Design and Simulation of Robotic Arm

Group 15

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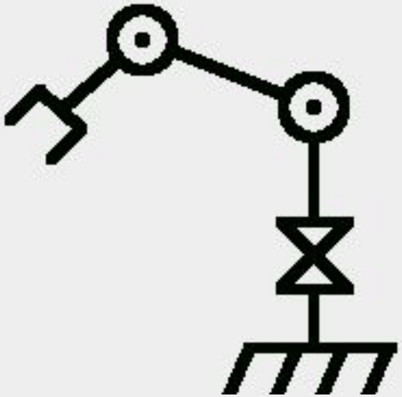
01

INTRODUCTION

The aim is to design and simulate a 3 degree of freedom robotic arm, code it to find optimal length and servo motor capacity, predict arm radius and joint stress, and simulate the design in Fusion 360 for industrial applications.

Background Analysis



There are two crucial concepts before we dive in -

1. **Degrees of Freedom -**
   a. DOF refers to the number of joints on a robotic arm that can bend, rotate, or translate.
   b. Having fewer DOF is preferable for a specific application as it reduces complexity and cost.

2. **Robot Workspace -**
   a. Robot workspace is the domain of the robotic arm where the end effector or gripper can access
   b. The workspace depends on DOF angle/translation limits, arm link lengths, and object orientation
   c. The workspace of the arm resembles a semi-sphere due to servo motor limitations of 180-degree rotation
   d. Modifying the link lengths can change the workspace size but retains the same shape

The 3 DOF design strikes a balance between simplicity and versatility which is why we choose it for this analysis!

Dynamic Analysis

M = Mass of payload
M_1 = Mass of links
M_2 = Mass of link 2
M_3 = Mass of link 3
M_A = Mass of servo motor at 'A'
M_B = Mass of servo motor at 'B'

F_A = Reaction force at "A'
F_B = Reaction force at B'
T_A = Moment at A'
T_B = Moment at 'B'

Now balancing moment at 'B'

$$T_B = MgL_3\cos(270-(\alpha_2+\alpha_3)) + M_3g(L_3/2)\cos(270-(\alpha_2+\alpha_3))$$

$$T_B = (M+M_3/2)g\, L_3\sin(\alpha_2+\alpha_3) \quad ..(1)$$

By balancing reaction force, we get

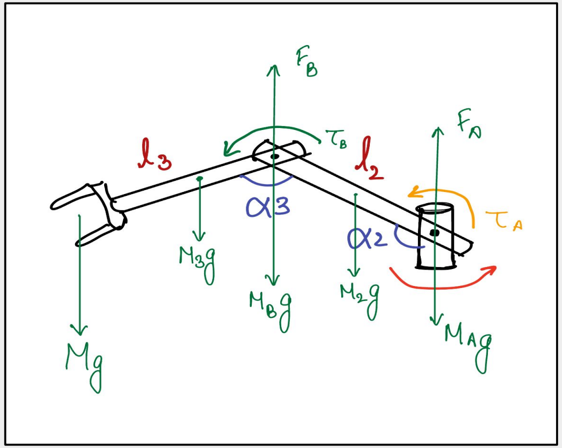
$$F_B = (M + M_3 + M_B)g \quad ..(2)$$

Now balancing moment at 'A'

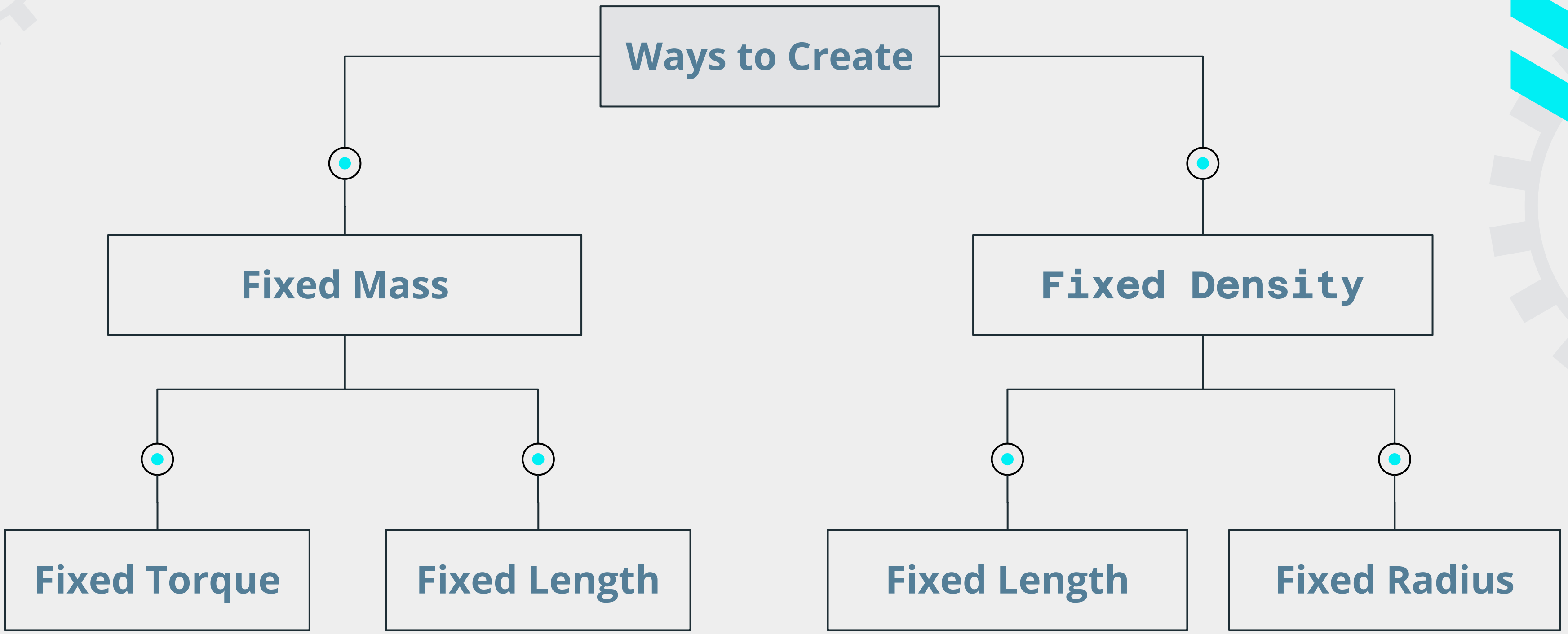
$$T_A = Mg\,[L_3\cos(270-(\alpha_2+\alpha_3)) + L_2\cos(\alpha_2-90)] + M_3g[(L_3/2)\cos(270-(\alpha_2+\alpha_3)) + L_2\cos(\alpha_2-90)] + (M_Bg-F_B)L_2\cos(\alpha_2-90) + M_2g(L_2/2)\cos(\alpha_2-90)$$

$$T_A = (M+M_3/2)g\, L_3\sin(\alpha_2+\alpha_3) + (M_2/2 + M_3 + M_B + M)g - F_2]L_2\sin(\alpha_2) \quad ..(3)$$

$$F_B = (M + M_3 + M_B + M_2 + M_A)g \quad ..(4)$$



System Versatility



Determination of Output

Alternative A : Choosing a longer arm with same servo motor

$T_B = T_3$ **..(5)**

$T_A = T_2$ **..(6)**

We will consider the mass of the link to be fixed while doing so.

From **(3), (5) and (6)..**

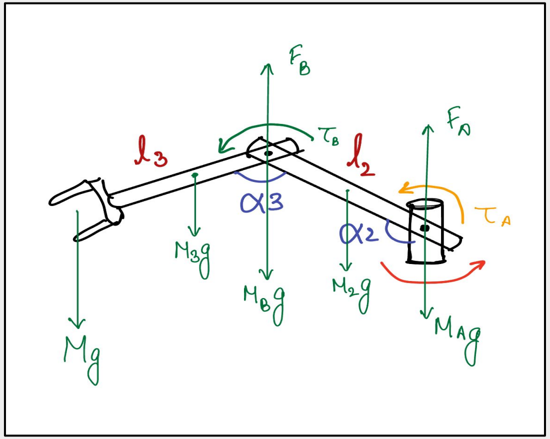
T_A = (M+M$_3$/2)g L$_3$sin(α$_2$+α$_3$) + (M$_2$/2 + M$_3$ + M$_B$ + M)g - F$_2$]L$_2$sin(α$_2$)

T_A = (1.2509) = (0.1 + 0.38/2)*9.8*0.33 + [(0.1 + 0.414/2 + 0.38 + 0.25)*9.8 - 11.074] * L_2

L_2 = 0.1655 m

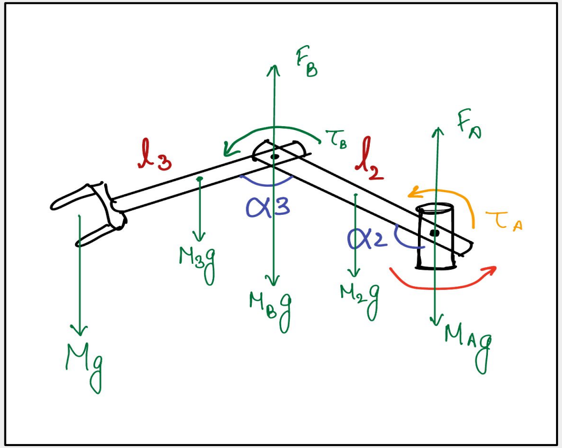
Given Inputs -

Initial Payload = 0.5 kg
M_2 = 0.414 kg
M_3 = 0.38 kg
M_B = 0.25 kg
L_2 = 0.15 m
L_3 = 0.14 m



Determination of Output

Alternative B : Choosing a cheaper servo motor (with less torque) with same length of segments



$L_2 = 0.15$ m ..(7)

$L_3 = 0.14$ m ..(8)

From **(1), (7) and (8)..**

$T_B = (0.1 + 0.19) * L_3 * g * 1$

$T_B = 0.29 * 0.14 * 9.8 * 1$

$T_B = 0.3978$

$T_A = [(0.1 + 0.19) * 0.14 * g * 1] + [(0.207 + 0.1 + 0.38 + 0.25) * 9.8] - 11.074 * 0.15$

$T_A = 0.11417$

Radius Calculation

Assuming the Arms to be cylindrical, we will find the radius

ρ = Density of Material

Volume of Cylinder = $\pi r^2 h$

For Arm 2, $\pi r_2^2 L = M_2$

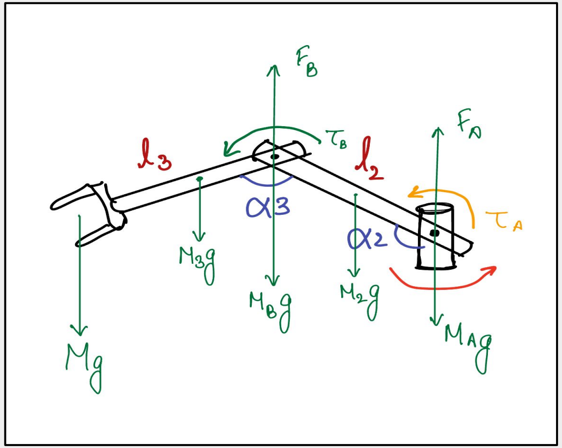
$0.414 = \rho * \pi r_2^2 * 0.1655$

$r_2 = (0.414/ \rho * \pi * 0.1655)^{½}$

For Arm 3, $\pi r_3^2 L = M_3$

$0.38 = \rho * \pi r_3^2 * 0.3331$

$r_3 = (0.38/ \rho * \pi * 0.3331)^{1/2}$



We thus obtain a density-radius relation from here, which can be used further to determine the value of Density.

Radius Calculation

Now after taking the the moment at joints and density of materials to be constant:

We will first take the length of the arms/links to be fixed followed by taking the moments at joints to be fixed.

Now, $T_B = (M+M_3/2)g\ L_3\sin(\alpha_2+\alpha_3)$

$r_3^2 = 2(T_B - ML_3)/\rho * \pi L_3^2$

Now, $T_A = (M+M_3/2)g\ L_3\sin(\alpha_2+\alpha_3) + (M_2/2 + M_3 + M_B + M)g - F_2]L_2\sin(\alpha_2)$

$r_2^2 = [T_A - M*g(L_3 + L_2) - \rho * \pi L_3^2 * r_3^2 *g(L_3 + L_2) - M_B*L_2*g + F_B*L_2)] / 0.5 * \rho * \pi L_2^2 *g$

Now from the above two expressions radii r_1 and r_2 can be calculated.

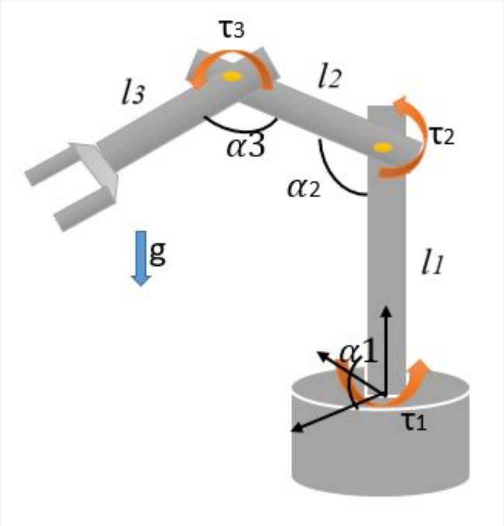
Length calculation

$T_B = (M+M_3/2)g\ L_3\sin(\alpha_2+\alpha_3)$

From the first expression l_3 can be calculated and after calculating that we need to put that value in the expression below.

$T_A = Mgl_3 + \rho\pi r_3^2 l_3^2 g + \mathbf{l_2}(\rho\pi r_3^2 l_3 g + M_B g - F_B) + \rho\pi r_2^2 g \mathbf{l_2^2}$

Here l_2 is in quadratic form and is calculated by solving it.



Fatigue Analysis

Factor of Safety -

To know the stability of the shaft we need to find the Factor of Safety of a solid shaft. We need to calculate Induced shear and allowable shear to find the Factor of Safety.

Induced Shear = $T * 32 / \pi * d^3$

As we know the torque produced at the base of the robotic arm is 100oz/in = 1.2509 Nm

The diameter of the solid circular shaft (d) = 0.06m

Induced Shear = $1.2509 * 32 / \pi * (0.06)^3$

Induced Shear = 29.7 MPa

Fatigue Analysis

Factor of Safety -

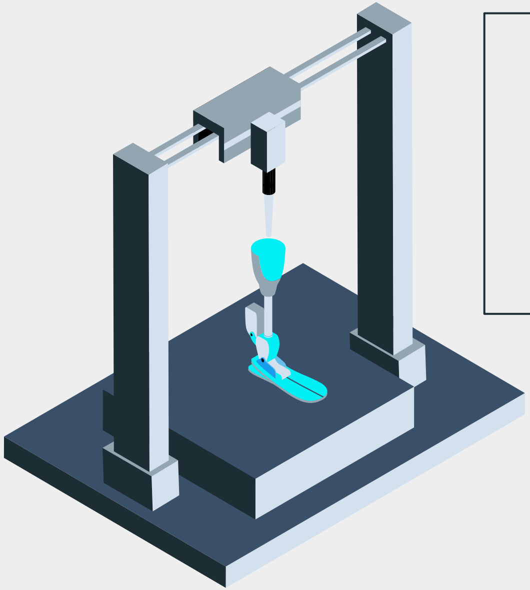
As we know the induced shear the allowable shear is to be taken from the ASME code depending upon the material we have considered. So, according to the ASME code for T6 6061 Aluminium material the allowable shear of the solid shaft is calculated below. The maximum shear stress should be 0.3 times tensile stress as per the ASME code.

For T6 6061 aluminium alloy the tensile = 276 MPa
For T6 6061 aluminium alloy the UTS = 310 MPa

We must take the highest value that is UTS for calculating the allowable shear as per ASME code.
Allowable shear = 0.57 * 310 = 55.8 MPa

Therefore, the factor of safety is = Allowable shear / Induced shear = 55.8 / 29.7

The Factor of safety of a solid shaft is = 3.49



PRACTICAL OVERVIEW!

LET'S MOVE TO THE CODE

Results and Discussions

The dynamic analysis were done of each and every link in the robotic arm by considering certain parameters which includes the mass of the links, density of material used, length and radius of major components by pertaining them to be cylindrical in shape.

The first case was done by taking mass of links and moment at joints (torque provided by servo motors) to be fixed which made the length available for optimization.

Followed by fixing the length and mass of the links to be fixed which provided us the opportunity of optimizing the servo motors we used in the revolute joint.

In the third and the last case we took the radius and length of the to be fixed respectively along with fixing the density of the material used to be fixed.

The factor of safety of 3.49 which made our design a more steady and stable ones.

Conclusion

1. In conclusion, the design and analysis of a 3 Degree of Freedom robotic arm is a critical topic in the field of industrial automation, allowing for precision and efficiency in repetitive tasks.

2. The number of degrees of freedom impacts the performance and cost of the robotic arm, with fewer DOFs being preferable for specific applications to reduce complexity and cost.

3. The robotic arm's workspace is dependent on the DOF limitations, arm link lengths, and orientation required for grasping an object, with the arm's configuration significantly impacting its workspace.

4. By simulating the design and analyzing the maximum reaction force on the base, we can predict the ideal arm length and servo motor capacity for a given application and provide valuable insight into the robot's performance.

5. Prospective buyers in the industry can benefit from this by determining the right robotic arm for their specific task by some minor customization, either by price (using cheaper servo motors for required torque) or by increased workspace through increased length while keeping the same motor.

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Thanks!

We are now open for questions!

This presentation was made for ME652 : Automation by

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