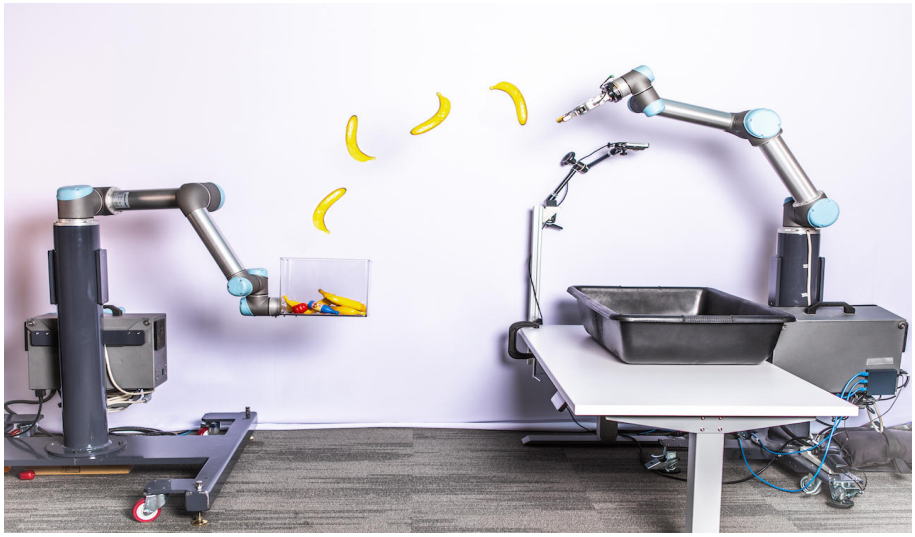
ENPM662 - PROJECT REPORT

Modeling a Tossing Robot



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Chapter 1

Introduction

Replicating a similar model on V-rep, a simulation software. The robot in the model picks and throws various objects placed around the base of the manipulator at various positions and various heights. A script was written to throw this after making the manipulator move along a path. A view of the setup is shown here in the image below:

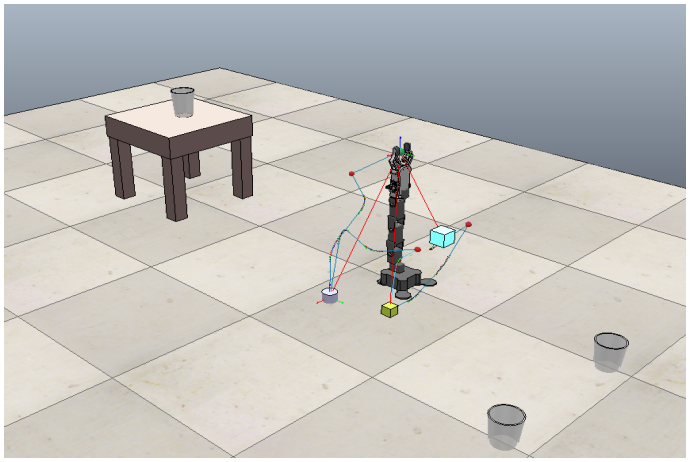

Figure. The manipulator setup developed by for this project on V-rep

The simulations performed on V-REP were validated and their kinematics along with dynamics were performed. Unlike the original TossingBot, the simulations here do not catch the object thrown at it. The objects thrown here are primitive shapes such as a cube or a cylinder. However, the shape and the size of the object is subject to change as per the end-effector and its position near the manipulator.

1.1 Motivation

This project was motivated by the TossingBot, spawned out of a research project conducted at the Princeton University. The project was an exercise in the concepts of grasping and throwing. The TossingBot developed was responsible to pick and throw arbitrary objects and could generalize itself to new objects using the concepts of deep learning. While this is largely out of scope, the simulation conducted here aims to grasp and throw an object into a basket placed at an appropriate distance. The plethora of applications and good the robot can do, drove the efforts toward completion of project and simulation of TossingBot on V-rep.

1.2 Applications of the Project

The applications of this project is endless and can find its use in various industries of practical relevance. Some of these industries are the rescue operations, manufacturing, athlete training, gaming, academia and so on and so forth. This simulation can be extended to multiple manipulators working in tandem in

the manufacturing industry. Co-bots and other collaborative mechatronics industry applications can use this project to its fullest potential for expedited manufacturing. A future version of this simulation will employ this and work with more feedback mechanisms and sensors to model the project into a relevant real-world technical exercise.

1.3 Assumptions

The following assumptions hold for the development of the project:

- The robotic arm is rigidly attached to the surface and the surface is immovable.
- There is no energy loss in the system, where the system consists of the robotic manipulator and the object.
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- There is no energy loss in the system, where the system consists of the robotic manipulator and the object.
- The container is out of the workspace of the robotic manipulator.
- The friction between the container and the surface is strong enough to keep the container stationary, even when the object drops in it.
- The object is inelastic. It does not bounce off surfaces.
- Firm contact is established between the object and the gripper when the gripper reaches the position of the object.

1.4 Timeline

The timeline of the project has changed itself during the course of the project. While steps were taken to make sure that the project adhered to the original timeline, the cause of unexpected delays and unforeseen challenges meant that the timeline skewed a bit off-course. However, all the goals were met and the timeline is depicted as follows:

September 27^{th}	Completing the project pre-proposal
October 2^{nd}	Selecting a 6-DOF CAD model
October 10^{th}	Building a custom parts for the robotic arm on SolidWorks
October 15^{th}	Finished CAD work for the prismatic joint of the arm
October 19^{th}	Finished CAD work for the gripper of the arm
October 21^{st}	Started working on the proposal
October 25^{st}	Working on forward kinematics of the robot
October 29^{th}	Submission of project proposal
November 1^{st}	Importing the URDF model of our arm into V-REP
November 3^{rd}	Deciding on the new manipulator and gripper
November 7^{th}	Completed simulation of inverse kinematics on V-REP
November 8^{th}	Completed grasping of dynamic objects in V-REP
November 9^{th}	Designing path of the arm to follow in V-REP
November 12^{th}	Making the robotic arm move along the designed path in V-REP

November 18thnd	Started working on the Inverse kinematics of the robot
November 23nd	Throwing objects using add force method
November 24th	Force calculation for throwing the robot
November 26th	Calculation for placement of baskets to throw the objects
November 27th	Accomplished throwing the object into the basket
November 30th	Accomplished throwing two separate objects into two separate basket
December 2nd	Presentation preparation for progress review
December 4th	Presentation of project progress in class
December 5th	Completion of Simulation with three baskets for three separate objects
December 6th	Code commenting on V-REP
December 7th	Started off with report writing for final submission
December 8th	Dynamics Calculations
December 9th	Calculations completed on MATLAB
December 10th	Project Validation
December 11th	Final Project Submission

1.5 Designing the Robotic Arm

The first task at hand was to either build a custom robotic arm from scratch or use an existing one and make modifications to make it work for our application. We went ahead with the latter option to modify a 6-DOF arm with another prismatic joint and a custom gripper. We modified the manipulator using SolidWorks. The image of the model is shown in Figure 1,1. The robotic arm worked well in SolidWorks but importing the robot model into V-REP for simulation was a problem. We had to convert the CAD model into a URDF (Universal Robot Description Format) file. We used the open-source SolidWorks-to-URDF convertor for the task. After the import into V-REP, the all of the joint alignments got messed up even when we manually entered coordinates of each links. The open-source software was not well-documented to figure out the problem.To avoid any further delays, we started working on a pre-included model in V-REP known as the PhantomX-Pincher.This manipulator was also attached with a different gripper known as the RG2 gripper.

The PhantomX Pincher is one of the smallest robotic arms developed by Interbotix. It was designed to be used as the robotic manipulator on top of the Turtlebot. It weighs only 550g with a vertical and horizontal reach of 35cm and 31cm respectively. Moreover, we went ahead with the RG2 to simulate realistic picking up scenarios. You can see the difference between the original and the modified version the robotic arm in figures 1.2 and 1.3.

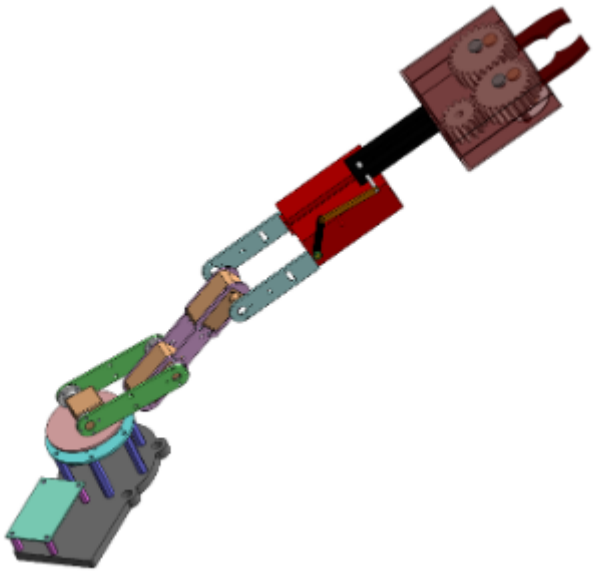

Figure 1.1: Custom designed 6-DOF Robotic Manipulator

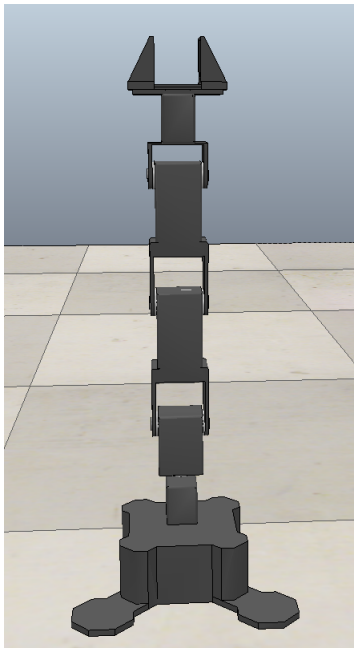

Figure 1.2: Original PhantomX Pincher

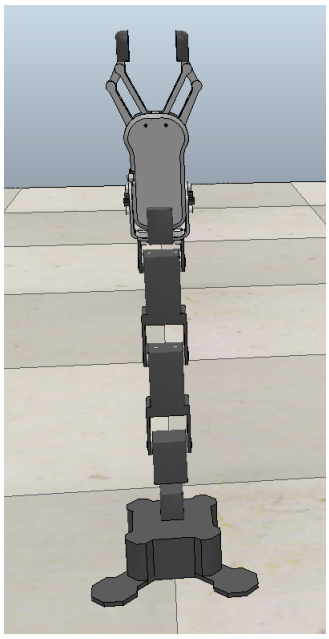

Figure 1.3: Modified PhantomX Pincher

Chapter 2

Modeling of the Robot

2.1 Inverse Kinematics

Inverse kinematics is used to determine the joint angles based on the given end-effector location. Since the last 3 axes of the robot were not coincidental and the robot had less than 6 degrees of freedom, we could not apply kinematic decoupling to simplify the inverse kinematics problem. We decided to use the inverse kinematics solver in MATLAB to find the joint angles.
The inverse kinematics solver in MATLAB requires a URDF file to evaluate which we could not find. All the URDF files for the robot available online were modified to rotate about y_0 axis in the Figure 2.1. One such robot description was available for the PhantomX Pincher arm designed to mount upon the Turtlebot. THe URDF file had to be modified to make the first joint rotate around z_0 axis. The IK was done for the following end-effector transformation:

$$\begin{bmatrix} 1.0 & 0.0 & 0.0 & 0.3 \\ 0.0 & 1.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 1.0 & 0.5 \\ 0.0 & 0.0 & 0.0 & 1.0 \end{bmatrix}$$

Joint angles: $q = [-0.0012 \quad 0.3787 \quad 2.2840 \quad -1.0927]^T$

2.2 Forward Kinematics

In contrast to inverse kinematics, forward kinematics is used to achieve an end-effector based upon a set of joint variables. Basically, if a set of joint variables are known an end-effector position can be achieved by the robotic manipulator. We did manual evaluation of the forward kinematics for the robot using the DH (Denavit Hartenberg) convention to obtain the DH table given below in Table 1. Moreover, all the frames for the deduction of the DH table are given in Figure 2.1.

Frames	θ_i	d_i	a_i	α_i
0 to 1	θ_1	l_1	0	90
1 to 2	θ_2	0	0	0
2 to 3	θ_3	0	0	0
3 to 3'	$\theta_4 + 90$	0	0	90
3'to 4	0	$l_2 + l_3 + l_4$	0	0

Table 1. DH Table for Forward Kinematics of the robot

The validation of forward kinematics and inverse kinematics of the robot can be done simultaneously by plugging in the joint variables received from inverse kinematics into final transformation matrix deduced by using the DH convention. The link lengths of the robot were obtained from the URDF used to evaluate the inverse kinematics in the previous section.
Link lengths: $L = [0.1318 \quad 0.0519 \quad 0.0519 \quad 0.0464]^T$

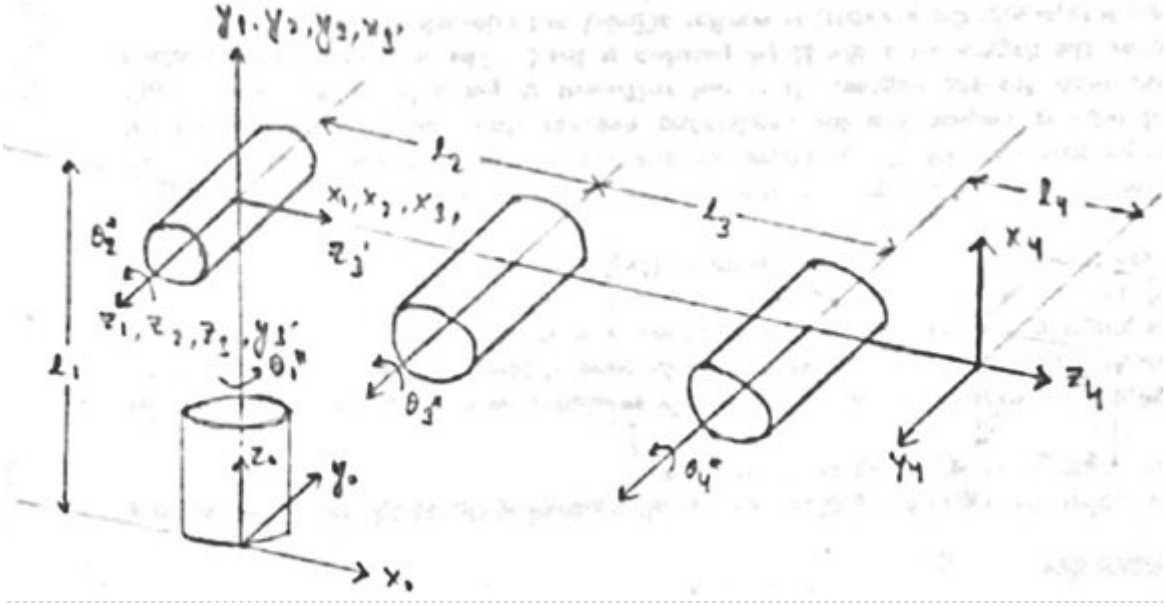

Figure 2.1: Forward Kinematics Frames

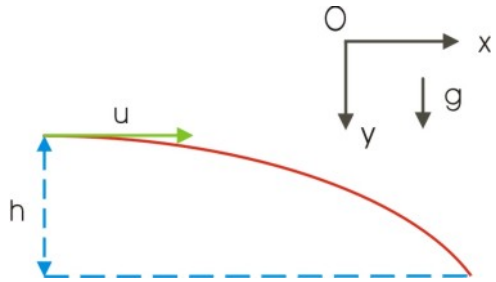

Figure 2.2: Half Projectile Motion

These link lengths and joint angles are put into their respective in the T_4^0 to finally get:

$$\begin{bmatrix} 0.998 & 0.0 & 0.0 & 0.306 \\ 0.0 & 0.998 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.998 & 0.495 \\ 0.0 & 0.0 & 0.0 & 1.0 \end{bmatrix}$$

The final transformation matrix obtained is very close to the original matrix with minute errors due to the tolerances set while performing inverse kinematics.

2.3 Force Calculation

Force calculations were done to throw each object to the desired location. In V-REP, the only way to simulate throwing of a dynamic object is by adding force to be object at the end of the path. The end of the path is the point from where is object is to be thrown by the manipulator. Using the equations of motion, we derived the velocities of the object at the initial throwing position. We considered an impulsive force acted on the object to throw it into the basket placed at the desired location.

To simplify the these calculations, we planned the object trajectory such that it followed a half projectile motion as shown below in Figure 2.2.

The coordinates from which the object had to be thrown were: $[x \quad y \quad z] = [-1. \quad 0.425 \quad 0.35]$ and the final end position of the object, that is the location of the basket, was at: $[x \quad y \quad z] = [-1 \quad 0.925 \quad 0.0425]$ Using equations of motions, initial velocity of the object, u, came out out be, 4.427m/s. Now, the force was evaluated based on a V-REP forum response for imparting impulsive forces by using a time interval of 0.002 seconds. The objects mass was 0.125 grams which gives a force of 27.67N using the formula $F = ma$, where $a = u/t$.

Chapter 3

Simulation

The simulation is carried out on V-Rep. The link to my GitHub repo for the scene and video of the simulation. The steps followed to do the simulation were as follows:

1. Import the CAD Models of the respective robotic elementss
2. Assemble the gripper onto the manipulator
3. Insert appropriate dummies for the the tip of the manipulator
4. Additionally, Insert appropriate dummies for each targtes
5. Connect tips and targets using the concepts of Inverse Kinematics on V-Rep
6. Design the desired path through which the Manipulator must move
7. Place the dummies along the ends of the individual paths
8. Import the primitive objects to be picked up
9. Import and place the baskets to throw the objects into
10. Apply force and torque to the object to throw the object into the basket
11. Connect all the above mentioned tasks using Lua script
12. Return the manipulator tip to the rest position
13. Stop the simulation and bring to home position when done

The image above shows the setup and the placement of the objects to be thrown and simulated. It can be seen that the objects are placed at varying distances to account for various motions and angles of the robotic arms, manipulator base rotation and orientation. The paths were fed manually and are taken by the end-effector to reach the goal (or target) position. The red spheres seen in the image below are not objects, but ends of the path. The main path was stitched together by making three separate paths and then getting the manipulator to traverse along those lines.
The paths to be traversed can be clearly seen in the image below. The paths are random and are strictly followed by the end-effector. Various dummies are placed throughout the path. The dummies named $target1$, $target2$ and $target3$ are placed at the $first\ object$, $second\ object$ and the $third\ object$ respectively.Once at the end of the path, a delay is fed into the code using the script $sim.wait(1)$ so as to make the simulation pause for a bit while the grippers open and close as per the need.
The tip of the manipulator can be moved to where necessary by attaching a dummy to the $RG2$ gripper. The tip is moved to all the targets through the defined path. The spheres highlighted in green and in red in the images above and below are all dummies. Additionally, there are dummies present where the objects that have to be picked up are placed. Additionally, it can be noted here that the dummies attached to the object coincide with those at the target positions so that when the gripper moves to a target, it is already primed to pick up the object, provided the object has the ideal size to fit into the claws of the gripper attached to the manipulator.

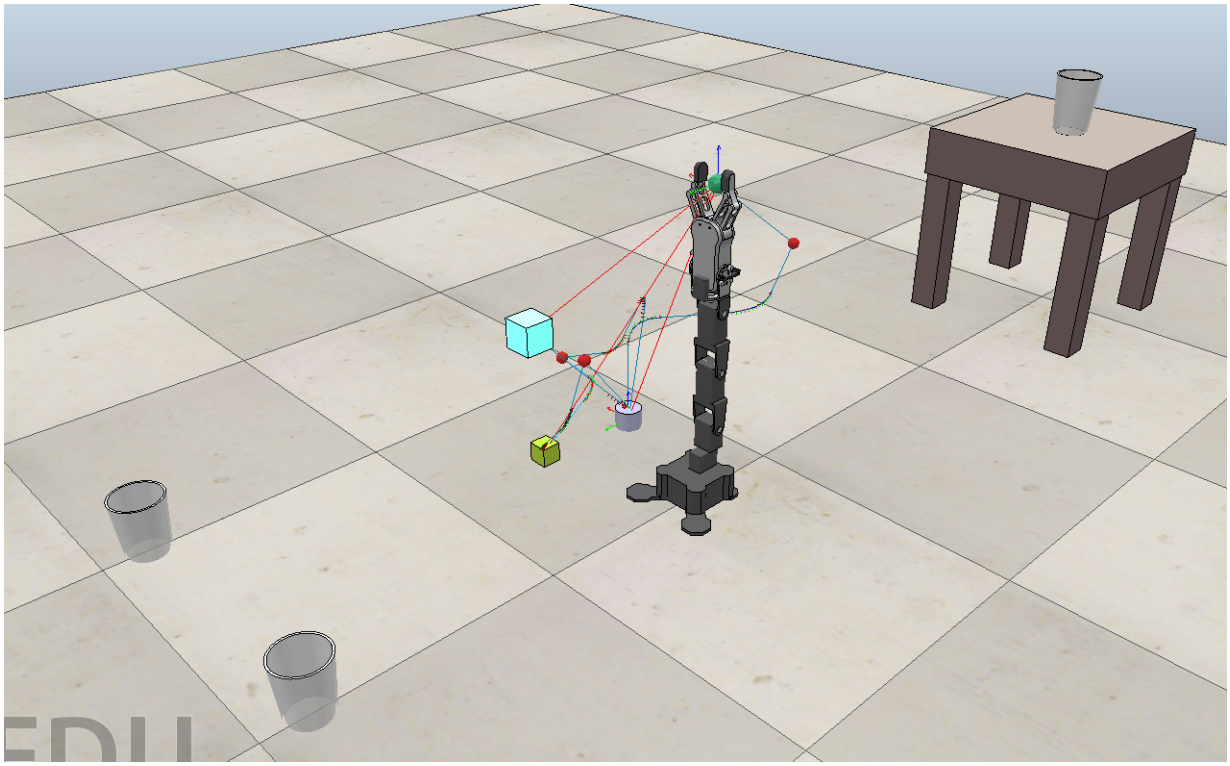

Figure 3.1: V-REP scene to throw 3 objects

Chapter 4

Appendix

4.1 V-REP Simulation Code

The V-REP code is written in the Lua Script. Various APIs from the standard list provided by Coppelia Robotics was used for guidance and the script was written to perform the simulation. You can use the code below or download the V-REP scene from my github repo:

```
–Initialization of the target variables
target=sim.getObjectHandle('Target')
target2=sim.getObjectHandle('Target2')
target3=sim.getObjectHandle('Target3')
–Initialization of the manipulator Velocity
manipVel=0.5
–Initialization of the gripper handle
gripper=sim.getObjectHandle('RG2_openCloseJoint')
motorVelocity=0.2 – m/s –Initialization of the motor velocity
motorForce=20 – N–Initialization of the motor force
–Initialization of the object sensor
objectSensor=sim.getObjectHandle('RG2_attachProxSensor')
–Initialization of the connector
connector=sim.getObjectHandle('RG2_attachPoint')
–Initialization of the object handles
object=sim.getObjectHandle('throwObject')
object2=sim.getObjectHandle('throwObject2')
object3=sim.getObjectHandle('throwObject3')
–for path variables
path = sim.getObjectHandle("Path")
path1 = sim.getObjectHandle("Path1")
path2 = sim.getObjectHandle("Path2")
path3 = sim.getObjectHandle("Path3")
path4 = sim.getObjectHandle("Path4")
finalReturnPath = sim.getObjectHandle("FinalReturnPath")
throw = true – assigning throw a true boolean value
–for objectThrowPosition
objectThrowPostion1 = -1.0, 0.425, 0.35
objectThrowPostion2 = -0.74, 0.475, 0.275
objectThrowPostion3 = -1.0, -0.045, 0.4
objectThrowOrientation = 0.0, 0.0, 0.0
–regular thread code is executed here
res,err=xpcall(threadedFunction,function(err) return debug.traceback(err) end)
if not res then
sim.addStatusbarMessage('Lua runtime error : '..err)
end
–main function that runs the simulation
```

```
threadedFunction=function()

    –code to signal the simulation to wait for 1 second
    sim.wait(1)
    –to get the position of the target
    position=sim.getObjectPosition(target,-1)
    sim.wait(1) –delay added so that we can see the motion clearly
    – code to move the manipulator to the position
    sim.moveToPosition(target,-1,position,nil,manipVel*0.05)
    sim.wait(1)
    – code to make the manipulator move along the path, named path
    sim.followPath(target,path,0.5,0.015,manipVel*0.4)
    sim.setObjectPosition(object, -1, objectThrowPostion1)
    – Code to set the orientation of the thrown object
    sim.setObjectOrientation(object, -1, objectThrowOrientation)
    sim.addForceAndTorque(object, 0, 27.5, 1.225 , 0.0, 0.0, 0.0)
    –adding the force and torque to throw the object into the basket
    sim.setIntegerSignal('RG2_open',1)
    –change 1 to 0 to close the gripper
    sim.wait(1)
    – to make the manipulator move along path 1
    sim.followPath(target,path1,0.5,0.015,manipVel*0.4)
    –change 1 to 0 to close the gripper
    sim.setIntegerSignal('RG2_open',0)
    –picking up the second cuboid here
    sim.wait(1)
    – to make the manipulator move along path 2
    sim.followPath(target,path2,0.5,0.015,manipVel*0.4)
    sim.setObjectPosition(object2, -1, objectThrowPostion2)
    sim.setObjectOrientation(object2, -1, objectThrowOrientation)
    sim.addForceAndTorque(object2, 16.5, 29.5, 1.225 , 0.0, 0.0, 0.0)
    sim.setIntegerSignal('RG2_open',1)
    – to make the manipulator move along path 3
    sim.followPath(target,path3,0.5,0.015,manipVel*0.4)
    –change 1 to 0 to close the gripper
    sim.setIntegerSignal('RG2_open',0)
    sim.wait(1)
    – to make the manipulator move along path 4
    sim.followPath(target,path4,0.5,0.015,manipVel*0.4)
    sim.setObjectPosition(object3, -1, objectThrowPostion3)
    sim.setObjectOrientation(object3, -1, objectThrowOrientation)
    sim.addForceAndTorque(object3, 0, -20.6, 25.5 , 0.0, 0.0, 0.0)
    –change 1 to 0 to close the gripper
    sim.setIntegerSignal('RG2_open',1)
    sim.wait(1)
    – to make the manipulator move along the final return path
    sim.followPath(target,finalReturnPath,0.5,0.015,manipVel*0.4)
    sim.wait(1)
    sim.addStatusbarMessage('—THE END——')
    sim.wait(1) end
```

4.2 MATLAB Codes

4.2.1 Forward Kinematics Code

Comment the red lines before running the code in MATLAB clear variables;
clc;
Define symbolic variables
syms t1 t2 t3 t4 len1 len2 len3 len4 real
Define tranformation matrices
$T_{01} = [cos(t1)\ 0\ sin(t1)\ 0;\ sin(t1)\ 0\ -cos(t1)\ 0;\ 0\ 1\ 0\ len1; 0\ 0\ 0\ 1]$
$T_{12} = [cos(t2)\ -sin(t1)\ 0\ 0; sin(t1)\ cos(t1)\ 0\ 0; 0\ 0\ 1\ 0; 0\ 0\ 0\ 1];$
$T_{23} = [cos(t3)\ -sin(t3)\ 0\ 0; sin(t3)\ cos(t3)\ 0\ 0; 0\ 0\ 1\ 0; 0\ 0\ 0\ 1];$
$T_{33prime} = [-sin(t4)\ 0\ cos(t4)\ 0; cos(t4)\ 0\ sin(t4)\ 0; 0\ 1\ 0\ 0; 0\ 0\ 0\ 1];$
$T_{3prime4} = [1\ 0\ 0\ 0; 0\ 1\ 0\ 0; 0\ 1\ 0\ len2 + len3 + len4; 0\ 0\ 0\ 1];$
$T_{34} = T_{33}prime * T_3prime_4;$
Get transformation matrices w.r.t base frame
$T_{02} = T_{01} * T_{12}$
$T_{03} = T_{01} * T_{12} * T_{23}$
$T_{04} = T_{01} * T_{12} * T_{23} * T_{34}$

4.2.2 Inverse Kinematics Code

You will have to download the phantomx rst master model from my GitHub repo:
clear variables;
clc;
pincher = importrobot('phantomx$_rst - master/turtlebot_arm_description/urdf/pincher_arm.urdf'$);
$ik = inverseKinematics('RigidBodyTree', pincher);$
$initialguess = pincher.homeConfiguration;$
$tform = [1000.3; 0100.0; 0010.5; 0001];$
$weights = [0.005, 0.05, 0.005, 0.001, 0.001, 0.001];$
[configSoln,solnInfo] = ik('gripper$_link', tform, weights, initialguess$);
for i = 1:4
configSoln(i)
end
show(pincher, configSoln);