Development of a Modular Below-Elbow Prosthesis with Bidirectional Signaling for Children

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Engineering Need

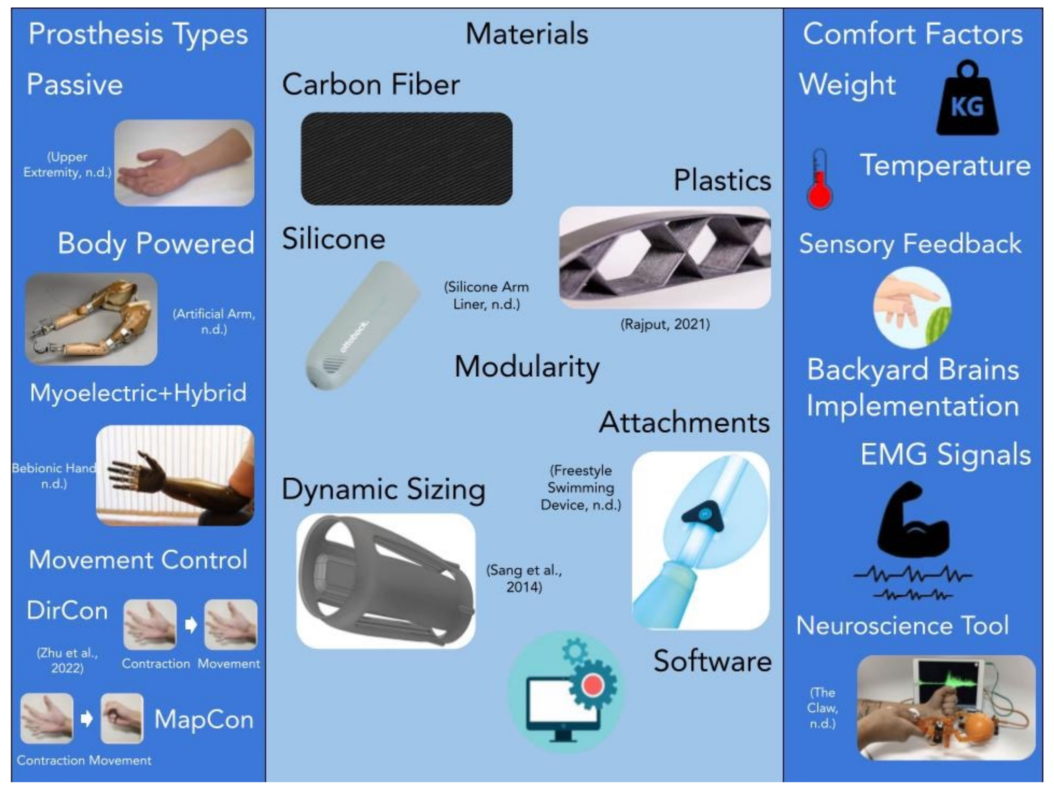
Today, many prosthetic options are too expensive for the majority of individuals to obtain, causing a lowered quality of life for millions of amputees around the world. For children with a limb difference, it is even harder to obtain functional prostheses, as the child outgrows the limb too quickly, thus, new prostheses are needed every 12-18 months.

Engineering Goal

In order to combat the price barrier surrounding advanced prostheses, a modular myoelectric prosthesis model was created.

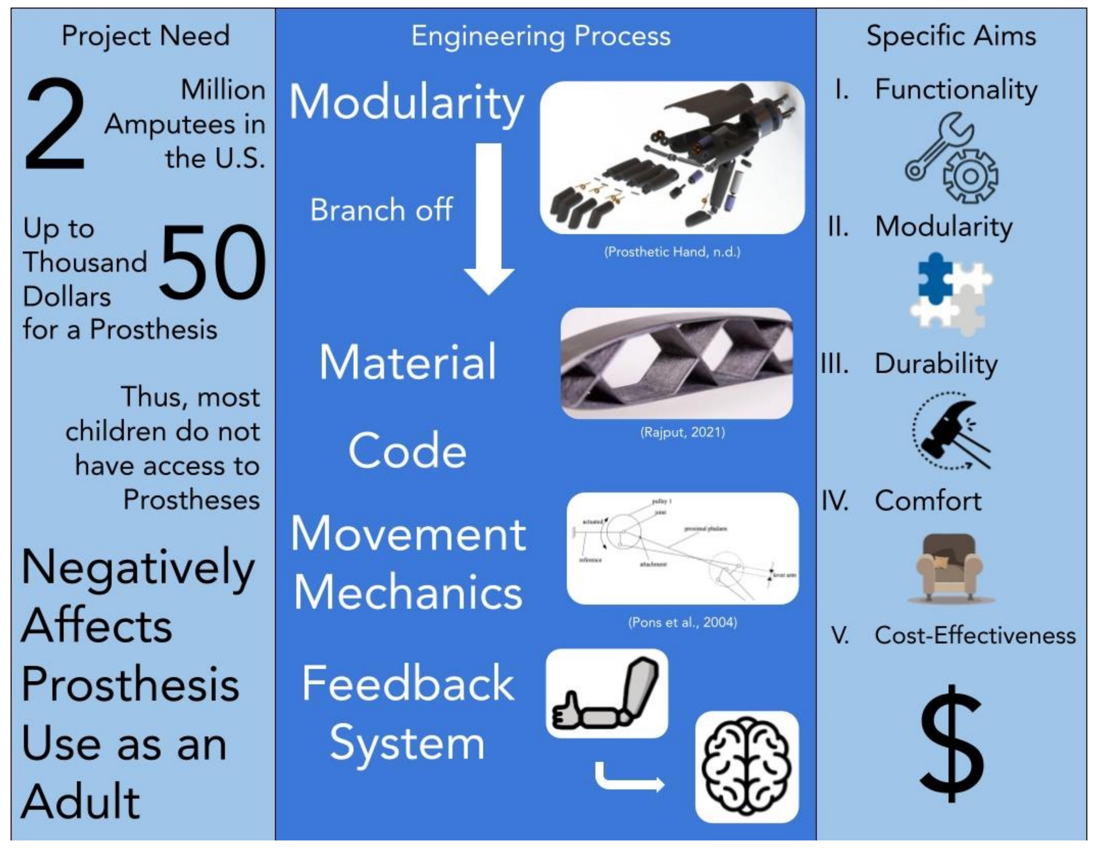
Background

- Prevalent prosthesis types: passive, body powered, myoelectric, and hybrid (Smail et al., 2021)
- Common materials: silicone, carbon fiber, polymers, aluminum, and titanium (Mota, 2017)
- Few are pursuing modular prosthetics in the field
- Main issues: heavy, hot, rigid, and bulky (Smail et al., 2021)
- A Backyard Brains (neuroscience company) product, "The Claw," will be the subject model
- "The Claw" contains electrodes, an Arduino-microcontroller, and a plastic claw which can be controlled by the user (The Claw, n.d.)
- Electrodes sense muscle contractions and relay the EMG signal (electromyography signal/electrical signal from the brain to the muscle) to the Arduino
- The Arduino, coded in C++, takes the signal to control a servo motor which rotates to move the plastic claw



A modular below-elbow prosthesis with bidirectional signaling is attainable and will allow children to grow up with and utilize prostheses better.

Design Process



Methodology

1. Create a schematic for the prototype that is to be made
2. Sketch the prototype
3. Design the prototype in CAD
4. Print out the parts for the prototype
5. Assemble prototype according to the schematic and sketch
6. Integrate the Backyard Brains system
7. Conduct trial 1, record results, repeat 3 times
8. Conduct trial 2, record results, repeat 3 times
9. Conduct trial 3, record results, repeat 3 times
10. Test for all other specific aims
11. Repeat steps 1-10 until a desirable
12. Select the best prototype via the engineering design matrix
13. Continue to test the final prototype
14. Go back to design phase if needed

Results

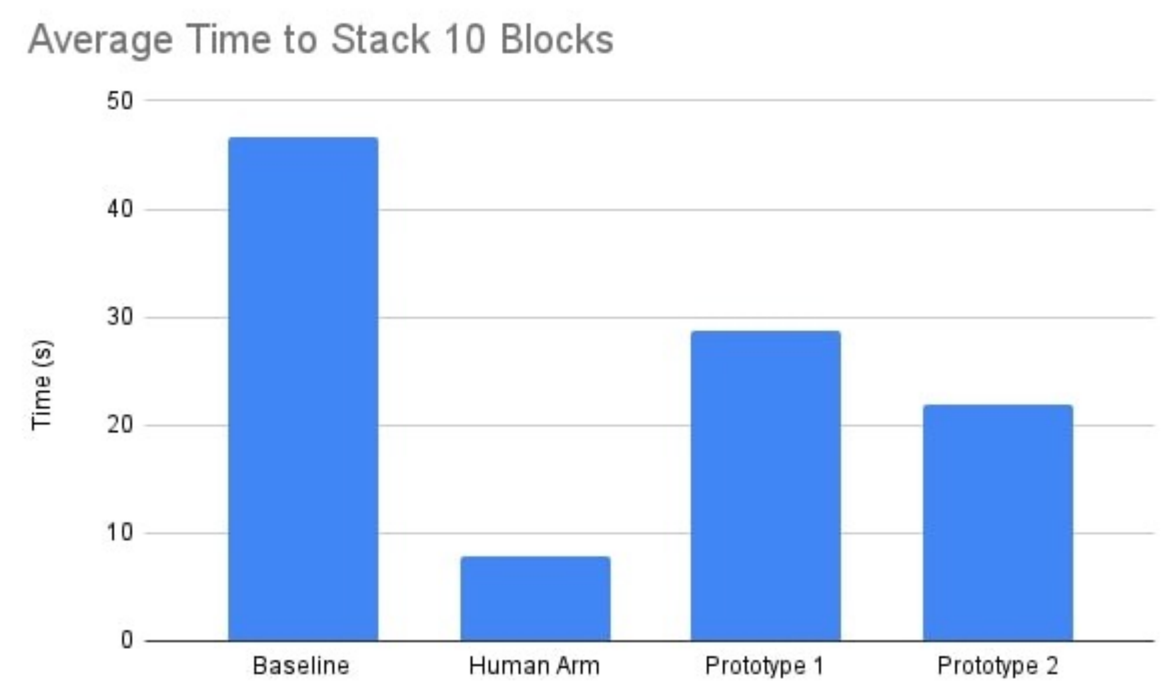
Prototype 1

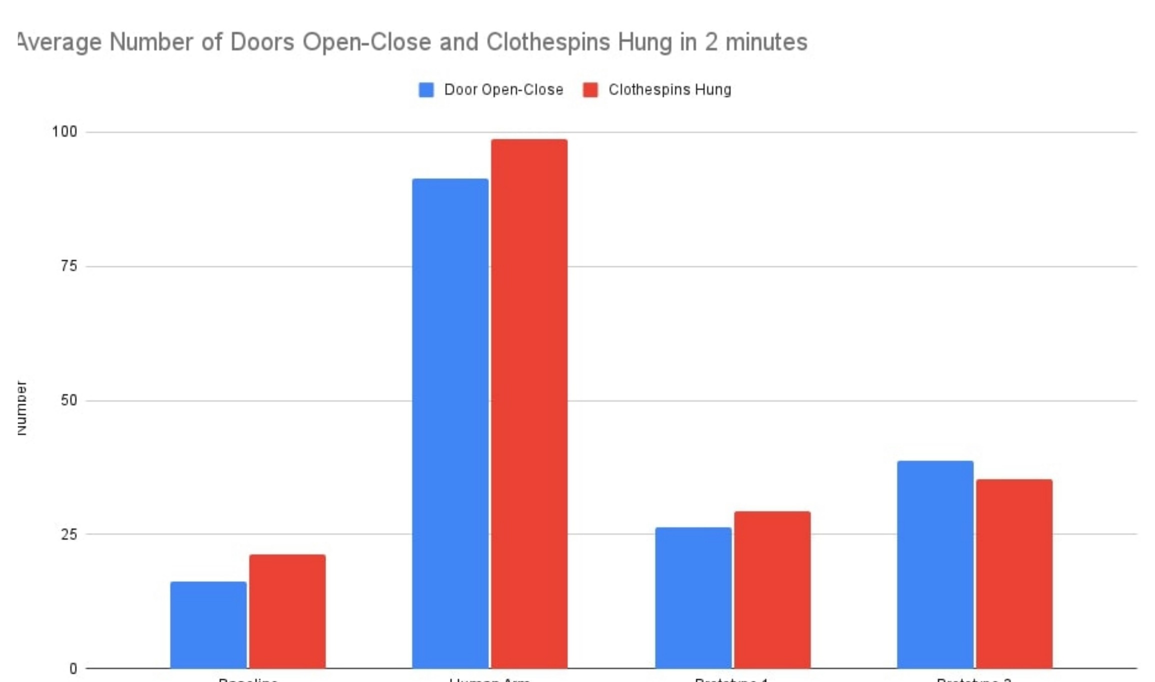
Functionality			
Attempt	Time to Stack 10 Blocks (s)	Clothespins Hung in 2 Minutes	Door Open-Closes in 2 Minutes
1	31.32	26	24
2	28.55	30	27
3	26.26	32	28
Average	28.71	29.33333333	26.33333333
	Comfort	Durability	
	Weight: 233g	Everyday Use: okay	
	Rigid Points: 4	Stress-test: 20MPa	

- Functionality – three trials similar to Zhu et al. (2022)
- Modularity – functionality tested at different sizes
- Durability – stress analysis and everyday degradation
- Comfort – rigidity and weight tests
- Cost-effectiveness – aggregate costs

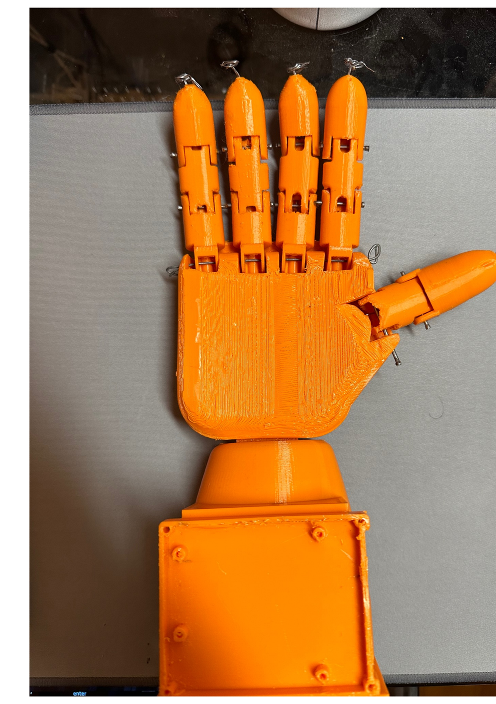
Prototype 2

Functionality			
Attempt	Time to Stack 10 Blocks (s)	Clothespins Hung in 2 Minutes	Door Open-Closes in 2 Minutes
1	26.88	33	34
2	21.55	35	38
3	17.22	38	44
Average	21.88333333	35.33333333	38.66666667
	Comfort	Durability	
	Weight: 303g	Everyday Use: good	
	Rigid Points: 1	Stress-test: 20MPa	

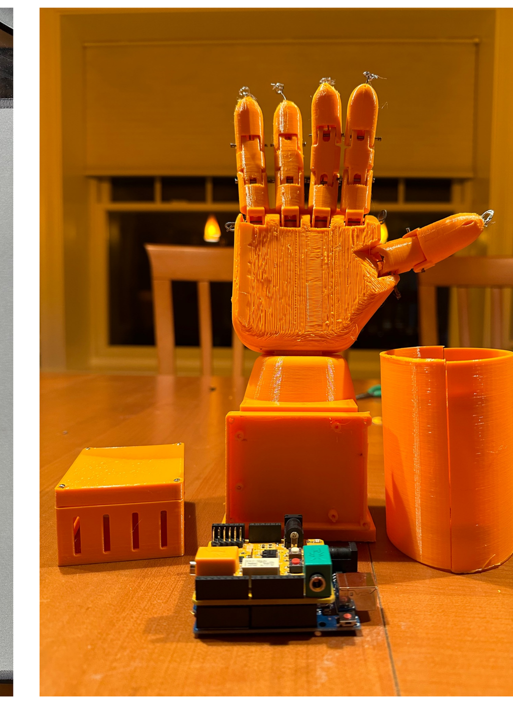




Prototype 1



Prototype 2



Analysis

- Statistical significance between the first and second prototypes as well as between the baseline and both prototypes ($p<0.05$ for all cases)
- Through the design matrices, the second prototype was determined to be the best
- Performs at 42% of the rate a normal human arm would

Criteria (Rank)	Prototype 2	Reasoning
Safety - how safe the user feels when using the prosthesis; how well the user trusts the prosthesis (10)	9	Very safe, almost no potential sources of harm
Functionality - determined from functionality methodology (9)	7	Performed in the trials fairly well
Modularity - determined from modularity methodology (9)	7	Fingers are modular, but the socket is not, performed similarly when fingers/socket shortened
Comfort - determined from comfort methodology (7)	6	Decent, but the design is a little bulky
Durability - determined from durability methodology (7)	8	20MPa is fairly durable compared to the baseline
Cost-effectiveness - determined from cost-effectiveness methodology (6)	9	3D printing out of plastic is much cheaper than buying a whole prosthesis system
Control - how well the user can manipulate the prosthesis to do desired actions (8)	6	Controlling the prosthesis had a learning curve and was hard to control at times, especially for fine motor movements
Sensory Feedback - how well the prosthesis conveys the sense of touch to the user (8)	6	Vibration from motor was the only sensory feedback
Total (Max 640)	464	

Discussion

- A functional, modular, durable, comfortable, and cost-effective prosthesis was prototyped
- In the field, this project introduces a new, modular myoelectric
- Functionality trials inspired by by Zhu et al. (2022)
- Future work: implementing better sensory feedback, other materials
- Limitations: quality of the 3D printing and quality of the Arduino parts

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