 Joint Manipulator

- Finally, we have extended our project to try out the Virtual Robot Module from the Roboanalyzer software.

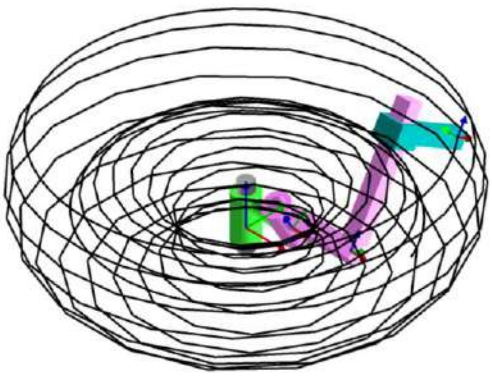
INTRODUCTION: -

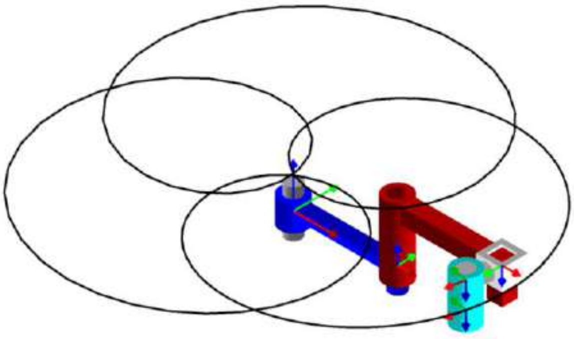
- The design philosophy behind RoboAnalyzer was as follows: While learning robot mechanics, its physics must not be obscured by the underlying mathematics.
- It has been developed with the objective of teaching and learning robotics using a few regular shapes of the links. That way we got started with the kinematic and dynamic analyses of the robots without spending too much time learning CAD modelling and/or programming a real robot if it exists.
- The emphasis is given to the visualization of the DH parameters used to define a

robot's architecture and the problems.

WORKFLOW: -

- In its present implementation RoboAnalyzer takes DH parameters of a serial robot (manipulator) with revolute joints as input.
- It then generates a 3D model of the robot as per the DH parameters. The 3D viewing window has zoom, pan and tilt capabilities using which the 3D model can be viewed from various angles.
- Simulation parameters can be set and forward kinematics analysis can be performed. The results can then be viewed in the form of animation of all the links and the trace of the end-effector position.
- The plots of the end-effector positions and the joint variables can be drawn and exported as comma-separated value (CSV) files.





Golden Ratio: -

golden ratio, also known as the golden section, golden mean, or divine proportion, in mathematics, the irrational number $(1 + \sqrt{5})/2$, often denoted by the Greek letter ϕ or τ, which is approximately equal to 1.618. It is the ratio of a line segment cut into two pieces of different lengths such that the ratio of the whole segment to that of the longer segment is equal to the ratio of the longer segment to the shorter segment. It is said to be a mathematical connection between two aspects of an object.

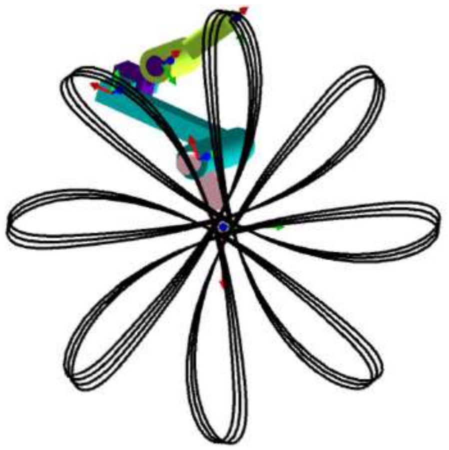
It is also called the Fibonacci sequence and it can be found across all of nature: plants, animals, weather structures, star systems – it is ever-present in the universe.

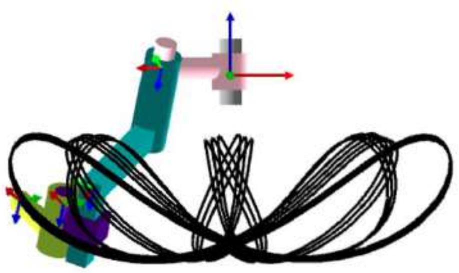
Some historians have suggested that this principle has also been used by Ancient Egyptians in building Pyramids.

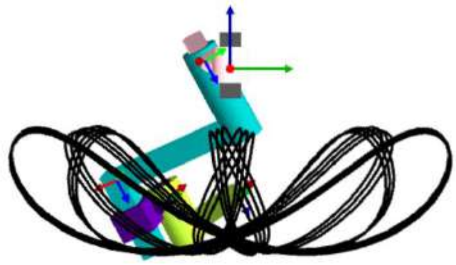
In terms of present day algebra, let the length of the shorter segment be one unit and the length of the longer segment be x units gives rise to the equation $(x + 1)/x = x/1$; this may be rearranged to form the quadratic equation $x2 – x – 1 = 0$, for which the positive solution is x = (1 + √5)/2, the golden ratio.

The Fibonacci sequence starts like this: 0, 1, 1, 2, 3, 5, 8, 13, 21, 34, 55 and continues on forever. Each number is the sum of the two numbers before it. It’s a simple pattern, and perhaps not that impressive on its own.

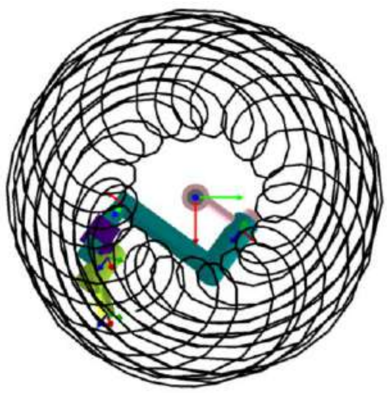
That is until you realize that this ratio is the key to everything from the number of spirals on a sunflower head, our own limbs, encrypting computer data, and why the Mona Lisa is so pleasing to the eye. It appears to be a kind of built-in numbering system to the cosmos.

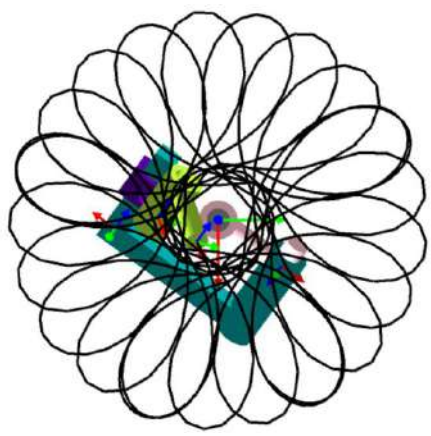






In this paper, a part of our experimentation is dedicated to finding the relations between manipulator dynamics and their behavior when joint variables are subjected to varied factors and multiples of the Golden ratio and other numeric multiples and factor patterns.





We experimented with various combinations of joint variables and initial and final positions, like the one that is given above. Our key focus was on one particular pattern that we have discussed below sections where we took initial and final parameters in golden ratio and at a particular multiple.

We will take two cases of DH parameters, the first one for 2-D and the second one for 3-D. Using the first one we will perform forward kinematics analysis and using the second one we will perform reverse dynamics analysis.

Coming to the aspect of golden ratio, the final position of second joint angle (ϴ) of the first joint is 49 times 180 (49 is 7^2 and & is the first Number who is a prime and the sum of the digits in its square is also prime) and the final final position of second joint angle (ϴ) of the first joint is 30.3 times 180 (30.3 is 49/Golden Ratio).

Forward Kinematics: -

- A study of forward kinematics of the 3-R 1-P robot shown in Figure will be carried out and that will be validated against the forward kinematics relations.
- The configuration of its end-effector (EE) in terms of the Cartesian coordinates of the EE and the orientation of the EE should be known in the fixed frame of reference located at the base.
- A relation between the configuration of the end-effector and the joint angles (in the case of a revolute joint) can be obtained as follows:

The i^{th} set of DH parameters connects coordinate frame Xi+1Yi+1Zi+1 attached to i^{th} link with frame XiYiZi attached to (i -1) th link.

The relationship can be expressed as the transformation matrix T^i, comprising both position and orientation information of the (i + 1) st frame concerning the ith frame terms.

The initial angular positions are zero.

In case of 2-D structure, both initial and final joint offset are zero.

Joint No	Joint Type	Joint Offset (b) m	Joint Angle (theta) deg	Link Length (a) m	Twist Angle (alpha) deg	Initial Value (JV) deg or m	Final Value (JV) deg or m
1	Revolute	0.01	Variable	0.2	0	0	5454
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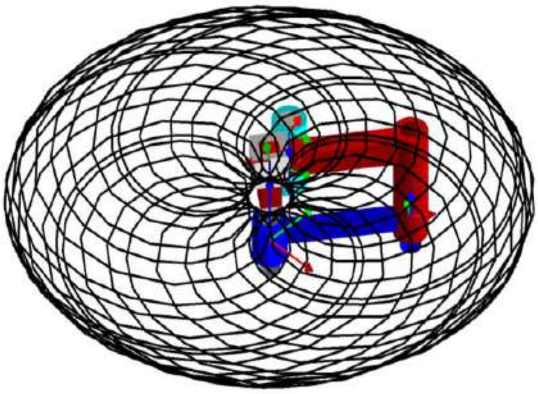
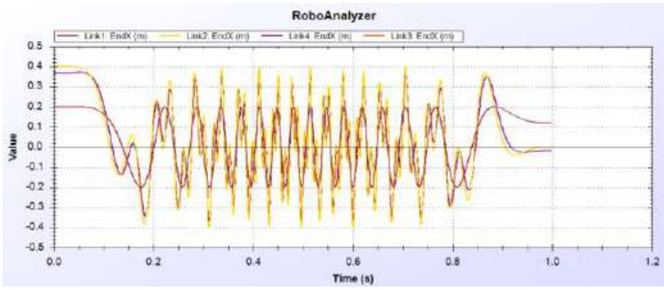
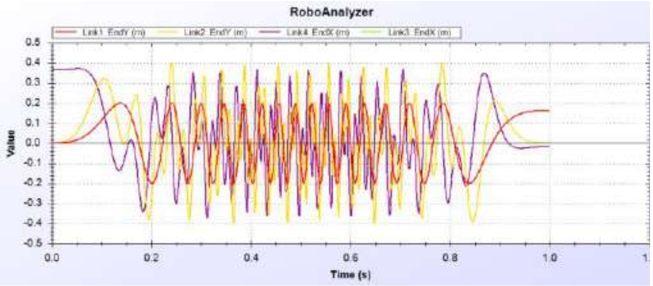
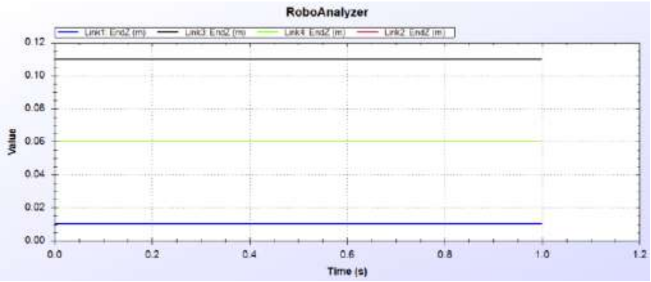
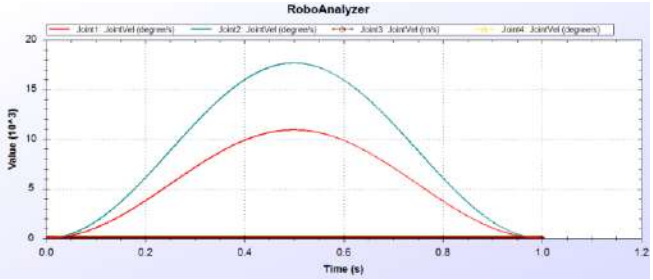


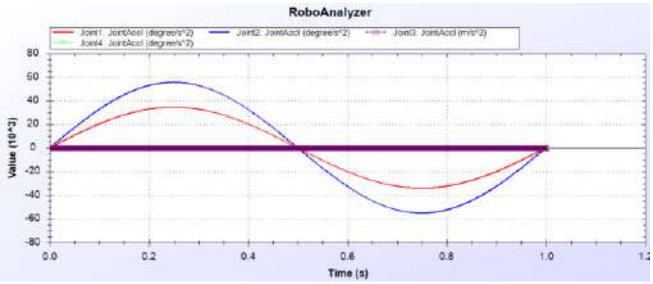
Upper View











INVERSE DYNAMICS: -

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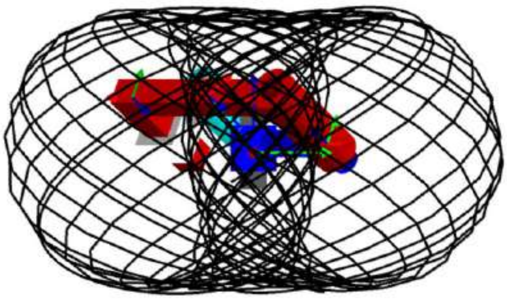
- To obtain solutions to the inverse kinematics problem, one is required to solve multiple multivariate transcendental equations. Sometimes no solution may exist for a given input pose. The inverse kinematics module of RoboAnalyzer was designed to tackle the above issues.
- The closed-form solutions of the inverse kinematics problem of several commonly discussed robots in a textbook were implemented. We can supply the position and orientation of the EE in the form of the Homogeneous Transformation Matrix (HTM) containing a 3×3 rotation matrix and the 3-dimensional end-effector position, and then obtain all possible solutions if they exist.
- This would help the user in appreciating various solutions for a single EE pose. The focus here is not the computational efficiency of the inverse kinematics solution, but the ease with which the solutions can be obtained and visualized. Using these, we were able to verify our results.

The initial angular positions are zero.

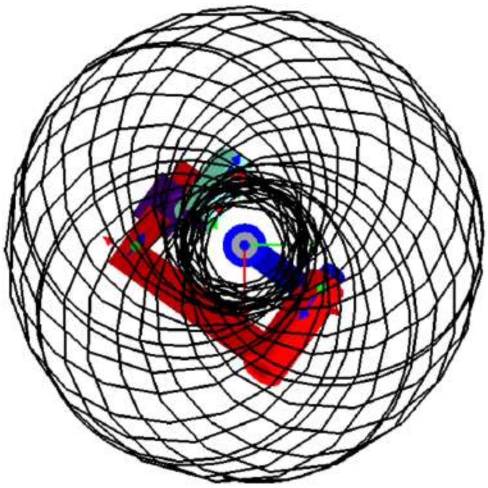
In case of 3-D structure, the initial and final joint offset are in a proportion of golden ratio. The lowest being 8:5, therefore we took initial as 0.05 and final as 0.08 m.

This roughly resembles a torus.

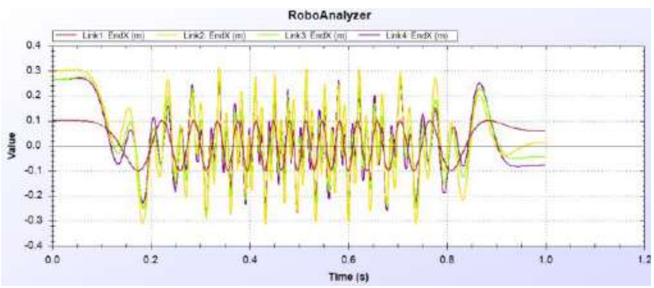
Joint No	Joint Type	Joint Offset (b) m	Joint Angle (theta) deg	Link Length (a) m	Twist Angle (alpha) deg	Initial Value (JV) deg or m	Final Value (JV) deg or m
1	Revolute	0.01	Variable	0.1	60	0	5454
2	Revolute	0.1	Variable	0.2	180	0	8820
3	Prismatic	Variable	3366	0.06	0	0.05	0.08
4	Revolute	0.05	Variable	0	0	0	0

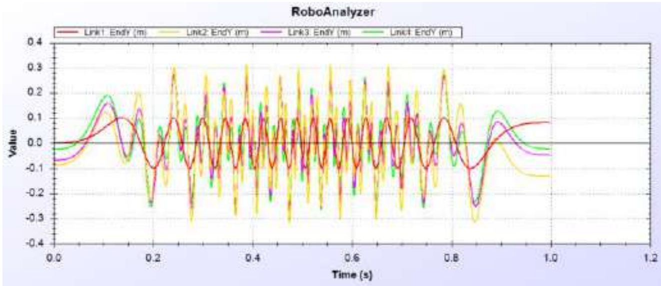


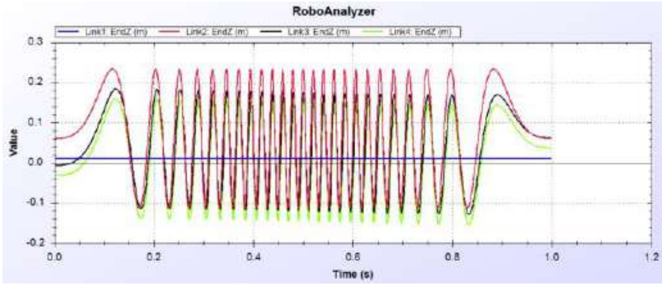
Front View

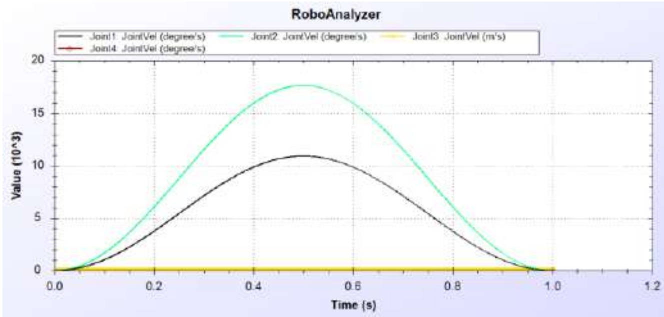


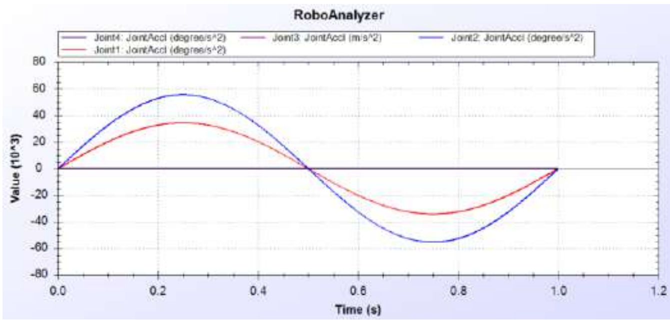
Upper View











JOINT CONTROL:

In this work, FANUC M10 iA robot is taken in virtual form and simulated for different joints and cartesian control simulation is performed to design any letter or geometrical shape. This robot is manufactured by FANUC.

FANUC stands for **"Fuji Automatic Numerical Control "** and they are one of the largest companies in the world.

FANUC M10 iA is a cables integrated small payload handling robot whose payload is 7 to 12 kg. This robot covers the motion range from 1.4m to 2.0m reach for various application adaptation. It is a six axis robot with servo driven motors . This material handling robot can be inverted, floor-mounted or installed on a track to give it complete flexibility. It can also position tools without vibration even after high speed motion .

Common application of FANUC M10 iA are :

- Small parts bin picking.
- Case parts polishing.
- 3D printing
- Arc welding

The virtual form of this robot was developed in the roboanalyzer software and its control movement are simulated .

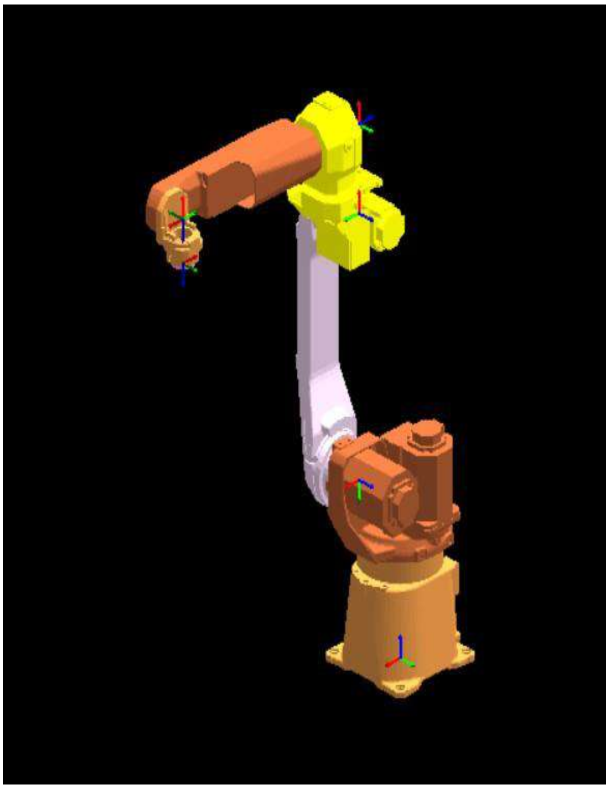


Fig. FANUC M10 iA

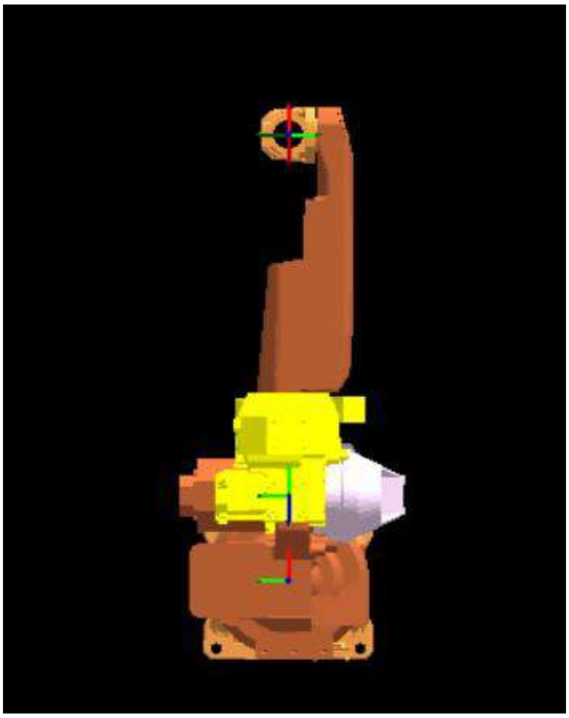


Fig. FANUC M10 iA (TOP VIEW)

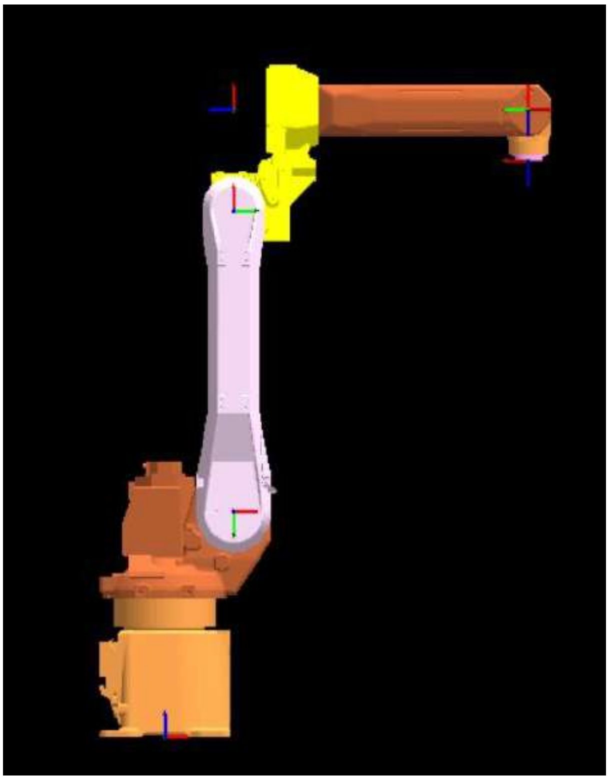


Fig. FANUC M10 iA (LEFT VIEW)

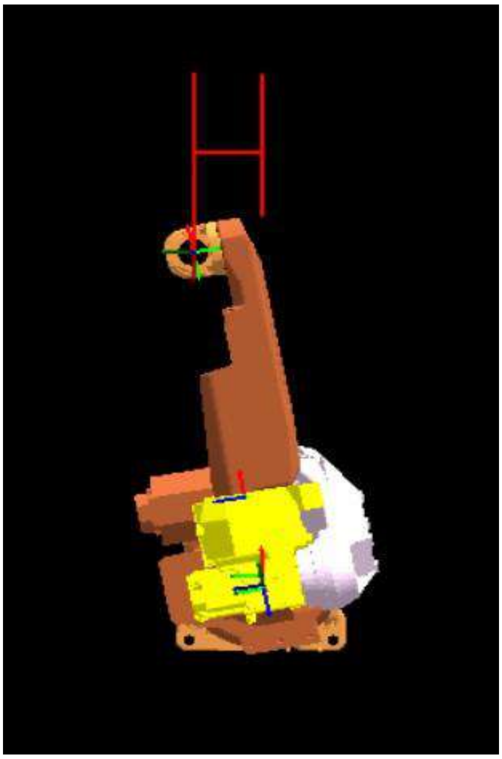


Fig. FANUC M10 iA (DESIGNING)

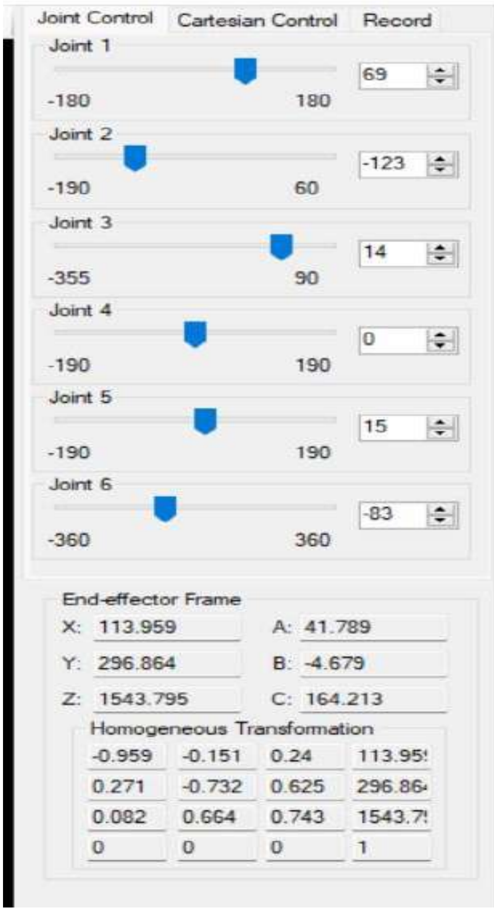


Fig: JOINT CONTROL PANEL

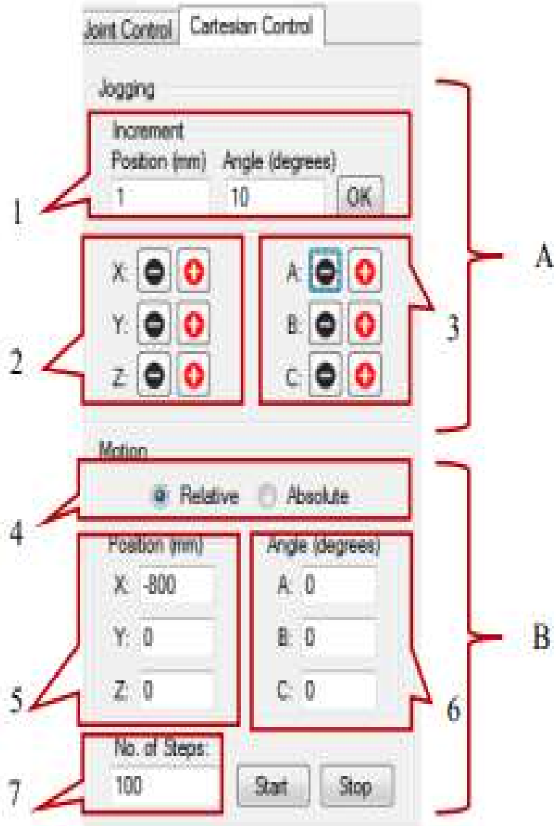


Fig: CARTESIAN CONTROL PANEL

A. Control for cartesian level jogging :

1. Increment in the position coordinates (X,Y,Z in mm) and RPY angles(A, B, C are roll, pitch and yaw respectively).
2. Buttons for postion increments.
3. Buttons for RPY angle increments.

B. Controls for Cartesian motion :

4. Set the motion as Relative or Absolute .
5. Required values for Position depending on Relative/Absolute motion required.
6. Required values for RPY angles depending on Relative/Absolute motion required.
7. Specify the number of steps or via-points between initial and final configurations.

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