Design of Prosthetic Elbow to Restore Arm Swing

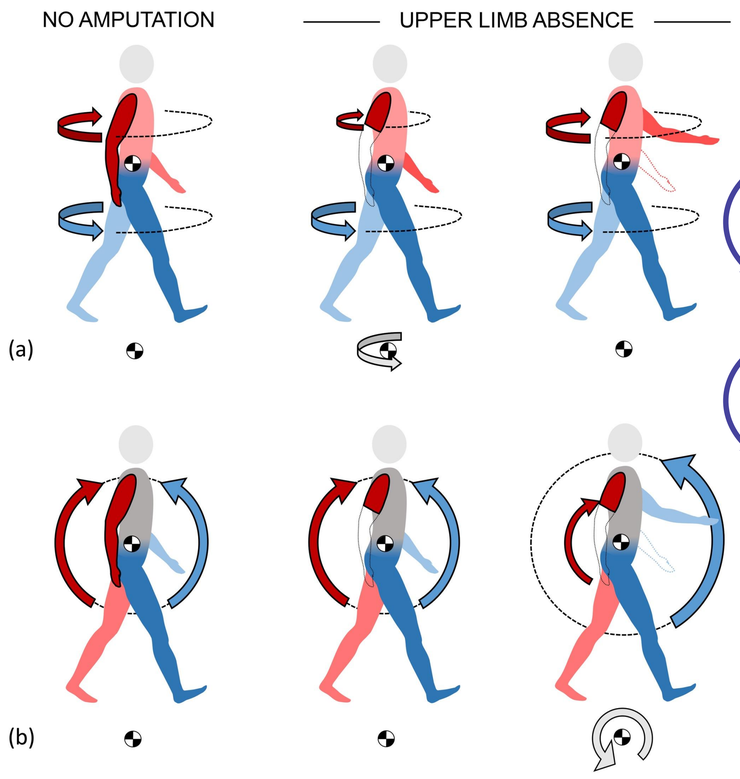
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Why restore arm swing in upper-limb prosthesis users?



[1]

Subjects show decreased arm swing on affected side regardless of prosthesis use

Whole body angular momentum regulation is disrupted

Individuals show higher risk of falling due to imbalance

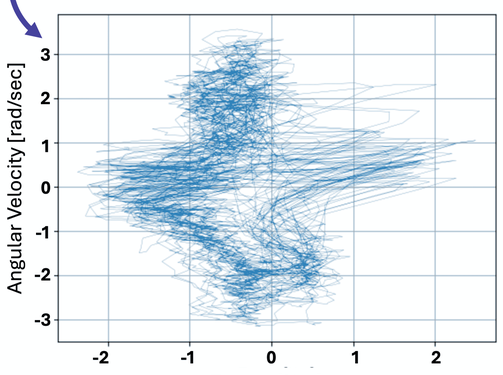
Externally powered prostheses may restore arm swing and improve gait in users

Project Goal and Modeling

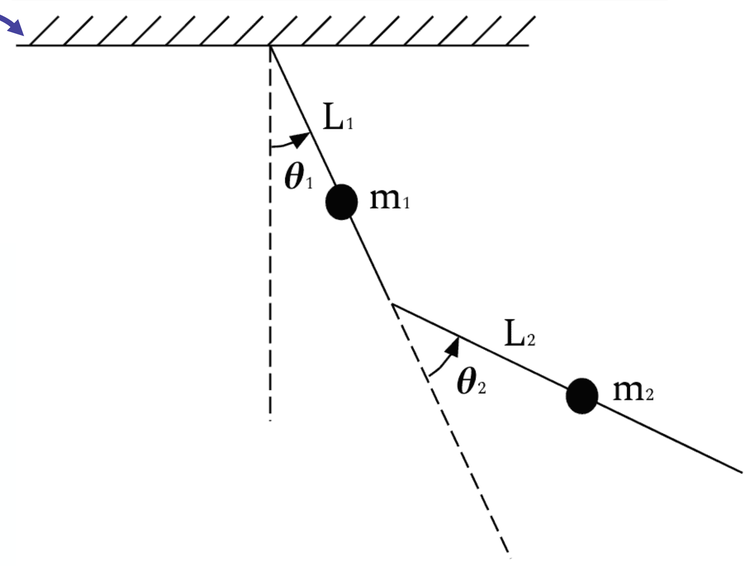
Project Goal: Use actuated elbow joint to generate arm swing for transhumeral prosthesis users

Use model to find torque requirements:

1. Collect arm swing trajectory data
2. Model the arm as double pendulum
3. Back calculate torque required to match the collected trajectory

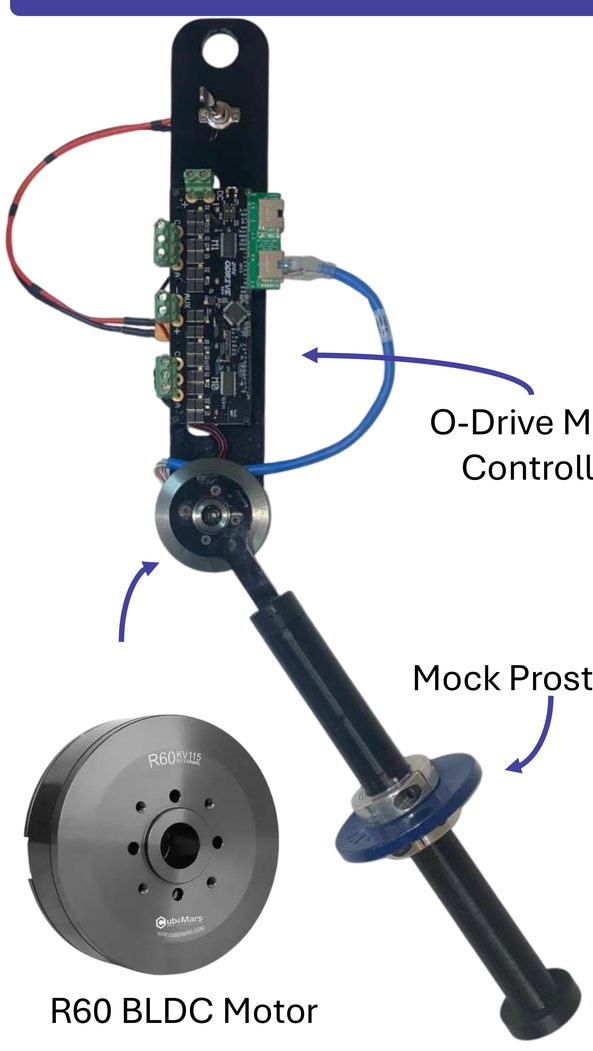


Required torque-speed profile

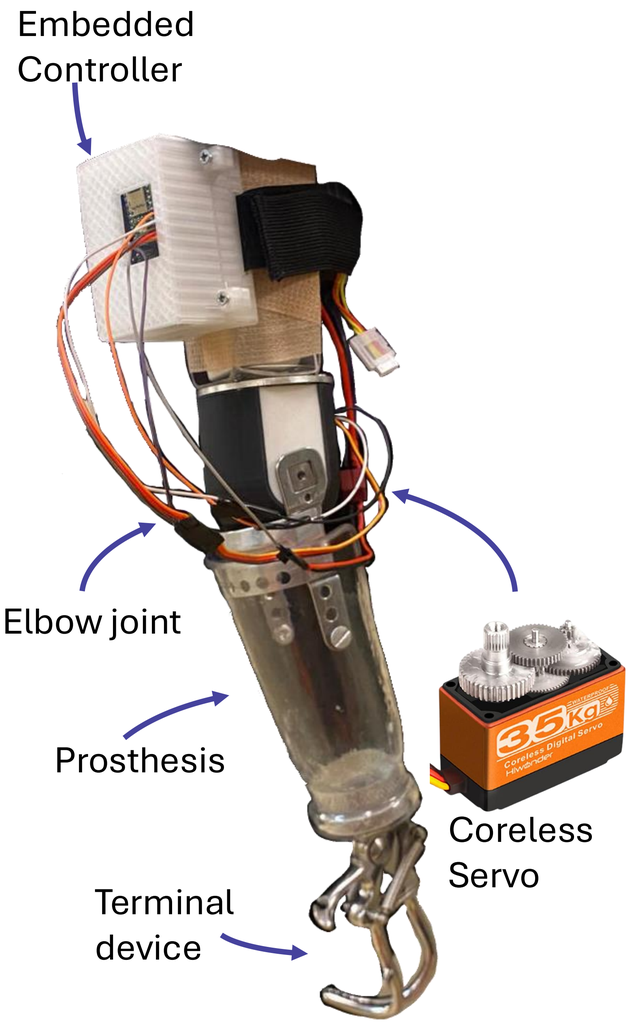


What motors can fulfill these requirements?

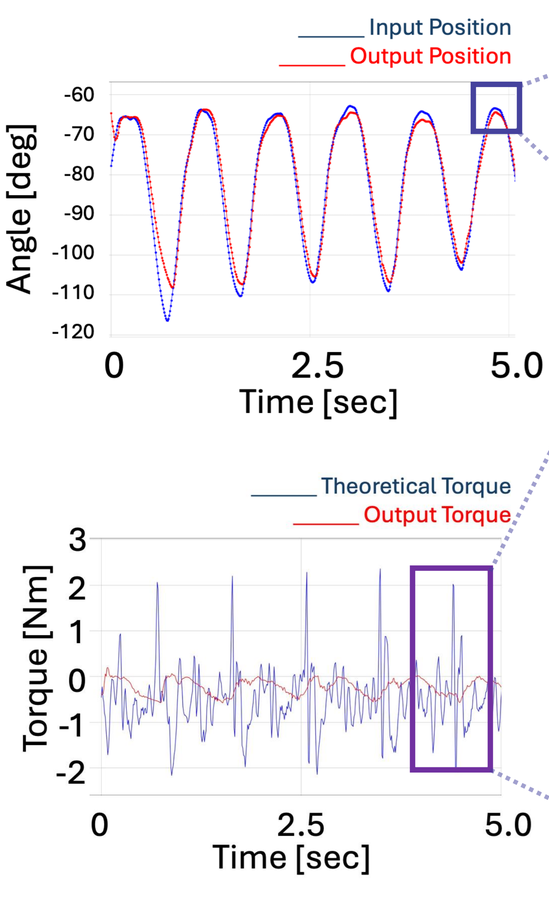
Methods: Development and comparison of two prototypes



	Version 1	Version 2
Size	**Large:** Controller and motor take the length of the upper arm, not suitable for real world use.	**Compact:** Motor housed in standard elbow joint with electronics housed externally.
Device	**Mock prosthesis:** 3D printed and weighted to mimic the mass of a prosthetic arm	**Traditional prosthesis:** A lightweight plastic prosthesis made to length for the user
Weight	**Total = 1538g** Motor = 248g Prosthesis = 550g Electronics, Housing = 320g Battery = 420g	**Total = 855g** Motor = 60g Prosthesis =400g Electronics, Housing = 225g Battery = 170g
Motor	**BLDC:** Cubemars R60 Peak torque = 2.3Nm (23.2A,48V) Dimensions = Φ69 x 29mm	**Servo:** HiWonder Coreless Peak torque = 3.4Nm (3.2A,8.4V) Dimensions = 40x20x38mm Gear ratio = 342:1
Testing	**Simulated:** Project engineers strapped prototype to upper arm and walked on treadmill at various speeds	**Informal:** Lab associates with transfemoral prosthesis walked on treadmill with the arm



Version 1 performed well; although a smaller motor may suffice



Plot 1: Treadmill ambulation at 1.4m/s

→ Followed pre-recorded arm swing trajectory
→ Maintained sub 5% absolute error

Plot 2: Comparison of calculated and actual torque output

→ Predicted torque far exceeds actual torque required
→ Actual torque output is far smoother

A smaller motor may be able to drive necessary torque

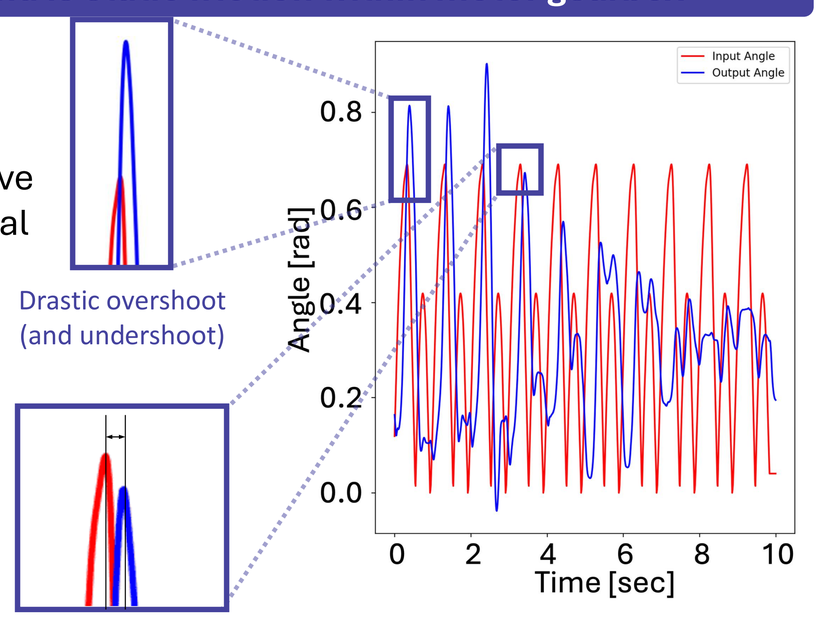
Source of deadband is static friction within motor gearbox

Plot 3: Treadmill ambulation at 1.3m/s

→ Constructive/destructive interference with natural arm swing

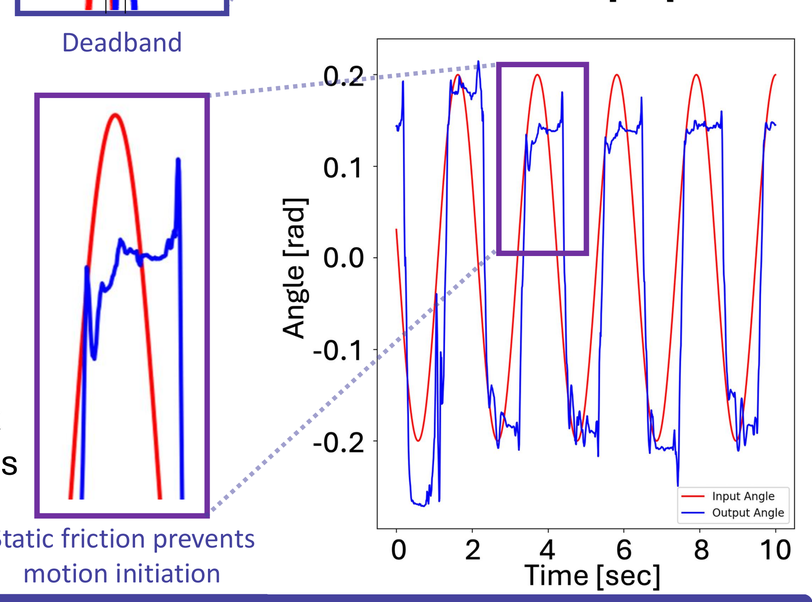
→ System output trails behind the desired trajectory (deadband)

What causes this deadband?

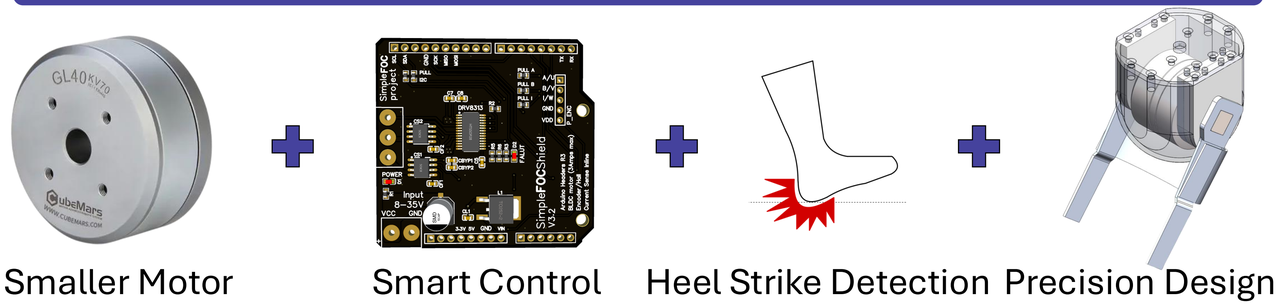


Plot 4: Bench testing following low frequency sinusoid trajectory

→ Motor exhibits a deadband at low speeds due to static friction in the gearbox
→ Fine position control is limited at low torque levels



New design will integrate success of V1 and V2 with advanced control



References

[1] J. A. Kent and M. J. Major, "Asymmetry of mass and motion affects the regulation of whole-body angular momentum in individuals with upper limb absence," Clinical biomechanics, vol. 76, p. 105015, Jun 2020.

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