# Robotic Arm

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# Project Description

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- Stroke is the leading cause of upper limb disability.
- Survivors often lose mobility in one arm, limiting daily activities.
- Goal: develop a **waist-mounted robotic arm** that
    - Offers **active gravity compensation**
    - Remains **lightweight, low-profile, and energy efficient**
    - Enables the arm to rest naturally by the user's side.
- **Client:** Dr. Zach Lerner, Associate Professor of Mechanical Engineering, NAU.
- **Sponsorship:** W.L Gore

# Black Box Model

Inputs

- Power Supply from Battery
- Sensor Feedback
- System Configuration
- User Input (Movement)

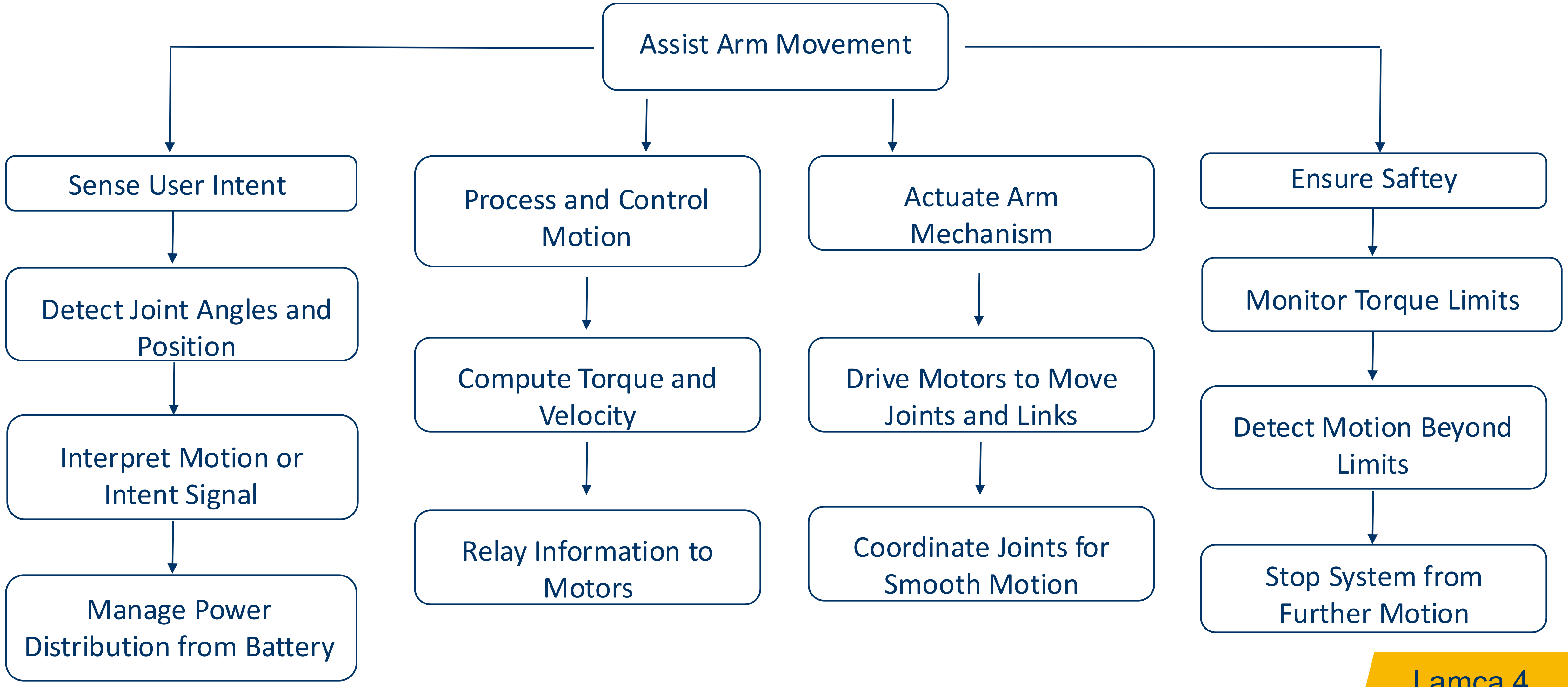
Robotic Arm System

- Control Processing
- Motor Control
- Safety Management
- Motion Planning

Outputs

- Arm Motion
- Power Consumption Data
- Alerts and Logs

# Functional Decomposition



# Concept Generation

- We generated/evaluated 3 different components of our device.
  - Motor
    - 3 different motors were given to us by our client to evaluate.
  - Joints
    - Standard mechanical joints were researched and DOF were considered with end goal of the device.
  - Link Geometry
    - Different simple cross-sections were considered and later evaluated.

# Concept Generation - Motor

| Model | Rated Voltage (V) | Rated Power (W) | Rated Torque (Nm) | Rated Current (A) | Rated Speed (RPM) | Peak Torque (Nm) | Peak Current (A) | No-load Speed (RPM) | Reduction Ratio | Weight (G) | Size (diameter *length) MM | Driver Board | Encoder |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AK45-36 KV80 | 24 | 33 | 8 | 2 | 40 | 24 | 6.5 | 52 | 36:1 | 340 | φ55*54 | Yes | Single |
| AK45-10 KV75 | 24 | 39 | 2.5 | 2.1 | 150 | 7 | 5 | 180 | 10:1 | 260 | Φ53*43 | Yes | Single |
| AK40-10 KV170 | 24 | 59 | 1.3 | 2.7 | 370 | 4.1 | 7.3 | 435 | 10:1 | 200 | φ53*37 | Yes | Single |

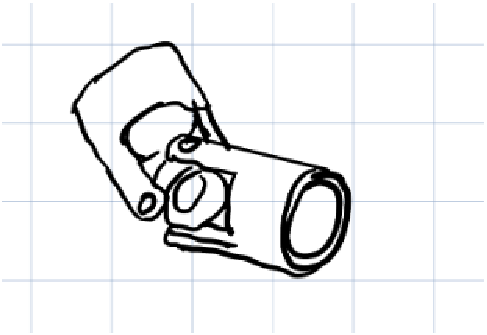
Figure 1: AK40-10 KV170 [1]

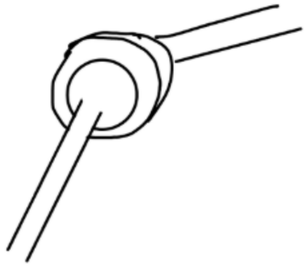
Figure 2:  A45-10 KV75 [2]

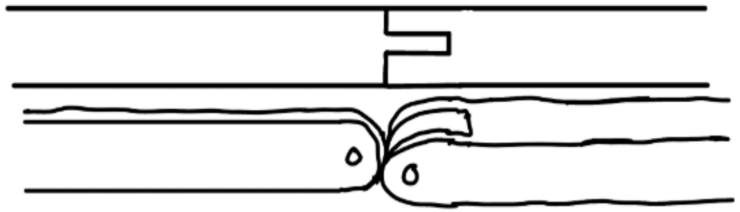
Figure 3: AK45-36 KV80 [3]

# Concept Generation - Joints

- **Different mechanical joint designs with varying DOF and geometries were researched.**
  - **Ring Joint (2 DOF)**
    - **Pros:** Allows for finer movements of the hand/arm.
    - **Cons:** Transmitting power to two different axis would increase cost and complexity.
  - **Ball Joint (3 DOF)**
    - **Pros:** Allows for smoother movement of the arm.
    - **Cons:** Requires three motors for each DOF.
  - **Revolute Joint (1 DOF)**
    - **Pros:** Simplifies transmission, only requires one motor.
    - **Cons:** Limited DOF leads to less smooth motion.

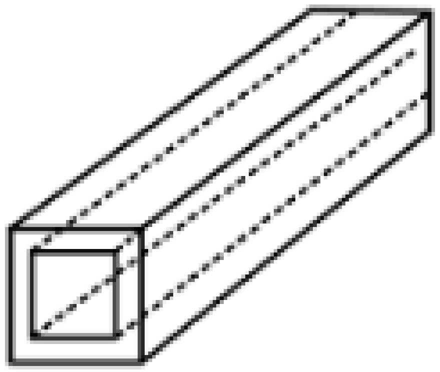


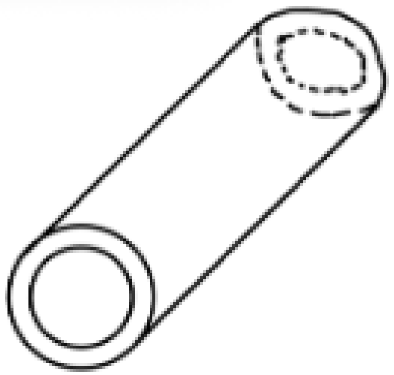




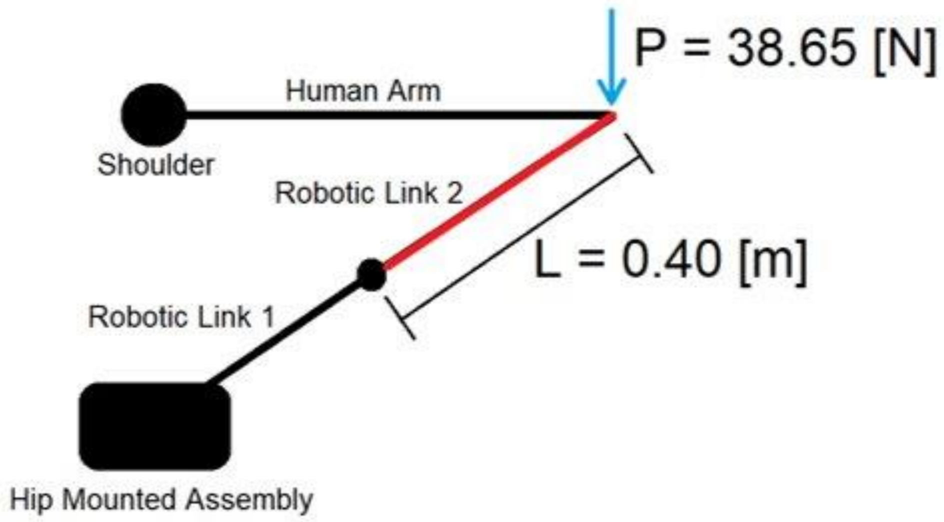
# Concept Generation – Link Geometry

- **Two different cross-sectional areas were evaluated.**
  - **Hollow Rectangular:**
    - **Pros:** Strong directional stiffness while keeping weight low.
    - **Cons:** Weak in torsion and off-axis bending.
  - **Hollow Circular:**
    - **Pros:** Resists twisting far better than rectangular.
    - **Cons:** Less stiffness per unit weight in one direction compared to rectangular.





# Bending Stress of Varying Beam Geometries in Link 2




- $\sigma_{\underset{c}{\max}} = \frac{M_{max} \cdot c}{I_c} = 15.4\,[MPa] \leq 80.33\,[MPa]$
- $\sigma_{\underset{s}{\max}} = \frac{M_{max} \cdot c}{I_s} = 69.4\,[MPa] \leq 80.33\,[MPa]$
- $\sigma_{allowable} = \frac{\sigma_{yeild}}{FoS} = 80.33\,[MPa]$

- What will be the bending stress in linkage 2 given different geometries?

Compared 2 geometries; a circular tube (c), and a square tube (s).
Material was chosen as 6061-T6 Aluminum due to its lightweight and higher strength properties.
Both geometries are strong enough for the application, however, the circular tube is over 4times stronger.
Achieving a FoS > 3 is only achievable with the circular cross-sectional geometry.
See Appendix A for assumptions, technical variables, and supporting calculations

# Capacity Required

What is the capacity needed for each of the three motors to last for 8 hours?

$$Capacity = \frac{Rated\ Power}{Rated\ Voltage} \cdot 8\ hours$$

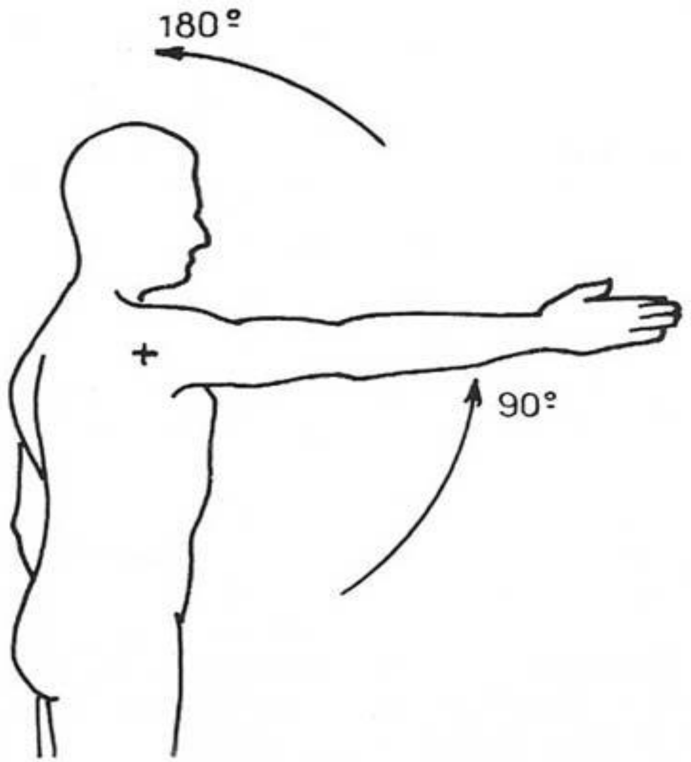
AK45-36: 11Ah

AK45-10: 13Ah

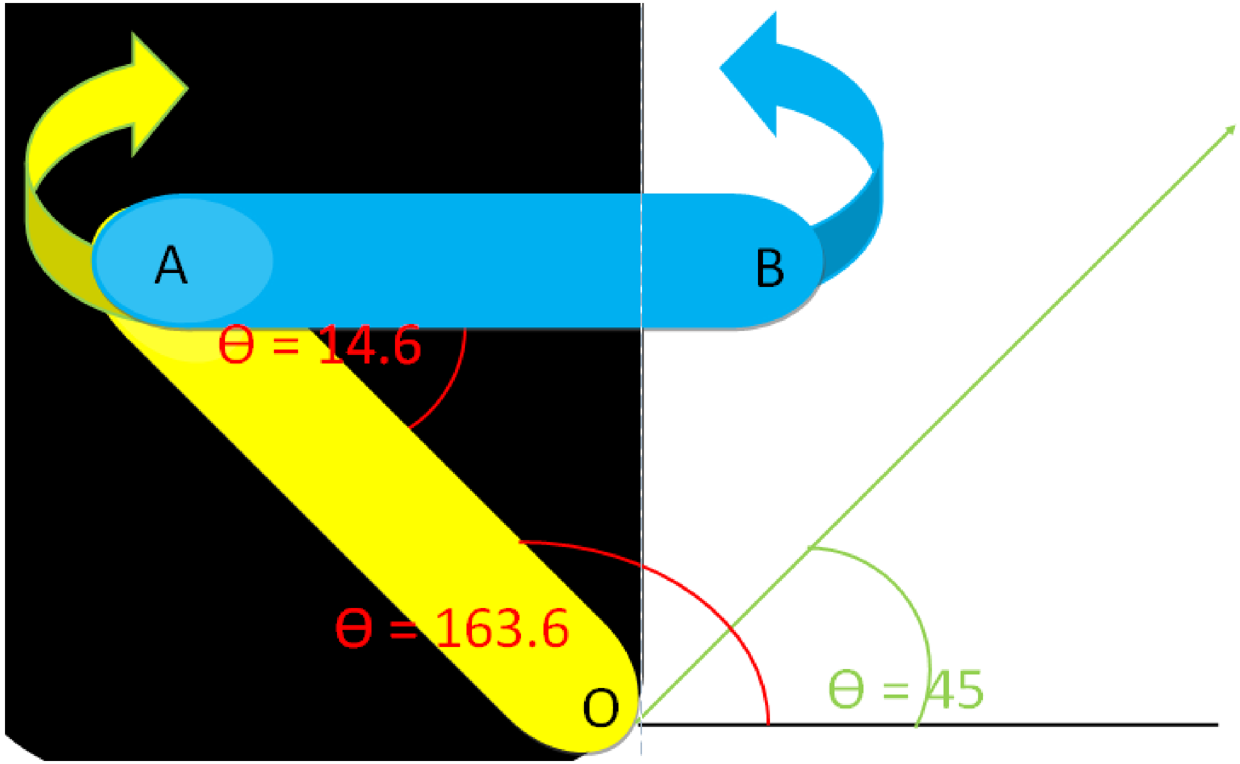
AK40-10: 20Ah

# Arm Motion

- Arm (shoulder flexion) velocity
- Shoulder flexion from hanging straight down (0 degrees) to straight forward (90 degrees)
- Average shoulder to elbow length: 330mm (13in)
- Average angular velocity: $w_{avg} = \frac{\Delta\ \theta}{Time\ t}$
- Using $\Delta\ \theta$ = 90 degrees and time 1.28 seconds.
- $w_{avg} = \frac{\Delta\ \theta}{Time\ t} = 1.227 \frac{rad}{s}$
- Linear velocity (elbow): $v = \ w_{avg} * r =$ $0.405 \frac{m}{s}$



# Link Motion




$O = (0,0)$

$A_s = (-238mm, 70mm)$

$B_s = (10mm, 70mm)$

$link\ 1 = 248mm$

$link\ 2 = 248mm$

$distance\ from\ elbow\ to\ waist = 70mm$

$\sin(\theta) = \left(\frac{opp}{hyp}\right)$

$\theta = 14.6\ degrees$

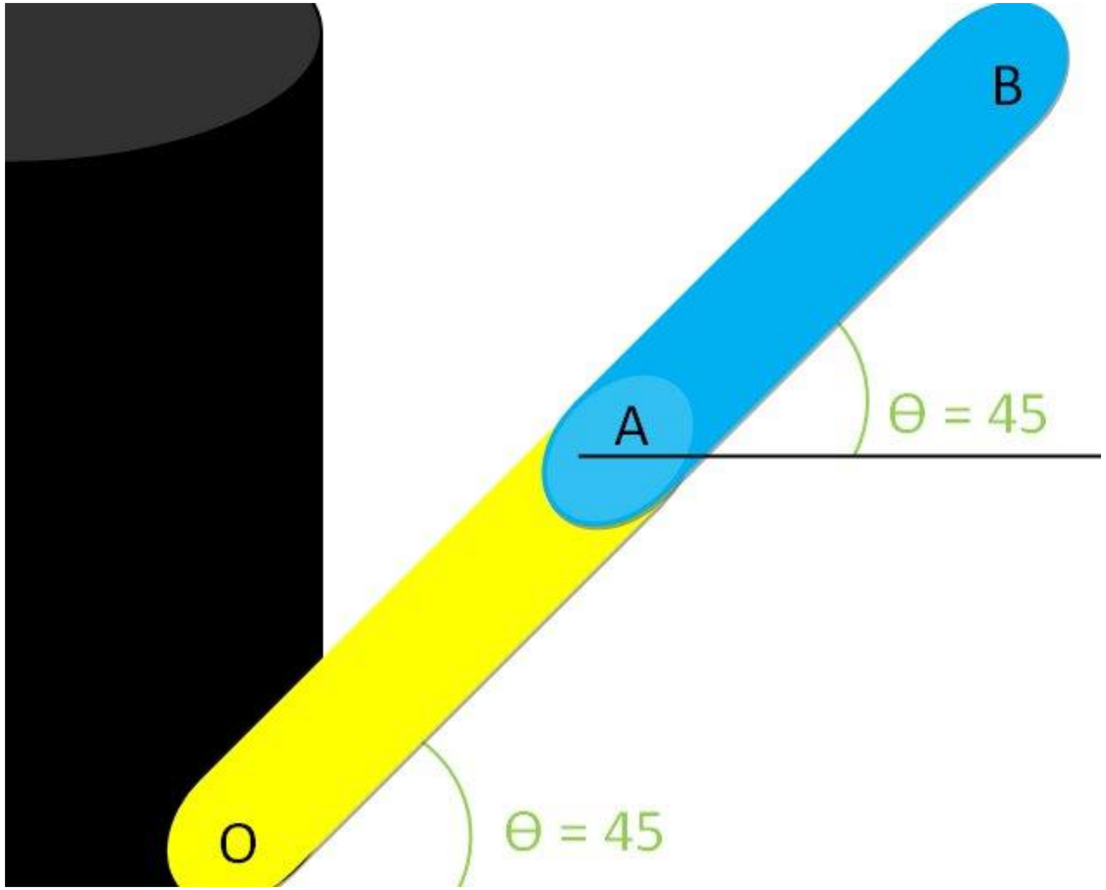
$l_1 x_1 = l * \cos(\theta) = -237.9mm$

$l_1 y_1 = l * \sin(\theta) = -70mm$

$B_{x1} = 10mm$

$B_{y1} = 10mm$

# Link Motion




$O = (0,0)$

$A_f = (175.36mm, 175.36mm)$

$B_f = (350.7mm, 350.7mm)$

$new\ position\ at\ 45\ degrees$

$l_1 x_2 = l * \cos(\theta) = 175.36\text{mm}$

$l_1 y_2 = l * \cos(\theta) = 175.36mm$

$B_{x2} = 350.7mm$

$B_{y2} = 350.7mm$

$time\ wanted\ to\ reach\ through\ 90\ degrees = 1.28s$

$\theta_1 = 163.6 - 45 = 118.6\ degrees$

$\theta_2 = 0 + 45 = 45\ degrees$

$$\omega_1 = \frac{\Delta\theta_1}{1.28} = -1.6171\ rad/s$$

$$\omega_2 = \frac{\Delta\theta_2}{1.28} = +0.6136\ rad/s$$

# Torque at Joints

- Remote Transmission
  - Hip:

$$\tau_1 = g[m_1 r_1 + m_2(L_1 + r_2) + m_p(L_1 + L_2)] + \alpha_1\left[m_1 r_1^2 + m_2(L_2 + r_2)^2 + m_p(L_1 + L_2)^2\right]$$

$$\tau_1 = 6.78\ N \cdot m$$

$$\tau_{1S} = 10\ N \cdot m$$

  - Elbow:

$$\tau_2 = g[m_2 r_2 + m_p L_2] + \alpha_2\left[m_2 r_2^2 + m_p L_2^2\right]$$

$$\tau_2 = 2.94\ N \cdot m$$

$$\tau_{2S} = 4.5\ N \cdot m$$

# Torque at Joints

- Direct Drive
  - Hip:

$$\tau_1 = g[m_1 r_1 + (m_2 + m_{m2})(L_1 + r_2) + m_p(L_1 + L_2)] + \alpha_1 \left[m_1 r_1^2 + m_2 (L_2 + r_2)^2 + m_p (L_1 + L_2)^2\right]$$

$$\tau_1 = 7.65 \ N \cdot m$$

$$\tau_{1S} = 11.5 \ N \cdot m$$

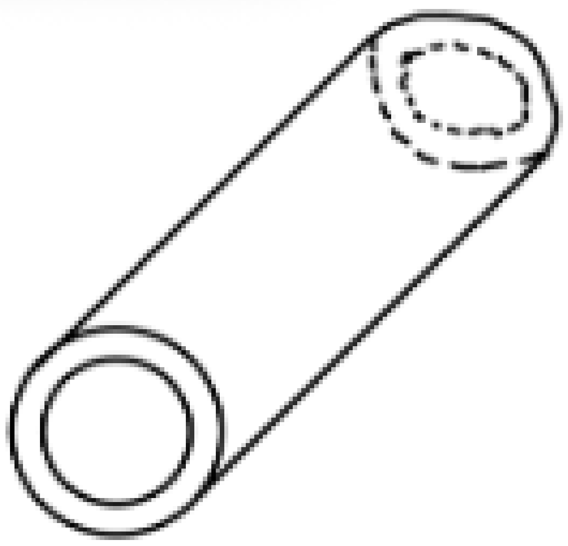
# Concept Evaluation

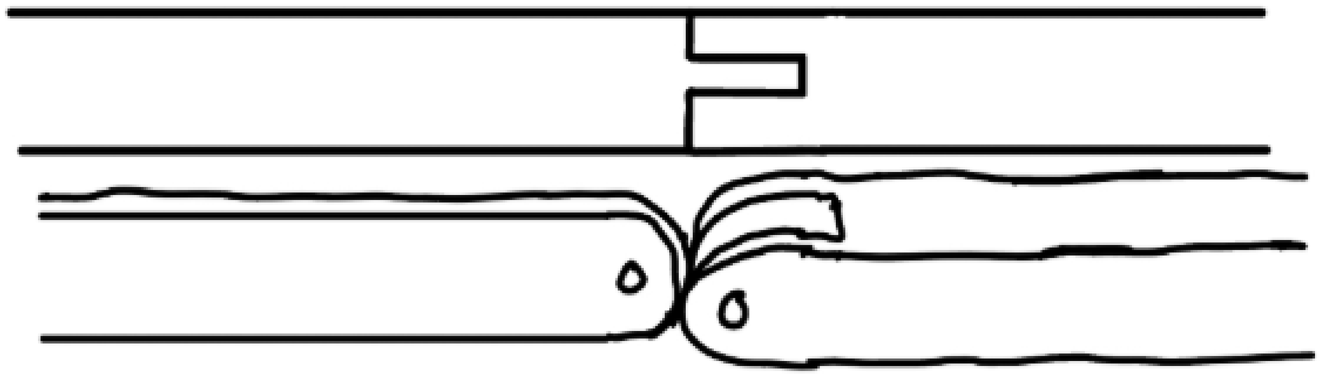
- We evaluated our sub-topics against our customer and engineering requirements.
  - Range of Motion: Determined by the joint selection. ( 3DOF)
  - Ease of Use: Determined by motor and joint selections.
    - Will be quantified by time to complete tasks.
  - Durability: Determined by link structure.
    - Will be quantified by stress analysis once more aspects of the device are determined.
  - Low-Profile: Combinations of joint structure, motor, and link structure.
    - Will be quantified by weight and the space that the device occupies.

# Joint and Link Selection

The hollow circular tube were chosen for being stronger than the rectangular tube and would be able to hit a factor of safety of 3.

The revolute joint was chosen by being able to have the movement wanted as well as being easiest to handle the Bowden cables needed for a transmission system.



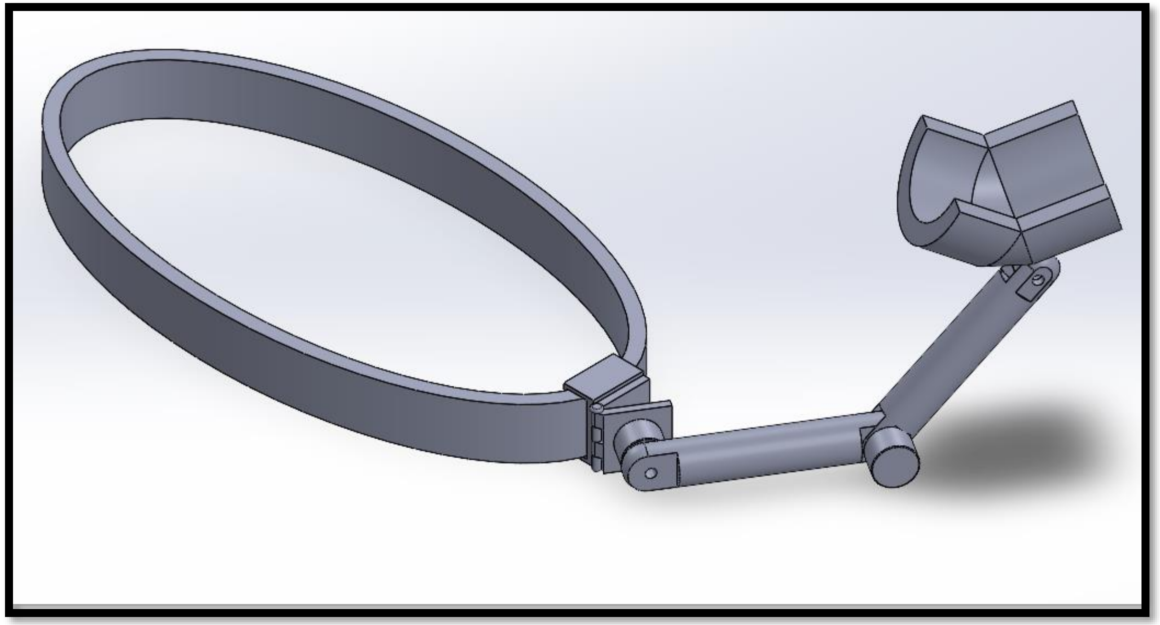


# Motor Selection

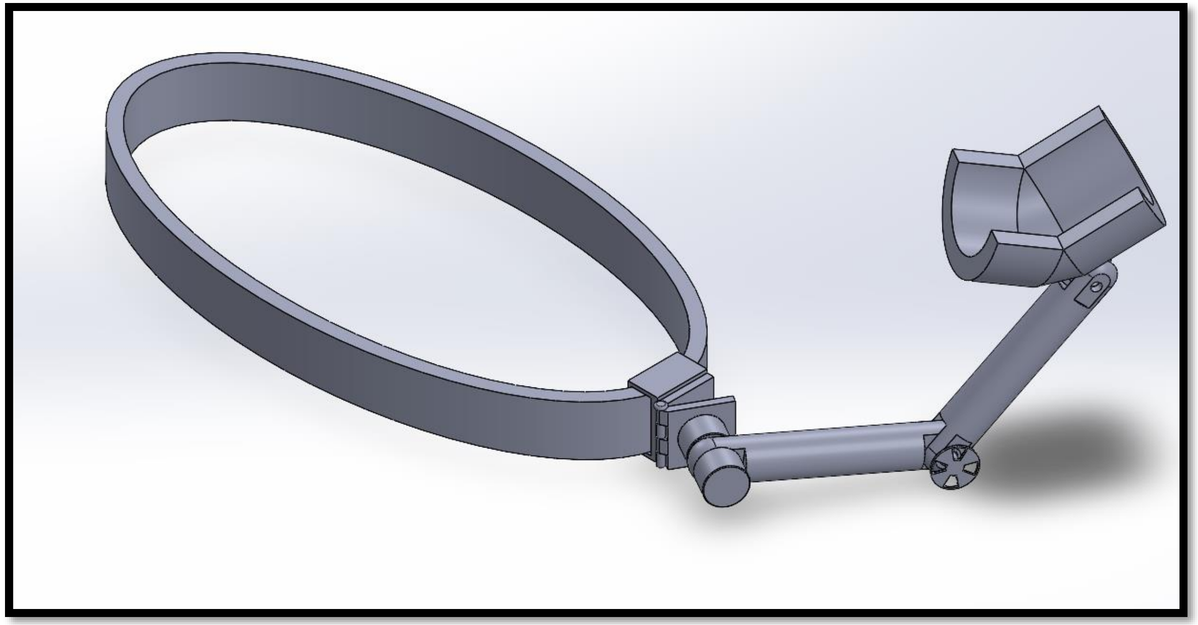
- We ultimately decided on:
  - AK45-36 KV80 Motor from CubeMars
    - Rated torque: 8 N*m
    - Peak Torque: 24 N*m
    - Can handle the torques for each joint in both a direct drive and transmission design.

# Model

Direct Drive



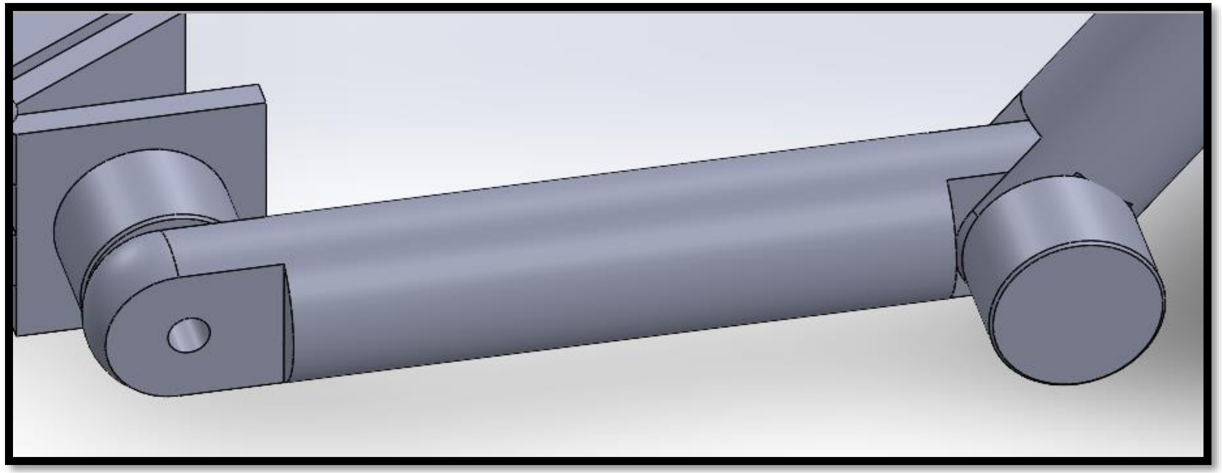
Transmission

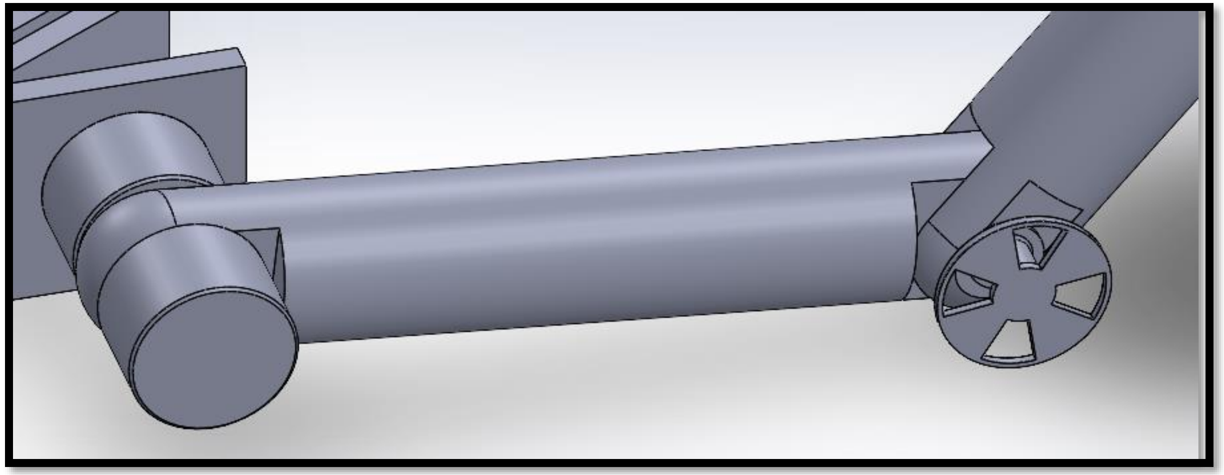


# Model

Direct Drive System:

- 2 Motors, 1 at each link
- Motor directly transmits power
- Weight further from body - increases the required output torque of the motor
- Less complex system – fewer moving parts





Transmission System:

- 2 Motors at the hip
- Pulley with cable to transmit power
- Weight kept close to body – reduces the required output torque of the motor
- More complex system – more moving parts

# Bill of Materials

| Item | Price |
|---|---|
| 2 AK45-36 motor | $371.80 |
| 3D filament | $100 |
| Battery | $300 |
| Waist belt | $50 |
| Hinge | $15 |

# Budget

- Funding from W.L Gore: $4000
- NAU 5% processing fee: -$200
- Fundraising (at least %10): $400
- Total Est. Budget: $4200

- We have an estimate of $3975 for total cost of possible items. The team will have a remaining balance of $225. We will need to fundraise more to begin prototyping.

| Expenses | | |
|---|---|---|
| Category | Items(s) | Cost |
| Tools and materials: | 3D printer Parts | $100 |
| | 3D printer Filament | $100 |
| Manufacturing: | | $300 |
| Parts: | Motors | $375 |
| | Battery | $300 |
| | Miscellaneous Parts | $700 |
| Prototyping: | 1st | $1200 |
| | 2nd | $900 |
| TOTAL: | | $3975 |

# Fundraising

- Need to accumulate 10% of the $4,000 budget for a minimum of $400 total
- In talks with multiple companies regarding sponsorships, services, or cash donations
- We plan to fundraise the entire 10% on or before week 8, or the testing of prototype 1

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# Schedule

Plan duration | Actual Start | Completed | Beyond Completion

| | August | | | | September | | | | October | | | | November | | | | December | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | wk1 | wk2 | wk3 | wk4 | wk5 | wk6 | wk7 | wk8 | wk9 | wk10 | wk11 | wk12 | wk13 | wk14 | wk15 | wk16 | |
| Requirements/ research | | | | | | | | | | | | | | | | | | | | |
| Equations | | | | | | | | | | | | | | | | | | | | |
| Presentation 1 | | | | | | | | | | | | | | | | | | | | |
| Conceptual designs | | | | | | | | | | | | | | | | | | | | |
| Fundraising | | | | | | | | | | | | | | | | | | | | |
| Presentation 2 | | | | | | | | | | | | | | | | | | | | |
| Begin modelling | | | | | | | | | | | | | | | | | | | | |
| Testing prototype 1 | | | | | | | | | | | | | | | | | | | | |
| Presentation 3 | | | | | | | | | | | | | | | | | | | | |
| 1st Prototype Demo | | | | | | | | | | | | | | | | | | | | |
| Begin prototype 2 | | | | | | | | | | | | | | | | | | | | |
| Testing for Prototype 2 | | | | | | | | | | | | | | | | | | | | |
| 2nd Prototype Demo | | | | | | | | | | | | | | | | | | | | |

# Thank you
# And
# Any Questions?

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# Appendix

[1] *Cubemars.com*, 2025. https://www.cubemars.com/product/ak40-10-robotic-actuator.html

[2]“AK45-10 Robotic Actuator – 10:1 Gear Ratio, 260g, Φ53×43mm,” *CubeMars*, 2025. https://www.cubemars.com/product/AK45-10-robotic-actuatuor.html

[3] “AK45-36 Robotic Actuator – Ultra-High Torque, 36:1 Gear Ratio,” *CubeMars*, 2025. https://www.cubemars.com/product/AK45-36.html

# Appendix A

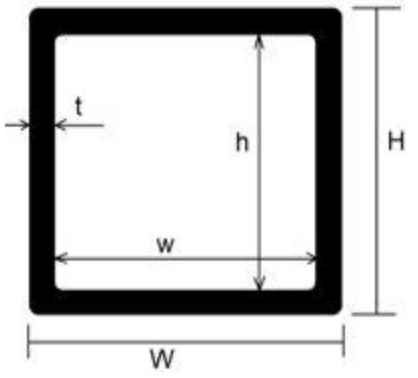
Broad Assumptions:

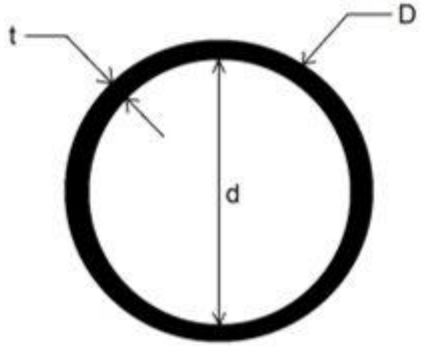
- Average Human male arm mass = 1.89 [kg]
  - Average total body mass of 75 [kg]
  - Forearm Mass + Wrist Mass = 2.52% of Total Body Mass
- Arm is fully outstretched in front of the body
- Linkage at 45 degrees
- Treat connection to link 1 as fixed
- Robotic linkage is split into 2 parts of equal length (0.40 [m])
- Deflection due to Axial compression is negligible

Technical Variables:

- Material: 6061-T6 Aluminum
- $FoS = 3$
- $g = 9.81 \left[\frac{m}{s^2}\right]$
- $m_{total} = 75\ [kg]$
- $\sigma_{yeild} = 241\ [MPa]$
- $a = 0.0525$
- $E = 6.89 \cdot 10^{10}\ [Pa]$ Elastic Modulus
- $L = 0.40\ [m]$
- $c = 0.015$
- $t = .003\ [m]$
- $\theta = 45^{\circ}$
- $D = 0.254\ [m]$
- $d = 0.0251\ [m]$
- $H = 0.0254\ [m]$
- $W = 0.0254\ [m]$
- $h = 0.0251\ [m]$
- $w = 0.0251\ [m]$

Geometries:




Calculations:

- $c = \frac{D}{2} = \frac{H}{2} = 0.0127\ [m]$
- $m_{arm} = m_{total} \cdot a = 3.94\ [kg]$
- $P = m_{arm} \cdot g = 38.65\ [N]$
- $P_{\perp} = P \cdot \cos\theta = 27.33\ [N]$
- $M_{max} = P_{\perp} L = 10.93\ [Nm]$
- $I_c = \frac{\pi}{64}(D^4 - d^4) = 9 \cdot 10^{-6}\ [m^4]$
- $I_s = \frac{HW^3 - hw^3}{12} = 2 \cdot 10^{6}\ [m^4]$
- $\delta_{\perp c} = \frac{P_{\perp} L^3}{3EI_c} = .00094\ [mm]$
- $\delta_{\perp s} = \frac{P_{\perp} L^3}{3EI_s} = .004\ [mm]$