ENPM662 INTRODUCTION TO ROBOT MODELING

PROJECT REPORT

FANUC manipulator performing pick and place with ROS Simulation

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ABSTRACT

Manipulators have become a widely adopted technology in numerous industries, such as manufacturing, material handling, and tele-operation, with renowned brands like FANUC, ABB, and Kuka leading the way. As robotic systems continue to expand their application range, tasks such as picking and placing objects have become increasingly prevalent. In this project, a FANUC manipulator was modeled and simulated in Gazebo and RVIZ environments for picking and placing objects. The simulation process aimed to showcase the manipulator's capabilities and demonstrate its potential for automating such tasks

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Introduction

Robotic arms have become a crucial tool across various sectors, ranging from manufacturing and automotive to aerospace, food processing, and healthcare. They offer accuracy, speed, and efficiency, enabling them to handle complex shapes and big weights while working continuously without rest, resulting in reliable, error-free output. Using robotic arms can increase productivity, save labor costs, and improve the quality of goods and services. In the medical field, they can perform precise, minimally invasive surgeries, while in the automotive industry, they handle tasks such as welding, painting, and vehicle part assembly.

The FANUC Manipulator is a popular robotic arm used extensively in the manufacturing industry for various applications. Manufactured by the renowned Fanuc Corporation, a leading company in the robotics industry, it comes with a two-finger end effector.
In this project, we focused on modeling and simulating the Fanuc Manipulator in Gazebo and RVIZ. The Fanuc Manipulator used in our project is a robot arm manufactured by the Fanuc Corporation, one of the leading companies in the robotics industry. The robot arm we used in our project is equipped with a two-finger end effector, which is commonly used for picking and placing objects.

The report is divided into several sections, starting with an overview of the various applications of the Fanuc Manipulator in different industries. We then provide a detailed description of the robot arm, including information about its type, size, and degrees of freedom.

Next, we discuss the crucial elements and steps involved in the CAD modeling process, which includes building the Denavit Hartenburg table for forward kinematics and calculating the system's final transformation matrix. We also explain the importance of using the Spong convention in the modeling process.

We then move on to the simulation part of the project, where we describe how we simulated the Fanuc Manipulator in Gazebo and RVIZ. We discuss the challenges we faced during the simulation and the lessons we learned from the project.

In conclusion, this project demonstrated the versatility and usefulness of the Fanuc Manipulator in various industries. The simulation of the robot arm in Gazebo and RVIZ helped us understand its capabilities and limitations, and provided valuable insights for future projects. Overall, this project highlights the potential of robotics in enhancing productivity, improving quality, and reducing labor costs in various industries.
This project focuses on describing the manipulator's applications, size, and degrees of freedom. It also covers the critical elements and steps of the CAD modeling processes, including building the Denavit Hartenburg table for forward kinematics using the Spong convention. Later, we calculated the system's final transformation matrix and conducted simulation using Gazebo and RVIZ, discussing the results and challenges encountered during the project. Lastly, the conclusions, future work, and references are presented.

APPLICATIONS

The Fanuc Manipulator is a highly adaptable robotic arm that finds use in a wide variety of fields due to its flexibility. It is commonly used in the automotive industry for welding, painting, material handling, and assembly, while the aerospace industry employs it for drilling, riveting, and fastening. The electronics industry uses the robot arm for soldering, assembly, and testing, and the pharmaceutical and food industries utilize it for packaging, labeling, sorting, and palletizing. It is also used in agriculture for harvesting, pruning, and planting. Its versatility makes it a popular choice for manufacturers in various industries as it increases productivity, reduces labor costs, and enhances product quality.

Moreover, the Fanuc Manipulator is capable of performing tasks that are difficult or impossible for humans, such as picking, sorting, and assembling products in warehouses and factories. It can also be used for quality control by attaching an end effector to an ultrasonography instrument to detect product flaws and cracks. In machine tending, the robot arm feeds raw parts into a CNC machine and removes machined parts after the process is complete. Programming the robot arm is simple, and it can load new parts into the machine with minimal human assistance, making it efficient for "first-off" parts.

Furthermore, the Fanuc Manipulator has applications in the medical industry. When the end effector is connected to a cyber knife, it can be utilized as a radiotherapy device and can assist in corneal transplantation and complicated surgeries. It can also be used for ultrasonography by replacing the gripper with an appropriate sensor, providing doctors with assistance during the process due to its flexibility.

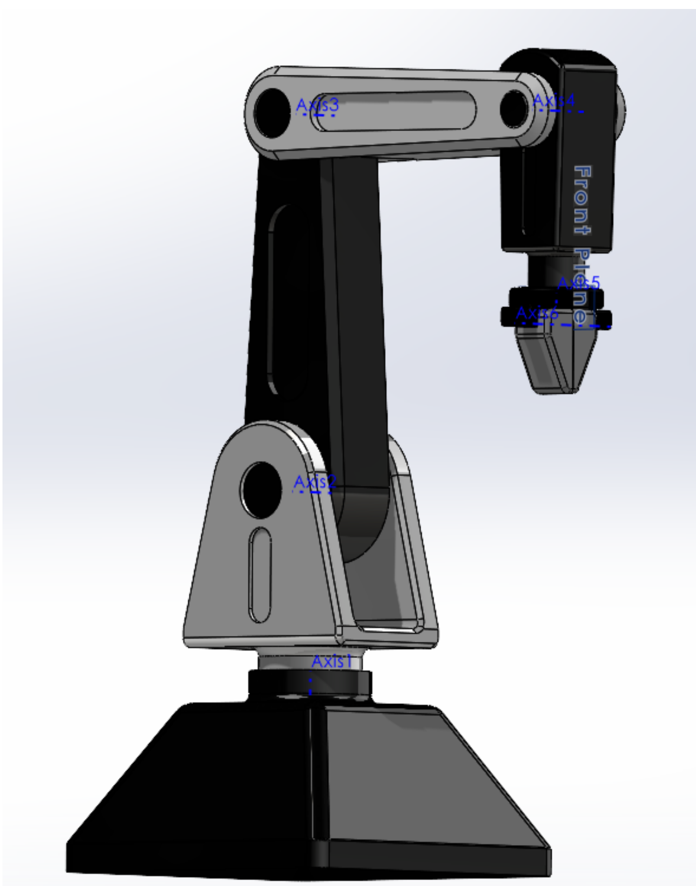
Robot Description

The FANUC manipulator is a product sold by FANUC Manufacturing. It consists of a six-degree-of-freedom arm and a custom-built two-finger end effector. The robot arm features five revolute joints, enabling a broad range of motion. The two-finger gripper end effector has a prismatic joint, allowing it to pick up and release objects. The table below outlines the specifications of the robot.

Degrees of Freedom	6
Mass	56.73 KG
Dimensions [LxBxH]	1450.22 x 621.14 x 1578
Number of Links	7
Number of Joints	5
End effector Velocity	2m/s
Payload	20 kgs
Applications	Industrial automation and numerous others
Maximum Joint Angular Displacement(varies as per link)	360 degrees

CAD MODEL

The robotic assembly is composed of seven distinct parts that are connected by five revolute joints to form a flexible arm. The arm is equipped with a two-finger gripper as an end effector, while the end effector itself is furnished with a prismatic joint. To avoid any joint locking, specific joint limits were defined for the system. The assembly and modeling of the robot required a considerable amount of time, as standard mates were insufficient for the task. Advanced mates, including profile center mates, were employed to achieve the desired functionality of the system. The base link was exported along with a reference coordinate system that was aligned with the gazebo coordinate system.



Forward Kinematics

The design of the robot's axes has been optimized for maximum efficiency, with the z-axis aligned in the direction of motion and the x-axis positioned at the front of the robot. This configuration makes it simple to derive DH parameters for the manipulator, using either the Spong or Craig convention. The axes are labeled sequentially from the base, with a total of six axes ascending in order. The first axis is labeled Z base, while the last one is labeled Z Tool axis to correspond to the end effector.

DH Table:

i	θ	α	a	d
1	Θ_1	90	69.55	342.96
2	$90 + \theta_2$	0	350.5	0
3	Θ_3	90	47.38	0
4	Θ_4	270	0	410.45
5	$270+\theta_5$	90	0	0
6	Θ_6	0	112.43	236.29

Based on known joint angles of theta1–6, the forward kinematic (FK) equations calculate a
transformation matrix of 0–6–T.
The obtained transformation matrix is defined as:

$$
\begin{aligned}
{}^{0}_{6}T(\theta_1, \theta_2, \theta_3, \theta_4, \theta_5, \theta_6) &= \begin{bmatrix} {}^{0}_{6}R & {}^{0}P_6 \\ 0 & 1 \end{bmatrix} \\
&= \begin{bmatrix} {}^{0}\hat{X}_6 & {}^{0}\hat{Y}_6 & {}^{0}\hat{Z}_6 & {}^{0}P_6 \\ 0 & 0 & 0 & 1 \end{bmatrix} \\
&= \begin{bmatrix} {}^{0}\hat{X}_{6x} & {}^{0}\hat{Y}_{6x} & {}^{0}\hat{Z}_{6x} & {}^{0}P_{6x} \\ {}^{0}\hat{X}_{6y} & {}^{0}\hat{Y}_{6y} & {}^{0}\hat{Z}_{6y} & {}^{0}P_{6y} \\ {}^{0}\hat{X}_{6z} & {}^{0}\hat{Y}_{6z} & {}^{0}\hat{Z}_{6z} & {}^{0}P_{6z} \\ 0 & 0 & 0 & 1 \end{bmatrix}
\end{aligned}
$$

INVERSE KINEMATICS

The inverse kinematic equations are used to calculate the joint angles based on the desired position and orientation of the end frame, which is represented by the transformation matrix 0 6T. We make sure that all angles in the solution, namely θ1 to θ6, fall within the range of [0, 2π].

$$\theta_1 = \operatorname{atan2}\left({}^0P_{5y}, {}^0P_{5x}\right) \pm \operatorname{acos}\left(\frac{d_4}{\sqrt{{}^0P_{5x}{}^2 + {}^0P_{5y}{}^2}}\right) + \frac{\pi}{2}$$

$$\theta_6 = \operatorname{atan2}\left(\frac{-{}^6\hat{X}_{0y} \cdot \sin\theta_1 + {}^6\hat{Y}_{0y} \cdot \cos\theta_1}{\sin\theta_5}, \frac{{}^6\hat{X}_{0x} \cdot \sin\theta_1 - {}^6\hat{Y}_{0x} \cdot \cos\theta_1}{\sin\theta_5}\right)$$

$$\theta_3 = \pm\operatorname{acos}\left(\frac{|{}^1P_{4xz}|^2 - a_2{}^2 - a_3{}^2}{2a_2a_3}\right)$$

$$\theta_2 = \phi_1 - \phi_2 = \operatorname{atan2}(-{}^1P_{4z}, -{}^1P_{4x}) - \operatorname{asin}\left(\frac{-a_3\sin\theta_3}{|{}^1P_{4xz}|}\right)$$

$$\theta_4 = \operatorname{atan2}({}^3\hat{X}_{4y}, {}^3\hat{X}_{4x})$$

$$\theta_5 = \pm\operatorname{acos}\left(\frac{{}^0P_{6x}\sin\theta_1 - {}^0P_{6y}\cos\theta_1 - d_4}{d_6}\right)$$

Forward Kinematics Validation

The transformation matrix is obtained from the code is shown below.

```
[[ 1.   -0.   -0.    0.18]
 [ 0.    1.   -0.    0.17]
 [ 0.    0.    1.    0.74]
 [ 0.    0.    0.    1.  ]]
```

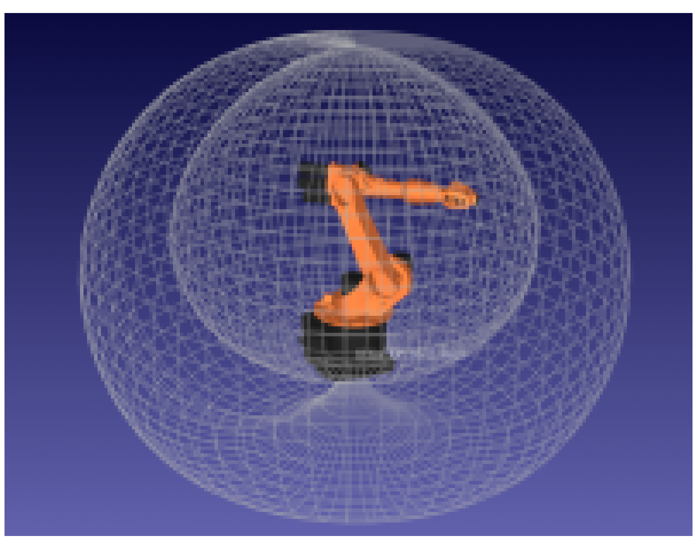
INVERSE KINEMATICS VALIDATION

a combination of velocity controllers, joint limits are used to confirm the accuracy of the forward kinematics calculation for a robotic arm using the DH table.

```
 -0.643432820697415

 -0.0489716115327524

  -0.52366144602273

  0.605067436438736

  0.52366144602273

-3.48786849800863e-17
-0.967440118053894

-0.639023493927356

 7.5556122696518

 1.0175226977273

 10.8256037533934

-18.4478026482692
-0.58789330423068

-0.173856584539996

0.144263602020163

0.594775387480844

 2.01658894586088

-1.98008233318958
-0.486942718710586

-0.198616512680259

0.179931740040671

0.496729006245772
```

Workspace study

The workspace of the system has a spherical shape, with an estimated diameter of 1.5 meters, as demonstrated by the accompanying images. The images were generated by extending the robot arm to its full length in one direction within the xy plane, followed by rotating the first joint a full 360 degrees, and finally flexing the three elbow joints to produce a complete spherical workspace. The resulting workspace is comparable to the illustration depicted below.



Assumptions

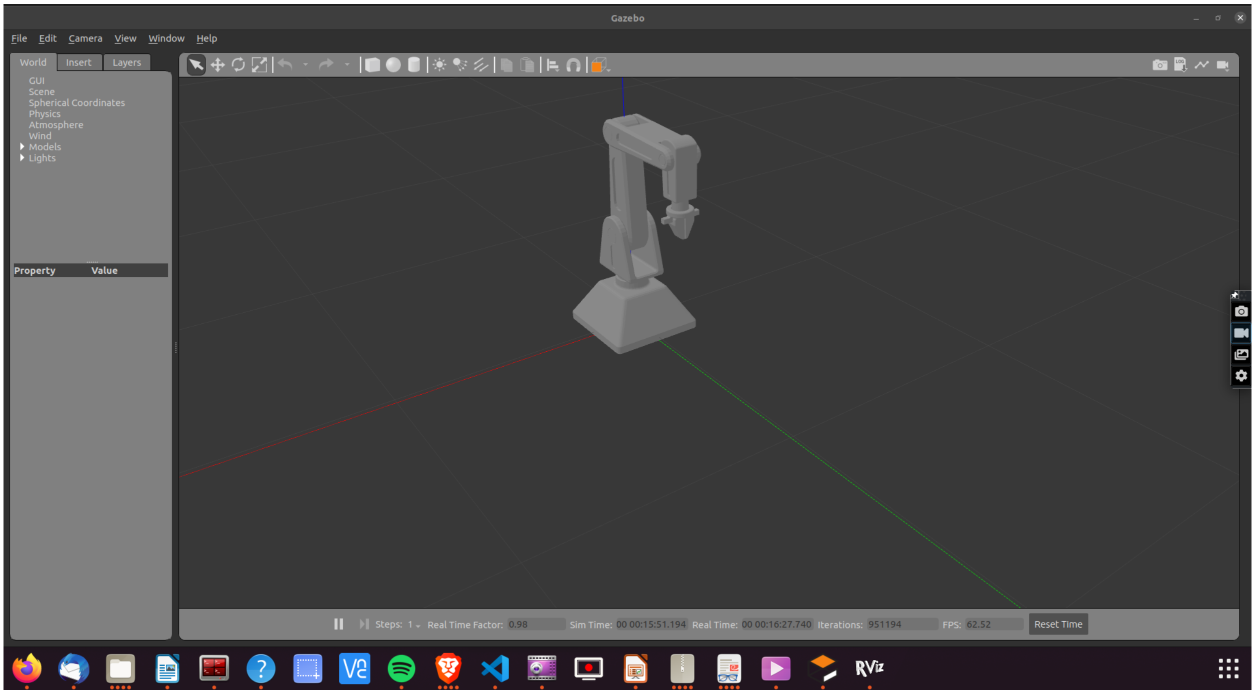
The robot system simulation assumes that the robot has 6 degrees of freedom and that all links and joints are structurally sound. External factors such as friction and vibrations are not taken into account. The objects to be picked and placed are assumed to have well-defined edges and shapes, and the robot arm path is defined but not necessarily optimal. The actuators are expected to have high torque for improved maneuverability, and thermal effects are not considered. Additionally, the material used for the robot is subject to change and may not remain fixed.

CONTROL METHOD

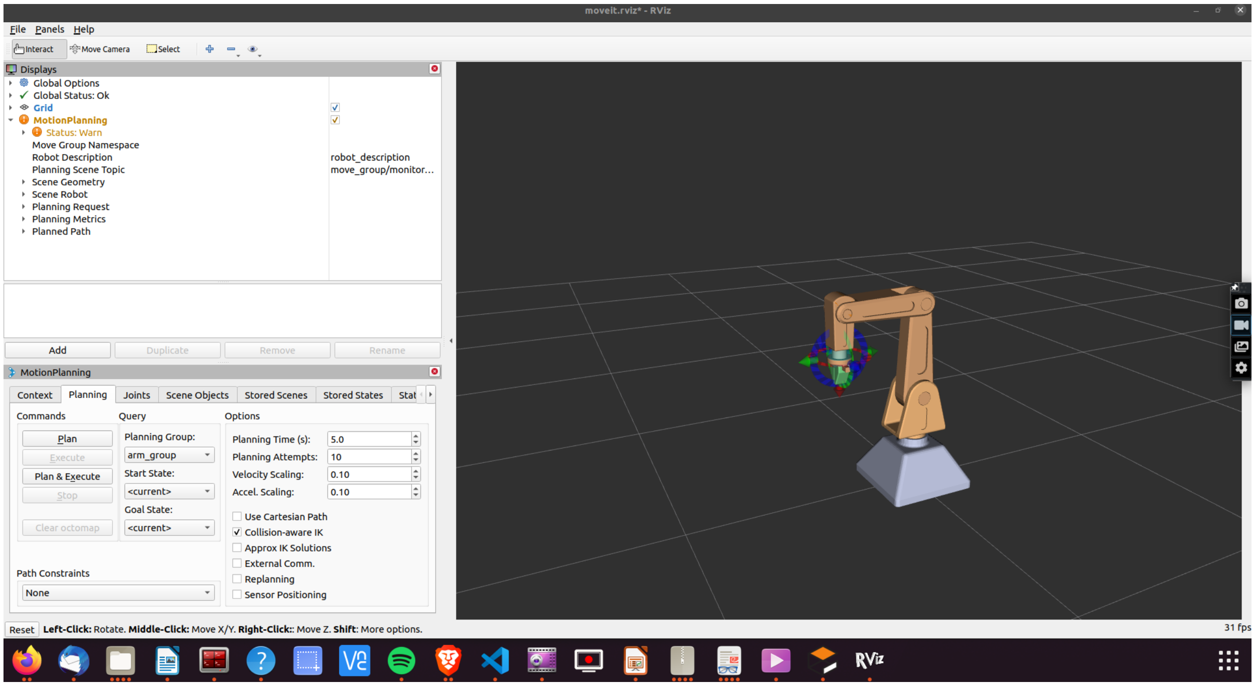
I opted for a simple PID controller that met my requirements. PID controllers are commonly used in most industries as they are feedback controllers that help achieve a set point despite disturbances or changes in a plant's characteristics. The controller's output is determined by the measured error and the three controller gains: proportional gain Kp, integral gain Ki, and derivative gain Kd. Additionally, we incorporated position controllers in our model, which allowed us to set joint boundaries and move them to specific positions using the controller input, rather than manually moving them. By aligning the joints precisely to the desired pose, e were able to ensure accurate forward kinematics validation, unlike the manual approach, which required adjustments to the joint restrictions to achieve the correct stance.

VISUALIZATION

GAZEBO:



RVIZ:


moveit.rviz* - RViz
File Panels Help
Interact
Move Camera
Select
Displays
Global Options
Global Status: Ok
Grid
MotionPlanning
Status: Warn
Move Group Namespace
Robot Description
Planning Scene Topic
Scene Geometry
Scene Robot
Planning Request
Planning Metrics
Planned Path
robot_description
move_group/monitor...
Add
Duplicate
Remove
Rename
MotionPlanning
Context
Planning
Joints
Scene Objects
Stored Scenes
Stored States
Commands
Query
Options
Plan
Execute
Plan & Execute
Stop
Clear octomap
Planning Group:
arm_group
Start State:
<current>
Goal State:
<current>
Planning Time (s):
5.0
Planning Attempts:
10
Velocity Scaling:
0.10
Accel. Scaling:
0.10
Use Cartesian Path
Collision-aware IK
Approx IK Solutions
External Comm.
Replanning
Sensor Positioning
Path Constraints
None
Reset
Left-Click: Rotate. Middle-Click: Move X/Y. Right-Click:: Move Z. Shift: More options.
31 fps

PROBLEMS FACED

- I had originally planned to use a CAD model straight off the FANUC manipulator website, but I ran into a lot of problems trying to convert it to URDF. I then proceeded to realign and assemble the same pieces after making small modifications to them.
- When spawning the robot in the gazebo the coordinates of the axis were off so i had to redo the coordinate axes to align with the gazebo's one.
- Controllers generated by the moveit were problematic so I had to write the controllers again and velocity controllers used resulted in various problems as I had changed them to position based controllers.

- And also I encountered an incorrect interface between the robot and MoveIt, which prevented me from successfully performing the pick and place operation. Unfortunately, due to time constraints, I was unable to resolve the issue, which led to having to abandon the initial goal. Though I plan to finish this in future.

LESSONS LEARNT

Completing this project has allowed us to apply all the knowledge we acquired during the course. We are now proficient in designing and modeling using SolidWorks, scaling and customizing the model to meet our requirements, and have acquired a solid foundation in kinematics and dynamics related to the field of robotics. We have learned how to create appropriate models, assign coordinate frames, obtain DH parameters, and apply forward and inverse kinematics on our preferred model, which is a popular industrial robot.

Through ROS, we have learned how to simulate a robot's behavior in a controlled virtual environment, taking into account the subtleties of modeling and simulation. We also learned how to remotely connect to and control the robot using a remote device, which required a thorough understanding of the robot in question.

Our skills in CAD modeling have improved, and we were able to reorient parts and assemblies according to the coordinate system in Gazebo. We also learned about advanced mates and used reference shapes to mate parts.

The choice of controllers depends on the type of joint. For a continuous joint, velocity controller is preferred, and for a revolute joint, effort controller is more appropriate. It is essential to implement the tele-op file thoughtfully, especially when there are many joints to be controlled. Similarly, key bindings need to be intuitive to make it easy for the human to maneuver the bot.

Conclusion

This project aimed to implement a pick-and-place operation that is commonly used in manufacturing and warehouse. The proposed robotic system consists of a lightweight manipulator and two finger end effector. This procedure is crucial in industries and warehouses to enhance productivity while reducing labor costs. The project provided me with a strong understanding of the fundamentals of modeling and simulating any robot, including kinematics, dynamics, rigid body transformations, forward and inverse kinematics, contact modeling, and grasping, which I learned throughout the course. Additionally, I gained knowledge on integrating sensors, controllers, plug-ins, and other essential tools in the ROS-Gazebo environment, which helped us in the project.

FUTURE WORK

Unfortunately, I was unable to successfully execute the pick-and-place operation as I had hoped. However, I remain determined to accomplish this task in the future by incorporating additional sensors such as cameras and ARCO markers. With these tools, I hope to accurately detect and sort various parts according to their unique characteristics. I am committed to improving my skills and knowledge in order to successfully complete this task.

REFERENCES

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5) https://robotics.stackexchange.com/