Design and Control of an Actuated Prosthetic Elbow to Restore Arm Swing for Persons with Upper Limb Absence

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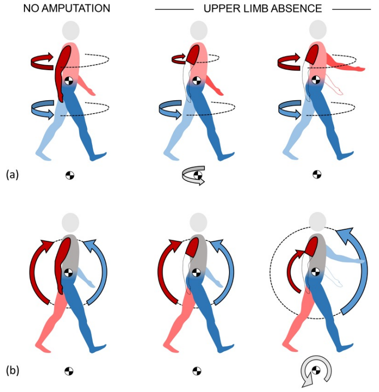
Why restore arm swing in for persons with upper limb absence?



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

[1] Kent and Major, 2020

Project Goal and Modeling

Project Goal: Develop an actuated elbow joint that can mimic arm swing for transhumeral prosthesis users

Model system to estimate torque requirements for the motor:

1. Collect arm swing trajectory data during walking on sound limb
2. Define configuration to represent shoulder and elbow angle (Figure 1)
3. Back calculate required torque to match the collected trajectory (Figure 2)

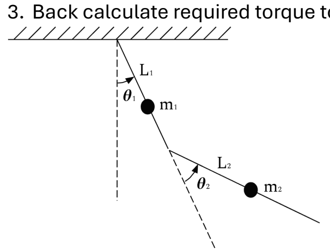


Figure 1: Arm model

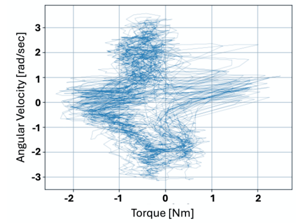
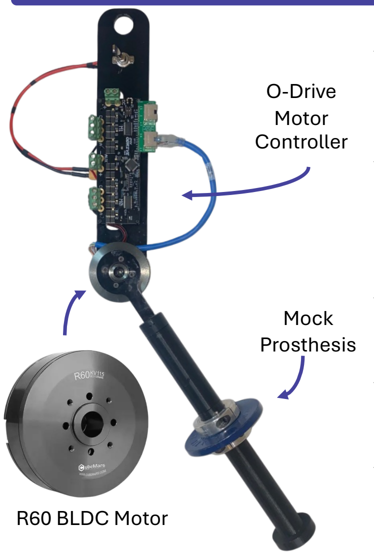
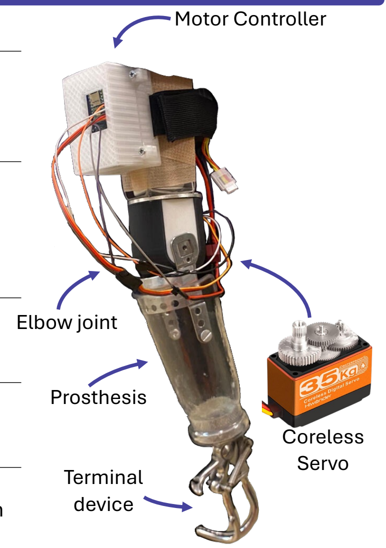


Figure 2: Theoretical speed-torque results

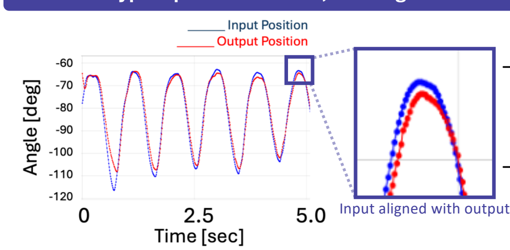
Methods: Development and comparison of two prototypes



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



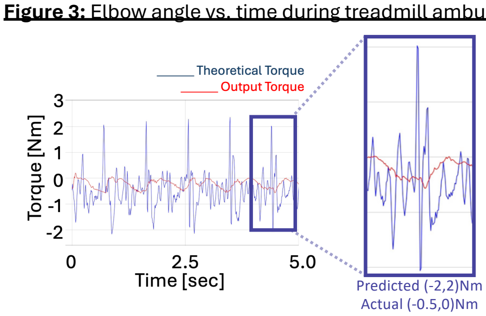
Prototype 1 performed well; although a smaller motor may suffice



→ Followed pre-recorded arm swing trajectory

→ Maintained sub 5% absolute error

Figure 3: Elbow angle vs. time during treadmill ambulation at 1.4m/s



→ Predicted torque far exceeds actual output

→ Actual torque output has smoother shape

A smaller motor can likely drive these lower torques

Figure 4: Motor torque vs. time comparing calculated and actual torque output

Source of deadband is static friction within motor gearbox

→ Constructive/destructive interference with natural arm swing

→ System output trails behind the desired trajectory (deadband)

What causes this deadband?

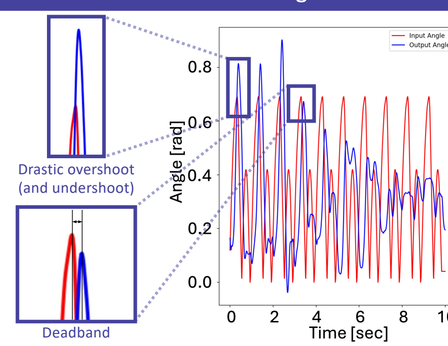


Figure 5: Elbow angle vs. Time during treadmill ambulation at 1.3m/s

→ Motor exhibits deadband at low speeds due to static friction in the gearbox

→ Fine position control is limited at low torque

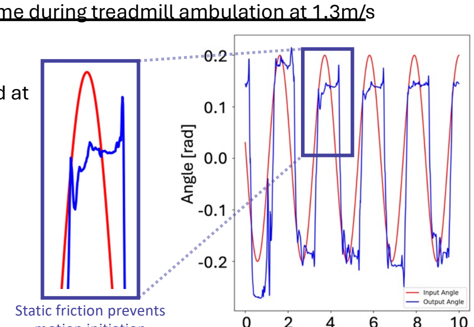
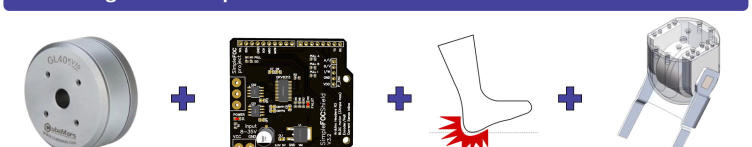


Figure 6: Elbow angle vs. time during bench testing tracking sinusoid trajectory

New design will incorporate lessons from P1 and P2 with advanced control



Smaller Motor + Smart Control + Step Detection + Precision Design

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.