PROJECT REPORT

ON

WHEEL-CHAIR MOUNTED ROBOTIC ARM

SUBMITTED BY

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Wheel-chair mounted Robotic Arm

MOTIVATION

The whole idea of this project is to incorporate a robotic arm to a mobile wheel-chair so that, this arm could be a great aid for people who are affected with paraplegics. The biggest problem for paraplegics/quadriplegics is that they always require a human support for every task they want to do. For example, even for a small task like, drinking water or eating a fruit, they will have to depend on a dedicated human support. It becomes even more difficult when the person must do the task during midnight when other human support may not be guaranteed. Given the current revolution of Robotic manipulator industry and Robotics as an area itself, there had always been significant efforts made to design Robotic manipulators as an aid to paraplegics. However, because of the constrains like the size, weight and complexity of the manipulators, no manipulator has come into extensive use. Now the time, when light-weight robotic manipulators are being designed and developed, incorporating these manipulators to wheel-chairs can greatly help the paraplegics.

A strong motivation which has started in me couple of years ago was to reduce the difficulties of paraplegics and quadriplegics. A couple of years ago, I have put some efforts in designing a *'smart wheel-chair'* which can be operated using Voice commands and hand Gestures. That wheel-chair made the user's life easy in navigating from one place to another place indoors. However, eventually the user had to again resort to a human support for acting in his/her immediate environment. Hence, I decided to work on a light-weight Robotic arm which can be mounted to this *smart wheel-chair* helping the user to act in his/her immediate surroundings. In conclusion this project augments the level of automation and greatly reduces the dependency on other human support.

OPERATION:

Figure 1 : Manipulator usage

The figure 1 shows exactly how the arm arrangement will look like in practice.

Initially the manipulator will be in a set position (generally the position convenient to the user to act upon it). The vision and microphone-based system attached to this wheel-chair will detect the objects in the surrounding. A voice input from the user is taken to identify the object that is desired. The computer vision algorithms associated with the vision system will then identify the object and compute the position and orientations of object with respect to the base frame of the manipulator. This position and orientation information is used to compute the joint variables of the manipulator that are required to reach the object. We use the Inverse kinematic equations developed for the robotic arm to compute the joint variable values.

Once the desired joint variables are found, the motion planning algorithm finds the best path to reach the goal by avoiding the obstacles in the path. This motion planning algorithm will also ensure that there will not be any self-collisions. Once the best path is found, the joints are actuated to reach the object and pick it. After picking the object, the same joint variables (computed using the inverse kinematic equations) which are used to reaching the object are used again to come back to the set position which the user can act on. When the arm is not in use, the manipulator goes from set configuration to a home configuration (i.e., using forward Kinematics).

In concern with this project, I have designed the Forward and Inverse Kinematics of the robotic arm theoretically and implemented them on the robot model in a software

SCOPE

APPLICATION OF THE MANIPULATOR

This manipulator can be easily incorporated to any other wheel chair, provided there is a system that can supply the target position and orientation of the object to our algorithm. This ensures the robustness (i.e., same algorithm can be used on different systems)

This robotic arm in not application specific. By making slight changes to the algorithm, the same robotic arm can also be incorporated to any other application where target position and orientations are given to the manipulator.

CONSTRUCTION

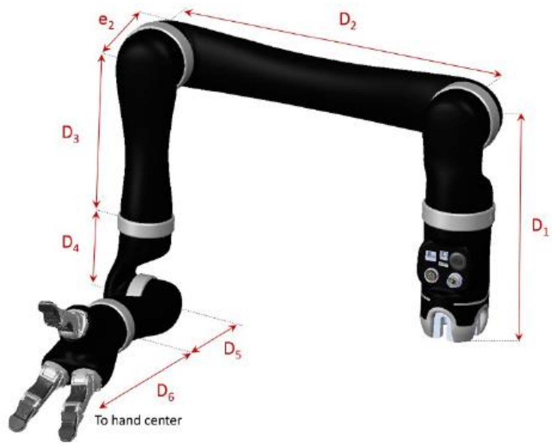
The construction of this robotic arm is similar to 6DOF Spherical Robotic arm designed by Kinova Robotics. Hence, we used the same design specifications in this project.

6DOF manipulator:

This RRR manipulator with a spherical wrist has 6 degrees of freedom. The main reason for using this type of manipulator is, this manipulator gives greater workspace/area of approach to work in. Another important reason for choosing this type of manipulator is the ease of analysis and implementation. Due to the spherical wrist this manipulator has, it becomes relatively easy to find the equations governing the inverse kinematic position and orientations.

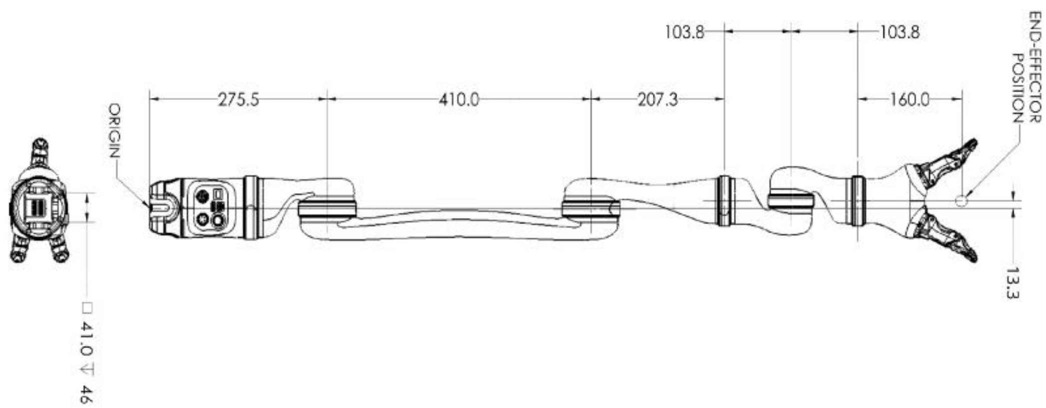
Figure 2 : CAD model of the manipulator

Link lengths and offsets:



Parameter	Description	Length(m)
D_1	Base to shoulder	0.2755
D_2	Upper length (shoulder to elbow)	0.4100
D_3	Forearm length (elbow to wrist)	0.2073
D_4	First wrist length	0.1038
D_5	Second wrist length	0.1038
D_6	Wrist to center of the hand	0.1600
e_2	Joint 3-4 lateral offset	0.0098

Figure 3 : link lengths and offsets of the manipulator



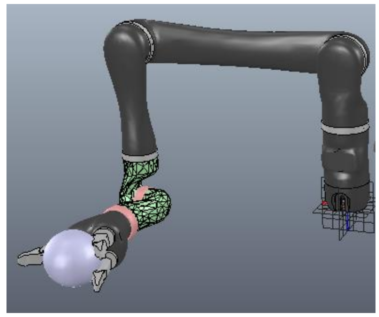
We use a 3 – finger gripper as the end effector which serves to pick and carry the object of interest to a certain position for the user to act on it.

CONFIGURATIONS

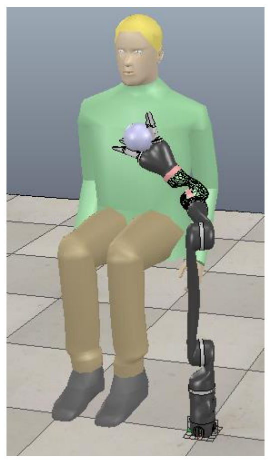
Below are two important configurations, that this arm will be frequently working with.

Home configuration – This is when the manipulator is at rest (almost no power is used).

The DH parameters are obtained with respect to the home configuration. The home configuration is assumed to be as below



Set Configuration – This is the configuration of the robotic arm, where the user of the wheel-chair will be acting upon the object that is picked. Below figure shows the set configuration



This set configuration is assumed at the position

$$O_s = \begin{pmatrix} -0.2237 \\ -0.1739 \\ 0.8 \end{pmatrix}$$

All the units are in meters

and the Orientation of the set configuration is assumed to be

$$R_s = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0.7071 & -0.7071 \\ 0 & 0.7071 & 0.7071 \end{pmatrix}$$

ASSUMPTIONS

The following assumptions are be made while implementation of this project

- The wheel chair is Static.
- It is assumed that the vision system is already incorporated and accurately detects and identifies the detected objects. Vision system will also identify the accurate position and orientation of the object to be picked
- Pre-defined set position and orientation which the end effector should reach are assumed

- The robot is completely Rigid.
- The robot and the objects are respondable
- The robot is non-dynamic
- The obstacles are static and not moving.
- The rotations of the joints are with respect to Z-axis.
- The kinematics are designed based on the Denavit-Hartenberg conventions. Hence the assumptions made in the convention are applied to this project.
- No frictional effects between the links at the joints.
- As the manipulator is attached to the wheel-chair, the base of the manipulator is fixed with respect to the wheel-chair.
- No effects of temperature
- No self-collisions
- The manipulator is attached to the ground instead of wheelchair while simulating.
- While simulating the Forward and Inverse Kinematics, the manipulator is operated in Inverse Kinematics mode (i.e., not in the torque mode.) Hence torques are not considered for this manipulator.
- Dynamics are not considered for Grasping the object. Effect of 'acceleration due to gravity' is considered. The bodies are considered to be respondable for grasping task.
- Joint angles and actuator utilizations are not constrained. The joints are assumed to be able to rotate cyclic
- Effects of manipulator weight are not considered

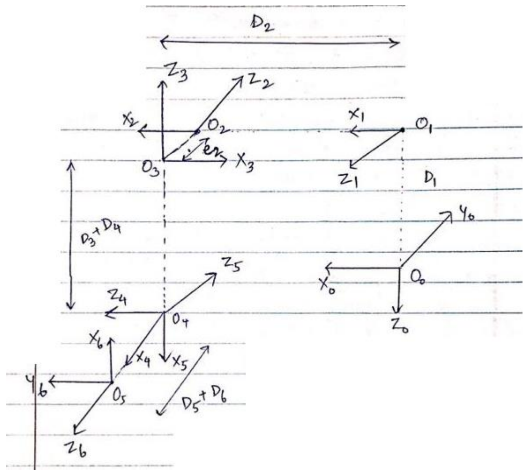
APPROACH

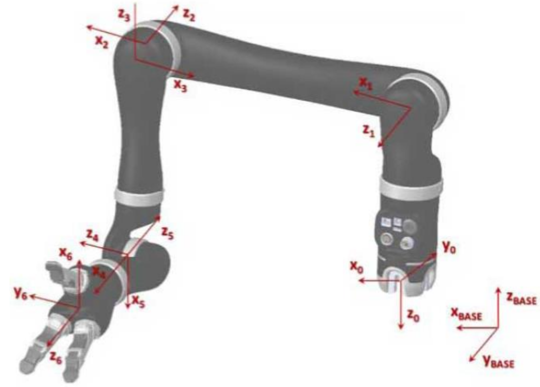
DESIGNING THE MODEL:

The CAD model is inspired from the 6DOF manipulator with Spherical wrist designed by Kinova Robotics. Original CAD model of (.STEP) format has been converted to (.OBJ) to import into VREP software. The model has been morphed into its convex decomposition to make the manipulator into a pure shape to start working with it.

SOLVING THE FORWARD KINEMATICS:

This project uses the classic Denavit-Hartenberg method to find the Forward Kinematics of the Manipulator



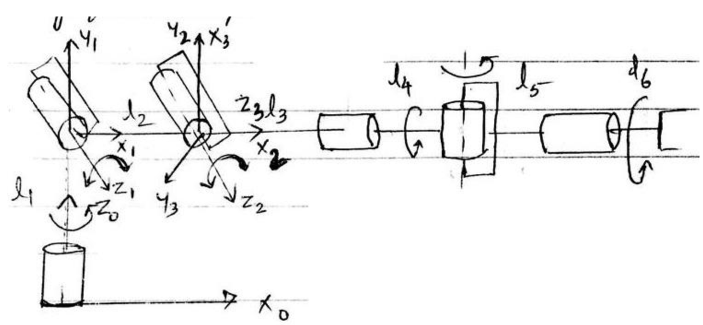


links	θ	d	a	α
0 to 1	θ_1^*	$-D_1$	0	90
1 to 2	θ_2^*	0	D_2	180
2 to 3	$\theta_3^* + 180$	$-e_2$	0	90
3 to 4	$\theta_4^* - 90$	$-(D_3 + D_4)$	0	90
4 to 5	$\theta_5^* - 90$	0	0	90
5 to 6	$\theta_6^* + 180$	$-(D_5 + D_6)$	0	-180

The above DH parameters are used to work on the forward Kinematics and validate them with the model designed in VREP

SOLVING THE INVERSE KINEMATICS

For the RRR Manipulator with ta spherical wrist, we can apply Kinematic decoupling to solve the inverse Kinematics problem. The first three revolute joints are used to achieve the position of the tool center and the revolute joints of the spherical wrist are used to achieve the desired orientation



Solving for the position of wrist center:

We are solving for the position of wrist center to take the advantage of Kinematic Decoupling.

Let the wrist center position be

$$\begin{bmatrix} X_c \\ Y_c \\ Z_c \end{bmatrix} = O_c$$

Let desired position to be O_d then the desired position can be written with the advantage of a spherical wrist as,

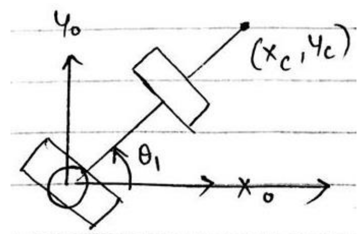
$$O_d = O_c + d_6 R_6^0 \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}$$

$$O_c = O_d - d_6 R_6^0 \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}$$

Here $d_6 = D_5 + D_6$

Solving for position:

Once the wrist center positions are calculated, they can be used to identify the joint angles that are required to reach that position. The first three revolute joints are used to achieve the desired position. The top view is given by

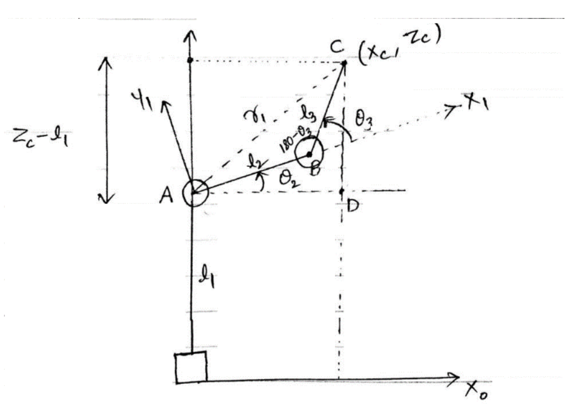


From this view we can obtain

$$tan(\theta_1) = \frac{Y_c}{X_c}$$

$$\text{Then, } \theta_1 = tan^{-1}\frac{Y_c}{X_c}$$

From the front view we can obtain



From the triangle ADC we can get

$$r_1^2 = (AD)^2 + (CD)^2$$

$$r_1 = \sqrt{(X_c)^2 + (Z_c - l_1)^2}$$

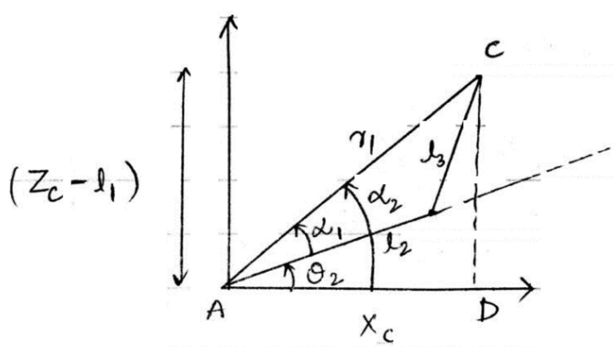
From the Triangle ABC we can get,

$$X_c^2 + (Z_c - l_1)^2 = l_2^2 + l_3^2 + 2l_2 l_3 \, cos(180 - \theta_3)$$

$$cos(\theta_3) = \frac{l_2^2 + l_3^2 - X_c^2 - (Z_c - l_1)^2}{2l_2 l_3}$$

$$\theta_3 = cos^{-1}\left(\frac{l_2^2 + l_3^2 - X_c^2 - (Z_c - l_1)^2}{2l_2 l_3}\right)$$

From the following figure we can obtain



$$l_3^2 = r_1^2 + l_2^2 + r_1 l_2 \, cos(\alpha_1)$$

$$\alpha_1 = cos^{-1}\left(\frac{l_3^2 + l_2^2 - X_c^2 - (Z_c - l_1)^2}{l_2\sqrt{X_c^2 + (Z_c - l_1)^2}}\right)$$

$$\alpha_2 = cos^{-1}\frac{X_c}{\sqrt{X_c^2 + (Z_c - l_1)^2}}$$

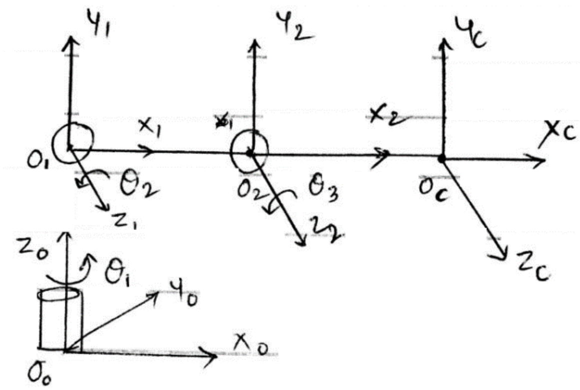
Now $\theta_2 = \alpha_2 - \alpha_1$

$$\theta_2 = cos^{-1}\frac{X_c}{\sqrt{X_c^2 + (Z_c - l_1)^2}} - cos^{-1}\left(\frac{l_3^2 + l_2^2 - X_c^2 - (Z_c - l_1)^2}{l_2\sqrt{X_c^2 + (Z_c - l_1)^2}}\right)$$

The above results give the $\theta_1, \theta_2, \theta_3$ required to achieve the position of the wrist center

In the above calculations $l_1 = D_1, l_2 = D_2, l_3 = D_3 + D_4$

DH parameters for the inverse kinematics are obtained as



links	θ	d	a	α
0 to 1	θ_1^*	l_1	0	90
1 to 2	θ_2^*	0	l_2	0
2 to 3	θ_3^*	0	l_3	0

The transformation matrices are obtained as

A_1 =

$$\begin{pmatrix} \cos(\theta_1) & 0 & \sin(\theta_1) & 0 \\ \sin(\theta_1) & 0 & -\cos(\theta_1) & 0 \\ 0 & 1 & 0 & l_1 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

A_3 =

$$\begin{pmatrix} \cos(\theta_3) & -\sin(\theta_3) & 0 & l_3\cos(\theta_3) \\ \sin(\theta_3) & \cos(\theta_3) & 0 & l_3\sin(\theta_3) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

A_2 =

$$\begin{pmatrix} \cos(\theta_2) & -\sin(\theta_2) & 0 & l_2\cos(\theta_2) \\ \sin(\theta_2) & \cos(\theta_2) & 0 & l_2\sin(\theta_2) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

H_1 =

$$\begin{pmatrix} \cos(\theta_1) & 0 & \sin(\theta_1) & 0 \\ \sin(\theta_1) & 0 & -\cos(\theta_1) & 0 \\ 0 & 1 & 0 & l_1 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

H_2 =

$$\begin{pmatrix} \cos(\theta_1)\cos(\theta_2) & -\cos(\theta_1)\sin(\theta_2) & \sin(\theta_1) & l_2\cos(\theta_1)\cos(\theta_2) \\ \cos(\theta_2)\sin(\theta_1) & -\sin(\theta_1)\sin(\theta_2) & -\cos(\theta_1) & l_2\cos(\theta_2)\sin(\theta_1) \\ \sin(\theta_2) & \cos(\theta_2) & 0 & l_1 + l_2\sin(\theta_2) \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

H_3 =

$$\begin{pmatrix} \cos(\theta_2+\theta_3)\cos(\theta_1) & -\sin(\theta_2+\theta_3)\cos(\theta_1) & \sin(\theta_1) & \cos(\theta_1)\,\sigma_1 \\ \cos(\theta_2+\theta_3)\sin(\theta_1) & -\sin(\theta_2+\theta_3)\sin(\theta_1) & -\cos(\theta_1) & \sin(\theta_1)\,\sigma_1 \\ \sin(\theta_2+\theta_3) & \cos(\theta_2+\theta_3) & 0 & l_1 + l_3\sin(\theta_2+\theta_3) + l_2\sin(\theta_2) \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

where

$$\sigma_1 = l_3\cos(\theta_2+\theta_3) + l_2\cos(\theta_2)$$

Solving the orientation problem:

If R_d is the desired orientation, the we can write

$$R_d = R_3^0 \, R_6^3$$

Then,

$$R_6^3 = (R_3^0)^{-1} \, R_d$$

$$R_6^3 = (R_3^0)^T \, R_d$$

Where R_3 and R_d are

R_3 =

$$\begin{pmatrix} \cos(\theta_2+\theta_3)\cos(\theta_1) & -\sin(\theta_2+\theta_3)\cos(\theta_1) & \sin(\theta_1) \\ \cos(\theta_2+\theta_3)\sin(\theta_1) & -\sin(\theta_2+\theta_3)\sin(\theta_1) & -\cos(\theta_1) \\ \sin(\theta_2+\theta_3) & \cos(\theta_2+\theta_3) & 0 \end{pmatrix}$$

R_d =

$$\begin{pmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{pmatrix}$$

The desired orientation R_6^3 can be obtained from the Euler angle solution for a spherical wrist as

$$R_6^3 = \begin{bmatrix} c_4c_5c_6 - s_4s_6 & -c_4c_5s_6 - s_4c_6 & c_4s_5 \\ s_4c_5c_6 + c_4s_6 & -s_4c_5s_6 + c_4c_6 & s_4s_5 \\ -s_5c_6 & s_5s_6 & c_5 \end{bmatrix}$$

The third row from the R_6^3 can be equated to third row of the R_3^0 matrix to obtain θ_5

Z_0_3 =

$$\begin{pmatrix} r_{33}\sin(\theta_2+\theta_3) + r_{13}\cos(\theta_2+\theta_3)\cos(\theta_1) + r_{23}\cos(\theta_2+\theta_3)\sin(\theta_1) \\ r_{33}\cos(\theta_2+\theta_3) - r_{13}\sin(\theta_2+\theta_3)\cos(\theta_1) - r_{23}\sin(\theta_2+\theta_3)\sin(\theta_1) \\ r_{13}\sin(\theta_1) - r_{23}\cos(\theta_1) \end{pmatrix}$$

By comparing above matrices, we can obtain

$$\theta_5 = tan^{-1}\left(\frac{\pm\sqrt{1-(s_1r_{13}-c_1r_{23})^2}}{s_1r_{13}-c_1r_{23}}\right)$$

In the above $\theta_5 \neq 0$

We can also get

$$\theta_4 = tan^{-1}\left(\frac{-c_1s_{23}r_{13} - s_1s_{23}r_{23} + c_{23}r_{33}}{c_1c_{23}r_{13} + s_1c_{23}r_{23} + s_{23}r_{33}}\right)$$

From the terms in the 3rd row of the R_6^3 matrix and comparing it with $(R_3^0)^T \, R_d$ we get θ_6 as

$$\theta_6 = tan^{-1}\left(\frac{s_1r_{12} - c_1r_{22}}{-s_1r_{11} + c_1r_{21}}\right)$$

If $\theta_5 = 0$, then we can only obtain $\theta_4 + \theta_6$,

In this case, we will then set an arbitrary value for θ_4 and find the value of θ_6.Hence we have obtained all the required angles for the inverse kinematics

RESULTS AND VALIDATION:

EXECUTION OF THE PROJECT:

This project used VREP software for constraining the joint angles and actuator utilizations. The algorithm to obtain forward and inverse Kinematics are coded in MATLAB and have been validated using VREP Software.

FORWARD KINEMATICS:

The script for forward Kinematics is attached as MATLAB script. The VREP scene for validating forward kinematics has been attached along with the animation. A predefined path is also experimented to guide the manipulator to reach a point and grab a cup. The animation is provided for the same.

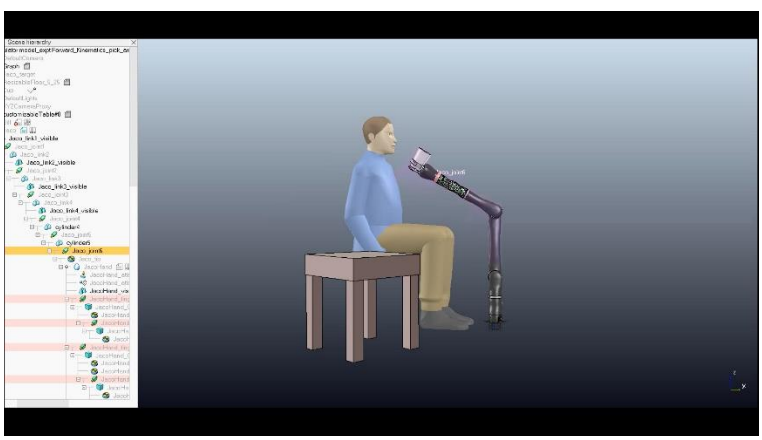
MATLAB code: Forward_Kinematics_working.mlx

(Note: While writing the DH parameters, the Z_0 direction is taken in the downward direction. But in the VREP scene the Z_0 is pointing upwards. Hence, there is a change in sign of $Z - axis$ and $Y - axis$ values. I have included a graph element in the VREP scene which gives us the corrected value.)

VREP scene: manipulator model_expt_Forward_Kinematics_Working_expt_V1.1.ttt

VREP Scene: manipulator model_expt Forward_Kinematics_pick_and _Place.ttt

Video: Manipulator model_predefined_trajectory_FK.avi



INVERSE KINEMATICS:

The Inverse Kinematics has been done in VREP software using the inbuilt inverse kinematics tools available in VREP. The MATLAB code, VREP scene and VREP Animation is also attached along with the project. The inverse kinematics have been implemented. However, there are significant amount of errors while validating.

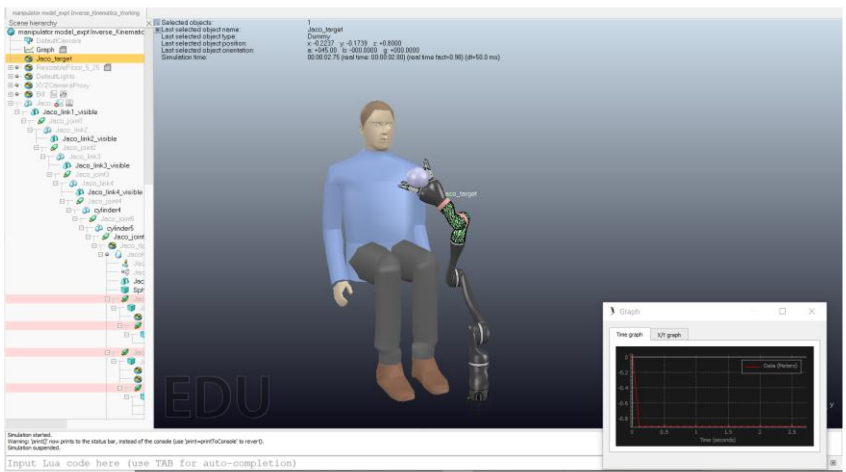
MATLAB Code: Inverse_Kinematics_V1_1.mlx

VREP Scene: manipulator model_expt Inverse_Kinematics_Working.ttt

VREP Scene: manipulator model_expt Forward_Kinematics_Working_expt_V1.2

VREP animation video: manipulator model_Inverse_Kinematics.avi

VREP Animation Video 2: manipulator model_Inverse_Kinematics_2



CONCLUSION

This project implemented a wheel-chair mounted robotic arm that will be a great aid for people who are affected with paraplegics. The key objectives achieved in this project are designing and implementing the Forward and Inverse Kinematics of a 6DOF robotic arm both theoretically as well as on software. This arm can be conveniently mounted to a wheel chair. The Forward Kinematics have also been accurately validated by designing the model in software. Significant Efforts are made to validate the inverse Kinematics accurately with the software model.