Workshop on Learning Robot Kinematics using RoboAnalyzer*

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*Developed at IIT Delhi
Contents

• Introduction
• Robotics Education
• Kinematics
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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 \((\theta)\)
  – Link length \((a)\)
  – Twist angle \((\alpha)\)
• Relates frames attached on consecutive links
Transformations

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

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

<table>
<thead>
<tr>
<th>Joint</th>
<th>( b_i )</th>
<th>( \theta_i )</th>
<th>( a_i )</th>
<th>( \dot{a}_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50 mm</td>
<td>90°</td>
<td>200 mm</td>
<td>90°</td>
</tr>
<tr>
<td>2</td>
<td>50 mm</td>
<td>90°</td>
<td>150 mm</td>
<td>90°</td>
</tr>
<tr>
<td>3</td>
<td>50 mm</td>
<td>-90°</td>
<td>100 mm</td>
<td>0°</td>
</tr>
</tbody>
</table>
Task 1: Transformations

- 2R Robot (Spatial)
- DH Parameters

<table>
<thead>
<tr>
<th>Joint No</th>
<th>Joint Type</th>
<th>Joint Offset (b) m</th>
<th>Joint Angle (theta) deg</th>
<th>Link Length (a) m</th>
<th>Twist Angle (alpha) deg</th>
<th>Initial Value (JV) deg or m</th>
<th>Final Value (JV) deg or m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Revolute</td>
<td>0</td>
<td>Variable</td>
<td>0.2</td>
<td>90</td>
<td>0</td>
<td>180</td>
</tr>
<tr>
<td>2</td>
<td>Revolute</td>
<td>0</td>
<td>Variable</td>
<td>0.2</td>
<td>0</td>
<td>0</td>
<td>90</td>
</tr>
</tbody>
</table>

- Verify Transformation

\[
\begin{bmatrix}
1 & 0 & 0 & 0.2 \\
0 & 0 & -1 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 0 & 1 \\
\end{bmatrix} \times \begin{bmatrix}
1 & 0 & 0 & 0.2 \\
0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1 \\
\end{bmatrix} = \begin{bmatrix}
1 & 0 & 0 & 0.4 \\
0 & 0 & -1 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 0 & 1 \\
\end{bmatrix}
\]

- Try for Different Joint Angles
Kinematics

Study of motion of links without considering the forces

$\theta_1$ and $\theta_2$

Forward Kinematics

Joint Angles

Inverse Kinematics

Demo
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
Dynamics

Study of forces and moments causing the motion of links

**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!!!
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 Boby, Mr. Sasanka Sinha
Complementary

- Illustrations
- Examples
- Effective!!!
Feedback

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

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

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