Bio-Inspired Hardware towards Dexterous Manipulation

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Introduction

The evolutionary design of the human hand is difficult to recreate and control in current robotic and prosthetic platforms. The detail of the anatomy and the nervous system in biological systems create challenges that are easier to ignore than to model[1]. It has been shown that correctly optimized, tendon-driven robotic platforms can outperform their human counterparts[2]. Unfortunately, current hands are cripplingly expensive, require human-made models, or are limited to grasp only functionality. This work is the preliminary stages of the development of an inexpensive, self-learning, dexterous hand.

Objective

Through the collective efforts of multiple team members, affordable hardware can be developed that can manipulate objects comparable with the dexterity of human hands. This hardware will be variable for different tasks and research platforms. Two preliminary pathways were explored with the following design constraints:

Underactuated prosthetic upper extremity:
- Underactuated function that allows for simple neural control
- Lightweight and affordable

Off-the-shelf robotic arm:
- Simple, modular design, with pre-manufactured components
- Task specific degree of freedom variability
- Versatile and robust

Methods

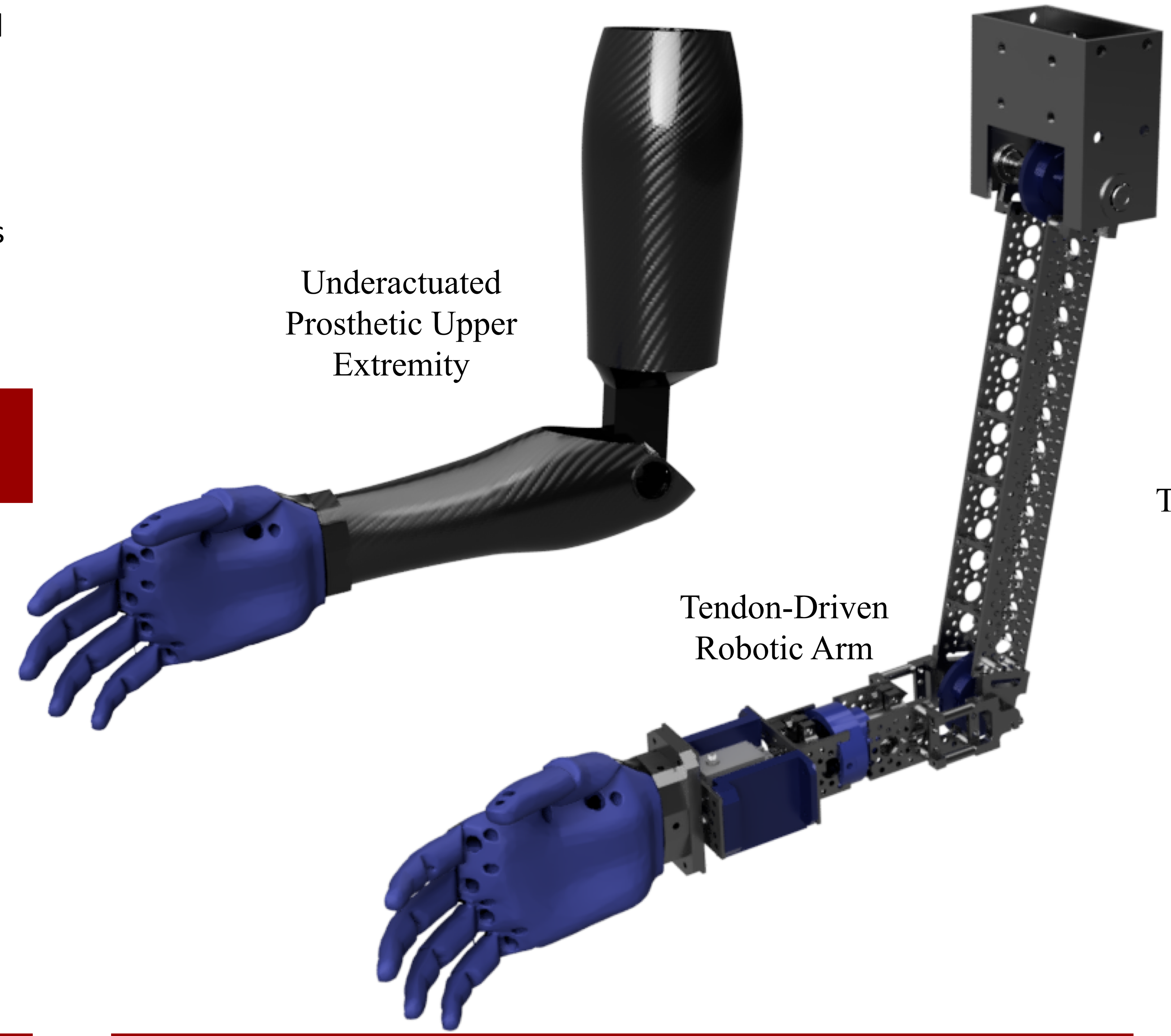
All design was constructed in Autodesk's Fusion 360 using pre-manufactured or 3D printed components. Neuromechanical calculations of limb endpoint position and forces were used to optimize tendon routing paths and moment arm sizes. The following mathematical equation was the basis for all neuromechanical calculations. The focus of optimization was in the moment arm matrix (R) in a planar, two joint (m=2), three muscle system (m+1). This reduced the endpoint wrench to forces in two dimensions and one torque.

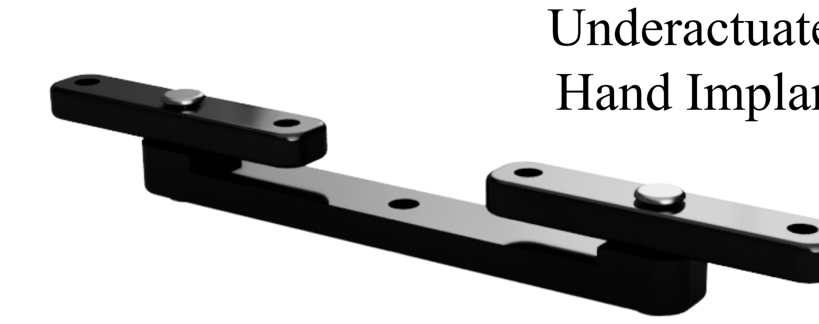
Endpoint Wrench
Joint Torque
Muscle Force
Nerve Activation

$$\underset{[6\times 1]}{\vec{W}} = \underset{[6\times m]}{J^{-T}}\,\underset{[m\times n]}{R}\,\underset{[n\times n]}{F_o}\,\underset{[n\times 1]}{\vec{a}}$$

m: Internal Degrees of Freedom n: Number of Muscles

Results





Optimal Moment Arm Matrix

$$\begin{bmatrix} -1 & -1 & 1 \\ -1 & 1 & 0 \end{bmatrix}$$

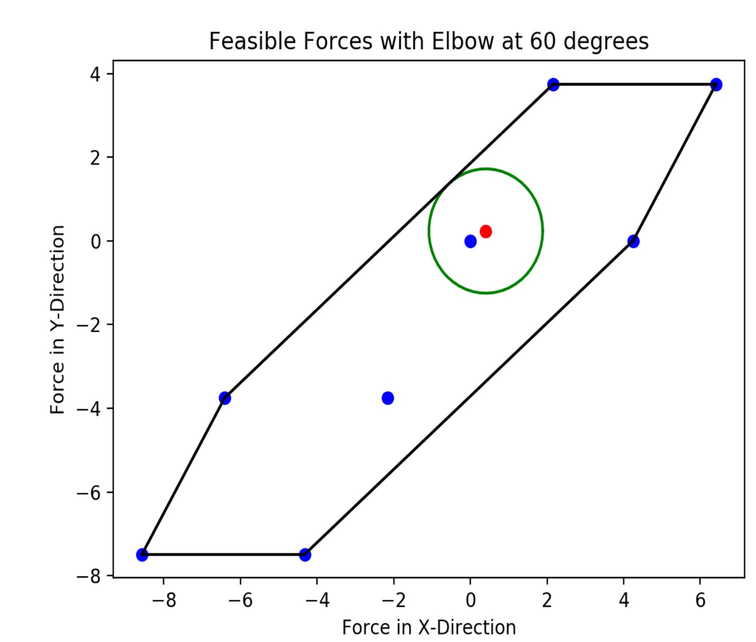


Figure 1: Feasible Force Set produced with the elbow flexed at 60 degrees. The 8 vertices are different combinations of maximum muscle activations. A Minkowski Sum is used to produced a convex hull and a circle's radius is maximized around the arm's endpoint.

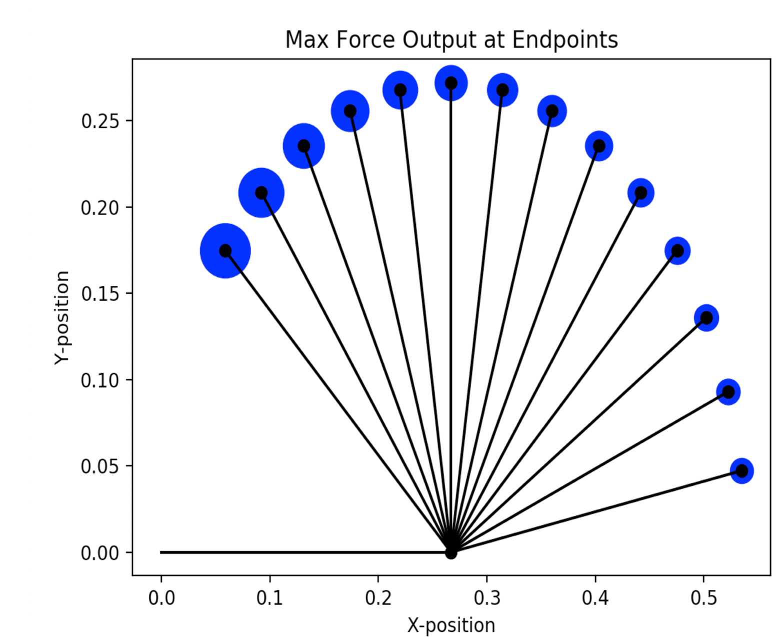


Figure 2: A visual representation of the largest force at a distribution of elbow angles. The blue circles are a scaled visualization of the maximum radius inside the feasible force set.

Discussion

The tendon-driven robotic arm was constructed and is currently undergoing integration with the neuromorphic system that is being developed in the lab. In addition, a next step is to implement G2P, a learning platform that has been demonstrated on other tendon driven systems. The hand on both designs is limited to grasp only while the arms were being developed, but in future iterations, the hand will gain dexterity for detailed oriented tasks while current designs can be used with brain-machine interfaces.

The optimal R matrix was narrowed down by eliminating duplicates and infeasible designs. The largest circle inside the feasible force set with the center at the endpoint was then calculated and integrated over the range of motion of the arm. This first optimization was looking at routing paths with constant moment arms across all musculotendons, but future exploration will consider variable and irregular moment arms to further develop a better platform for neuromorphic control.

References

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