Modeling and Simulation of Two Link Flexible Manipulator Using Bond Graph Technique

Amardeep Singh¹, Aman Kumar Maini²

¹Assistant Professor, SBBSIET Hoshiarpur (Pb), India
²Assistant Professor, DAVIET, Jalandhar, India

Abstract: A mechanism involves a number of interconnected rigid bodies. To design and control a system, modeling of mechanism plays an important role. There are many methods used for modeling like Newton–Euler, Lagrange’s Euler and Hamiltonian method. These methods become very laborious and cumbersome for complex multibody systems. The above-mentioned techniques, however, do not expose the cause and effect relationship. In this paper, bond graph approach is used for modeling two link manipulator by considering the flexibility at the joints. Bond graph technique shows the pictorial representation of the dynamics of the system. Moreover, it may also be used for modeling multi-energy domain systems.

Keywords: Bond Graph, Modeling, Two Link Flexible Manipulator

1. Introduction

A robotic manipulator consists of several rigid bodies that are connected together by various types of joints. A typical robotic manipulator consists of various joints and links. Modeling of two link manipulator has been done by various researchers using different methods like Lagrange (1987), Newton’s Euler method (1990), and Assume mode method (1993) but the flexibility at the joints has rarely been considered (2013). These methods never show the physical aspects of the system and also mathematical too inclined for the complex system. Bond graph technique overcomes all these problems. Bond graph is a graphical modeling technique. In bond graph approach any system whether it is mechanical, electrical, or hydraulic system may be modeled. Therefore, it means that bond graph is a multi-energy domain system. Elements in a system interact with each other by exchanging energy or power. Bond graph clearly depicts how the exchange of energy in terms of effort and flow variables takes place. Moreover, it gives the first order state space equation. In addition, modification in the model developed using bond graph method can be easily done as compared to the other method. In this paper, bond graph technique is used to model the two link flexible manipulator. To provide the flexibility at the joints, stiffness and damping of various magnitudes are being considered. The reason behind considering the stiffness and damping at the joints is to protect the joints from wear and tear which occurs due to impact forces at joints. Owner and Vegte (1987) modeled the planar motion of a manipulator having two flexible links and two rotor joints with the help of Lagrangian approach. De Luca and Siciliane (1990) obtained the equation for two-link flexible manipulator by Lagrangian based Finite dimension method and Assume Mode Method. S Yu and M Aelbestawi in 1993 developed the model of two link manipulator using Lagrangian and Assume mode method approach. Morris and Madani (1995) derived the equation of two link flexible Manipulator. V.O. Gamarra- Rosado and Yuhara (1999) presented the model of two link flexible manipulator having two revolute joints and flexible links. The dynamic equations for the manipulator is derived using Newton–Euler formulation and finite element method. M A. Ahmad et al (2008) used Euler Lagrangian approach and Assume mode method to derive the equation for flexible manipulator. Simulation was done for dynamic model using Matlab. P Kalra, A.M Sharan (1992) used Finite element method to develop the equation of motion of two link manipulator. M . Farid and S A. Lukasiewicz (2000) used Lagrangian approach and finite element method to develop the dynamic model of flexible manipulator. The experimental validation was carried out on a single flexible manipulator and compared with numerical finite element model in both frequency and time domain. The result from FEM model is very close to the experimental validation. M.O. Tokhi et. al (2001) showed the dynamic modeling of flexible links and joints. The elastic deformation on each link is assumed due to bending and torsion. Rajesh et. al (2013) discussed two link flexible spatial manipulators modeled considering both link and joint flexibility. The deformation occurs on each link and joint is due to bending, torsion, and pure torsion, respectively. The equation of motion for the manipulator is obtained using principal of virtual work and FEM. The numerical simulation of different cases considering rigid links and rigid joints, flexible links and flexible joints, flexible links and flexible joints is performed. The simulation result shows significant effect of flexibility on the overall manipulator motion.

2. Model Description

In this paper, Two link flexible manipulator has been modeled using Bond graph technique. The whole mechanism consists of three rigid links and connected by turning joints. Springs and dampers are provided at each joint for considering the flexibility. Denavit – Hartenberg convention is used to fix the reference frames on each
link (Craig 2005). The link 0 is called a fixed frame and also called inertial frame. The link 1 and 2 connected together and have relative motion with each other, and also with inertial frame. Inertial frame does not have any movement that is translational and rotational. In figure 1 O₁, A₁ are origin of link 0 and link 1 respectively and A₂ is the end point of link 2, on the other hand B₁ is the origin of link 2 , end point of link 2 is B₂. θ₁ is the angle made between the X axis and arm 1 whereas angle between the X₁ and X₂ is θ₂. Center of masses of the respective links are C₁ , and C₂.

The bond graph of the mechanism is shown in the figure 2. In the bond graph the thick and thin lines shows the vector and scalar bonds respectively. The left side of the bond graph shows rotational dynamics and translational dynamics is represented on the right side of the bond graph. Translational dynamics of link 2 is restricted by applying sf equal to zero. For the flexibility, Stiffness k₁₁ , K₁₅ , k₅₂ and damping r₁₁ , r₁₆ , r₅₂ are provided at the joints of link 0 and link 1 The stiffness K₄₈ and damping r₄₉ at the joint of link 1 and link 2. For simulation, angular velocity of 25 rad/s and torque of 2N-m has been applied at link 1 and link 2 respectively. The both links made to rotate about point A₁ and B₁ that is about z axis. The movement of both link in X and Y direction will be restricted by applying sf equal to zero.

3. Simulation and Result

Matlab has been used for simulation. Table 1 shows the parameter and Table 2 shows the stiffness and damping value used for simulation. The time span for simulation is takes as 5 sec.

![Figure 1: Two Link Flexible Manipulator](image)

Table 1: Link parameters for Simulation

<table>
<thead>
<tr>
<th>Link</th>
<th>l₁</th>
<th>l₂</th>
<th>l₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Link 1</td>
<td>1m</td>
<td>.01m</td>
<td>.01m</td>
</tr>
<tr>
<td>Link 2</td>
<td>.75m</td>
<td>.01m</td>
<td>.01m</td>
</tr>
</tbody>
</table>

Table 2: Different value of stiffness and damping

<table>
<thead>
<tr>
<th>Location</th>
<th>Stiffness (k)</th>
<th>Damping (R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Translation coupling between Link 1 and Link 2(at joints)</td>
<td>K₁₂=10⁷ N/m</td>
<td>R₁₂=10³ N-s/m</td>
</tr>
<tr>
<td>Link 2 and Link 3(at joints)</td>
<td>K₄₈=10⁷ N/m</td>
<td>R₄₈=10³ N-s/m</td>
</tr>
<tr>
<td>Rotational coupling Link 1 and Link 2(at joints)</td>
<td>1) K₁₁=10⁷ N/m</td>
<td>1) R₁₁= 10 N-s/m</td>
</tr>
<tr>
<td>Z axis component</td>
<td>2) K₁₅=10⁷ N/m</td>
<td>2) R₁₅= 10² N-s/m</td>
</tr>
<tr>
<td>X axis component</td>
<td>3) K₁₅=10⁷ N/m</td>
<td>3) R₁₅= 10³ N-s/m</td>
</tr>
<tr>
<td>Y axis component</td>
<td>1) K₁₁=10⁷ N/m</td>
<td>1) R₁₁= 10 N-s/m</td>
</tr>
<tr>
<td></td>
<td>2) K₁₅=10⁷ N/m</td>
<td>2) R₁₅= 10² N-s/m</td>
</tr>
<tr>
<td></td>
<td>3) K₁₅=10⁷ N/m</td>
<td>3) R₁₅= 10³ N-s/m</td>
</tr>
</tbody>
</table>
Figure 2: Bond graph of two link flexible Manipulator
Figure 3: Displacement-time graph for joint of 2 link manipulator with $R=100 \text{Ns/m}$ damping at various stiffness
(a) $k=0$, (b) $K=10^6 \text{N/m}$ (c) $k=10^9 \text{N/m}$

The figure 3 shows the displacement–time graph for various stiffness at joint. Which the graph shows the role of flexibility at damping value $100 \text{Ns/m}$. When the value of $k=0$ (a) then the displacement of the link varies from $0.03 \text{m}$ to $-0.005 \text{m}$. In case of $k=10^6 \text{N/m}$ (b) the displacement value lies between $7 \times 10^{-3} \text{m}$ to $-7 \times 10^{-3} \text{m}$ but when value of $k=10^9 \text{N/m}$ (c) then displacement at joints is close to zero. It means minimum flexibility is provided at joint.

Figure 4: Displacement-time graph for joint of 2 link manipulator with $R=10 \text{Ns/m}$ damping at various stiffness
(a) $k=0$, (b) $K=10^6 \text{N/m}$ (c) $k=10^9 \text{N/m}$

The figure 4 shows the displacement at the joints of a two link manipulator for constant damping value $R=10$ and different stiffness value (K). When there is no stiffness $k=0$ (a) then the displacement at joint varies from $0.15 \text{m}$ to $0.225 \text{m}$. In case of stiffness value $k=10^6 \text{N/m}$ (b) the joint displacement is negligible for one second then displacement is increased as the time increased and lies between $-0.01 \text{m}$ to $0.01 \text{m}$. The joints show minimum displacement when the stiffness $k=10^9 \text{N/m}$ (c).

Figure 5: Displacement-time graph for joint of 2 link manipulator with $R=1000 \text{Ns/m}$ damping at various stiffness
(a) $k=0$, (b) $K=10^6 \text{N/m}$ (c) $k=10^9 \text{N/m}$

The figure 5 displacement–time graph for damping value $R=1000$. The displacement is varies from $4 \times 10^{-3} \text{m}$ to $-4 \times 10^{-3} \text{m}$ to stiffness value $k=0$. The displacement for the joint is negligible at the start after $0.5 \text{sec}$ it starts increasing and lies between $3 \times 10^{-3} \text{m}$ to $-3 \times 10^{-3} \text{m}$ for $k=10^6 \text{N/m}$ (b). The displacement is minimum when the $k=10^9 \text{N/m}$ (c).

4. Dynamics of links

Figure 6: Position of center of mass Link1

The Link 1 rotates at origin $O_1$ about z axis. So the path traced by center mass $C_1$ of the link is circle as shown in figure 6.
The figure 7 (a) shows only the z component of angular momentum varies because other two moments have been constrained. The angular momentum increases sharply in the initial period of time due to high angular velocity and then remain constant. The angular momentum of link 2 is decrease with time as shown in figure 7 (b).

5. Conclusion

In this paper, Bond graph technique has been used to model the two link flexible manipulator. Matlab is used for simulation. Various plots have been analyzed for the dynamics of links by considering different value of stiffness and damping at each joints.

References