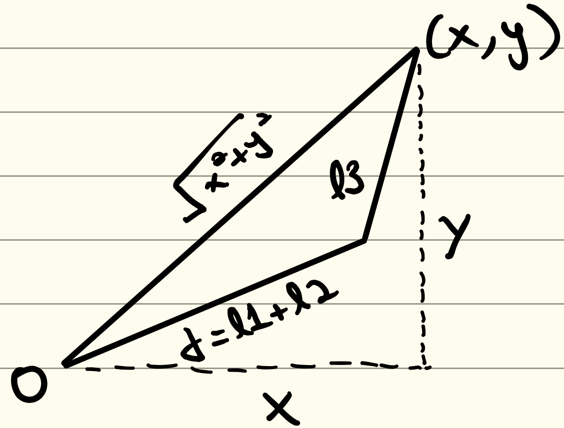
Intro To Robotics Homework # 3

Huzaifah Tariq Ahmed (ha07151) & Syed Asghar Abbas Zaidi (sz07201)

Q.1:) a) Looking it geometrically;



We can establish that l1 and l2 combined with l3, and the Position Vector for end-effector form a triangle. In this, length of Position Vector $\sqrt{x^2+y^2}$ and l3 are fixed constant values. While the length d varies, due to the prismatic joint b/w link 1 and link 2. With this configuration where 2 lengths are fixed and one is varied, infinite number of triangles can be constructed. Moreover, the triangle can be formed on either side of the position vector, thus adding more variations. Therefore, given (x, y) there are infinite number of inverse kinematics solutions for the arm. However, at the boundary of reachable workspace, there will be only one possible solution as d extends to it's maximum value or minimum value and θ_3 is either 0° or 180°, which will extend the arm to it's minimum or maximum value respectively.

b) $X = L1\cos\theta_1 + L2\cos(\theta_1+\theta_2)$

$Y = L1\sin\theta_1 + L2\sin(\theta_1+\theta_2)$

* Taking $L1 = d = l1 + l_2$, $\theta_2 = \theta_3$, $L2 = l_3$;

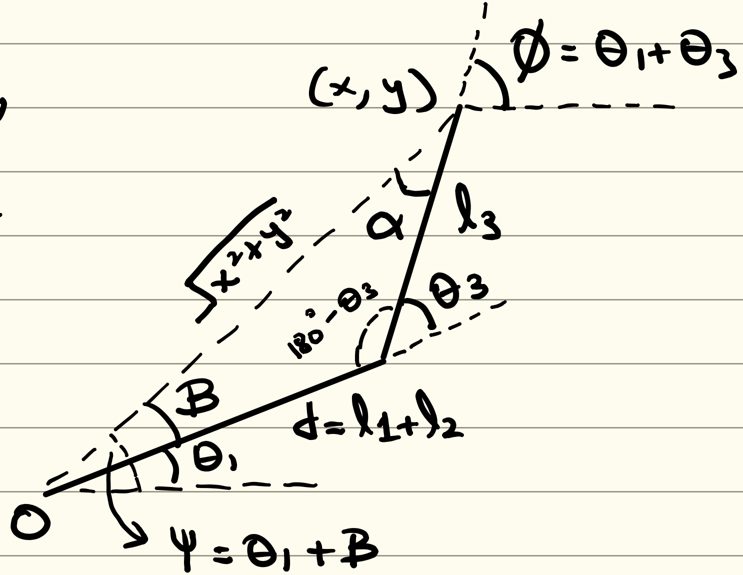
$\Rightarrow X = d\cos\theta_1 + l_3\cos(\theta_1+\theta_3)$

$\Rightarrow Y = d\sin\theta_1 + l_3\sin(\theta_1+\theta_3)$

* Now we are also provided orientation of the end effector, which provides us with another Inverse Kinematic equation;

$\phi = \theta_1 + \theta_3$

* As we Know ϕ $(\theta_1+\theta_3)$, the angle α from link 3 to the position vector of end effector from origin, is fixed.



$$\Rightarrow \tan(\psi) = \frac{y}{x}$$

$$\Rightarrow \psi = \tan^{-1}\left(\frac{y}{x}\right)$$

$$\Rightarrow B = \psi - \theta_1$$

$$\Rightarrow B + (180-\theta_3) = (\psi-\theta_1) + (180-\theta_3)$$
$$= \psi - \theta_1 + 180 - \theta_3$$
$$= \psi + 180 - (\theta_1+\theta_3)$$
$$= \psi + 180 - \phi$$

* As we know ϕ, and ψ can be calculated from $\tan^{-1}\left(\frac{y}{x}\right)$, we know $\beta + (180 - \theta_3)$.

* If we know sum of 2 angles in a triangle, we know the third angle as well.

$$
\begin{aligned}
\alpha &= 180 - \left(\beta + (180 - \theta_3)\right) \\
&= \cancel{180} - \beta - \cancel{180} + \theta_3 \\
&= \theta_3 - \beta \\
&= \theta_3 - (\psi - \theta_1) \\
&= \theta_3 - \psi + \theta_1 \\
&= (\theta_3 + \theta_1) - \psi \\
&= \phi - \psi
\end{aligned}
$$

<u>Using Cosine Rule</u>

$$\Rightarrow d^2 = \left(\sqrt{x^2+y^2}\right)^2 + l_3^2 - 2(l_3)\left(\sqrt{x^2+y^2}\right)\cos(\alpha)$$

$$\Rightarrow d^2 = x^2 + y^2 + l_3^2 - 2l_3\sqrt{x^2+y^2}\,\cos(\alpha)$$

* For end-effector positions at the boundary of reachable workspace, we might not get a solution. If for e.g, $d = d_{max}$, $\theta_3 = 0°$ and $\phi = \theta_1$. So, we will only be able to get a solution where;

$\phi = \tan^{-1}\left(\frac{y}{x}\right)$ is true. ✓

What about interior?
How many solutions?

c)

$$\Rightarrow X = d\cos\theta_1 + l_3\cos(\theta_1+\theta_3)$$
$$\Rightarrow Y = d\sin\theta_1 + l_3\sin(\theta_1+\theta_3)$$
$$\Rightarrow x^2+y^2 = \left[d\cos\theta_1 + l_3\cos(\theta_1+\theta_3)\right]^2 + \left[d\sin\theta_1 + l_3\sin(\theta_1+\theta_3)\right]^2$$
$$= d^2\cos^2\theta_1 + 2(d\cos\theta_1)(l_3\cos(\theta_1+\theta_3)) + l_3^2\cos^2(\theta_1+\theta_3) + d^2\sin^2\theta_1 + 2(d\sin\theta_1)(l_3\sin(\theta_1+\theta_3)) + l_3^2\sin^2(\theta_1+\theta_3)$$
$$= d^2(\cos^2\theta_1+\sin^2\theta_1) + l_3^2(\cos^2(\theta_1+\theta_3)+\sin^2(\theta_1+\theta_3)) + 2d\cos\theta_1 l_3\cos(\theta_1+\theta_3) + 2d\sin\theta_1 l_3\sin(\theta_1+\theta_3)$$

$$= d^2 + l_3^2 + 2 d l_3 \cos(\theta_3)$$

$$\Rightarrow \cos(\theta_3) = \frac{x^2 + y^2 - d^2 - l_3^2}{2 d l_3}$$

Assuming Joint 3 can rotate 360°

$$-1 \leq \frac{x^2 + y^2 - d^2 - l_3^2}{2 d l_3} \leq 1$$

$$(d - l_3)^2 \leq x^2 + y^2 \leq (d + l_3)^2$$

→ this implies infinite solutions in the workspace.

$$\sqrt{x^2 + y^2} - l_3 \leq d \leq \sqrt{x^2 + y^2} + l_3$$ ✓

* Theoratically, we can find all IK solutions in this case too, where value of d get's bounded by the above range.

* If we chose any value of d, which is unique with respect to case (ii) and is within the range defined above, we will get 2 solutions for (θ_1, θ_3) for every d value.

* Expressions for θ_3 and θ_1 will be;

$$\rightarrow \theta_3 = \tan^{-1}\left(\frac{\sin\theta_3}{\cos\theta_3}\right), \text{ where}$$

$$\Rightarrow \cos(\theta_3) = \frac{x^2 + y^2 - d^2 - l_3^2}{2 d l_3}$$

$$\Rightarrow \sin(\theta_3) = \pm\sqrt{1-\cos^2(\theta_3)}$$

$$\rightarrow \theta_1 = \tan^{-1}\left(\frac{y}{x}\right) - \tan^{-1}\left(\frac{H_2}{H_1}\right)$$

where;

$$H_1 = d + l_3\cos(\theta_3)$$

$$H_2 = l_3\sin(\theta_3)$$

* So we choose (θ_1, θ_3) pair, which satisfies $\theta_1 + \theta_3 = \phi$.

* So we will have many solutions for case (i) and only 2 potential solutions for case (ii)

X

I'm confused! I can choose any d within the range for case (i). How do I choose d for case (ii)?

d = ? (-2.5).   No algo is provided for choosing (θ_1, θ_3) −1

Q1 - Part D - Bomb disposal robot

Introduction

In this task, you'll decide a trajectory through the workspace of the robot and determine the corresponding joint angles to execute that trajectory. It is based on the MATLAB example

Construct The Robot

Create a `rigidBodyTree` object and rigid bodies with their associated joints. Specify the geometric properties of each rigid body and add it to the robot.

```
% Start with a blank rigid body tree model.
robot = rigidBodyTree('DataFormat','column','MaxNumBodies',3);

% Add |'link1'| body with |'joint1'| joint.
body = rigidBody('link1');
joint = rigidBodyJoint('joint1', 'revolute');
setFixedTransform(joint,[0, pi/2, 0, 0],'dh');
body.Joint = joint;
addBody(robot, body, 'base');

% Add |'link2'| body with |'joint2'| joint.
body = rigidBody('link2');
joint = rigidBodyJoint('joint2','prismatic');
setFixedTransform(joint, [0, -pi/2, 1, 0],'dh');
body.Joint = joint;
addBody(robot, body, 'link1');

% Add |'link3'| body with |'joint3'| joint.
body = rigidBody('link3');
joint = rigidBodyJoint('joint3','revolute');
setFixedTransform(joint, [1, 0, 0, 0],'dh');
body.Joint = joint;
addBody(robot, body, 'link2');
```

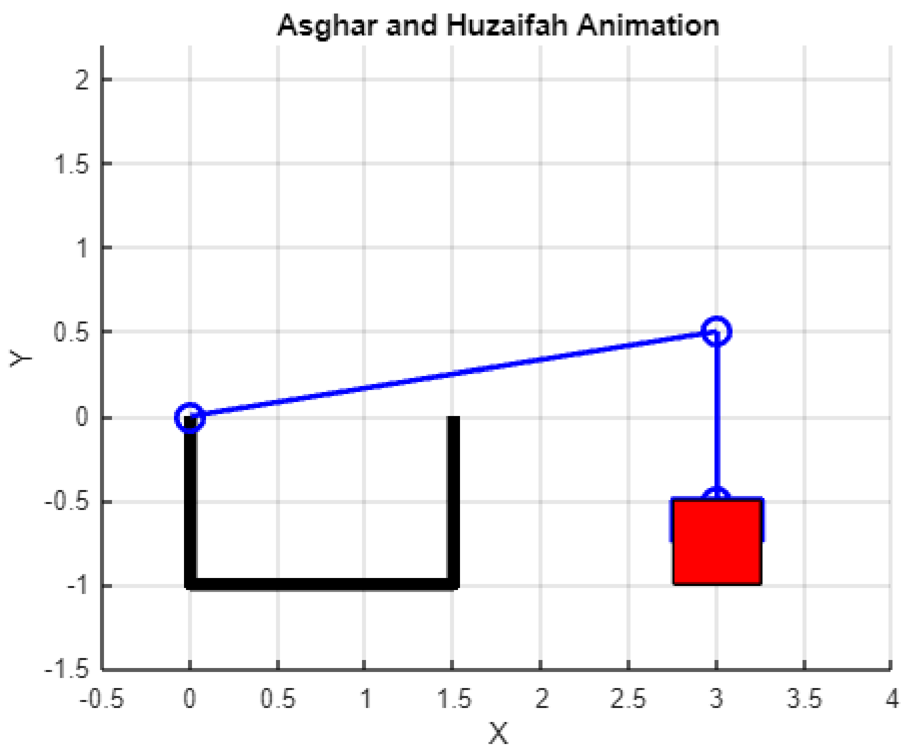
Display the robot

```
figure;
axis([-0.5 4 -1.5 2.2]);
grid on;
xlabel('X');
ylabel('Y');
title('Asghar and Huzaifah Animation')
% Draw the container
line([0 0 1.5 1.5],[0 -1 -1 0],[0 0 0 0],'Color','black','LineWidth',5);

% Configuration and End-effector location
q = [9.4623,3.0414,-99.4623];
```

```
% Draw the arm
P = [q(2)*cosd(q(1)), q(2)*sind(q(1))];
l1 = line([0, P(1)], [0,
P(2)],'LineWidth',2,'Color','blue','Marker','o','MarkerSize',10);
Q = [P(1)+cosd(q(1)+q(3)), P(2)+sind(q(1)+q(3))];
l2 = line([P(1), Q(1)], [P(2),
Q(2)],'LineWidth',2,'Color','blue','Marker','o','MarkerSize',10);

% Draw the end-effector and bomb
phi = q(1)+q(3);
p1 = [[0.25, .25, -.25, -.25 ]; [-.25, 0, 0, -.25]];
R = eul2rotm([deg2rad(phi+90) 0 0]);
p1 = R(1:2,1:2)*p1+[Q(1); Q(2)];
l = line(p1(1,:),p1(2,:),'Color','blue','LineWidth',3);
p2 = [[-.25 .25 .25 -.25];[0 0 -.5 -.5]];
p2 = R(1:2,1:2)*p2+[Q(1); Q(2)];
b = patch(p2(1,:),p2(2,:),'red');
```



Write your script here

You're expected to construct the following array of joint variables. Each row is the values of three joint variables at a particular time instant.

```
% Define the range for the loop
% start_value = 1;
% end_value = 30;
```

```
%
% % Loop from start_value to end_value
% for i = start_value:end_value
%     if i < 8
%         theta1[] = 30 + i*5;
%     end
% end


% theta1 = [30:5:70, 70:5:40];
% theta2 = [-120:5:-160, -160:-5:-100];
% d = [3.5:0.2:1.7, 1.5:0.15:0.8]
theta1 = [10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 70,...
    65, 60, 55, 50, 45, 40]; % Example values for theta1 at different time
instants
d = [2.7, 2.9, 3.1, 3.3, 3.5, 3.28, 3.06, 2.84, 2.62, 2.4, 2.18, 1.96,
1.74, 1.52,...
    1.4, 1.3, 1.2, 1.1, 0.9, 0.8];
theta2 = [-100, -105, -110,-115 ,-120, -125, -130, -135, -140, -145, -150,
-155, -160, -160,...
    -155, -150, -145, -140, -135, -130];

%Define desired length (three times longer)
desired_length = 2 * length(theta1);

% Generate indices for the new arrays
new_indices = linspace(1, length(theta1), desired_length);

% Interpolate values for theta1
new_theta1 = interp1(1:length(theta1), theta1, new_indices);

% Interpolate values for d
new_d = interp1(1:length(d), d, new_indices);

% Interpolate values for theta2
new_theta2 = interp1(1:length(theta2), theta2, new_indices);

%concatanating d as well?
%qs = [theta1', d', theta2'];
qs = [new_theta1', new_d', new_theta2'];







%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

Animate The Solution

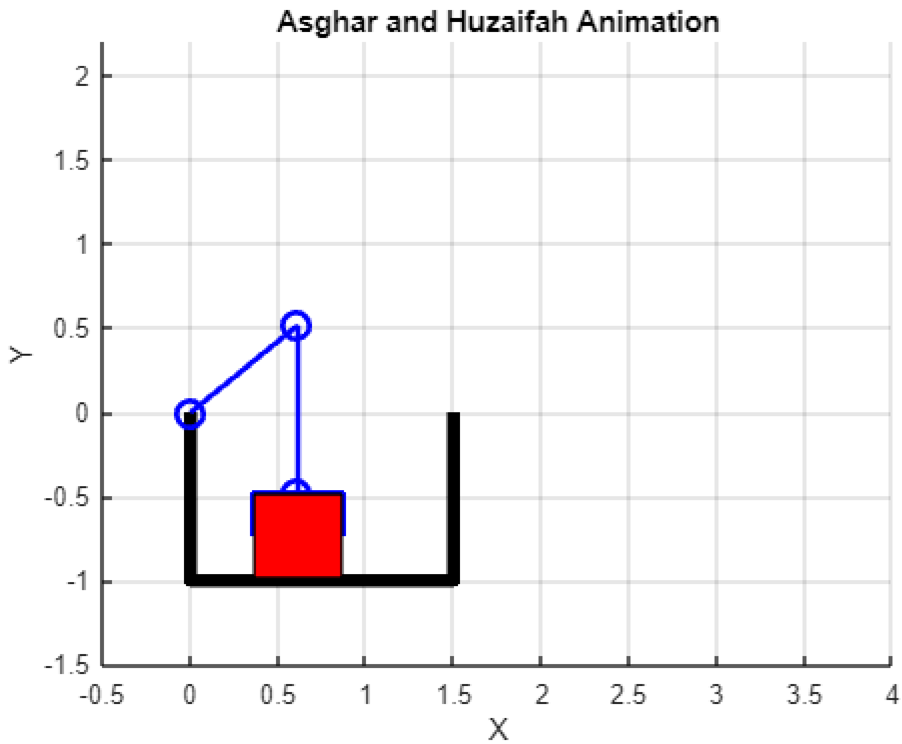
Plot the robot for each frame of the solution.

```
framesPerSecond = 9;
r = rateControl(framesPerSecond);
% Uncomment if you want to create a video
v = VideoWriter("bombDisposal.mp4");
open(v);
for i = 1:size(qs,1)
    q = qs(i,:);

    % Update the arm
    P = [q(2)*cosd(q(1)), q(2)*sind(q(1))];
    l1.XData = [0, P(1)];
    l1.YData = [0, P(2)];
    Q = [P(1)+cosd(q(1)+q(3)), P(2)+sind(q(1)+q(3))];
    l2.XData = [P(1), Q(1)];
    l2.YData = [P(2), Q(2)];

    % Update the end-effector and bomb
    phi = q(1)+q(3);
    p1 = [[0.25, .25, -.25, -.25 ]; [-.25, 0, 0, -.25]];
    R = eul2rotm([deg2rad(phi+90) 0 0]);
    p1 = R(1:2,1:2)*p1+[Q(1); Q(2)];
    l.XData = p1(1,:);
    l.YData = p1(2,:);
    p2 = [[-.25 .25 .25 -.25];[0 0 -.5 -.5]];
    p2 = R(1:2,1:2)*p2+[Q(1); Q(2)];
    b.XData = p2(1,:);
    b.YData = p2(2,:);

    % Uncomment if you want to create a video
    frame = getframe(gcf);
    writeVideo(v,frame);
    waitfor(r);
end
```



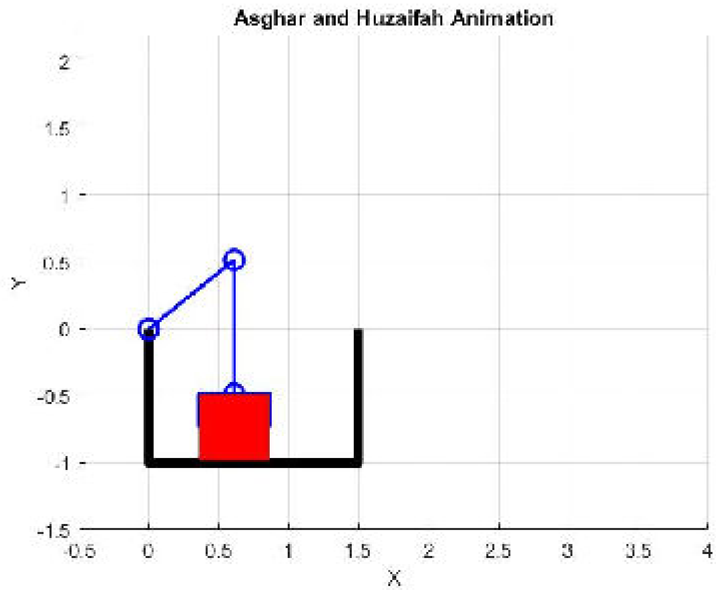

```
close(v)
```

Play the file

```
% Load the .avi file
videoObj = VideoReader('bombDisposal.mp4.avi');

% Create a figure to display the video
figure;

% Read and display each frame of the video
while hasFrame(videoObj)
    frame = readFrame(videoObj);
    imshow(frame);
    drawnow;
end
```

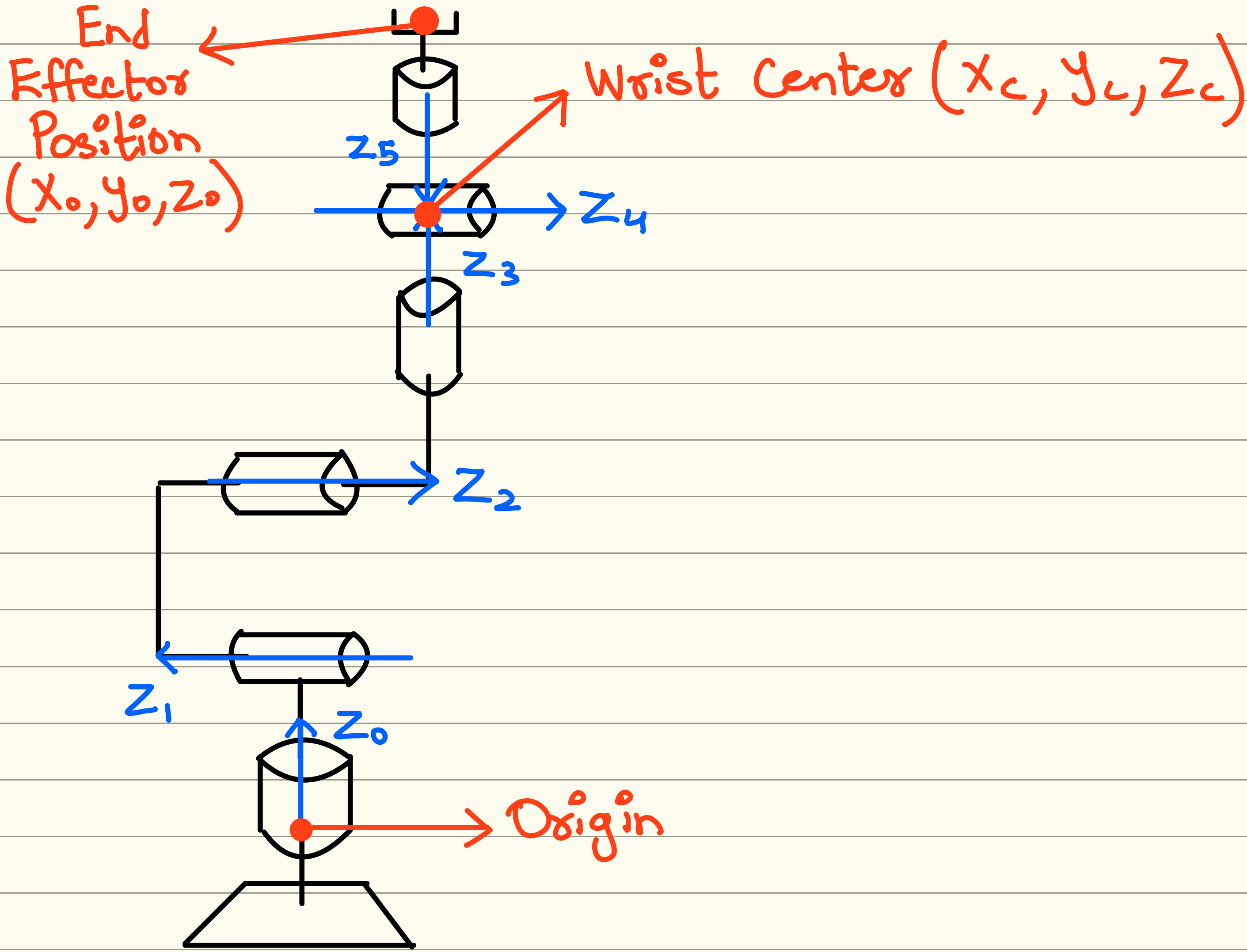

Asghar and Huzaifah Animation
Y
X
2
1.5
1
0.5
0
-0.5
-1
-1.5
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4

Q.2:) * Our goal is to find closed form expressions of all possible inverse Kinematics solutions of the 6 DOF Kinova Gen 3 Robot; ($\theta_1, \theta_2, \theta_3, \theta_4, \theta_5$ and θ_6), given that we know x_0, y_0, z_0 and ϕ of the end-effector with respect to base frame $\{0\}$.

* There exists a closed form IK solution of a 6 DOF manipulator if;

1) 3 consecutive R-joint axes intersect at a common point.
2) Any 3 joints are prismatic.

Condition (1) is being satisfied by our manipulator.


End Effector Position (X_o, Y_o, Z_o)
Wrist Center (X_c, Y_c, Z_c)
Z_5
Z_4
Z_3
Z_2
Z_1
Z_0
Origin

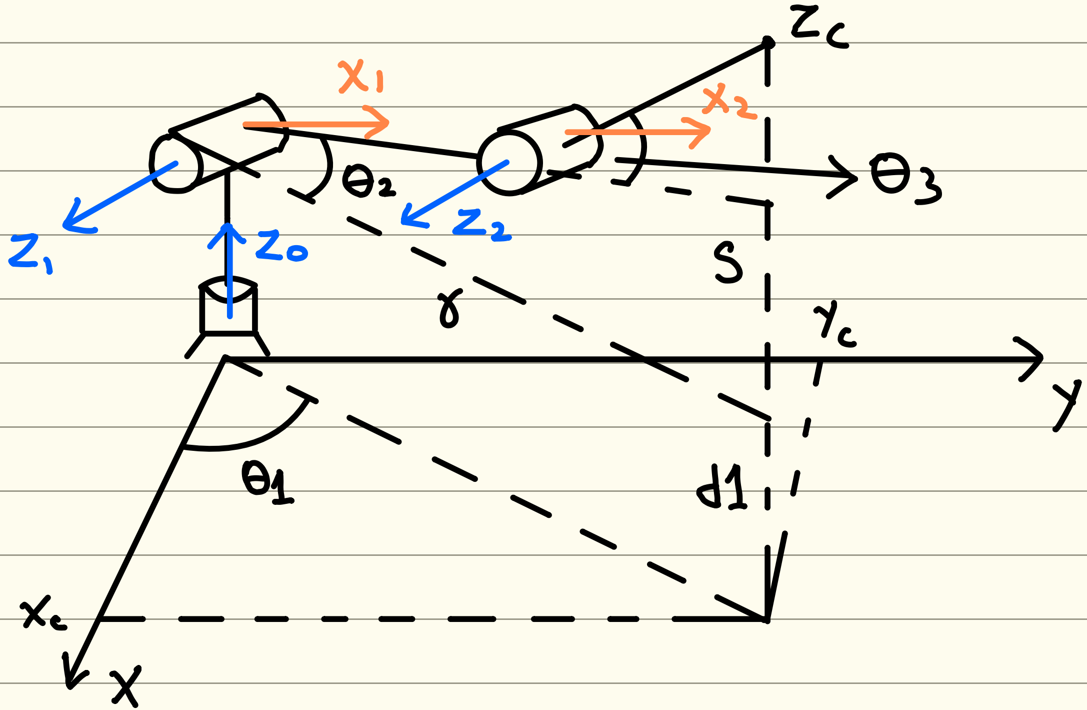
* We can break our problem into two parts;

→ Inverse Position Kinematics (For finding $\theta_1, \theta_2, \theta_3$)

→ Inverse Orientation Kinematics (For finding $\theta_4, \theta_5, \theta_6$)

Inverse Position Kinematics

* To find θ_1, θ_2 and θ_3, we will project the arm onto the horizontal x-y plane and try to calculate values of these, using geometric method.



$(x_c, y_c) = ?$

$\Rightarrow \theta_1 = \tan^{-1}\left(\frac{y_c}{x_c}\right)$ ✗

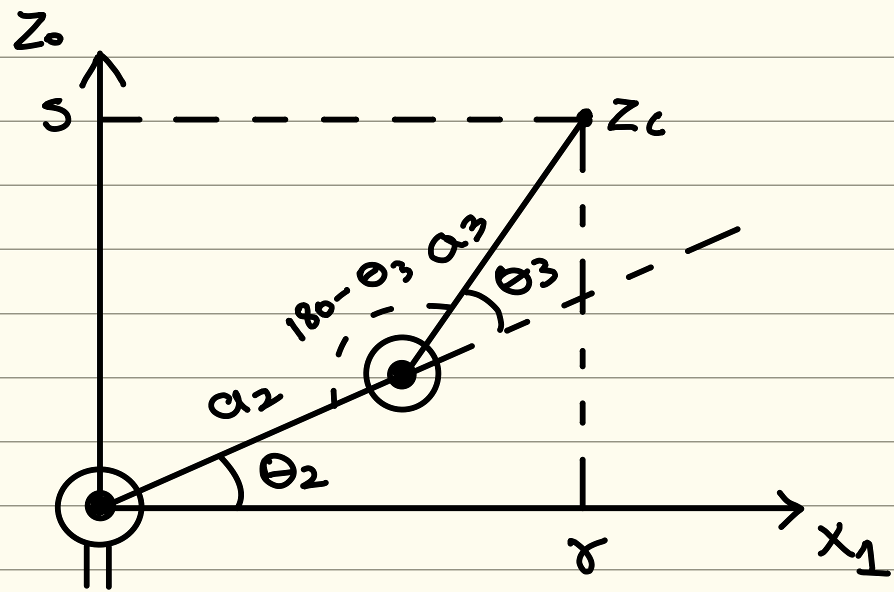
You've ignored the bend in the geometry.

* another solution for θ_1 will be;

$\Rightarrow \theta_1 = 180 + \tan^{-1}\left(\frac{y_c}{x_c}\right)$ ✗

* So the corresponding θ_2 and θ_3 will be different for both θ_1 values.

* Now to find θ_2 and θ_3, we will project onto the $(X_1 - Z_0)$ plane



Using Cosine Rule:

$$\Rightarrow \left(\sqrt{s^2+r^2}\right)^{\cancel{2}} = a_2^2 + a_3^2 - 2a_2a_3\cos(180-\theta_3)$$

$$\Rightarrow s^2+r^2 = a_2^2+a_3^2-2a_2a_3\cos(180-\theta_3)$$

$$\Rightarrow \cos(180-\theta_3) = \frac{s^2+r^2-a_2^2-a_3^2}{-2a_2a_3}$$

$$* \cos(180-\theta) = -\cos(\theta)$$

$$\Rightarrow \cos(\theta_3) = \frac{s^2+r^2-a_2^2-a_3^2}{2a_2a_3} = D$$

$$* \; r^2 = x_c^2 + y_c^2$$

$$* \; s^2 = (z_c - d_1)^2$$

* Therefore, $\theta_3 = \tan^{-1}\left(\frac{\pm\sqrt{1-D^2}}{D}\right)$

* This gives two solutions for θ_3, one being elbow down and the other being elbow up.

* Similarly, $\theta_2 = \tan^{-1}\left(\frac{s}{r}\right) - \tan^{-1}\left(\frac{a_3 \sin(\theta_3)}{a_2 + a_3 \cos(\theta_3)}\right)$

* So, we will get 2 solution pairs for (θ_2, θ_3)

Other 2 for other θ_1?

Inverse Orientation Kinematics

* If we try to solve this algebraically, we need to find ${}^3R_6$, to see the effect of θ_4, θ_5 and θ_6. We can find this using Euler's angles.

$$^3R_6 = R_z(\theta_4)\, R_y(\theta_5)\, R_z(\theta_6)$$

$$= \begin{bmatrix} C_{\theta 4} & -S_{\theta 4} & 0 \\ S_{\theta 4} & C_{\theta 4} & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} C_{\theta 5} & 0 & S_{\theta 5} \\ 0 & 1 & 0 \\ -S_{\theta 5} & 0 & C_{\theta 5} \end{bmatrix} \begin{bmatrix} C_{\theta 6} & -S_{\theta 6} & 0 \\ S_{\theta 6} & C_{\theta 6} & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} C_{\theta 4} C_{\theta 5} C_{\theta 6} - S_{\theta 4} S_{\theta 6} & -C_{\theta 4} C_{\theta 5} S_{\theta 6} - S_{\theta 4} C_{\theta 6} & C_{\theta 4} S_{\theta 5} \\ S_{\theta 4} C_{\theta 5} C_{\theta 6} + C_{\theta 4} S_{\theta 6} & -S_{\theta 4} C_{\theta 5} S_{\theta 6} + C_{\theta 4} C_{\theta 6} & S_{\theta 4} S_{\theta 5} \\ -S_{\theta 5} C_{\theta 6} & S_{\theta 5} S_{\theta 6} & C_{\theta 5} \end{bmatrix}$$

$$^3R_6 = {^0R_3}^T \, {^0R_6}$$

$$= \begin{bmatrix} C_{\theta 1} C_{\theta 2+\theta 3} & -C_{\theta 1} S_{\theta 2+\theta 3} & S_{\theta 1} \\ S_{\theta 1} C_{\theta 2+\theta 3} & -S_{\theta 1} S_{\theta 2+\theta 3} & -C_{\theta 1} \\ S_{\theta 2+\theta 3} & C_{\theta 2+\theta 3} & 0 \end{bmatrix}^T \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix}$$

$$\Rightarrow \begin{bmatrix} C\theta_4 C\theta_5 C\theta_6 - S\theta_4 S\theta_6 & -C\theta_4 C\theta_5 S\theta_6 - S\theta_4 C\theta_6 & C\theta_4 S\theta_5 \\ S\theta_4 C\theta_5 C\theta_6 + C\theta_4 S\theta_6 & -S\theta_4 C\theta_5 S\theta_6 + C\theta_4 C\theta_6 & S\theta_4 S\theta_5 \\ -S\theta_5 C\theta_6 & S\theta_5 S\theta_6 & C\theta_5 \end{bmatrix} = \begin{bmatrix} C\theta_1 C\theta_{2+\theta_3} & -C\theta_1 S\theta_{2+\theta_3} & S\theta_1 \\ S\theta_1 C\theta_{2+\theta_3} & -S\theta_1 S\theta_{2+\theta_3} & -C\theta_1 \\ S\theta_{2+\theta_3} & C\theta_{2+\theta_3} & 0 \end{bmatrix}^T \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix}$$

* Assuming we know wrist center coordinates, (x_c, y_c, z_c), we will know exact values of θ_1, θ_2, θ_3, and therefore RHS of the above equation will be completely known to us, which can be used to calculate $\theta_4, \theta_5, \theta_6$

* Now we can multiply the two matrices in RHS to get a single matrix, which we can compare with LHS matrix to get expressions for $\theta_4, \theta_5, \theta_6$.

$$\Rightarrow \begin{bmatrix} C\theta_4 C\theta_5 C\theta_6 - S\theta_4 S\theta_6 & -C\theta_4 C\theta_5 S\theta_6 - S\theta_4 C\theta_6 & C\theta_4 S\theta_5 \\ S\theta_4 C\theta_5 C\theta_6 + C\theta_4 S\theta_6 & -S\theta_4 C\theta_5 S\theta_6 + C\theta_4 C\theta_6 & S\theta_4 S\theta_5 \\ -S\theta_5 C\theta_6 & S\theta_5 S\theta_6 & C\theta_5 \end{bmatrix} = \begin{bmatrix} t_{11} & t_{12} & t_{13} \\ t_{21} & t_{22} & t_{23} \\ t_{31} & t_{32} & t_{33} \end{bmatrix}$$

* There will be 2 cases to consider here;
  - → Non-Singular
  - → Singular.

Non-Singular Case:

Two Possible Solutions

1) $\theta_4 = \tan^{-1}\left(\dfrac{\sqrt{1-t_{33}^2}}{t_{33}}\right)$, $\theta_5 = \tan^{-1}\left(\dfrac{t_{23}}{t_{13}}\right)$, $\theta_6 = \tan^{-1}\left(\dfrac{t_{32}}{-t_{31}}\right)$

2) $\theta_4 = \tan^{-1}\left(\dfrac{-\sqrt{1-t_{33}^2}}{t_{33}}\right)$, $\theta_5 = \tan^{-1}\left(\dfrac{-t_{23}}{-t_{13}}\right)$, $\theta_6 = \tan^{-1}\left(\dfrac{-t_{32}}{t_{31}}\right)$

* These are the 2 possible solutions for θ_4, θ_5 and θ_6.

Singular Case:

* There can be infinite possible solutions for every singular case.

* Now in this whole calculation, some assumptions were made.

→ ${}^0R_6$ was considered as known, as that could be calculated using the end effector orientation.

→ Wrist center coordinates were considered available, as that can easily be calculated from end-effector position using the following equation;

$$\begin{bmatrix} x_c \\ y_c \\ z_c \end{bmatrix} = \begin{bmatrix} o_x - K r_{13} \\ o_y - K r_{23} \\ o_z - K r_{33} \end{bmatrix}$$; where K is the length from end effector to wrist center

→ Also, the robotic arms link lengths a_2, a_3 were considered to be Known, as they can easily be measured.

Introduction to Robotics - L1

Huzaifah and Asghar

Question 4:

(a) How many hours did each of you spend on this homework and specifically state your contribution in this homework assignment? Answer as accurately as you can, as this will be used to structure next year's class.

Asghar:
I spent 15 hours on this homework, with 7 hours being together with Huzaifah solving Question 1 and 2 together on an online discord call.

Huzaifah:
I spent 15 hours on this homework, with 7 hours being together with Asghar solving Question 1 and 2 together on an online discord call.

(b) Do you have any specific advice for students attempting this homework next year?

Asghar:
The same old advice from HW2 still applies here. I would recommend students to have strong fundamentals before attempting this question. It will be a far more fruitful experience if you start the homework long before, and co-ordinate with the professor for any query that you have along the way. Your knowledge for sure will be tested and you will be very much confused but that's part of the learning process. It's important to understand how much to prepare beforehand, how much to work hard on your own before asking for help e.t.c.

Huzaifah:
It feels sort of repetitive but practice is the key as always. Performing Lab 6 on inverse kinematics, also helped us brush up the skills that were inevitably required for this homework as well.

(c) **This question has been revised compared to the previous homework assignments.** Each group member is to provide their reflections as answers to each of the following questions. You are expected to be precise in your responses.

1. Explain each of the outcomes, stated at the beginning of this document, in your own words.
2. Why is it important for you to achieve each of the outcomes in relation to understanding or building any robot?
3. What do you currently understand about content related to these outcomes? Do you have unanswered questions?
4. Have you achieved these outcomes? What went wrong? How will you enable yourself to achieve these outcomes? What could you do to know more or enhance your skills in this context?

Asghar:

Explanation of Outcomes

- Appreciating the existence of multiple solutions for the inverse kinematics problem. Understanding that for a given desired end-effector position, there can be multiple configurations of joint angles that achieve that position!

- Determining the inverse kinematics mapping of manipulators. This outcome entails the ability to derive mathematical expressions or geometric relationships that describe how joint angles correspond to end-effector positions and orientations

Importance of Achieving Outcomes:

Multiple solutions to the inverse kinematics problem is crucial because it allows for flexibility in robot motion planning. It enables the robot to choose the most suitable configuration based on factors like joint limits, obstacle avoidance, or task-specific constraints. It allows us to control the robot effectively and allows for precise manipulation.

Current Understanding and Unanswered Questions:

I understand that it is the inverse kinematics that actually allows us to understand how we should move to reach our deserved location. As I still haven't completed Lab 6, I would like to see it being done more practically in a real robotic system.

Progress towards Achieving Outcomes:

Although I expected it, inverse kinematics was even more difficult than the forward counterpart. It feels like I was able to do this robot "barely" by repeatedly asking questions but I just feel like this isn't enough. I plan to practise a lot more robotics questions from the book to further my understanding

Huzaifah:

Explanation of Outcomes

Understanding how closed form and multiple solutions can exist (meaning a robot can reach a position through various configuration). Then understanding how do you map inverse kinematics onto the robot itself. Using the geometric approach to find the orientation.

Importance of Achieving Outcomes:

It is inverse kinematics that is the most important aspect of controlling the robot. If you want to reach-out to something, how do you do that? For that you must first calculate the joint angles of your shoulder and arm joints. Something that you do so naturally, a robot needs to do appropriate calculations for that. Unlike Forward kinematics where you find the end effector position given the joint angles, Inverse Kinematics has more practical use. Although Forward Kinematics is still very important in feedback system especially in physical robots cause that helps us ensure if the robot is moving as expected or not.

Geometric approach to solving the problem gives a more intuitive understanding. It is essential in designing and programming the robot.

Introduction to Robotics - L1

Huzaifah and Asghar

Current Understanding and Unanswered Questions:

I understand inverse kinematics and geometric approaches' importance.

I would be interested in looking into how do we solve singularities, and how exactly in real-life they come up to be. I would also like to delve into joint limits, joint velocity and real-time implementation.

Progress towards Achieving Outcomes:

I have a good grasp of the theoretical aspects but need more practical experience.

To enhance my skills:

- I'll work on solving more complex inverse kinematics problems.
- I'll practice implementing solutions in simulation environments.
- I'll study real-world examples and case studies.
- I'll collaborate with peers and seek guidance from professor.

APPENDIX:

Latest version of this document, as well as **livescript code of Q1(d)**

Robotics_HW3_Asghar_Huzaifah

THANK YOU!