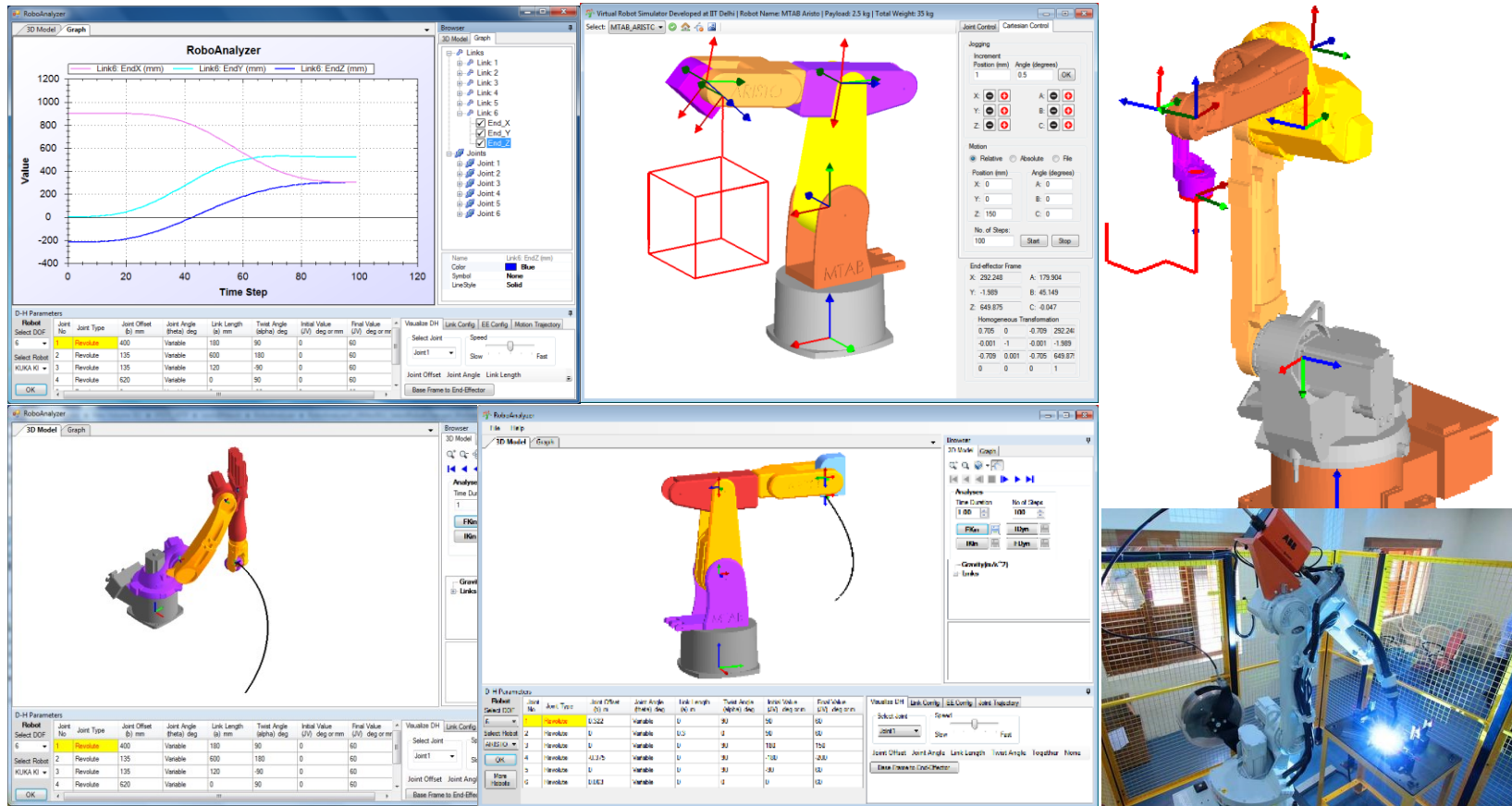


Workshop on Learning Robot Kinematics using RoboAnalyzer*



Mr. Rajeevlochana G. Chittawadigi

PhD Scholar at IIT Delhi/ Asst. Professor, Dept of Mech Engg.

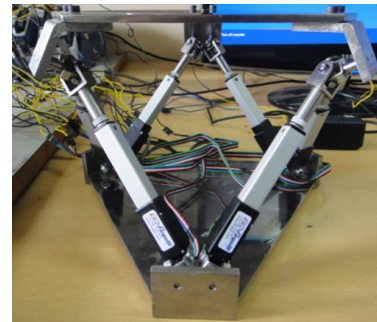
Amrita Vishwa Vidyapeetham, Bengaluru

Contents

- Introduction
- Robotics Education
- Kinematics
- Motion Planning
- RoboAnalyzer
- Tasks (Hands On)
- Feedback

Robotics

- Design, development, control and application
 - Industries
 - Academics
 - Research
 - Entertainment
 - Medical applications etc.
- Included in curriculum of universities

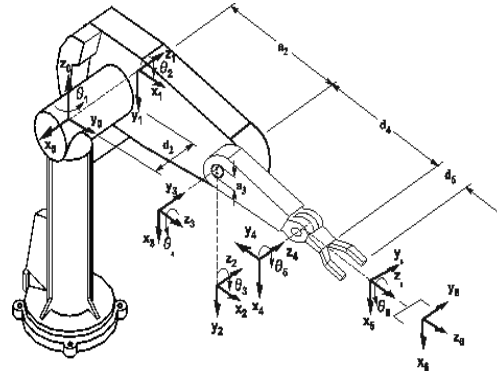


Robotics Education

Courses* usually include:

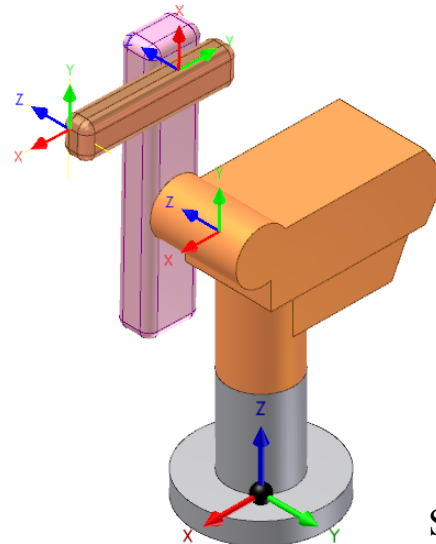
1. Theory:

- Design and working of robot in the form of drawing and pictures
- Mathematically intensive



2. Practical:

- CAD modeling and simulation
- Real robots in action
- Not many institutes have facilities



*Mechanical Engineering

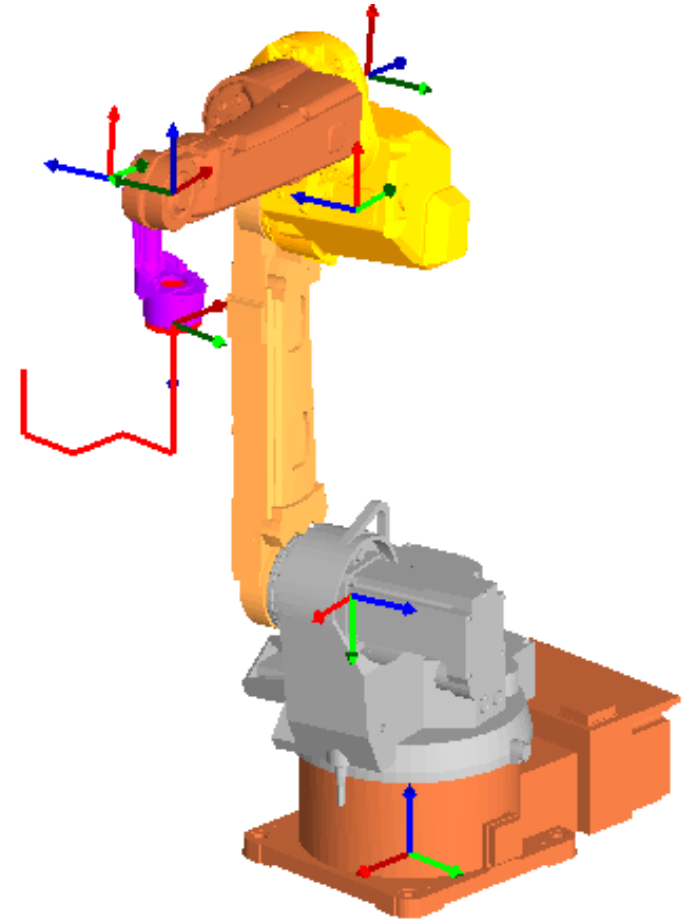
Source: <http://images.google.com>

Robotics Concepts

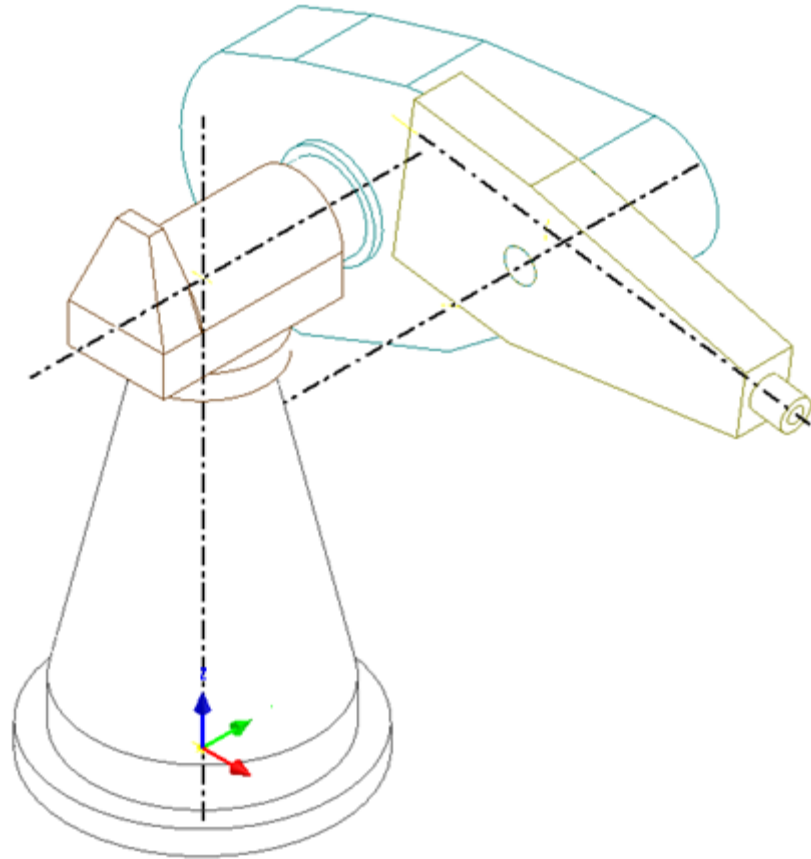
- DH Parameters
- Transformations
- Kinematics
- **Dynamics**
- Motion Planning
- ...

Geometric Model

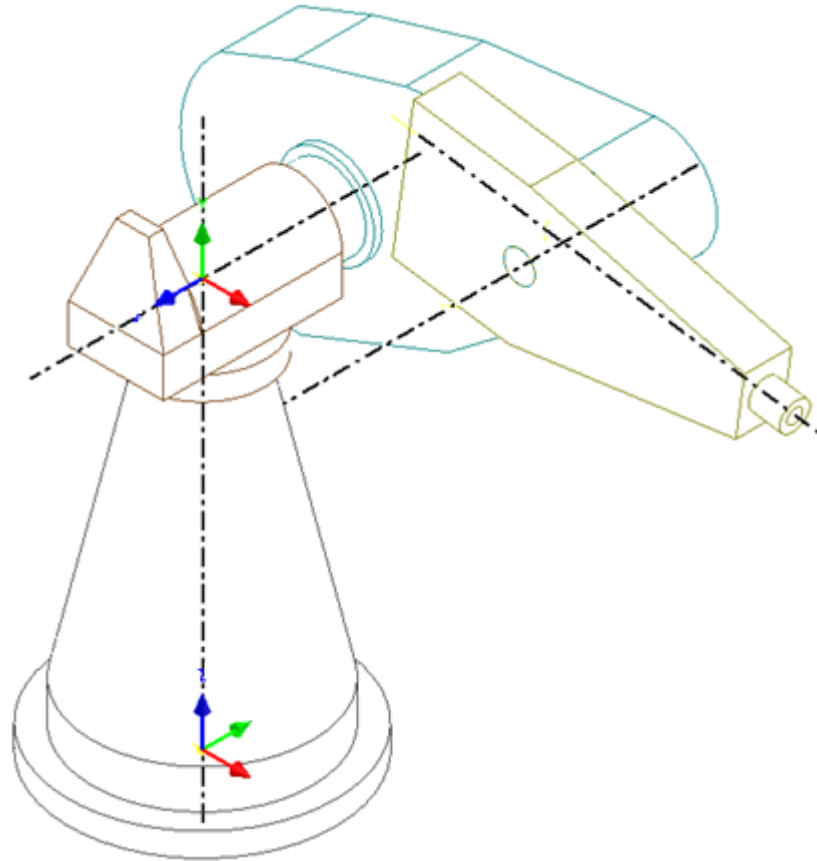
- Robot
 - moves in Cartesian frame
 - controlled at joints
- Mapping
 - Geometric model
 - Robot Architecture
 - Denavit-Hartenberg (DH) Parameters



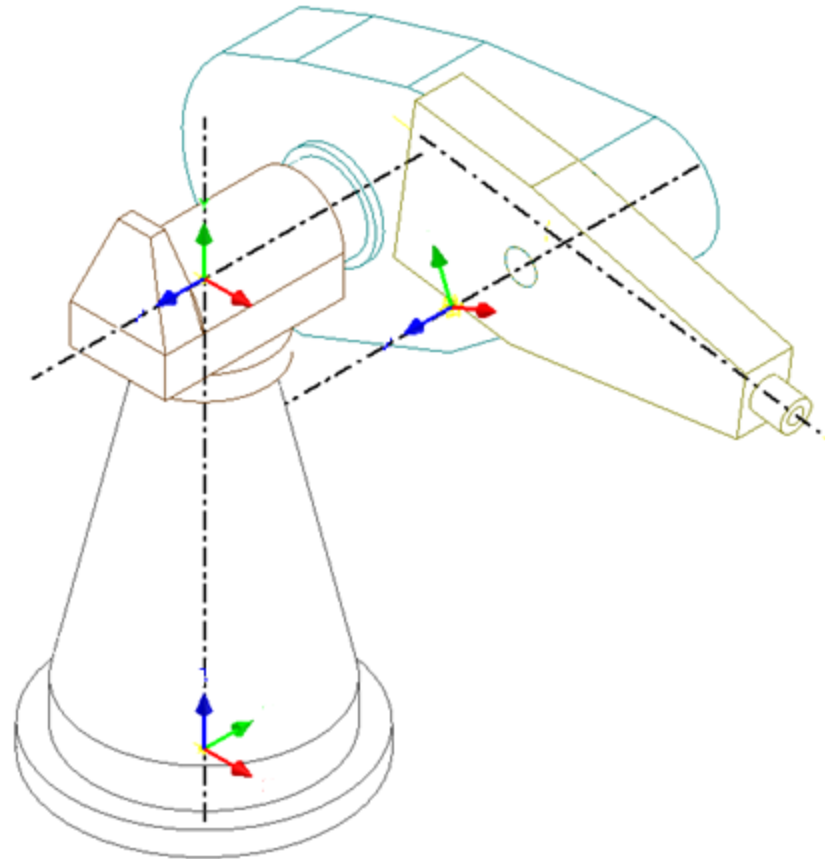
Joint Axes



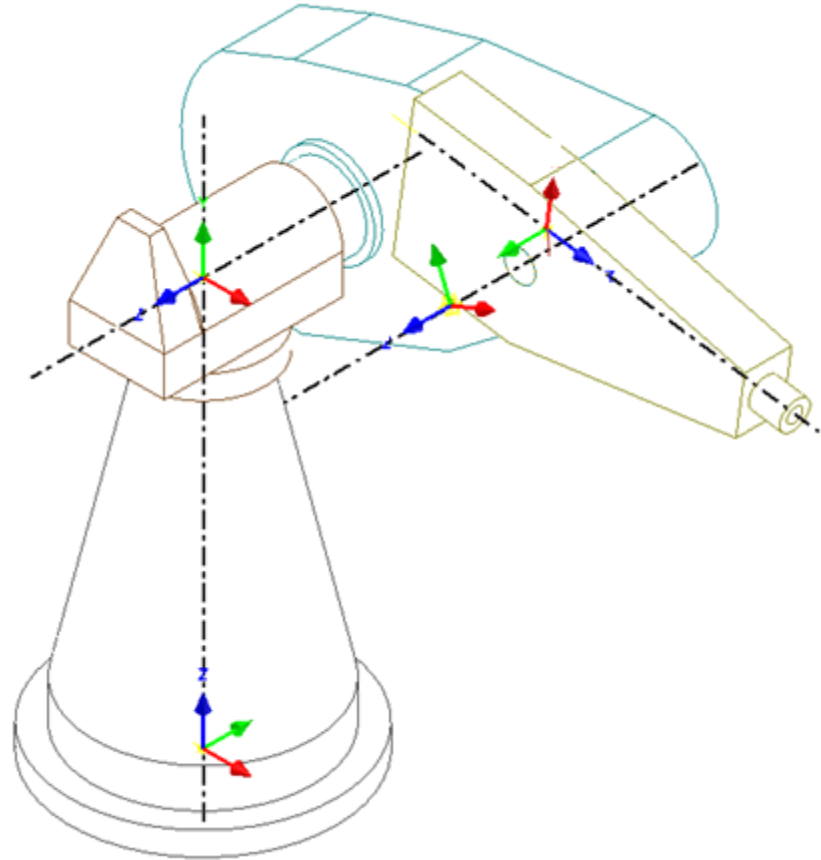
Joint Axes



Joint Axes

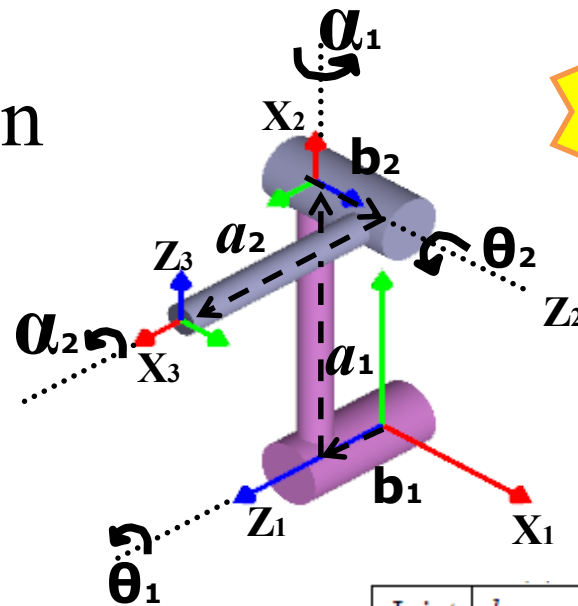


Joint Axes



DH Parameters

- Geometrical description
- 4 parameters
 - Joint offset (b)
 - Joint angle (θ)
 - Link length (a)
 - Twist angle (α)
- Relates frames attached on consecutive links

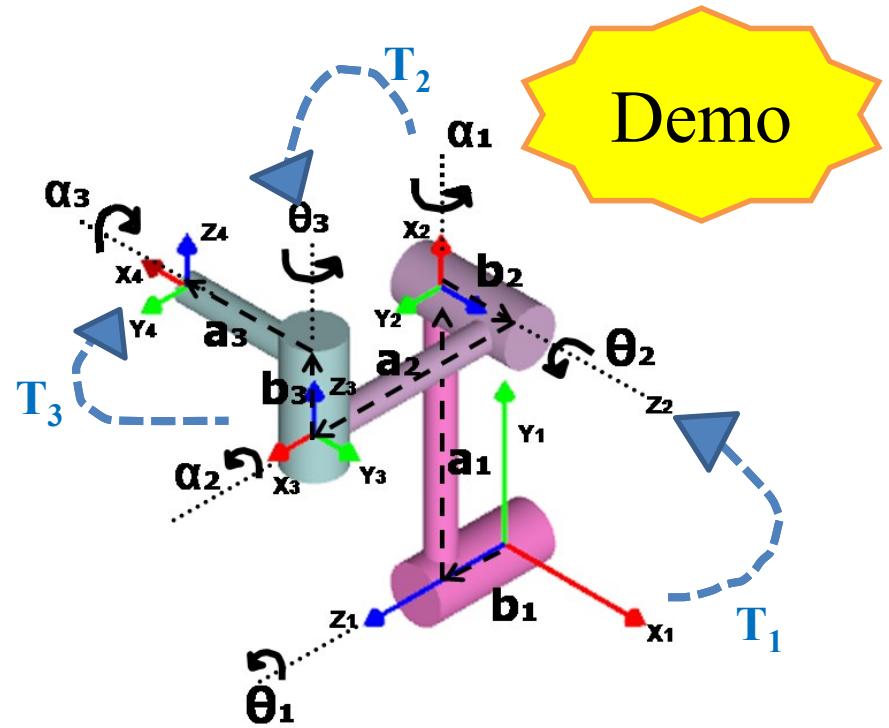


Joint	b_i	θ_i	a_i	α_i
1	50 mm	90°	200 mm	90°
2	50 mm	90°	150 mm	90°

$$T_i = \begin{bmatrix} C\theta_i & -S\theta_i C\alpha_i & S\theta_i S\alpha_i & a_i C\theta_i \\ S\theta_i & C\theta_i C\alpha_i & -C\theta_i S\alpha_i & a_i S\theta_i \\ 0 & S\alpha_i & C\alpha_i & b_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Transformations

- Joint to Cartesian space
- End-effector configuration in base frame



$$T_{ee} = T_1 T_2 T_3 = \begin{bmatrix} Q & P_x \\ & P_y \\ & P_z \\ \hline 0 & 0 & 0 & 1 \end{bmatrix}$$

Joint	b_i	θ_i	a_i	α_i
1	50 mm	90°	200 mm	90°
2	50 mm	90°	150 mm	90°
3	50 mm	-90°	100 mm	0°

Task 1: Transformations

- 2R Robot (Spatial)
- DH Parameters

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	Variable	0.2	90	0	180
2	Revolute	0	Variable	0.2	0	0	90

- Verify Transformation

Visualize DH | Link Config | EE Config | Joint Trajectory

Visualize DH | Link Config | EE Config | Joint Trajectory

Visualize DH | Link Config | EE Config | Joint Trajectory

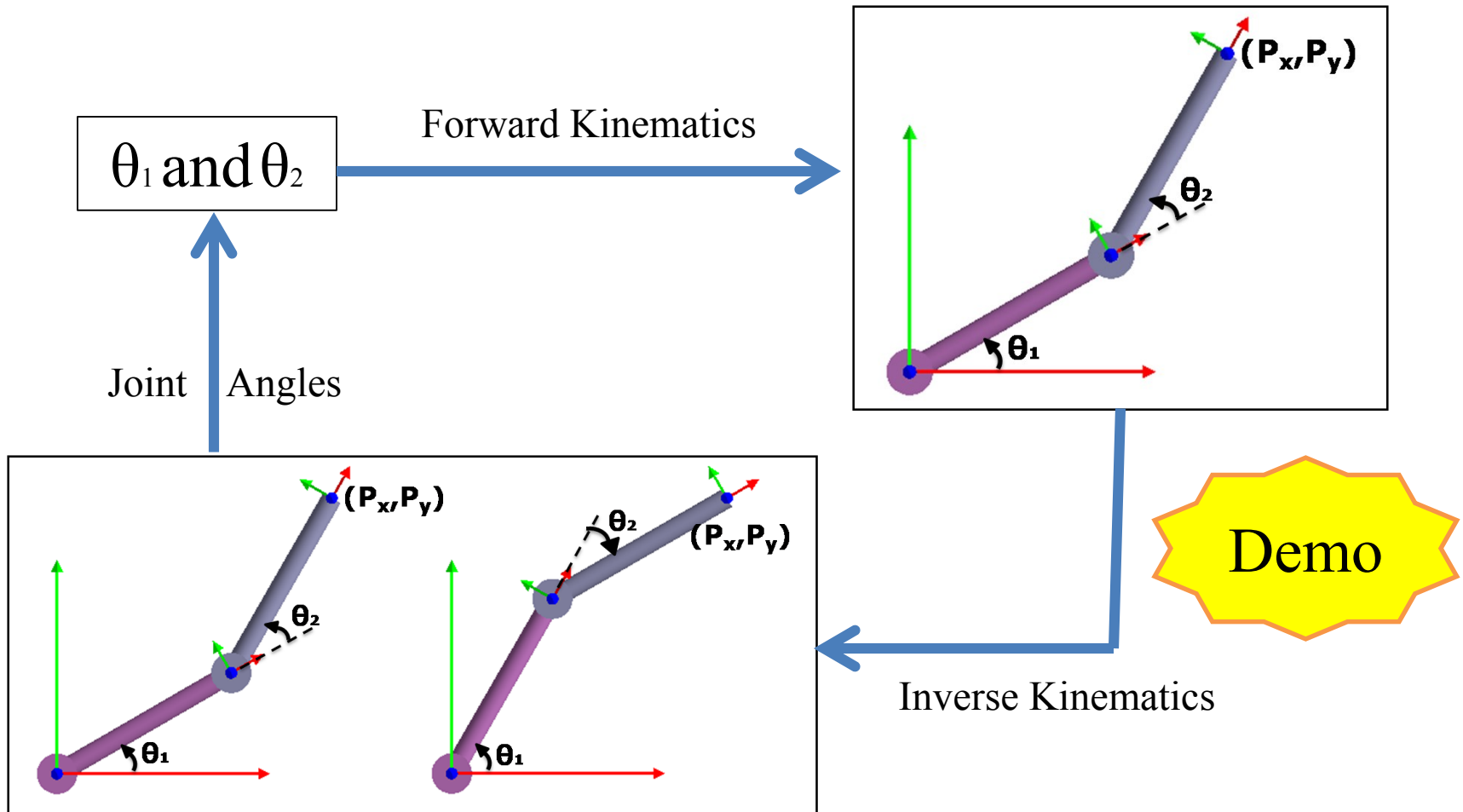
$$\begin{bmatrix} T \\ \text{Link1} \\ \text{Previous Link Frame} \\ \text{Update} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0.2 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} T \\ \text{Link2} \\ \text{Previous Link Frame} \\ \text{Update} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0.2 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} T \\ \text{Link2} \\ \text{Base Frame} \\ \text{Update} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0.4 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

- Try for Different Joint Angles

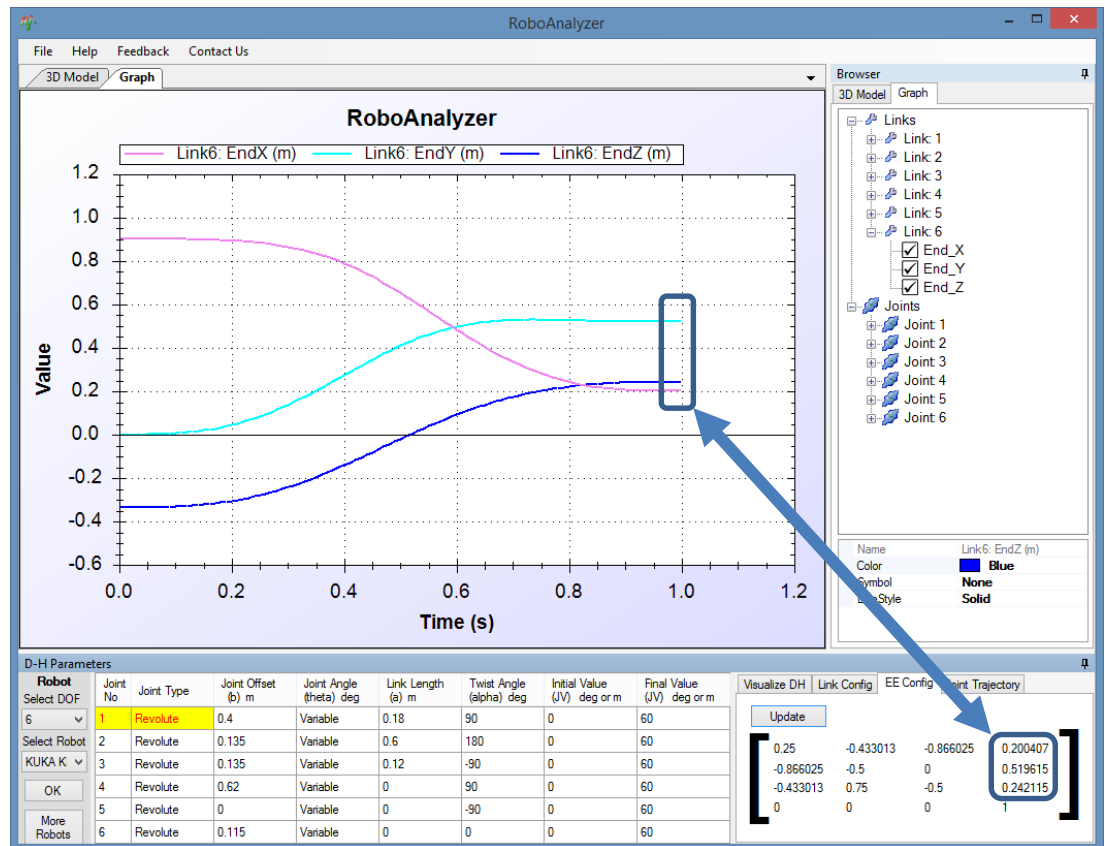
Kinematics

Study of motion of links without considering the forces



Task 2: Forward Kinematics

- KUKA KR5 Arc
- FKIn
- Animation
- Plots
- Verify Position of EE Config
- Try Different Motion



Task 3: Inverse Kinematics

- IKin
- MTAB Aristo Robot
- IKin: 8 Solutions
- Verify in RA
- Visualize in RA
- Try Different Robots

Select Robot: MTAB Aristo

Joint Offset (b) m	Link Length (a) m	Twist Angle (alpha) deg
1: 0.322	1: 0.001	1: 90
2: 0	2: 0.3	2: 0
3: 0	3: 0	3: 90
4: -0.375	4: 0	4: 90
5: 0	5: 0	5: 90
6: 0.063	6: 0	6: 0

End Effector's Position
 X (m): 0.35
 Y (m): 0.1
 Z (m): 0.5

Orientation Matrix		
1	0	0
0	-0.866	0.5
0	-0.5	-0.866

IKin
Analysis Complete

For FKIn
 Select Initial Values: Solution 1
 Select Final Values: Solution2
 OK

Solution1: Theta(deg)	Solution2: Theta(deg)	Solution5: Theta(deg)	Solution6: Theta(deg)
1: -168.926	1: -168.926	1: 11.074	1: 11.074
2: 87.844	2: 87.844	2: 92.541	2: 92.541
3: 12.484	3: 12.484	3: 167.144	3: 167.144
4: 329.552	4: -210.448	4: 149.553	4: -30.447
5: -75.538	5: 75.538	5: 75.549	5: 75.549
6: 4.383	6: -175.617	6: 39	6: -175.61

Solution3: Theta(deg)
 1: 11.074
 2: -26.178
 3: 12.855
 4: 120.843
 5: -145.143
 6: 66.692

Solution4: Theta(deg)
 1: 11.074
 2: -26.178
 3: 12.855
 4: -59.157
 5: 145.143
 6: -113.308

Solution7: Theta(deg)
 1: -168.926
 2: -153.913
 3: 167.517
 4: 301.11
 5: -144.998
 6: 66.271

Solution8: Theta(deg)
 1: -168.926
 2: -153.913
 3: 167.517
 4: -238.812
 5: 144.998
 6: -113.729

Visualize DH | Link Config | EE Config | Joint Trajectory

Update

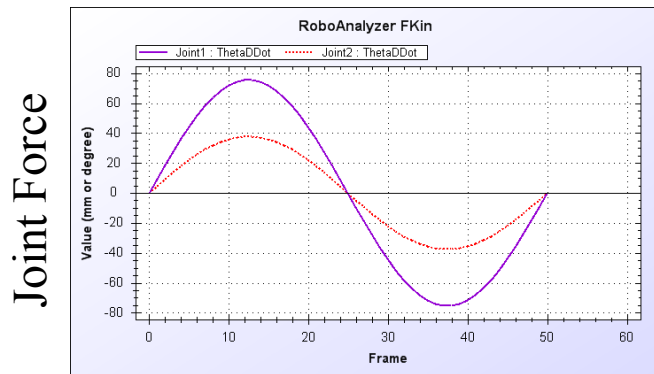
$$\begin{bmatrix} 1 & -1E-06 & 1E-06 & 0.35098 \\ -2E-06 & -0.866019 & 0.500011 & 0.100192 \\ 0 & -0.500011 & -0.866019 & 0.499998 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Dynamics

Study of forces and moments causing the motion of links

Forward Dynamics

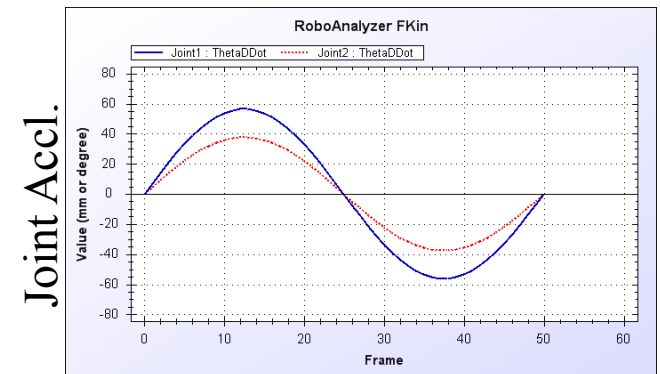
Inverse Dynamics



Forward Dynamics



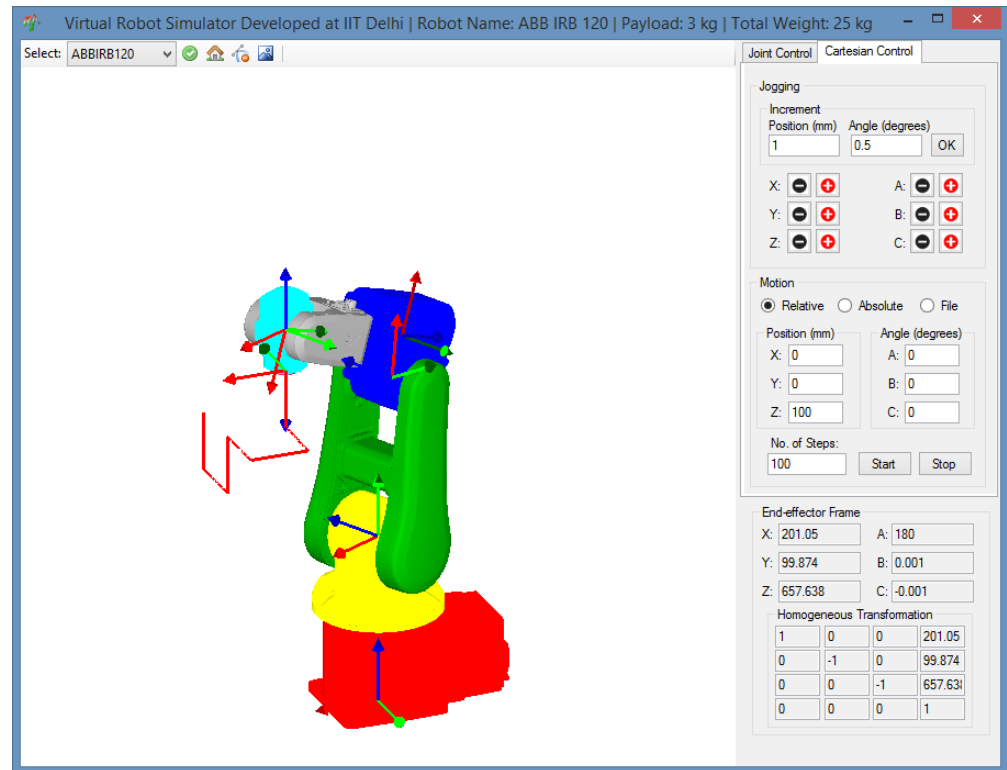
Inverse Dynamics



Due to complexity, these are usually not taught in most of the UG courses

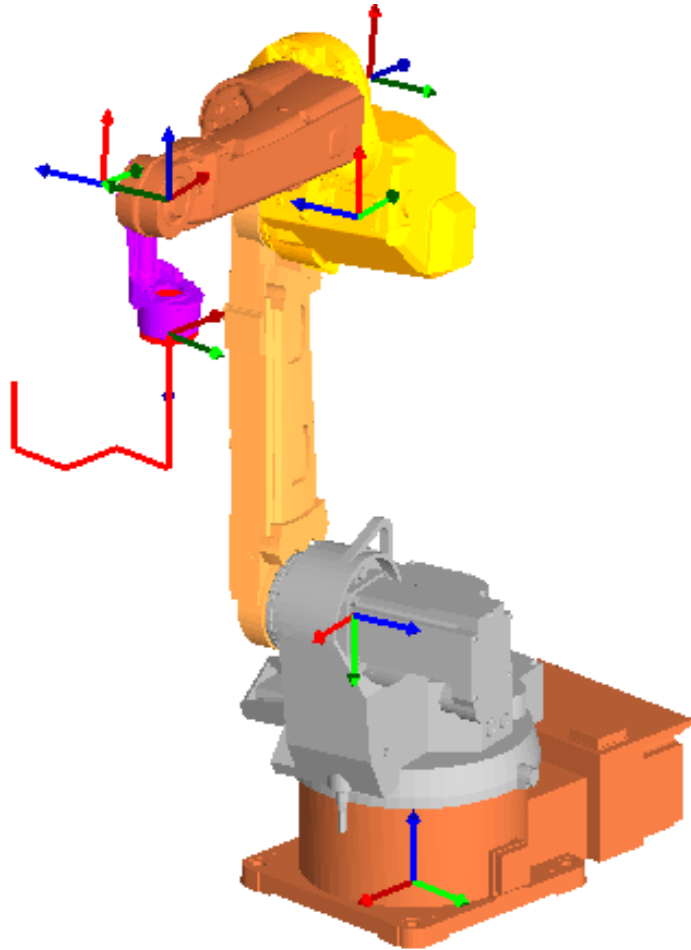
Virtual Robot Module

- Joint Jogging
- Cartesian Jogging
- 17 Robots
- Integration with MATLAB
- Interface with Physical Teach Pendant



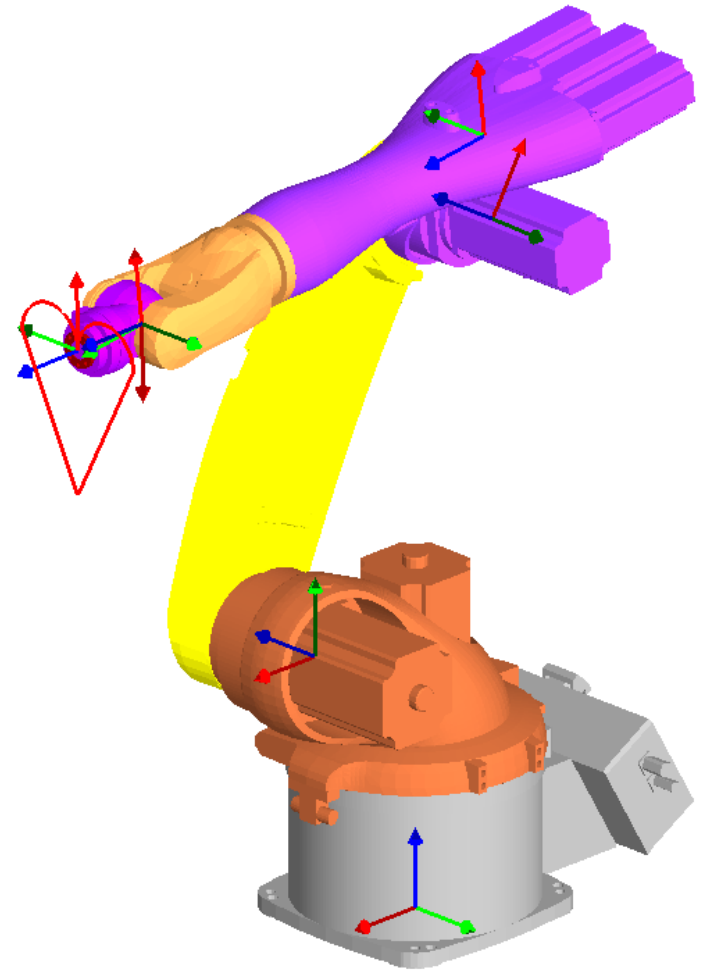
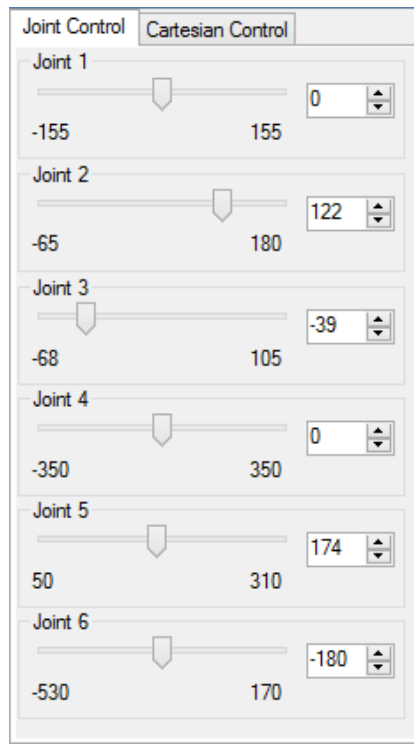
Task 4: Virtual Robot Module

- VRM_XML...
- ABB IRB1520
- Start Record Motion
- Cartesian Control
- Draw a Square of Side 100mm
- Stop Record Motion
- Read and Playback



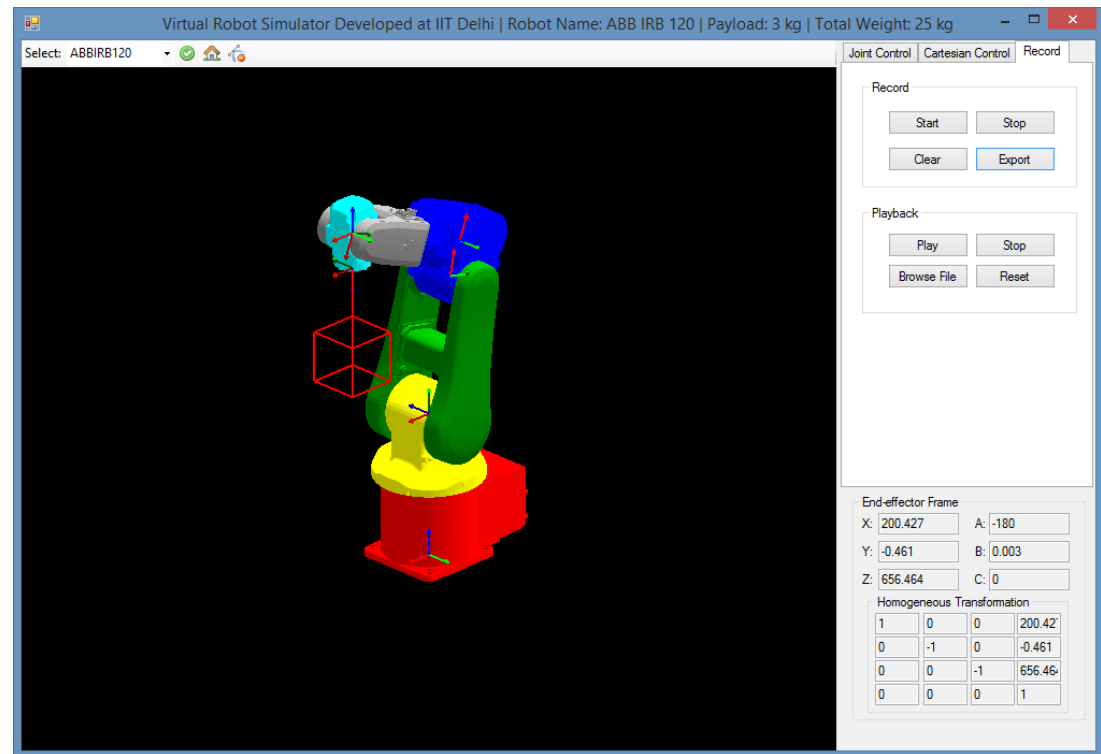
Task 5: Virtual Robot Module

- Move Joints
- Cartesian Motion
- Motion from File
“Heart_KUKAKR5.csv”



Contest: Virtual Robot Module

- VRM_XML...
- ABB IRB1520
- Start Record Motion
- Cartesian Control
- Draw a Cube of Side 100mm
- Stop Record Motion
- Read and Playback
- Least Number of Motion Sequences!!!



RoboAnalyzer Team

- Subir K. Saha (1996- present)
- S. Goel and S. Ramakrishnan (1996-97)
- A. Patle (2000-01)
- Rajat Jain (2009-10)
- Suril V. Shah (2007-11)
- Rajeevlochana G. Chittawadigi (2009 – 2013, 2015-present)
- Amit Jain (2010-11)
- Jyoti Bahuguna (2011-12)
- Ratan Sadanand (2012-15)
- Ravi Joshi (2014-15)
- Keshav Bimbraw and Ishaan Mehta (2016 Summer)

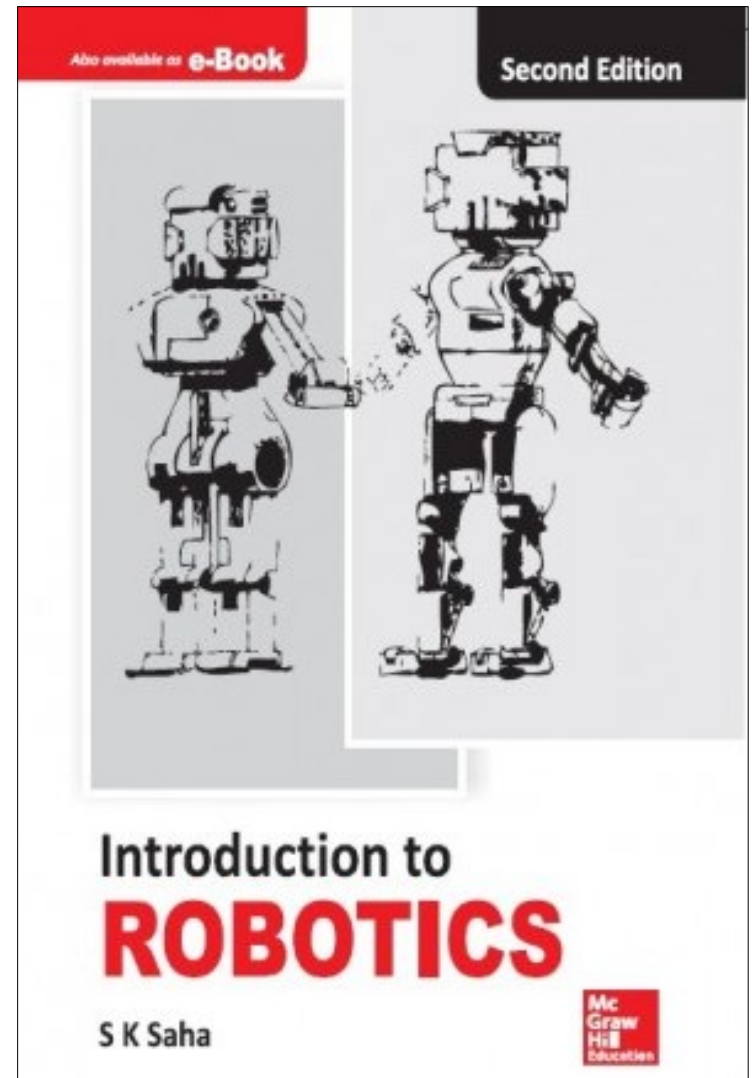
www.roboanalyzer.com

The feedback/suggestion of the below are sincerely acknowledged:

- Mr. Arun Dayal Udai (2010): Suggested importing of CAD files in STL format
- Dr. Sandipan Bandyopadhyay (2012): Suggested to make RA/VRM as an API/COM server to be integrated with other software
- Prof. Sudipto Mukherjee (2012-13): Suggested an interfacing with MATLAB
- Dr. Nayan Kakoty (2013): Suggested to have custom trajectory file input for joints
- Prof. Peter Corke (2015): Discussion on integration of RoboAnalyzer (VRM) with Robotics Toolbox
- Mr. Vinay Gupta (2016): Suggestion on having a link in the software for online feedback and contact form
- Mr. Dharmender Jaitly, Dr. Majid Koul, Mr. Aamir Hayat, Mr. Riby Bobby, Mr. Sasanka Sinha

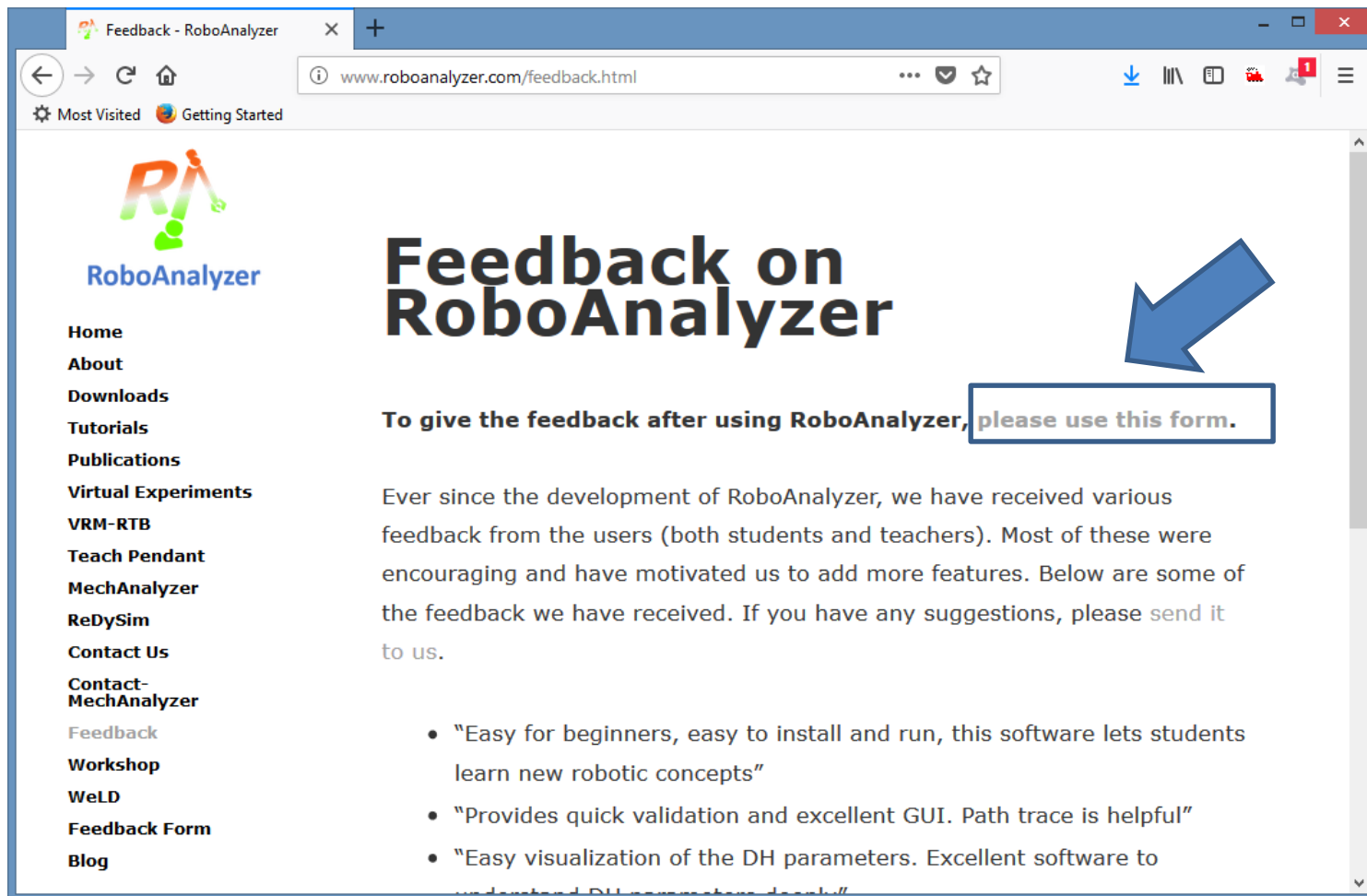
Complementary

- Illustrations
- Examples
- Effective!!!



Feedback

<http://www.roboanalyzer.com/feedback.html>



The screenshot shows a web browser window with the URL www.roboanalyzer.com/feedback.html. The page features the RoboAnalyzer logo on the left, a navigation menu, and a main heading "Feedback on RoboAnalyzer". A blue arrow points to a text box that says "To give the feedback after using RoboAnalyzer, please use this form." Below this, there is a paragraph of text and a list of feedback points.

RoboAnalyzer

- Home
- About
- Downloads
- Tutorials
- Publications
- Virtual Experiments
- VRM-RTB
- Teach Pendant
- MechAnalyzer
- ReDySim
- Contact Us
- Contact-MechAnalyzer
- Feedback
- Workshop
- WeLD
- Feedback Form
- Blog

Feedback on RoboAnalyzer

To give the feedback after using RoboAnalyzer, please use this form.

Ever since the development of RoboAnalyzer, we have received various feedback from the users (both students and teachers). Most of these were encouraging and have motivated us to add more features. Below are some of the feedback we have received. If you have any suggestions, please send it to us.

- "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"

Thank You

- rg_chittawadigi@blr.amrita.edu
- saha@mech.iitd.ac.in
- roboanalyzer@gmail.com