Blood Sample Handling Robot

ENPM662 - Final Project Report

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Introduction

Robotic manipulators find applications across diverse industries, serving purposes ranging from healthcare and disaster management to home services. In the field of medical diagnostics, there is always a need for precision and effectiveness and so these manipulators are specifically designed to cater the above needs. One such application is in the handling of blood samples in laboratories, where a reliable service is much needed. So this report outlines the development and implementation of a Blood Sampling Handling Robotic System using UR10 series and further implementing with UR10 Robotic Arm.

UR10 series is known for its agility and versatility along with its compactness and thus can be integrated in small scale ecosystems. This system will try to contribute to the ease of operations in laboratories.

Throughout the report, we will try to highlight the design of the robotics arm including the end effector design and the working of it. Moreover, this report will delve deeper into the forward kinematics, inverse kinetics and automating the pick and place of the lab equipment. Few examples videos will also guide for a better understanding of the system. Finally, the outcomes of this project may have the potential application to this industry and can increase the efficiency in the controlled environment.

Application

The application of this robotic arm extends to the crucial tasks of blood smear handling and placing it onto the testing equipment for further studies. The arm uses a vacuum gripper which makes sure that there are no fingerprints on the glass palette which is crucial to examine the blood samples. Physical grippers on the other hand can damage the smears and there are chances of accident as these are made of glass material. That is the reason behind the choice of vacuum gripper.

Robot Used

This project uses a 6DOF Robotic Manipulator, UR10, developed by Universal Robotics. It is developed on the basis of cobot technology and includes various models with different payload capacity. It is versatile based on its compactness with its precision and accuracy in most of the fields.

Image courtesy - www.universal-robots.com

The robot has 6 joints including the end effector joint and all of them are revolute joints. The reachability of this robot is close to 1300mm and so it can be used in multiple working environment. For this project, we have used this 6 degrees of freedom which also includes a vacuum gripper attached to the end effector frame.

These 6 Degree of freedom are located on each individual 6 joints. The dimensions
and frame assignment are shown below.

Solidworks Model

The model is built using different parts attached to combine and form an assembly.

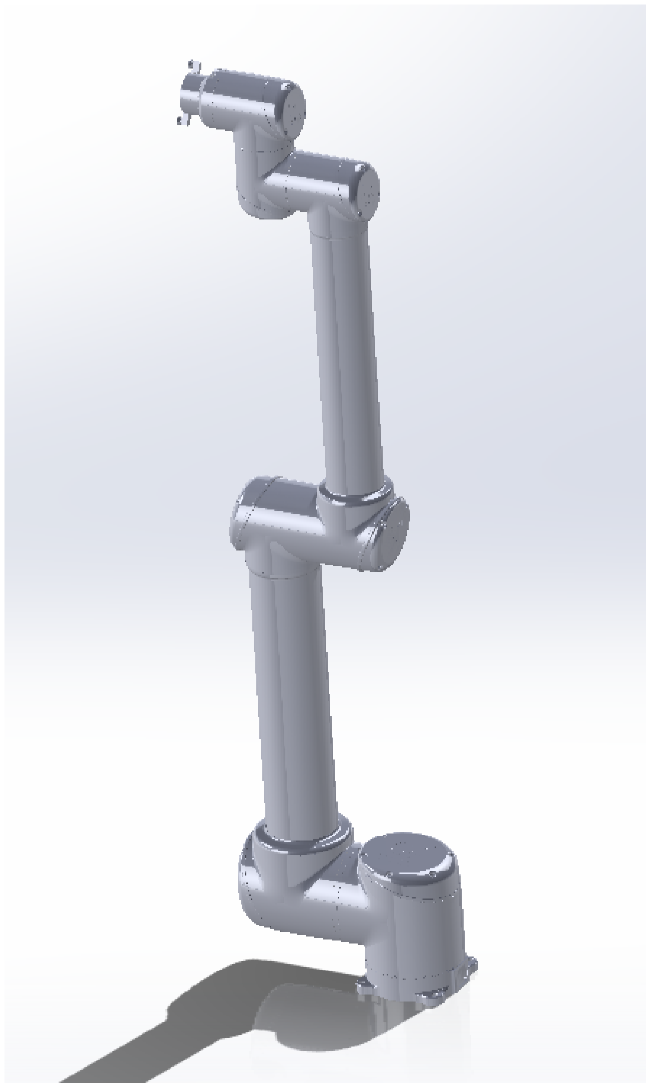


Fig 1 - CAD Model With Vacuum Gripper

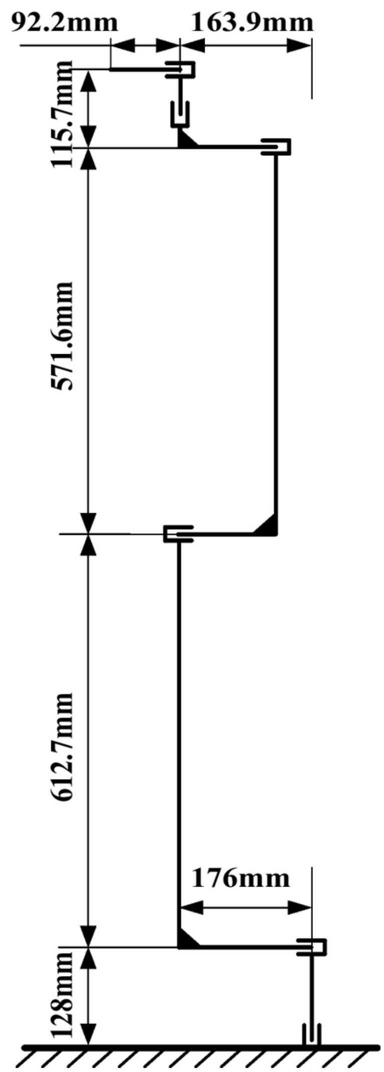


Fig 2 - Dimensions of the model

Frame Assignment

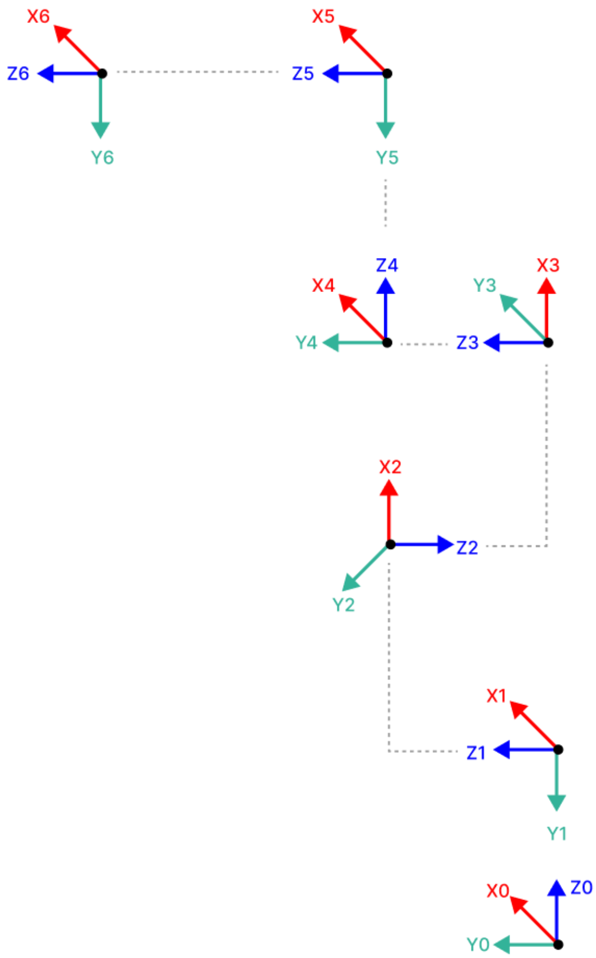


Fig 3 - Frame Assignment

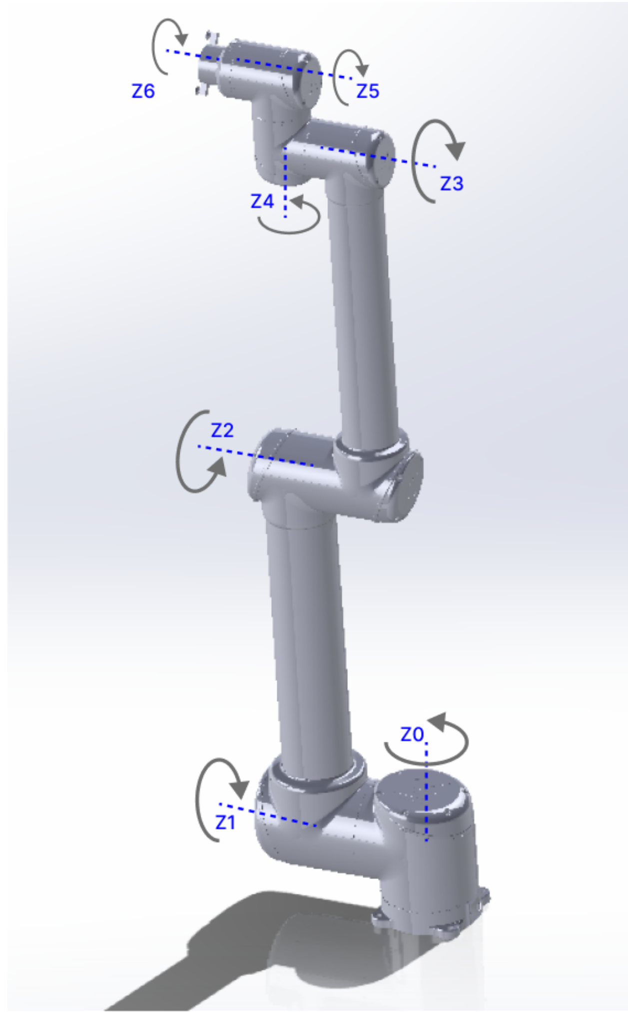


Fig 4 - Joint Rotations

The frames were assigned following certain rules, so basically it states the the rotary axis is always z-axis and based on that x and y axis should be assigned based on the below conventions.

DH Parameter

The Denavit-Hartenberg Parameters were assigned following the convention by Spong and which follows the basic principle of finding four parameters (Spong et al.) which define the robot state and transformation given the input joint angles or position

a_i : $represents\ the\ distance\ between\ zi - 1\ to\ zi\ measured\ along\ xi$

α_i : $represents\ the\ angle\ from\ zi - 1\ to\ zi\ measured\ about\ xi$

d_i : $represents\ the\ distance\ from\ xi - 1\ to\ xi\ measured\ along\ zi - 1\ axis$

θ_i : $represents\ the\ angle\ from\ xi - 1\ to\ xi\ measured\ about\ zi - 1\ axis$

The DH Parameter Table is shown below for this UR10 Manipulator

Link Name	θ	d	a	α
0 - 1	θ_1*	0.128	0	-90
1 - 2	θ_2* - 90	0.176	0.6127	180
2 - 3	θ_3 *	0.1639	0.5716	180
3 - 4	θ_4 * + 90	0.1639	0	90
4 - 5	θ_5 *	0.1157	0	-90
5 - 6	θ_6 *	0.2152	0	0

Forward Kinematics

Forward Kinematics denotes the end-effector position given the joint angles. So in order to get the position of the end-effector with respect to the base frame, an approach of transformation matrix is used.

The final transformation matrix for the given DH Parameter Values is shown below, as the output is long, the matrix is shown half.

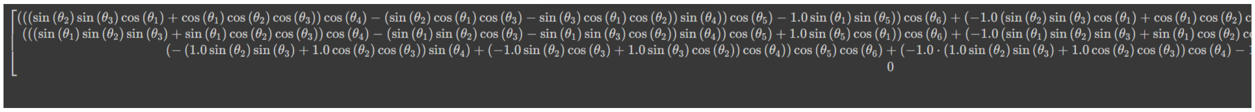


Fig 5 - Final Transformation Matrix

The final transformation matrix at the given home configuration, where all the joint angles are zero is given below. As the end effector length is included, this matrix gives the position and orientation of the end effector with respect to base frame.

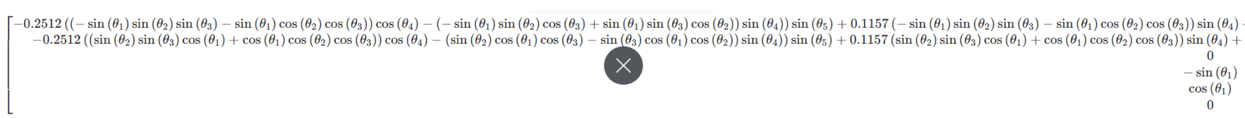
$$\begin{bmatrix} 1.0 & 0 & 0 & 0 \\ 0 & 0 & 1.0 & 0.3912 \\ 0 & -1.0 & 0 & 1.428 \\ 0 & 0 & 0 & 1.0 \end{bmatrix}$$

Fig 6 - Transformation Matrix at Home Position

Inverse Kinematics

Inverse kinematics involves finding the joint angles which can be used to position the end-effector at a specific location. It involves finding the jacobian which eventually relates the joint velocities with the linear and angular velocities of its end-effector. Jacobian Inverse is then used calculate joint angular velocities, which when further integrated, will provide the joint angles of each joints.

The Jacobian Matrix is shown below



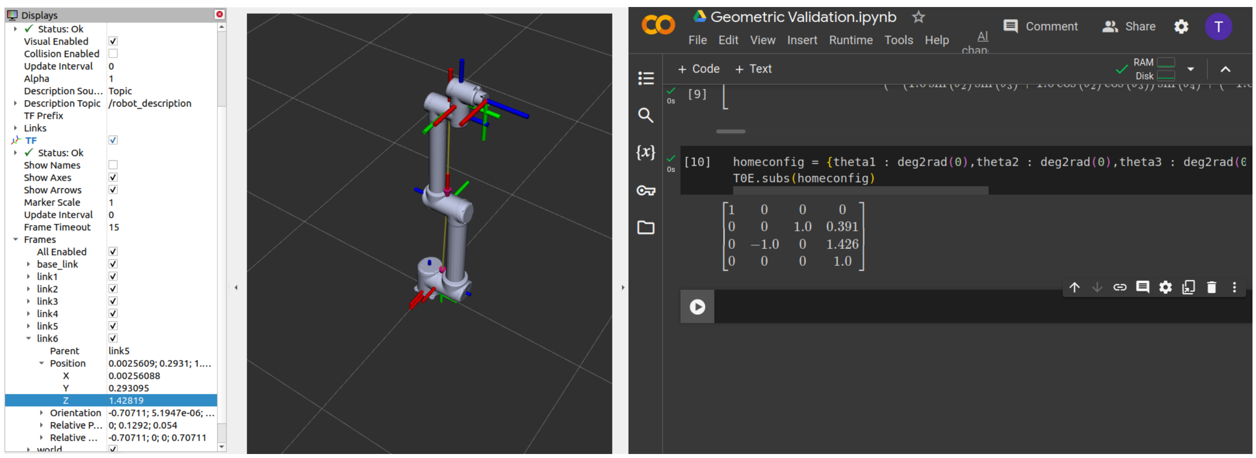
And the jacobian at home position is

$$\begin{bmatrix} -0.4272 & 1.3 & -0.6873 & 0.1157 & -0.2512 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & -1.0 & 1.0 & 0 & 1.0 & 1.0 \\ 0 & 0 & 0 & 1.0 & 0 & 0 \end{bmatrix}$$

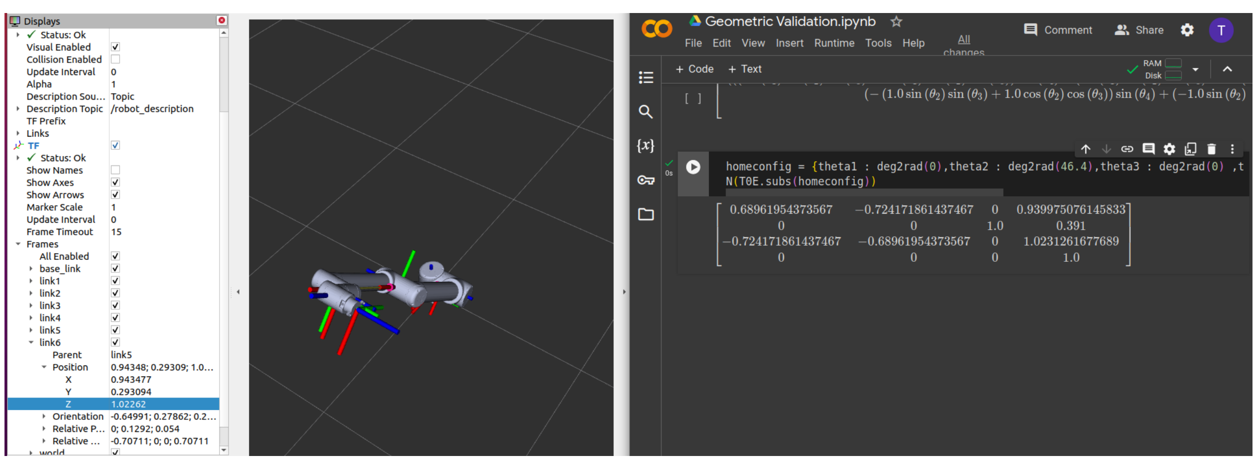
Forward Kinematics Validation

To validate the the end effector position at given join angles, there are the below validations shown. In the left, the RViz coordinates of end effector frame are seen and in the right, the transformation matrix at those joint angles are seen. Comparing these two results, we can validate the Forward Kinematics approach.

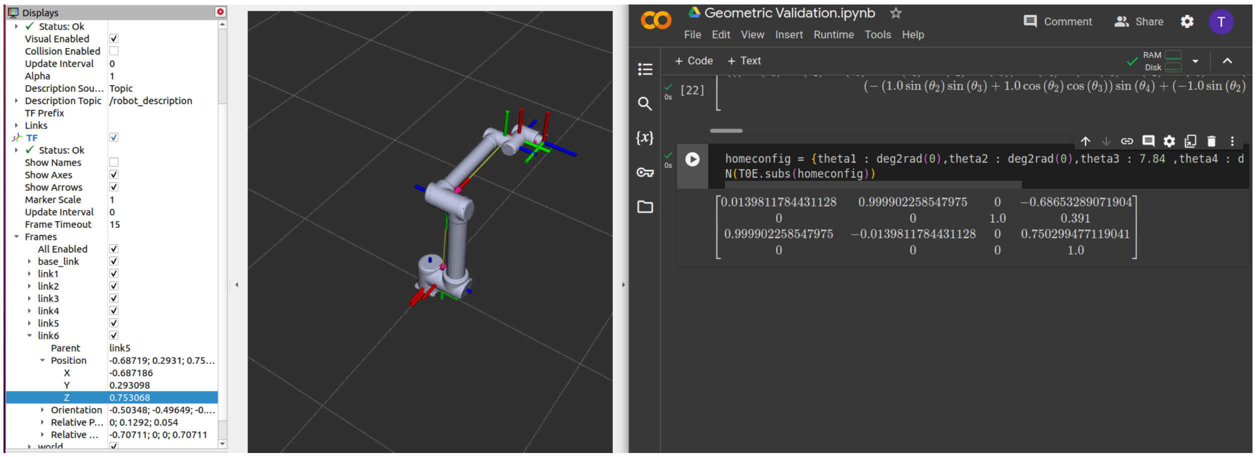
Validation 1 - When all joint angles are zero



Validation 2 - When $\theta_2 = 46.4^{o}$ *and other angles are zero*

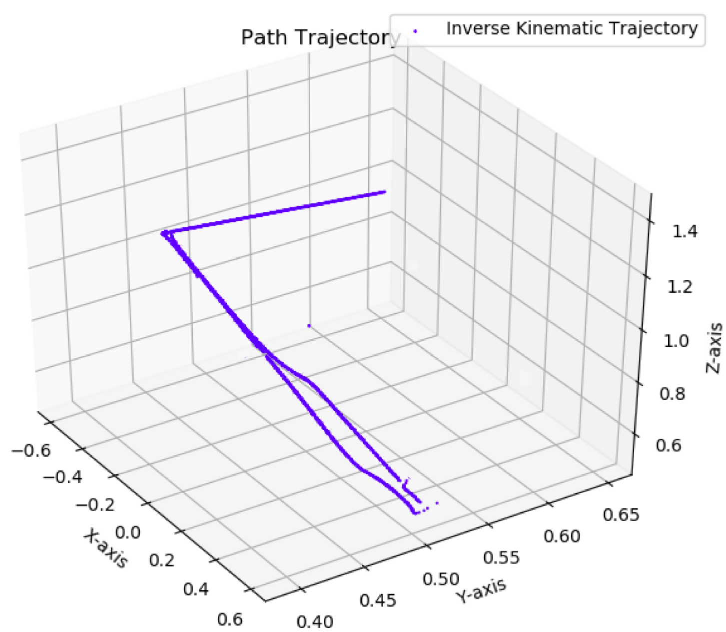


Validation 3 - When $\theta_3 = 92^o$ and other angles are zero



Inverse Kinematics Validation

During the project the robot was tasked to pick and place the object following two straight line paths, and the trajectory it followed was plotted during the time of simulation. The below graph outlines the trajectory of the robot which validates the inverse kinematics approach.



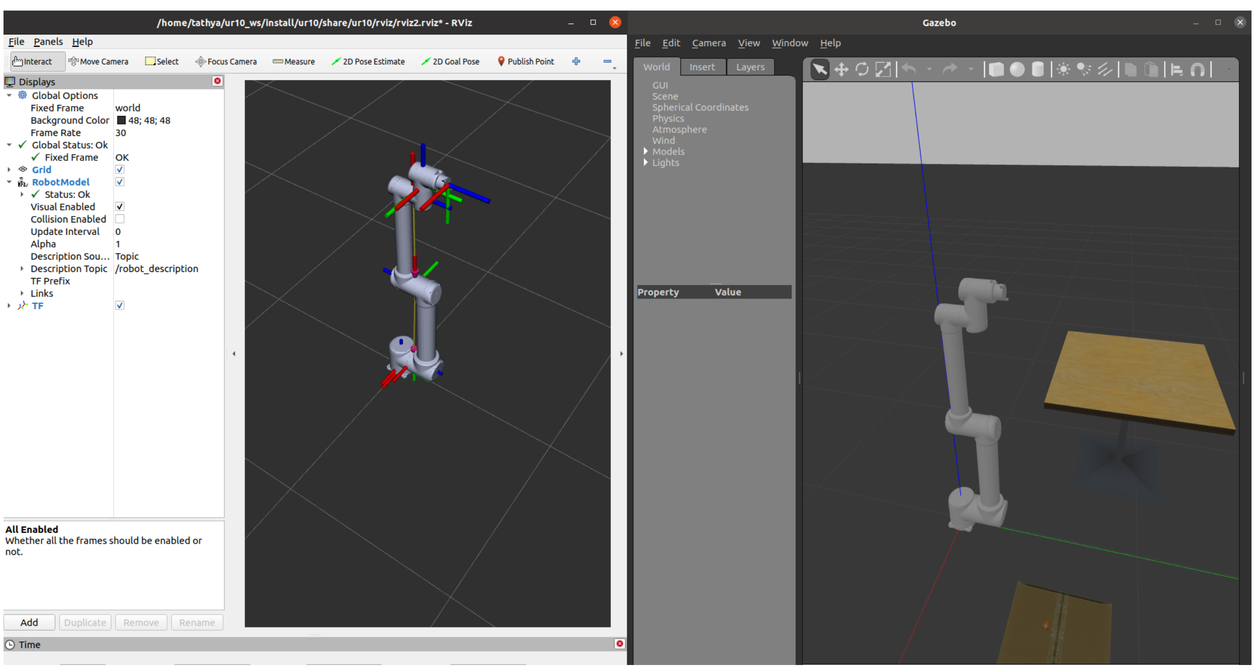
For this, the tool velocity was calculated based on the $\Delta x/\Delta t$ which gives the velocity at that time instant. So the delta x represents the difference between the next position value and the previous position coordinate and dividing by time to get the velocity.

Control Method

The control method used was closed loop control using joint position controller,which can be directly commanded to give joint angles, as we couldn't get time to implement the PID control to this project. Basically, the joint angles which are calculated based on end effector position and using jacobian and numerically integrating the joint angular velocities is then published to the robot using the joint state ("2") publisher and it gives the necessary commands to the robot.

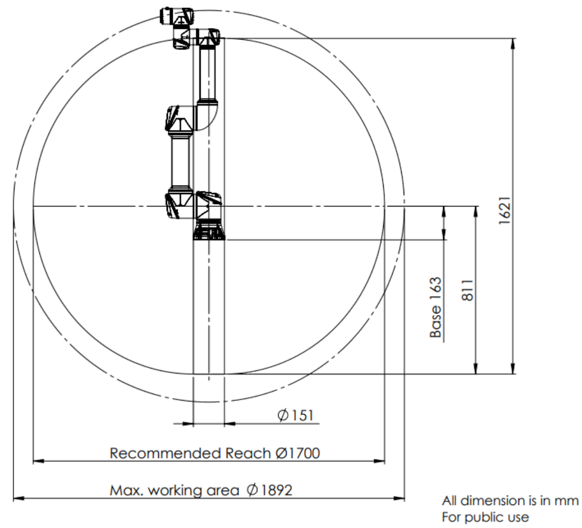
Gazebo and RViz Visualization

On the right, a gazebo world including the UR10 robotic manipulator and on the left is the RViz visualization with frames attached to each joint. To view the working of this system, here is the [video animation].



Workspace Study

During the workspace study. It was found that all the six joints have same workspace ranging from 0 to 2π. So all the joints can rotate to a full circle providing the reachability of 1300mm.



Joint 1: $-\ 2\pi\ \leq\ \theta_1 \leq\ 2\pi$

Joint 2: $-\ 2\pi\ \leq\ \theta_2 \leq\ 2\pi$

Joint 3: $-\ 2\pi\ \leq\ \theta_3 \leq\ 2\pi$

Joint 4: $-\ 2\pi\ \leq\ \theta_4 \leq\ 2\pi$

Joint 5: $-\ 2\pi\ \leq\ \theta_5 \leq\ 2\pi$

Joint 6: $-\ 2\pi\ \leq\ \theta_6 \leq\ 2\pi$

Assumptions

As the project focuses on the implementation of the pick and place method, it demonstrates perfectly given the task. However, it is assumed that the object which is being picked is subsided by the blood smears and the placing surface should be testing equipment instead of the table here in the simulation. The vacuum gripper is assumed to work with its maximum efficiency.

Problems & Solutions

Building this project was a little bit challenging from the start as we face couple of challenges which we were able to fix alongside.

- Mating in solidworks resulted in over defined constraints and so the sketches were modified to be able to make the robot rotate in the desired direction.
- URDF Frame assignments were not accurate to be considered for rotations which made the rotations during the execution behave weirdly. To fix that we assigned the axis and coordinate frames manually to make it perfect.
- Vacuum Gripper (“1”) was creating a vortex when large objects were picked and so after a few seconds of pickup, it was thrown out. To fix that we picked the object accordingly and were able to mimic the application more accurately.

- Many times the inverse kinematics didn't work as per desired trajectory and so it were just random motions that it was exhibiting. Number of iterations were changed and the timesteps were altered to get the desired results.
- Dummy link which was fixed was not working in the RViz studio and hence the urdf file was changed accordingly and a world link (fixed) was added to visualize the respective rotations in RViz together with frames using TF.

Conclusion

The project came out to be successful achieving all the tasks that it was planned to do. Starting with the desired robot model and mating the parts to obtain the desired axis rotations. Validating the forward kinematics and inverse kinematics was a bit challenging inverse kinematics relied more on the calculation which might be inaccurate and so it was tuned to perfection based on multiple iterations. Using ROS, publisher and subscriber nodes were used to publish the joint angles which were found from the inverse kinematic process. Finally after a lot of debugging, the project turned out to be working fine, although it needs couple of tweaks to perfection but it works fine certainly.

Future Works

To extend this project, we would like to work specifically on the custom gripper design to be able to pickup the blood samples perfectly without damaging the samples.

If this is achieved, we plan to automate this to pickup multiple smears/samples at once and fasten the process and make the testing more effective.

Considering the safety aspect of this project, we are thinking of including the obstacle avoiding pathways to the target.

References

1. UR10e Medium-sized, versatile cobot
2. ROS WIKI (www.wiki.ros.org)
3. gazebo_plugins: Plugin XML Reference and Example (ros.org)
4. Robot Modelling and Control, Spong. 2nd Edition.