Design and Control of a Serial Robotic Arm using ROS (Robot Operating System)

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Abstract

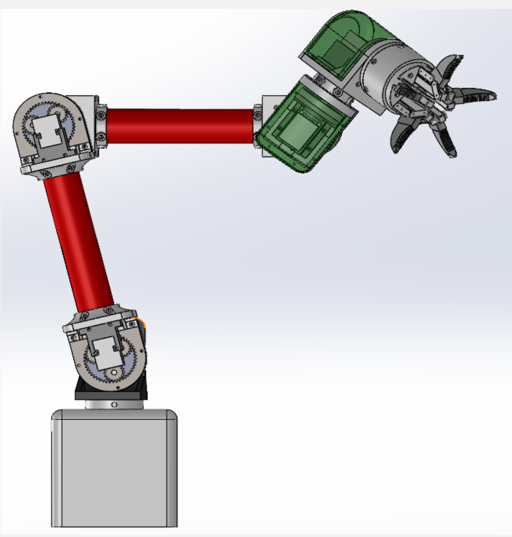
In this study, the control and dynamic analysis of a 5 degree of freedom serial robot manipulator using Robot Operating System (ROS) thoroughly investigated. The manipulation system was seamlessly integrated with the ROS framework, employing Gazebo simulation environment, Rviz visualization tool, and Moveit motion planning framework. Kinematic analysis enables precise control and planning of the manipulator's movements, while dynamic analysis provides insights into its forces and torques. The study demonstrates successful manipulation control using ROS, highlighting the feasibility of kinematic and dynamic analysis, enhancing understanding, and aiding in the development of control strategies

1. Introduction

Serial robot manipulators[1] are versatile and flexible mechanical systems widely used in various fields such as industrial automation, assembly lines, material handling, and surgery. The control, motion planning, and analysis of these manipulators are of critical importance to ensure accurate and efficient operation. In this context, the forward kinematic, inverse kinematic, dynamic analyses and control method of serial robot manipulators are performed using advanced tools such as the Robot Operating System (ROS)[2, 3]. Serial robot manipulators consist of multiple links and joints, forming complex mechanical systems. Kinematic analysis[4] is employed to mathematically model and control the manipulator's movements. Dynamic analysis involves the examination of forces, torques, and accelerations generated during the motion of a serial robot manipulator. Understanding and optimizing the effects of the manipulator's movements are crucial in dynamic analysis. RoboAnalyzer is a software tool used for dynamic analysis of serial robot manipulators. It enables the analysis of the impact and interaction of forces and torques generated during the manipulator's movements. These analyses provide fundamental information for controlling and programming the manipulator's precise and accurate movements. For controlling and simulation, ROS integrates the necessary components for controlling serial robot manipulators and coordinates their communication. Additionally, ROS components such as the Gazebo simulation environment, Rviz visualization tool, and Moveit motion planning framework facilitate the simulation, visualization, and generation of optimized motion plans for serial robot manipulators.

2. Structural Design

3D model of the system was designed in Solidworks prior to the prototype manufacturing. Structural representation of serial robotic arm can be seen in Figure1.



The robotic arm has
- 5 degrees of freedom,
- 6 revolute joints, 7 links,
- A pick and pack gripper
- Total grip diameter is 100mm
- Total length is 822.52mm
- Total weight is 2756g

Figure 1: Structure of the Serial Robot Ar

3. Theoretical Calculations

$$p_x = d_6C_1C_{234}S_5 - d_5C_1S_{234} + a_3C_1C_{23} + a_2C_1C_2 + d_6S_1C_5 + d_4S_1$$

$$p_y = d_6S_1C_{234}S_5 - d_5S_1S_{234} + a_3S_1C_{23} + a_2S_1C_2 - d_6C_1C_5 - d_4C_1$$

$$p_z = d_6S_{234}S_5 + d_5C_{234} + a_3S_{23} + a_2S_2 + d_1$$

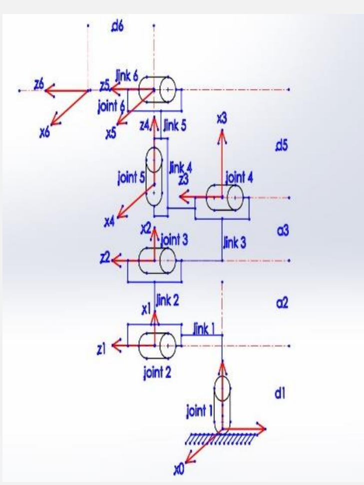


Figure2: Kinematic model of Serial Manipulator

Joint i	α_i (°)	a_i (m)	d_i (m)	θ_i (°)
1	$\frac{\pi}{2}$	0	d_1	θ_1
2	0	a_2	0	θ_2
3	0	a_3	0	θ_3
4	$-\frac{\pi}{2}$	0	d_4	θ_4
5	$\frac{\pi}{2}$	0	d_5	θ_5
6	0	0	d_6	θ_6

Table 1: D-H table

4. Experimental Setup

Production of the system based on structural design made by 3D printer with a material PLA and ABS. For reduction sheet material used in 1:3 planetary gear as shown below.

Figure 3: 2 DoF Spherical Manipulator Proposed for the Orientation System

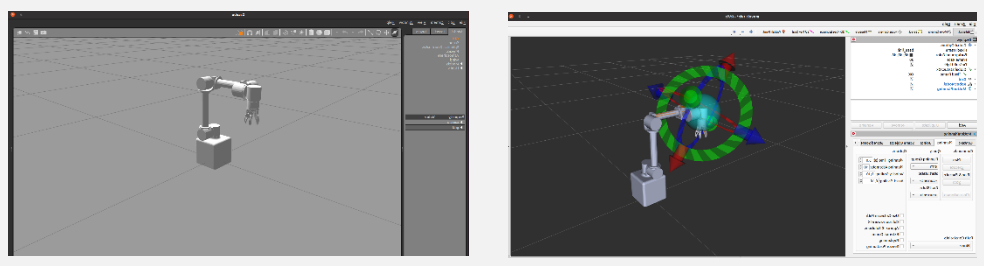
In order to obtain desired power, gear reduction added. There are 2 reduction system as 1:3 and 1:25.

Figure 4: Planetary Gear with 1:3 Gear Ratio Produced by Sheet Material

As a result, the robot arm, which was originally designed as 6 DOF, decreased to 5 as the 6th motor was used to move the gripper. After all the necessary parts were produced, the assembly process was carried out and the final 5 DOF robot arm was obtained.

Figure 5: Experimental Setup

After the production phase was completed, the tests and controls of the robot arm were made using ROS.



5. Conclusions

In this study, the control and dynamic analysis of a 5-degree-of-freedom serial robot manipulator using ROS has been extensively studied. The kinematic model of the robot was created on the Solidworks program and forward kinematic analysis was performed with the Denavit-Hartenberg method. There are 4 modes for controlling the motors used in the robot arm. The most suitable mods for our system were mods 0 and 3. We first aimed to check it with the 0th mod, the location mod. But in this mode, the range of motion of the motors was limited to 360 degrees. Due to the 1/25 planetary gear reducer we designed for the 2nd and 3rd motors, the angle value we observed in the links as a result of 1 full revolution of the motors was approximately 14.4 degrees. Since this value is too limited for the movement of the robot arm, we gave up using this mode. In step mode, which is the 3rd mode, the range of motion of the motors is not limited to 360 degrees. For this reason, we decided to drive the motors in the 3rd mode in order to ensure the movement of the robot arms and verified right datas are written to the servo motors by feedback that taken from motors.

In summary, The integration of ROS into the methodology of the study allowed for extensive exploration of control and dynamic analysis of the 5-degree-of-freedom serial robot manipulator. The utilization of ROS provided a robust environment for developing and controlling the system

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