Robot Modelling Final Project – Gear Picking Robot

- **Hrishikesh Tawade (116078092)**

1) Motivation:

- I have worked for 2 years in industrial automation industry where AGV were very common. I have seen many AGVs in my life and but AGVs with robotic arm on it is rare.
- When I was working on a project back then we had a project which required an AGV to go to a store, pick up some sacks and put it on the AGV and then unload it at a given location.
- This idea has been inspired from the requirement of the customer we got 2 years ago.
- Also, such a combination of AGV will remove the need of human assistance completely.
- Not only will such a robot be used in automation industry but will also prove its capabilities in disaster Management.

2) Introduction:

- In the project gear robot my robot aims at picking up small objects and then placing it at a desired location.
- I have picked Kuka Robot YOUBOT which is readily available in the world and also has good simulation packages available.
- I have first discussed the link lengths I got.
- Then the report discusses FK and IK supporting it with a validation of MATLAB and VREP.
- Then it also discusses the demo I have built in VREP wherein the robot picks up an object placed on its platform, then moves to a desired location and unloads the object there.

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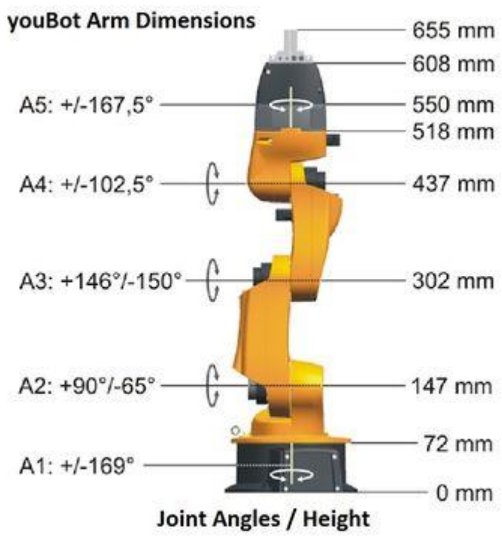
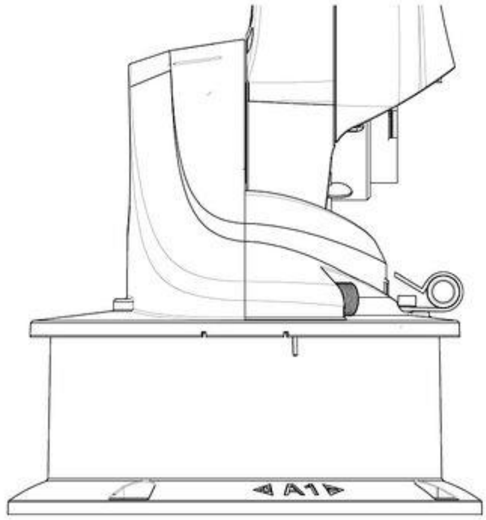
3) CAD model and link lengths of YOUBOT.





[LINK]

Challenges:

The CAD model which you can see about is what is accessible in case of YOUBOT. But the problem is for verification in MATLAB and VREP the link lengths of the YOUBOT model which is given in this figure do not match.

Solution

Therefore, I tried getting the link lengths of the model in VREP by commanding the robot in VREP to rotate in positions such that the link lengths of the robot is measurable and then finally I have used them I code. The final link lengths which are used in the MATLAB code are as follows. You can refer the frame diagram discussed below to get the reference of the links.

```
%length param
l1 = 0.033;
l2 = 0.1012;
l3 = 0.155;
l4 = 0.1348;
l5 = 0.1087;
l6 = 0.085;
```

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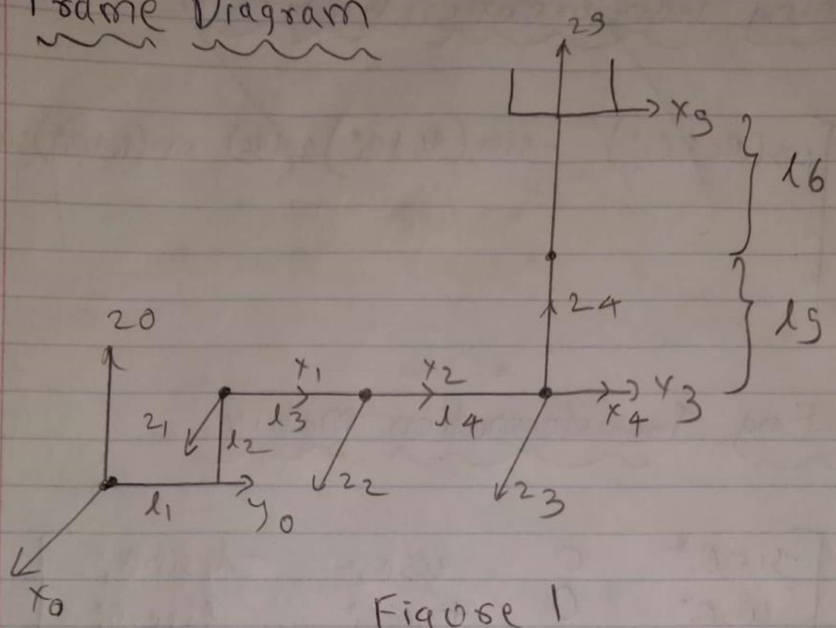
4) Forward Kinematics

This section discusses the forward kinematics of YOUBOT. The derivation of forward kinematics is in the below image.

Frame Diagram



Figose 1

D-H Table

Link	θ_i	d_i	α_i	a_i
0-1	θ_1^*+90	l_2	90	l_1
1-2	θ_2^*	0	0	l_3
2-3	θ_3^*	0	0	l_4
3-4	θ_4^*	0	-90	0
4-5	θ_5^*	0	0	0

This image covers the frame diagram and D-H table of the YOUBOT.

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Calculating Transformation Matrix

$$A_1 = \begin{bmatrix} -\sin\theta_1^* & 0 & \cos\theta_1^* & -l_1\sin\theta_1^* \\ \cos\theta_1^* & 0 & +\sin\theta_1^* & -l_1\cos\theta_1^* \\ 0 & 1 & 0 & l_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_2 = \begin{bmatrix} \cos\theta_2^* & \sin\theta_2^* & 0 & l_3\cos\theta_2^* \\ \sin\theta_2^* & -\cos\theta_2^* & 0 & l_3\sin\theta_2^* \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_3 = \begin{bmatrix} \cos\theta_3 & \sin\theta_3^* & 0 & l_4\cos\theta_3^* \\ \sin\theta_3 & -\cos\theta_3^* & 0 & l_4\sin\theta_3^* \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_4 = \begin{bmatrix} \cos\theta_4^* & 0 & +\sin\theta_4^* & 0 \\ \sin\theta_4^* & 0 & -\cos\theta_4^* & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_5 = \begin{bmatrix} \cos\theta_5^* & -\sin\theta_5^* & 0 & 0 \\ \sin\theta_5^* & +\cos\theta_5^* & 0 & 0 \\ 0 & 0 & 1 & l_5+l_6 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Now,

$$T^0_5 = A_1 * A_2 * A_3 * A_4 * A_5$$

The calculation is done in MATLAB.

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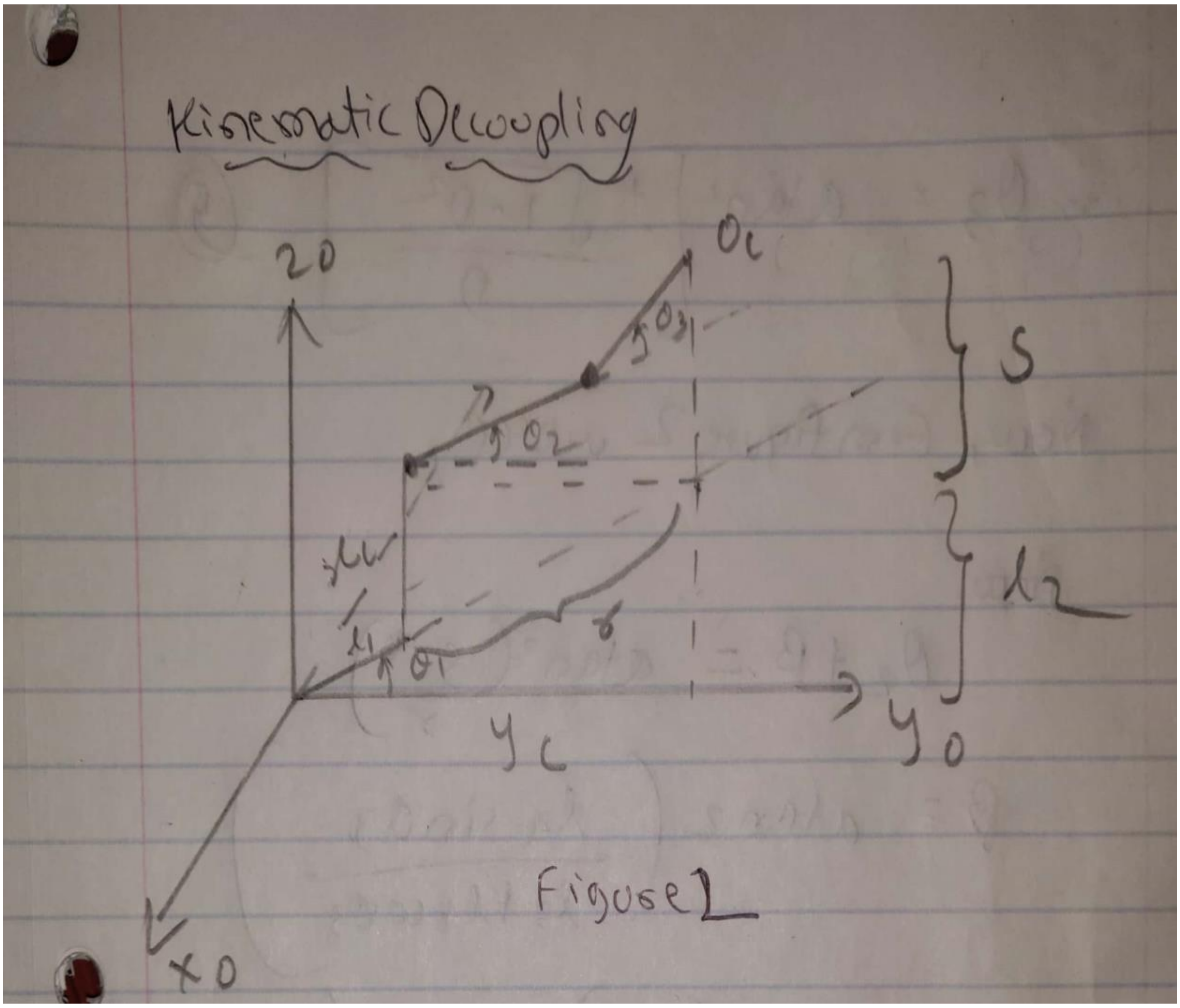
The earlier image has the calculation of transformation matrix for A1 to A5 and final the transformation matrix was calculated using MATLAB.

5) Inverse Kinematics

The below set of images will cover the inverse kinematic derivations calculated for YOUBOT. We will be using the kinematic decoupling method to do that, The below image shows the frame diagram after the joint 4 and 5 have been decoupled.



The below section has the results which are derived from this diagram.

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From figure 2

$$r = \sqrt{x_c^2 + y_c^2} - r \quad -(1)$$

and $s = z_c - l_2 \quad -(2)$

Also,

$$\theta_1 = \operatorname{atan2}(-x_c / y_c) \quad -(3)$$

The above figure shows kinematic Decoupling.

We have been given R and d

$$\therefore \left.\begin{aligned} x_c &= O_x - (l_5 + l_6) * r_{13} \\ y_c &= O_y - (l_5 + l_6) * r_{23} \\ z_c &= O_z - (l_5 + l_6) * r_{33} \end{aligned}\right\} -(1)$$

Now, from figure 2,

$$r = \sqrt{x_c^2 + y_c^2} - r \quad -(2)$$

and $s = z_c - l_2 \quad -(3)$

Also,

$$\theta_1 = \operatorname{atan2}(-x_c / y_c) \quad -(4)$$

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The below figure has the diagram which is a close up view of the triangles formed in figure 2.

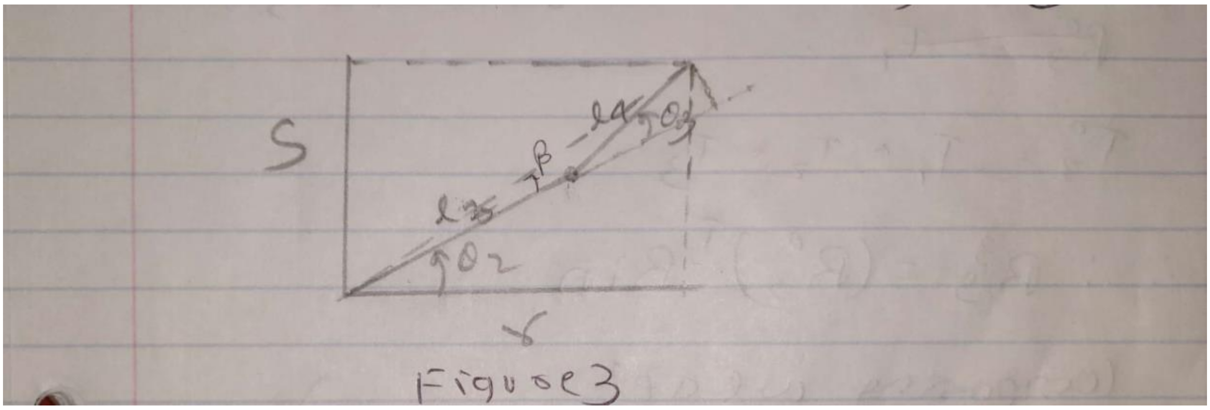

Figure3

The below image will now show the results from this diagram.

Now from figure 3,

$$s^2+r^2 = (l_3+l_4\cos\theta_3)^2 + (l_4\sin\theta_3)^2$$

$$= l_3^2 + 2l_3l_4\cos\theta_3 + l_4^2\cos\theta_3^2 + l_4^2\sin^2\theta_3$$

$$s^2+r^2 = l_3^2 + 2l_3l_4\cos\theta_3 + l_4^2$$

$$D = \cos\theta_3 = \frac{s^2+r^2-l_3^2-l_4^2}{2l_3l_4} \quad -(5)$$

$$\therefore \theta_3 = \operatorname{atan2}\left(\frac{\pm\sqrt{1-D^2}}{D}\right) \quad -(6)$$

We can also see,

$$\theta_2+\beta = \operatorname{atan2}\left(\frac{s}{r}\right)$$

and

$$\beta = \operatorname{atan2}\left(\frac{l_4\sin\theta_3}{l_3+l_4\cos\theta_3}\right)$$

$$\therefore \theta_2 = \operatorname{atan2}\left(\frac{s}{r}\right) - \operatorname{atan2}\left(\frac{l_4\sin\theta_3}{l_3+l_4\cos\theta_3}\right)$$

We will feed this values in T_1, T_2 and T_3 and calculate,

$$T^0_3 = T_1 * T_2 * T_3.$$

We extract R^0_3 from T^0_3.

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The below image has the calculation of theta4 and theta 5.

We know,

$$R^0_3 R^3_5 = R$$

$$\therefore \quad R^3_5 = (R^0_3)^T R \qquad -(7)$$

Now,

$$R^3_5 = R_4 R_5$$

$$R^3_5 = \begin{bmatrix} C_4 & 0 & +S_4 \\ C_4 & 0 & -C_4 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} C_5 & -S_5 & 0 \\ S_5 & +C_5 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\therefore R^3_5 = \begin{bmatrix} C_4C_5 & -C_4S_5 & +S_4 \\ C_4C_5 & -C_4S_5 & -C_4 \\ S_5 & +C_5 & 0 \end{bmatrix}$$

Now, we can see

$$\theta_4 = \text{atan2}\left(-\frac{r_{13}}{r_{23}}\right) \qquad -(8)$$

$$\theta_5 = \text{atan2}\left(\frac{r_{31}}{r_{32}}\right) \qquad -(9)$$

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6) Assumptions for FK and IK simulation and validation.

- The links are perfectly rigid and there is no kind of deformation in the links and joints for any torque load.
- The sensory information on the position and the orientation of the object is accurate.
- The feedback from the sensors to the system is in real time and there is no lag.
- The actuators of the revolute joints are vibration free.
- The actuators have sufficient power and force/torque to execute any task and possible movements.
- The robot is defect free.
- There is no external disturbance
- The robot is capable of going to a position without the need to specify the velocity of individual joints.
- The properties of the robot such as density, thermal resistivity, toughness, deformability is uniform throughout.

7) Reference:

- Derivation of Kinematic Equations for the KUKA YOUBot and implementation of those in Simulink

8) Simulation and Validation.

- The robot is simulated on VREP with the control instructions being given from MATLAB.
- The FK and IK has been calculated and it has been verified by giving those angles to the robot and verifying whether the final angles and position of the robot's end-effector is same.

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