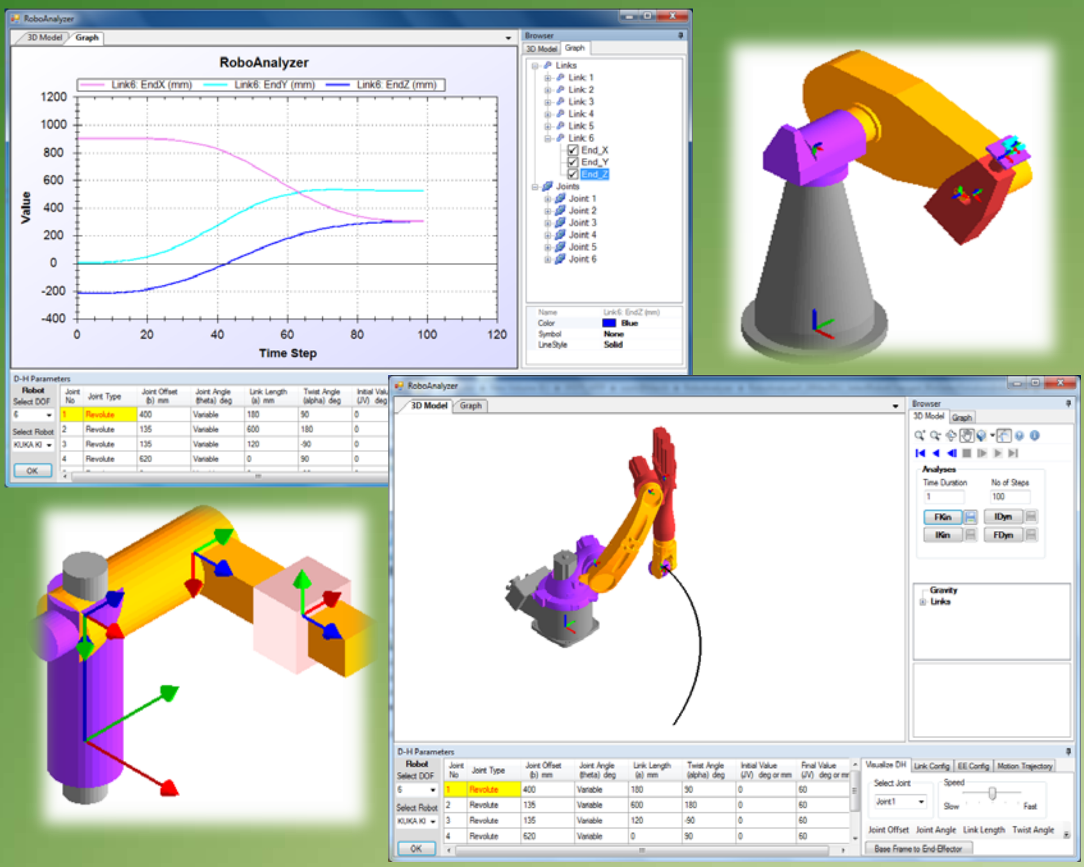
# RoboAnalyzer

## User Manual

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March 2012


Developed by Prof S. K. Saha & Team
Mechatronics Lab, Mechanical Engineering Department, IIT Delhi



Courtesy: CD Cell, QIP, IIT Delhi
**http://www.roboanalyzer.com**

## PREFACE

Robotics is a field related to the design, development, control and application of robots in industry, education, research, entertainment, medical applications etc. It has been progressing at a faster rate and hence it finds its place in the curriculum of the various universities and is in great demand. Since the mathematics involved in the study of robotics, e.g., kinematics and dynamics is initially difficult to understand by students and same is the case by a teacher to convey the essence of mathematics of robotics to the students. This is due to fact that, for example, forward and inverse kinematics involve 3D transformations, solutions to polynomial equations etc and inverse and forward dynamics involves solution of differential and algebraic equations. Also it has been difficult for students to learn because of limited ability to perceive and visualize the concepts appropriately at the time of teaching. Without seeing a real robot it is very difficult to comprehend its motion in three-dimensional Cartesian space. Hence, there exists a great demand for teaching aids that help students to visualize robots movement in the form of 3D animations.

The work of combining the robot analyses algorithms in the form of software started in 1996 in the name of RIDIM (Recursive Inverse Dynamics for Industrial Manipulator). But it had only analysis part with plot facilities. The visualization of the physical system was difficult. As a result, it was decided to come up with software which can make user analyze a serial manipulator to begin with for its visualization through 3D CAD models, and this resulted in the development of RoboAnalyzer since 2009.

RoboAnalyzer aims to ease out the above mentioned difficulties for students and teachers. RoboAnalyzer, a 3D model based software, can be used to teach robotics subjects to undergraduate and postgraduate courses in engineering colleges in India and elsewhere. It can be used to learn DH parameters, kinematics and dynamics of serial robots and allows 3D animation and graph plots as output. In essence learn/teach the physics of robotics with the joy of RoboAnalyzer animations before attempting to learn the mathematics of robots.

RoboAnalyzer is developed in the Mechatronics Lab, Department of Mechanical Engineering at IIT Delhi, India under the guidance of Prof. S. K. Saha. The following students are given due credits in its development.

- S. Goel and S. Ramakrishnan (1996-97) : Algorithm development for Recursive Inverse Dynamics for Industrial Manipulators (RIDIM)
- Patle (2000-01) : Windows-interface for RIDIM
- Rajat Jain (2009-10) : Added Graph-plots to RIDIM
- Suril V Shah (2007-11) : Recursive Dynamics Simulator (ReDySim) Algorithm
- Rajeevlochana C.G. (2009 - present) : User Interface, 3D Modeling of robot, Forward Kinematics, Animation, Graph-plot, DH Visualize
- Amit Jain (2010-11) : C# implementation of DeNOC-based Inverse and Forward Dynamics (ReDySim)
- Jyoti Bahuguna (2011-12) : Inverse Kinematics Module and Motion Planning

## CONTENTS

# 1. GETTING STARTED

This section helps you get started with the installation of RoboAnalyzer, a 3D Model Based Robotics Learning System.

## 1.1. MINIMUM SYSTEM REQUIREMENT

- Processor: Atleast 1.5 GHz
- RAM: Atleast 512 MB
- Operating System: Windows XP, Windows Vista, Windows 7
- Dependencies: Microsoft .Net 2.0 framework

## 1.2. INSTALLATION

RoboAnalyzer can be installed on a computer by downloading it from our website. The latest version of the software (version 5) is available for free at http://www.roboanalyzer.com . The following are the steps to install RoboAnalyzer:

**Step 1:** Visit http://www.roboanalyzer.com
**Step 2:** Click on **Downloads** tab
**Step 3:** Click on **RoboAnalyzer V5** (or latest version) to download a .zip file
**Step 4:** A popup window will appear. Select the folder where the file has to be saved and click on **Save**
**Step 5:** After downloading is complete, unzip RoboAnalyzer5.zip to any folder on your computer. Open the folder RoboAnalyzer5
**Step 6:** Double-click on RoboAnalyzer5.exe to start RoboAnalyzer.

# 2. INTRODUCTION TO ROBOANALYZER

RoboAnalyzer is a 3D Model Based Robotics Learning Software. It has been developed to help the faculty to teach and students to learn the concepts of Robotics. It also acts as a supporting material for the contents on various robotics topics in text book entitled "Introduction to Robotics", S. K. Saha, 2008 [1].

## 2.1. MODEL A ROBOT

Double click on RoboAnalyzer4.exe starts RoboAnalyzer. By default, it shows a robot model (2-R). Users can select a robot from the options given at the left bottom corner of the application as shown in Figure 1. After selecting a robot model, users can modify the Denavit-Hartenberg (DH) parameters shown in the tabular form and the robot model updates automatically. A few industrial robots are also listed, when selected shows a 3D CAD model of the robot (Figure 2).

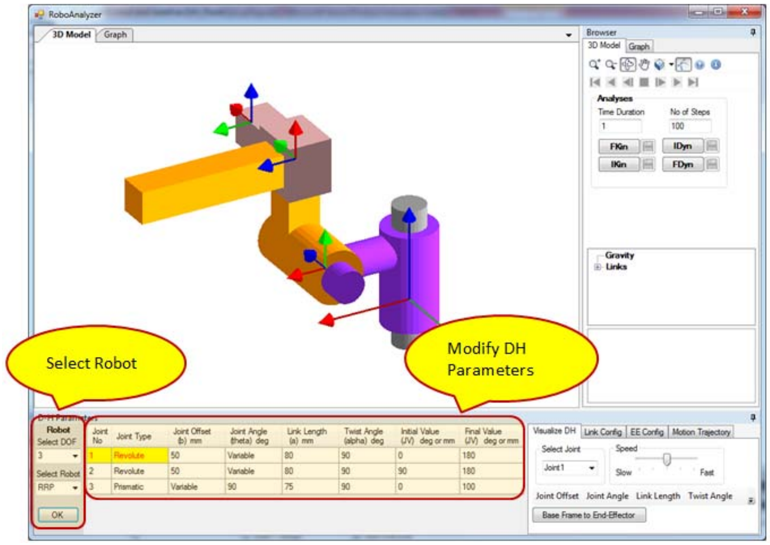



Figure 1: Select Robot Model and Redefine DH Parameters

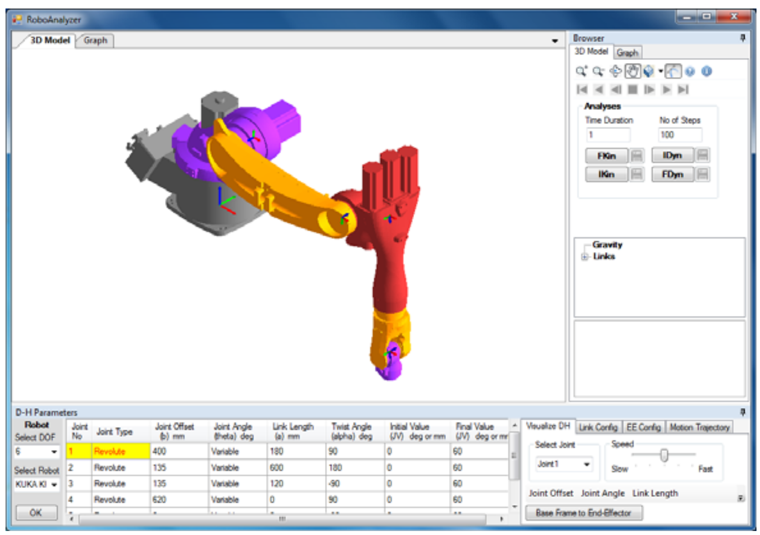


Figure2: 3D CAD Model of Industrial Robot

## 2.2. FEATURES OF ROBOANALYZER

RoboAnalyzer can be used to perform kinematic and dynamic analyses of serial chain robots/manipulators. The following are the main features of RoboAnalyzer:

- DH Parameter Visualization (Section 3)
- Forward Kinematics (Section 4)
- Inverse Kinematics (Section 5)
- Inverse Dynamics (Section 6)
- Forward Dynamics (Section 7)
- Motion Planning (Section 8)

## 2.3. OVERVIEW OF USER INTERFACE

RoboAnalyzer's easy to use Graphical User Interface (GUI) consists of the following as shown in Figures 3, 4 and 5.

1. Robot Selection and DH Parameters section
2. Visualize DH section
3. 3D Model Browser
4. 3D Model View
5. Graph Plot Tree View
6. Graph Plot Window
7. Inverse Kinematics Window

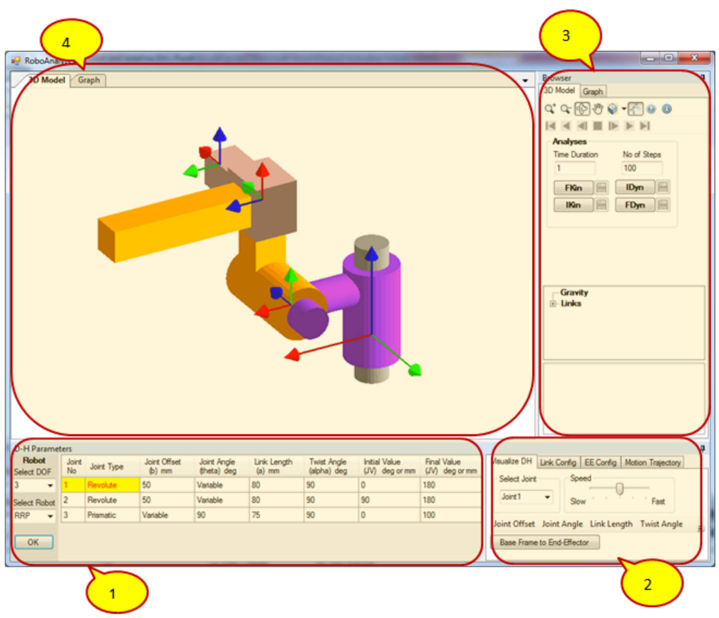



Figure 3: User Interface of 3D Model View

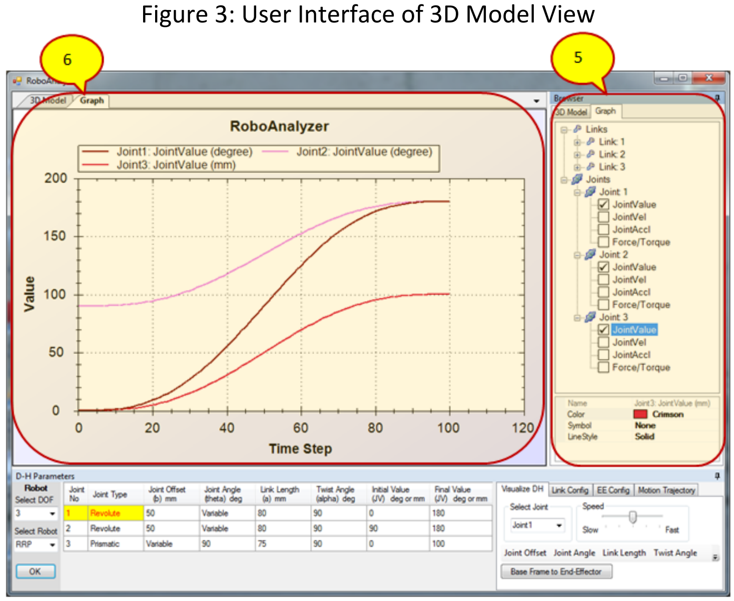



Figure 4: User Interface of Graph Plot View

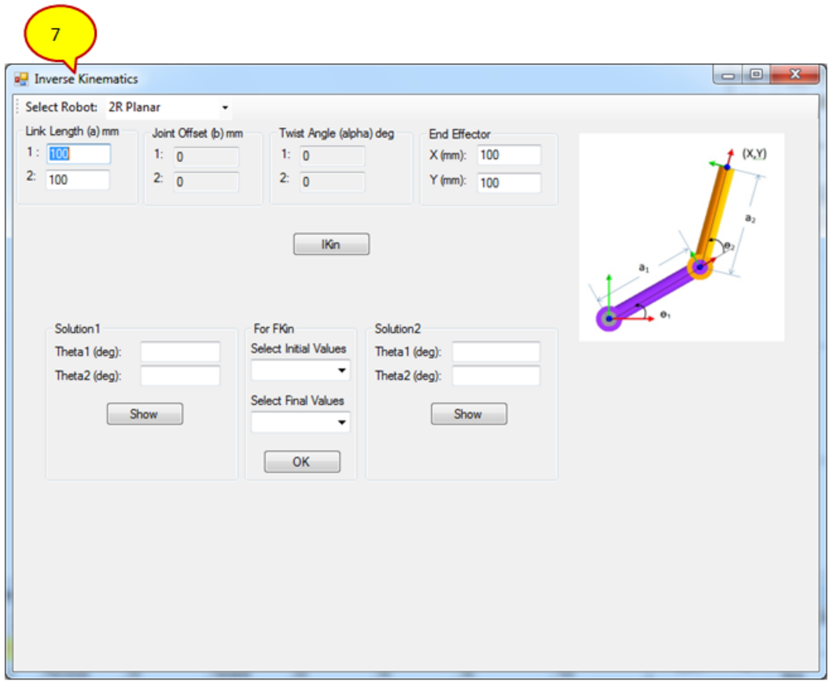



Figure 5: User Interface of Inverse Kinematics Window

## 2.4. 3D MODEL VIEW OPTIONS

RoboAnalyzer lets the user to zoom, rotate and pan the 3D model to have better visualization. These can be used as explained below and shown in Figure 6.

- **Zoom:** Place the mouse cursor anywhere on 3D Model View and use the mouse-wheel to zoom in and zoom out. It can also be done by clicking on **Zoom In** and **Zoom Out** buttons.
- **Rotate:** Click on **Rotate** button to make it active. Place the mouse cursor anywhere on the 3D Model View and rotate the model by clicking on left-mouse button and dragging the mouse.
- **Pan:** Click on **Pan** button to make it active. Place the mouse cursor anywhere on the 3D Model View and translate the model by clicking on left-mouse button and dragging the mouse.
- **Standard Views:** Select any standard view from the dropdown and the model view updates.

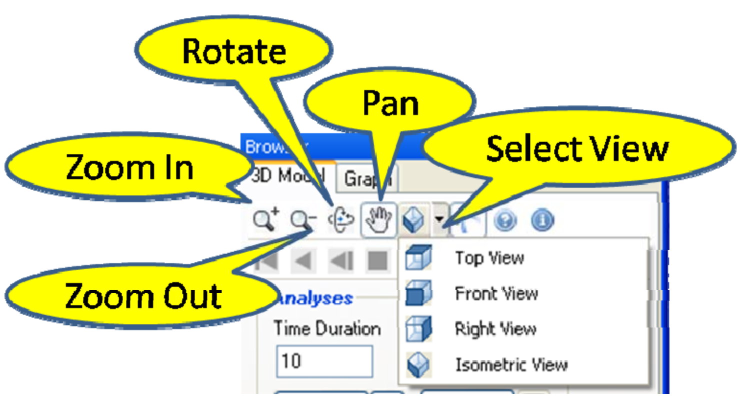



Figure 6: 3D Model View Options

# 3. DENAVIT-HARTENBERG PARAMETERS VISUALIZATION

The architecture of industrial robots is usually represented by Denavit-Hartenberg (DH) parameters. It forms the basis for performing kinematic and dynamic analyses of robots. A set of four DH parameters is used to represent the position and orientation of a robot-link with respect to its previous link. More details on DH parameters can be found in Chapter 4 of [1].

## 3.1. VISUALIZE DH

After selecting a robot and redefining DH parameters as explained in Section 2.1, users can visualize each DH parameter by selecting a joint and then selecting a DH parameter type as shown in Figure 7. Once it is done, the corresponding DH parameter is highlighted in the DH parameter input table and a transformation frame moves in the 3D robot model. It shows the two co-ordinate frames corresponding to the selected DH parameter.

Users can click on **Together** button and a co-ordinate frame moves covering all the four DH parameters corresponding to the selected joint.

Users can click on **Base Frame to End-Effector** button to see a co-ordinate frame moving from base frame to end-effector frame covering all the DH parameters of the robot model.

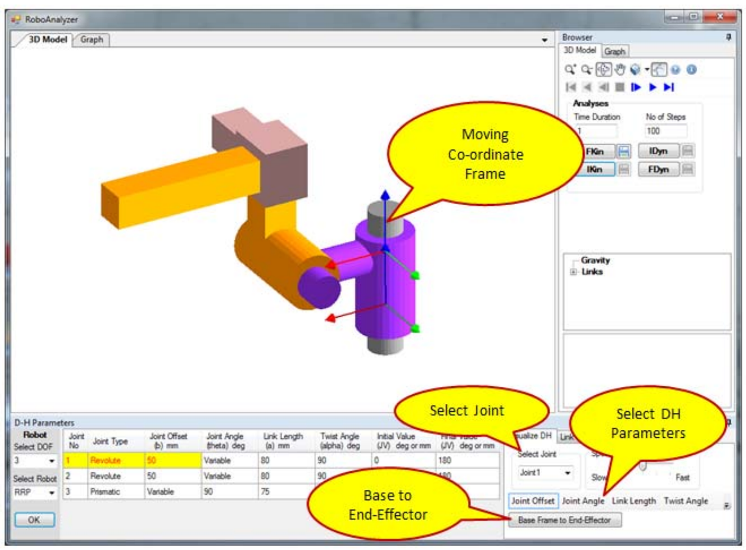



Figure 7: Visualize DH Parameters

## 3.2. LINK CONFIGURATION

The configuration/ transformation of a co-ordinate frame (DH frame) attached on each robot-link can be determined with respect to a frame attached to its previous link or base frame by following the steps below and as shown in Figure 8.

- Select a joint. If **Joint1** is selected, it corresponds to co-ordinate frame attached on Link1.
- Select **Previous Link Frame** or **Base Frame** as the reference frame with respect to which the transformation needs to be determined.
- Click on **Update** button and 4X4 transformation matrix is populated. A pair of co-ordinate frames is shown in 3D robot model to help user in visualizing the transformation.

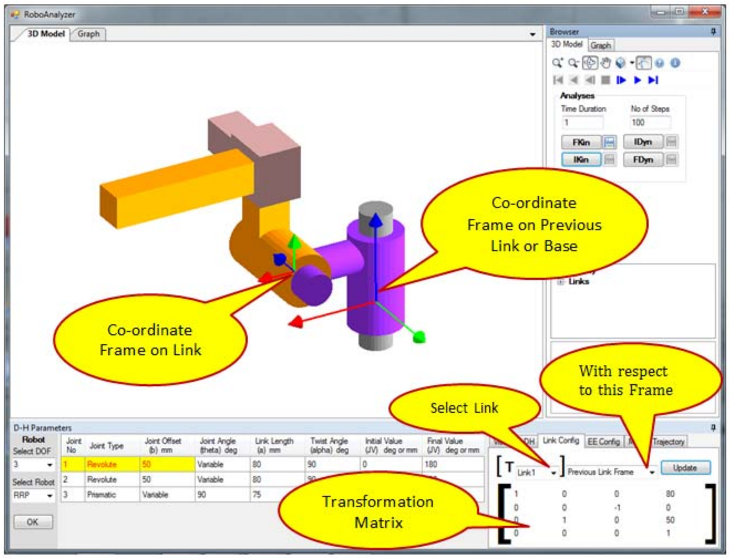



Figure 8: Link Configuration

## 3.3. END-EFFECTOR CONFIGURATION

The end-effector configuration/transformation can be determined with respect to the base frame directly by using the **Update** button as shown in Figure 9. The 4X4 transformation matrix is populated and a pair of co-ordinate frames is shown in 3D robot model to help user in visualizing the transformation.

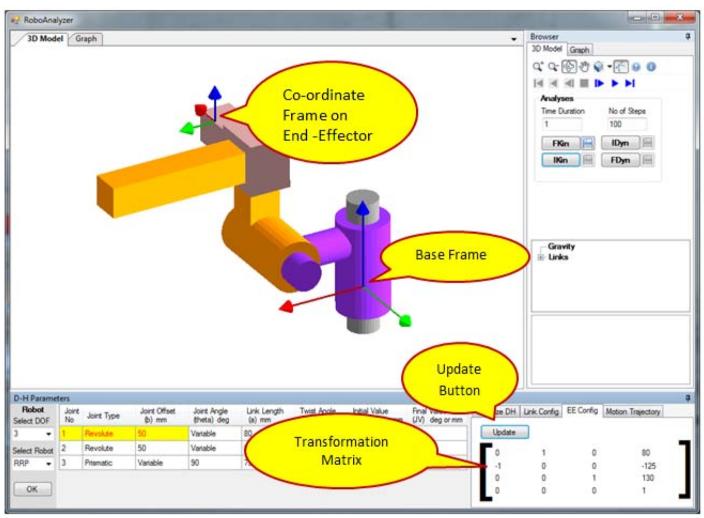



Figure 9: End-Effector Configuration

# 4. FORWARD KINEMATICS

In the forward or direct kinematics, the joint positions, i.e. the angles of the revolute joints and the displacements of the prismatic joints, are prescribed. The task is to find the end-effector's configuration/transformation consisting of its position and orientation. More details can be found in Chapter 6 of [1]. After selecting a robot and redefining DH parameters as explained in Section 2.1, forward kinematics (FKin) is performed which updates the 3D model.

## 4.1. ANIMATION OF FKIN

To perform animation of the robot motion between two sets of initial and final values of joint variables, the following are the steps as shown in Figures 10 and 11. The trajectory of joint values, joint velocities and joint accelerations follow Cycloidal trajectory mentioned in Chapter 8 of [1]. The trajectory can be changed as explained in Section 8.

1. Set the **initial** and **final** values of joint variables
2. Set **Time Duration** and **Number of Steps**
3. Click on **FKin** button
4. Click on **Play** button to see the animation
5. The end-effector trace can be viewed

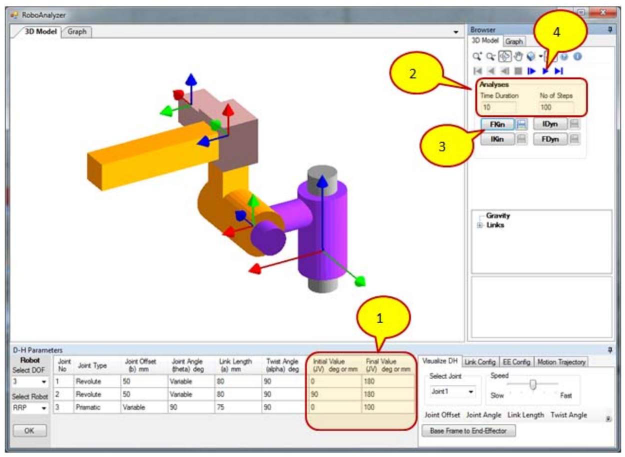



Figure 10: Initial Position of all Joints

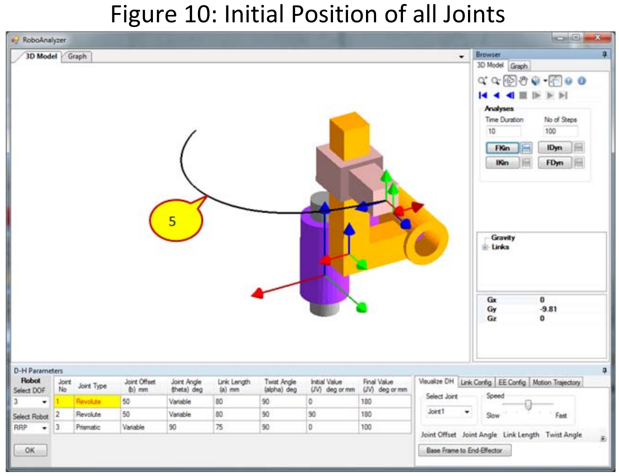



Figure 11: Final Position of all Joints and Trace of End-Effector

## 4.2. GRAPH PLOTS OF FKIN

To view the graph plots of a forward kinematics (animation) analysis, the following are the steps as shown in Figures 12, 13 and 14.

1. Click on **Graph** tab

2. Click on **+** next to the link of which the plots are to be viewed
3. Click on **box** to plot graph of a particular node to see X, Y and Z plots
4. Click on **+** next to the joint of which the plots are to be viewed
5. Click on **box** to plot graph of a particular node to see joint value (joint angle for revolute joint and joint offset for prismatic joints), joint velocity and joint acceleration

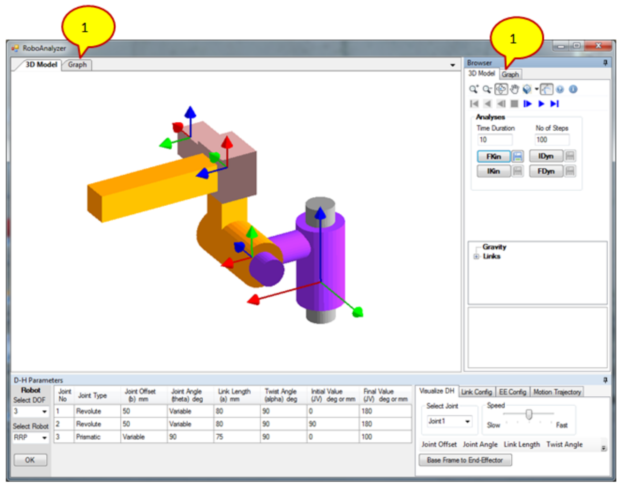



Figure 12: Graph Plots of FKin Data

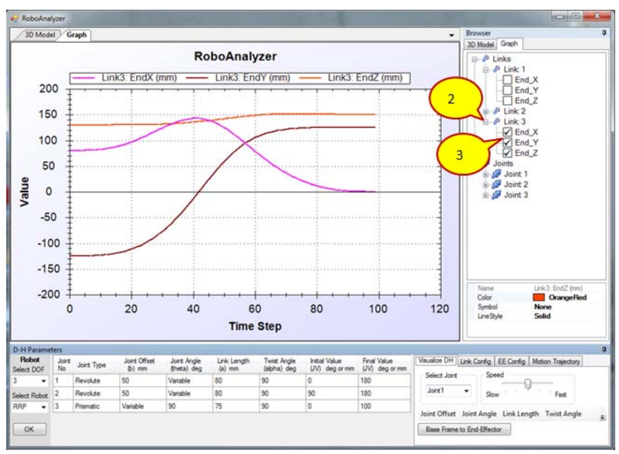



Figure 13: Graph Plots of Position of Coordinate Frame attached to Link3

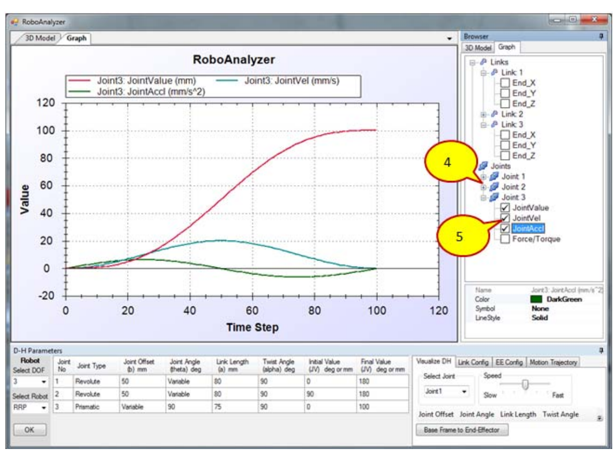


Figure 14: Graph Plots of Input Trajectory to Joint3 (Cycloidal Trajectory)

More details and information on the Graph Plot options can be found in Section 9.

# 5. INVERSE KINEMATICS

Inverse Kinematics (IKin) consists of determination of the joint variables corresponding to a given end-effector's orientation and position. The solution to this problem is of fundamental importance in order to transform the motion specifications assigned to the end-effector in the operational space into the corresponding joint space motions. There may be multiple or no results possible for a given end-effector position and orientation. More details can be found in Chapter 6 of [1].

## 5.1. SOLUTIONS OF IKIN

To select a robot and view the solutions of its Inverse Kinematics, the following are the steps as shown in Figures 15 and 16. In future, an IKin solution can be selected and 3D model will be updated accordingly.

1. Click on **IKin** button. It shows a separate window (Figure 16)
2. Select a Robot
3. Enter Input parameters
4. Click on **IKin** button
5. View the possible solutions
6. Click on **Show** button. It shows the selected solution in 3D Model window. To see this go back to main window by minimizing IKin window
7. Select any of the obtained solution as initial and final solution
8. Click on **OK.** This step replaces the initial and final joint values in DH Parameter table (Main window) by values selected in step 7
9. Click on **FKin** button to view animation i.e. how robot moves from one solution to another solution selected in step 7

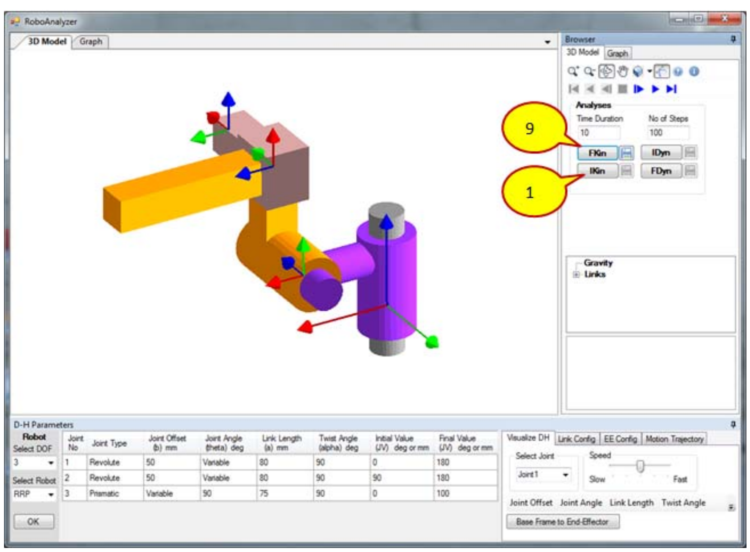



Figure 15: Inverse Kinematics Button

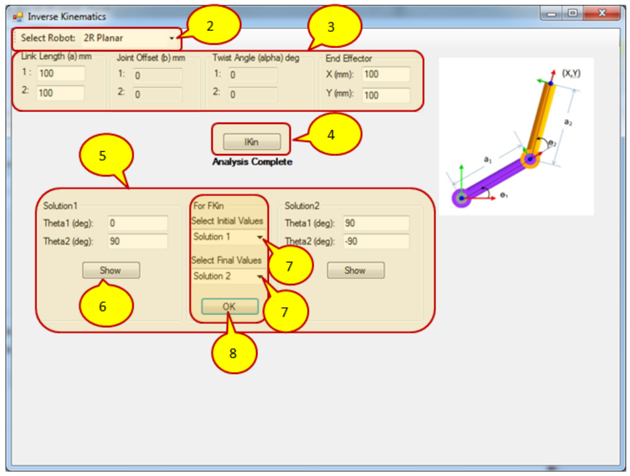



Figure 16: Inverse Kinematics of 3R Articulated Robot

## 6. INVERSE DYNAMICS

Inverse Dynamics (IDyn) is a dynamics problem, where the robot geometric, inertial parameters, and the joint motions i.e its positions, velocities and acceleration are given and the corresponding joint torques or forces are calculated. In RoboAnalyzer, the dynamics solver is based on ReDySim algorithm, which uses Decoupled Natural Orthogonal Complement (DeNOC) Matrices based recursive formulation. More details on ReDySim can be found at [2]. More details on Inverse Dynamics and DeNOC can be found in Chapters 8 and 9 respectively of [1].

### 6.1. SOLUTION OF IDYN

Select a robot and redefine DH parameters as explained in Section 2.1, to solve for IDyn of the robot between two sets of initial and final values of joint variables, the following are the steps as shown in Figures 17, 18, and 19. The trajectory of input joint values, joint velocities and joint accelerations follow Cycloidal trajectory mentioned in Chapter 8 of [1]. The trajectory can be changed as explained in Section 8

1. Set the **initial** and **final** values of joint variables
2. Set **Time Duration** and **Number of Steps**
3. Set **Gravity** (all values should be in SI units, i.e. m/s^2)
4. Select a robot-link to enter its Center of Gravity (**CG**) location. It corresponds to a vector from the CG of the robot-link to the origin of the co-ordinate frame attached to that link, measured in the reference of the co-ordinate frame attached to that link.
5. Select **Mass Properties** of a robot-link. Set **Mass** of each robot-link (values should be in SI units, i.e. kg) and set **Inertia** tensor of each robot-link with respect to the co-ordinate frame attached at the CG of the robot-link and the co-ordinate frame is parallel to the one attached to the robot-link (values should be in SI units, i.e. kgm^2). These values are to be entered manually and not calculated automatically from the shape of the robot-links.
6. Click on **FKin** button (required to populate the input joint trajectory)
7. Click on **Play** button to see the animation (only for visualization purpose, not necessary for IDyn)
8. Click on **IDyn** button to perform Inverse Dynamics
9. lick on **Graph** tab to view the graph

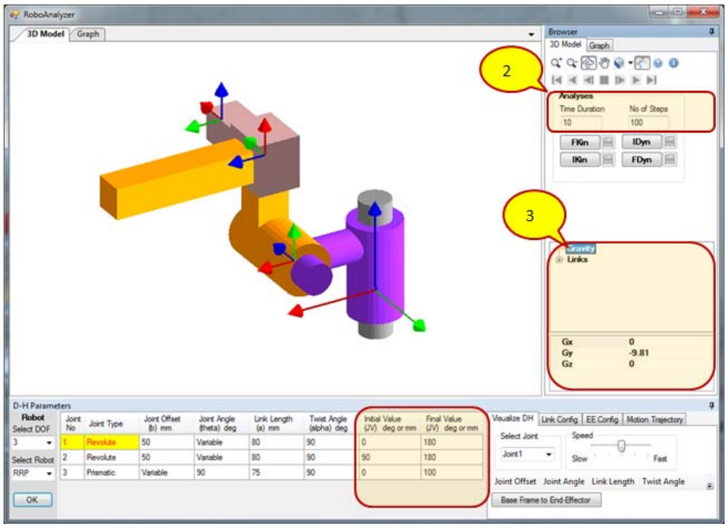


Figure 17: Inverse Dynamics Settings

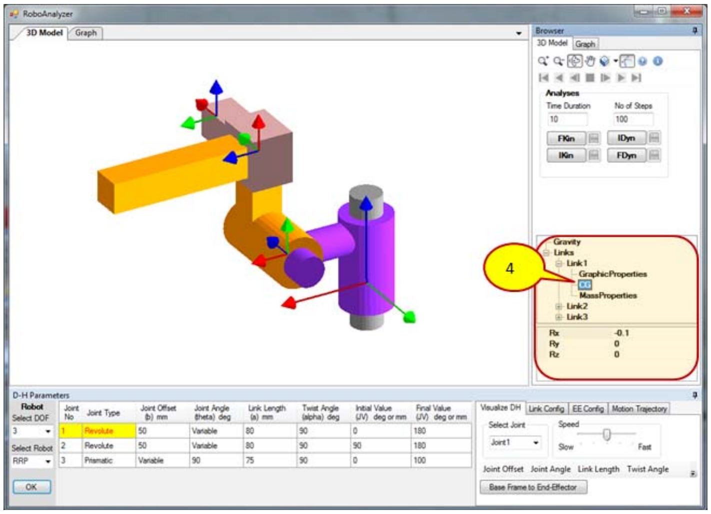


Figure 18: Set Center of Gravity for Inverse Dynamics

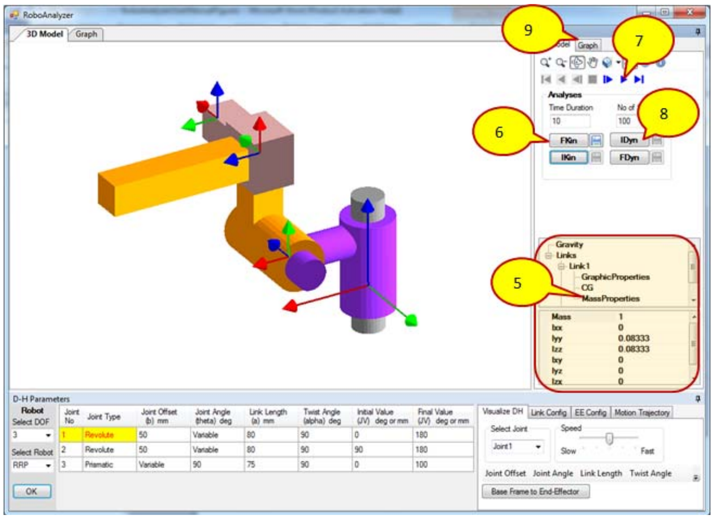


Figure 19: Set Mass and Inertia Properties and Perform Inverse Dynamics

### 6.2. GRAPH PLOTS OF IDYN

To view the graph plots of joint torques and forces, the following are the steps as shown in Figure 20.

1. Click on **+** next to the joint of which the plots are to be viewed
2. Click on **box** to plot graph of joint torque/force

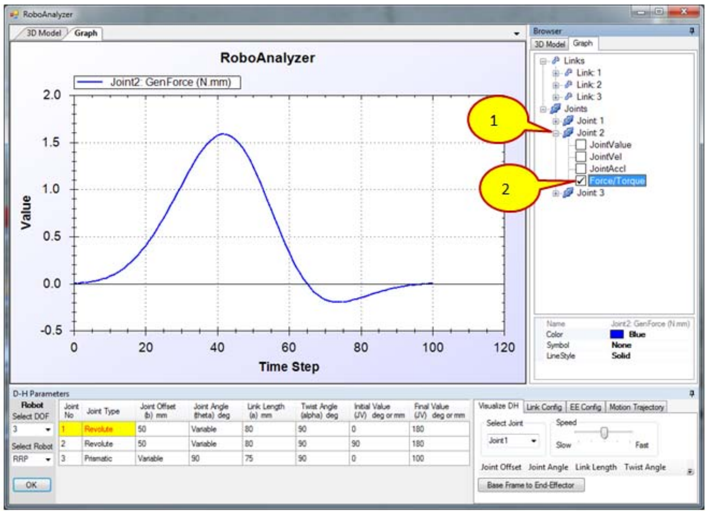



Figure 20: Graph Plot of Joint Torque/Force

More details and information on the Graph Plot options can be found in Section 9.

## 7. FORWARD DYNAMICS

Forward Dynamics (FDyn) is a dynamics problem, where the robot geometric, inertial parameters, and the joint torques and forces are given and the joint accelerations are calculated. The dynamics solver uses ReDySim[2] as in IDyn. More details on Forward Dynamics can be found in Chapters 8 and 9 of [1].

### 7.1. SOLUTION OF FDYN

Select a robot and redefine DH parameters as explained in Section 2.1, to solve for FDyn of the robot for a given initial values of joint variables, please refer to Section 6.1 to perform steps 1 to 5 mentioned below. Then perform steps 6, 7 and 8 as shown in Figure 21.

1. Set the **initial** value of joint variables
2. Set **Time Duration** and **Number of Steps**
3. Set **Gravity** (all values should be in SI units, i.e. m/s^2)
4. Select a robot-link to enter its Center of Gravity (**CG**) location. It corresponds to a vector from the CG of the robot-link to the origin of the co-ordinate frame attached to that link, measured in the reference of the co-ordinate frame attached to that link.
5. Select **Mass Properties** of a robot-link. Set **Mass** of each robot-link (values should be in SI units, i.e. kg) and set **Inertia** tensor of each robot-link with respect to the co-ordinate frame attached at the CG of the robot-link and the co-ordinate frame is parallel to the one attached to the robot-

link (values should be in SI units, i.e. kgm^2). These values are to be entered manually and not calculated automatically from the shape of the robot-links.

6. Click on **FDyn** button to perform Forward Dynamics. The robot is simulated for free-fall due to the action of gravity. In future, joint torques/forces can be set as input.
7. Click on **Play** button to see the animation
8. Click on **Graph** tab to view the graph

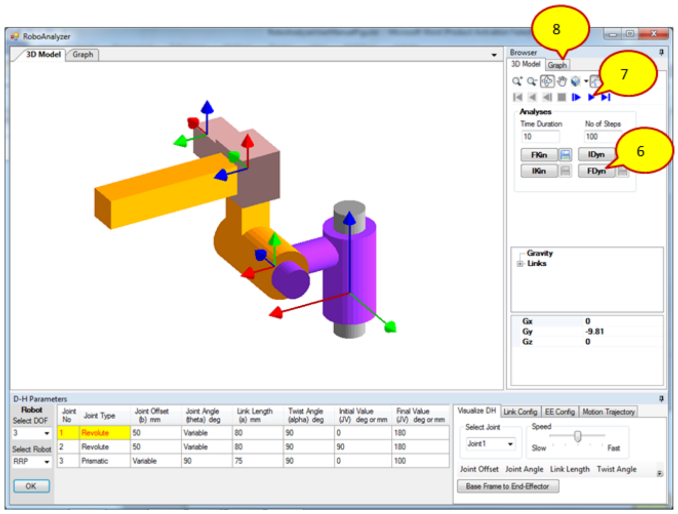



Figure 21: Forward Dynamics

### 7.2. GRAPH PLOTS OF FDYN

To view the graph plots of joint accelerations and position of links, follow the steps mentioned in Section 4.2.

## 8. MOTION PLANNING

The goal of motion planning of a robot is to generate a function according to which a robot will move. This function generation depends on the robot tasks. A robot user typically specifies a number of parameters to describe a point-to-point or continuous-path task. Trajectory planning algorithm then generates the reference inputs for the control system of the manipulator, so as to be able to execute the motion. The geometric path, the kinematic and dynamic constraints are the inputs of the trajectory planning algorithm, whereas the trajectory of the joints (or of the end effector), expressed as a time sequence of position, velocity and acceleration values, is the output. Trajectory planning can be done either in the joint space, i.e., in terms of joint positions, velocities and accelerations, or Cartesian space (also called operational space) i.e., in terms of the end-effector positions, orientations, and their time derivatives. More details on Motion Planning can be found in Chapter 11 of [1].

### 8.1. SOLUTION OF MOTION PLANNING

Select a robot and redefine DH parameters as explained in Section 2.1. For a given initial values of joint variables, Motion planning of the selected robot can be performed by selecting particular motion trajectory as shown in Figure 21 followed by steps 1 to 5 mentioned in section 4.1.

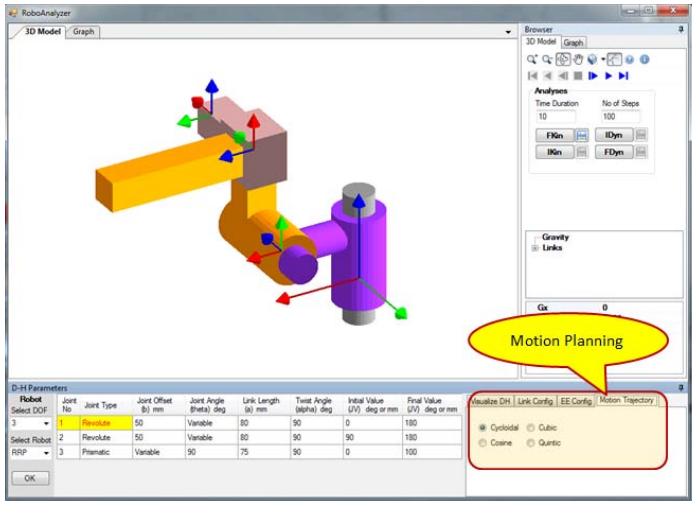



Figure 21: Motion Planning

## 9. GRAPH PLOT OPTIONS

The analyses results for FKin, IDyn and FDyn can be viewed as graph plots as explained in Sections 4.2, 6.2 and 7.2 respectively. Several options for graph plot functionalites are explained below and as shown in Figure 22 .

1. Select a graph plot node
2. Set the plot color, symbol and line style
3. Right click on graph to show a menu. Here you can use various options to zoom, print etc
4. Export Data as CSV: Export plot data that can be opened in a spreadsheet such as MS Excel
5. Use Mouse wheel to zoom in and out
6. Press Mouse wheel and drag the mouse to pan around the graph

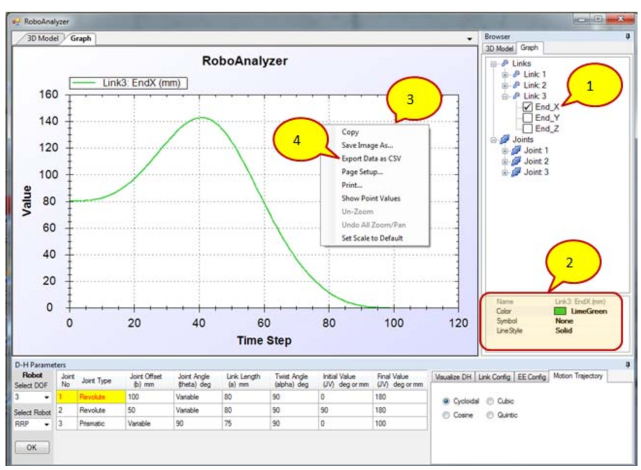


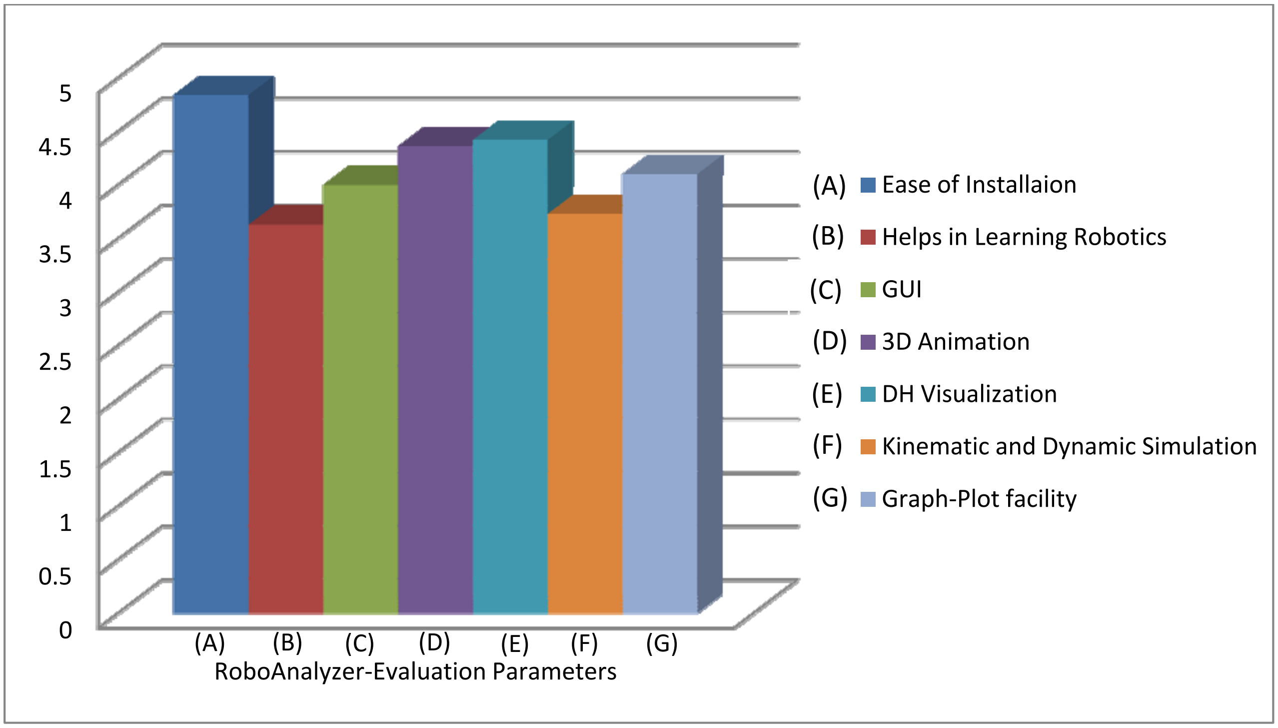

Figure 22: Graph Plot Options

## 10. REFERENCES

[1] S. K. Saha, “Introduction to Robotics,” Tata McGraw Hill, New Delhi, 2008
[2] ReDySim, website accessed on December 28, 2011, http://www.roboanalyzer.com/redysim.html

## Survey on RoboAnalyzer

A survey on RoboAnalyzer was conducted over a group of 20 students. They used the software in "Design of Machines and Mechanism" course conducted by IIT Delhi. A brief summary of the survey is shown below.




*Rating: 0-5 (0=not included or component is far below standard, 5=excellent)

## Feedback on RoboAnalyzer

" Easy for beginners, easy to install and run, this software lets students learn new robotic concepts"

"Provides quick validation and excellent GUI. Path trace is helpful"

"Easy visualization of the DH parameters. Excellent software to understand DH parameters deeply "

"Very user friendly, good for beginners"

"Good to visualize DH parameters, saves time in Forward and Inverse Kinematic analysis but input-output data can't be saved"

" It is especially an infotainer giving boost to robotic analysis as well as not tiresome....Rather it develops interest to work again & again. Try to improve it regarding graphics point of view, Enhanced User Interface for better involvement"

"Easy to visualize kinematics and dynamic analysis"

"Path trace is helpful, excellent software"

# RoboAnalyzer

## 3D Model Based Robotics Learning Software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