P5: Portable Printed Pneumatic Pediatric Prosthetic

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Problem Statement / Research Question and Background

The need for a prosthetic arm fit for children is more prevalent than one might imagine. The Centers for Disease Control and Prevention estimates that approximately 1,500 babies are born with upper limb reductions every year\(^1\). Limb deficiencies affect roughly around 4,500 children yearly, with congenital limb deficiency twice as prevalent as traumatic amputation. Children with limb deficiencies have a greater need for prostheses than adults because the prostheses aid in the proper development of motor learning, muscle development, and neuroplasticity of the remaining limb. However most devices available in the market only meet the requirements of adults and even when the prosthetic arm for children is available, the burdensome price may act as a major deterrent for adolescents who require the changing of the prosthetic arm every few years due to natural growth.

This project aims to deliver a lightweight, water-resistant, and affordable externally powered prosthetic arm for children. The device will deliver enough grip strength and precision to carry and hold most objects encountered in daily life. The device will be shock and water-resistant to promote daily usage. The device will have easily removable components, allowing for only the casing of the device to be reprinted and replaced while preserving the electrical components. This will not only simplify and expedite the resizing process, but also reduce the resizing cost significantly by eliminating the need to purchase a new device to sustain bodily growth.

Methods / Approach / Solutions Considered

Table 1. Design Alternatives Summary

<table>
<thead>
<tr>
<th>Design Alternatives</th>
<th>Actuator</th>
<th>Control Mechanism</th>
<th>Power Source</th>
<th>Casing Material</th>
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<tbody>
<tr>
<td>Servo</td>
<td>Myoelectric</td>
<td>9 Volt Battery</td>
<td>Wood</td>
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<tr>
<td>Stepper Motor</td>
<td>Targeted Muscle Re-innervation</td>
<td>Lithium Ion</td>
<td>Leather</td>
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<td>DC Motor</td>
<td>Switch</td>
<td></td>
<td>Aluminum</td>
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<tr>
<td>Linear Actuator</td>
<td>Force Sensor</td>
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<td>Steel</td>
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<td>Mckibben Air Muscle</td>
<td>Touch Sensor</td>
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<td>Titanium</td>
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<td></td>
<td></td>
<td></td>
<td>Magnesium Alloy</td>
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<td>Thermoplastic</td>
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Materials and components that are easily accessible to build the device were classified and evaluated in four main categories: actuator, control system, power source, and casing. The actuators are most responsible for the grip strength and speed, and the control medium is critical in accurately determining the desired movement and it determines how long the patient will take to learn to use the device. The power source is closely related to safety of the device and its battery life. Lastly, the prosthetic housing will determine the resizing cost, aesthetics, and durability of the device.

Of the alternative summarized in Table 1, different combinations of control systems and actuators were considered. The first set of control system and actuator studied is myoelectric control system with servos. A myoelectric control system is regarded as one of the more suitable options for the device because 1) it is more natural than switches, which require the user to manually turn the device on or off, 2) switches lack feedback processing during motion and 3) the activation of force or touch sensors require patient’s ability to move her arm within a socket. However, a silicone sleeve acts as a barrier between the socket and the patient’s arm, preventing direct signal and making it difficult to use touch or force sensors to be used in this design. Also, myoelectric platform paired with servo suffers from weak grip strength, heavy weight, and loosening of servo strings that pull the fingers close when used regularly.

A second approach is a myoelectric system with air muscles. The advantages of this alternative include water resistance, light weight, and relatively low cost. However, this design requires a CO₂ tank to fill the muscle with air, posing a potential risk of explosion or rupture.

A third option involves combining two types of control systems: a myoelectric system with a system of switches. This design attempts to separate two different types of motions that the device aims to perform: opening and closing of the hand and wrist rotation. This alternative reduces the complexity of algorithm, thereby increasing the speed of the information processing and accuracy of onset timing of the prosthetic arm movement. A myoelectric system regulates opening and closing movements while the switches control wrist pronation and supination – considered to be supplementary to gripping objects.

The last design approach uses a hybrid body-powered and externally powered design. A cable would run to the opposite shoulder of the patient and when it is pulled past a certain amount, it will activate the program to open or close the hand. The benefit of this design is that it is easy to implement and control. The activation of an actuating system would also allow for higher grip strength than a normal, purely body powered prosthetic. The downside is that the motion to activate the device is unnatural and requires a long cable and harness. Both of these factors are undesirable by most patients. There would also be no force feedback like that in most body-powered prosthetics.
**Description of Final Approach and Design**

The listed elements were compared and the best option for each of the four actuator, control system, power supply, and casing material categories was decided: myoelectric sensor for control mechanism, air muscle for actuator, lithium battery for power source, and thermoplastics for casing material.

![Mckibben Air Muscle](image)

**Figure 1. Mckibben Air Muscle**

Figure 1 represents a Mckibben air muscle. It is a type of pneumatic, linear actuator that can imitate a force of pull curve as in an activating muscle. The force is based on a silicone tube expanding within a nylon sheath, which constricts the expansion of the muscle and causes the entire unit to shorten.

![Air Muscle System Diagram 1](image)

**Figure 2. Air Muscle System Diagram 1**

![Air Muscle System Diagram 2](image)

**Figure 3. Air Muscle System Diagram 2**

Figure 2 and Figure 3 represent the mechanical design of the air muscle system. It consists of a three-way solenoid, an air muscle, a needle valve, and a regulator containing a CO₂ cartridge connected to the solenoid with an icemaker pipe. The prosthetic design uses normally closed three way valves that block the flow of CO₂ when un-actuated and allow the flow of CO₂ into the air muscle when actuated.
Figure 4 shows the assembly of the prosthetic arm with the Mckibben air muscle and servo.

**Outcome (Results of any outcomes testing and/or user feedback)**

A preliminary air muscle for testing was assembled using a 12cm silicone tube, nylon sheath, a barbed industrial air compressor adaptor, a cylindrical rubber piece, and zip tie. The air muscle was suspended by a clamp to the lab bench and weights of 0.500kg, 0.544kg, and 0.636kg were tied to the lower end of air muscle. The initial position of the muscle was marked with lab tape and the air compressor connected to the air muscle was stepped up in 1kg/cm² intervals. At each interval, the new displacement was measured, recorded, and marked with lab tape.

![Figure 5. Preliminary Air Muscle Test Data](image-url)
Figure 5 shows that the muscle was able to contract at a greater magnitude when the applied air pressure was higher. Also, when comparing the air muscle response to different amounts of loaded weights at the same air pressure, the lighter weights led to smaller displacements. The testing demonstrated that the air muscle can contract more than 1.5 cm at various weights, which is the minimum distance required to make the opening and closing of the hand possible.

Cost (Cost to produce and expected pricing)

Clinicians want a child to wear an active device by 18 months but that is impossible for most because of weight, or more likely, cost. Highly effective pediatric prosthetics do exist but cost up to $100,000, which is too high for a cost to have exchanged two to four times a year to complement bodily growth in children. Our device will not only cost much less ($210.76), but will also be resizazable for about $20 in materials, as only the casing will be replaced with the electrical components preserved. A major factors that reduces the price by such a great amount is the usage of thermoplastic casing material. The cost of 3D printing the casing with thermoplastic is so low that it can be reprinted and sized up with age. Moreover, a thermoplastic such as polypropylene is highly durable and is used in leg prosthetics for its ability to be shaped and absorb shock.

Significance

Prosthetic devices used in rehabilitation processes have undergone major developments recently, but a large number of amputees still express dissatisfaction with the available technology. Factors involved in such rejection include late age of fitting, insufficient training, restricted practicality of devices, and high repair costs. Also, discomfort, heavy weight, and unnatural look as well as “low self-esteem, lack of acceptance of disability [and] unrealistically high expectations regarding prosthetic function” lead to disappointments in its use. Due to these common issues, most children with limb deficiencies, particularly those with congenital reduction, prefer to develop one-handed proficiency to prevent reduction in performance of simply daily activities.

The new prosthetic device aims to increase the retention of prosthetic devices by children in early life and encourage its continuous usage, as it is customizable for each child and sufficiently lightweight to be controlled with ease by children’s relatively weak muscles. Despite the fact that low weight is often associated with minimized function, the new design also maintains enough grip strength to lift objects that children would encounter on a daily basis and also feature advanced precision to pick up differently shaped objects. Moreover, most functional prostheses contain electrical components inside the casing, which have prevented its use in wet environments. Taking into account that most children would want to explore attend sporting activities and recreations, the device is water-resistant and provides comfort wear.
Reference:


