Global Perspective: Do prosthetic limbs really have to cost an arm and a leg? - Exploring the development of an open-source, low-cost operational transradial prosthesis prototype

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Abdul Nafea Zuberi
Mechanical Engineering, Class of 2023
McMaster University

Abdulrahman Hajjaj
Automation Engineering, Class of 2023
McMaster University

Adeel Niaz
Computer Engineering, Class of 2023
Ryerson University

Ahmed Allam
Computer Engineering, Class of 2023
McMaster University

Haashim Shahzada
Biomedical Engineering, Class of 2023
Ryerson University

Hashim Ali
Electrical Engineering and Management, Class of 2023
McMaster University

Mohammed Nigm
Computer Engineering, Class of 2023
McMaster University

Samiuddin Danish Mohammed
Honours Health Sciences, Class of 2023
McMaster University

Yousuf Khilji
Aerospace Engineering, Class of 2023
Ryerson University

Introduction

With the average cost of commercially available prosthetics ranging from $4,000 to $75,000 CAD[1], the inaccessibility of these essential devices is prevalent. Production expenses of the various prosthesis types required for each individual's functional needs will only continue to increase in coming years. This is one of the many factors that contributes to the history of health inequity affecting people with disabilities, specifically physical disabilities, in the Canadian healthcare system. Prosthesis coverage across the country is highly variable and many individuals are forced to rely on personal resources, fundraising, or contributions from non-governmental organizations in order to meet this basic healthcare need. Several studies conducted by the Institute for Research on Public Policy and Statistics Canada support the fact that individuals living with a disability are more likely to be unemployed, have lower median incomes, and are less likely to graduate with a university degree than persons without a disability, further contributing to this disparity.[2, 3] As a team, we intend to address the lack of accessibility to low-cost prostheses by establishing Brachïum, a humanitarian initiative focused on creating an affordable, 3D printed, open-source transradial prosthesis prototype that could eventually be distributed to marginalized communities to increase their quality of life.

Personal Experiences and Health Topics

Starting Brachïum

The idea was sparked when over the last few years, some members of our initiative volunteered with SMILE Canada to help support Muslim youth with disabilities and their families. During this time, we had several first-hand experiences working with children who had physical disabilities requiring prostheses. The SMILE Canada organization has sponsored over 180 financial assistance scholarships within the last year to support youth with disabilities belonging to diverse Muslim communities including refugee and new immigrant families. Their vision is to ensure that all children are provided with the resources and support network for a happy, healthy lifestyle. While volunteering with this organization we had the chance to become involved in the mentorship program where we developed meaningful relationships with our SMILE mentees and learned more about their personal stories and experiences.

As we continued to hear the stories of our SMILE mentees, we noticed how many of the families that were supported by the organization had a hard time affording high-quality assistive devices. As we learned more about the societal and financial barriers associated with physical disabilities, we realized how inaccessible these devices could be. With some prostheses costing as much as $75,000 CAD[1], many families are unable to afford the immense price tag and do not benefit from using them. We saw first-hand how this creates a barrier that prevents many children who require these devices from receiving them, which served as inspiration for our group of engineering and health sciences students. Together, we decided to create the Brachïum humanitarian initiative, an effort that focuses on increasing the accessibility of prostheses and filling the gap in the healthcare system.

Manufacturing the Prostheses

Through research, we discovered that by using manufacturing techniques such as 3D printing and the use of open-source electronics, the cost of a prosthetic could be significantly reduced.[4,5] Our goal was to create custom Computer-Aided Design (CAD) models that would make both assembly and repairs easy to conduct. Furthermore, to calibrate the function of the arm to each user we decided to go with open-source microcontrollers that would take analog electromyography (EMG) signals and convert them into digital pulse-width modulation signals used to control the movement of the arm.

Our CAD models were made and assembled in an online cloud platform known as Onshape. Onshape has 2D sketching and 3D modelling tools that allow users to create complex parts that can be arranged and exported using the online service provided by the company. Our models were designed to be assembled using parts that are commonly available in hardware stores for ease of access. Through countless test prints and multiple revisions of the CAD models, we were able to come up with an efficient and functioning design. After we finished developing our models, they were exported as high-quality STL files (3D models) and imported into a 3D Slicer program known as Ultimaker Cura. Cura is a software that allows users to configure CAD models for 3D printing and customize infill and layer settings for their 3D printing environment. Additionally, Cura acts as the program that converts STL files to G-Code in preparation for the print. G-Code, a language used to control many automated machines, is then processed by the 3D printer which converts it to x, y and z coordinates and prints out the models layer by layer.

These models were designed to work simultaneously with the open-source electronics previously mentioned. Specifically, our prosthetic arm uses an Arduino UNO microcontroller in combination with a Myoware EMG sensor, PCA9685 servo driver board and five SG90 servo motors. Using C++, we coded a program that runs on the Arduino UNO and is constantly checking the sensor for EMG voltage signals coming from a muscle. The EMG sensor is placed on the bicep of the user at the middle of the muscle body and aligned with the orientation of the muscle fibers to increase the accuracy of its readings.[6] The program averages out the last 20 values it receives and based on that, sends commands to another function in the code that angles the servos to control which fingers move. Once the code is sent to the servos, a high tensile strength wire previously in tension is put on an increased strain. This strain value is attained using a predetermined scale that analyses tension compared to resulting flexion. These steps all occur in sequential order starting from the reading of the EMG values to move the prosthesis calibrated to each separate individual.

Using these production steps, our completed prototype is capable of flexion/extension, abduction/adduction and circumduction in multiple planes of movement at the metacarpophalangeal, interphalangeal and radiocarpal joints. Additionally, our prosthesis benefits from low latency and a lightweight design at a combined weight of under 2 lbs. The total production cost of the prosthesis device was approximately $83 CAD including all costs associated with the 3D prototyping and manufacturing of the device. With this in mind, in comparison to the high costs of other prosthesis devices, the Brachïum initiative introduces an economical and open-source alternative to modern-day assistive devices.

Conclusion and Future Steps

With the rate of amputees projected to double by 2050, our open-source prostheses aims to address a crucial gap in the local and global healthcare industry.[7] In the first phase of Brachïum's future plan, the prototype will be piloted and design/assembly instructions will be uploaded to an open-source website to provide users worldwide with access to the files. Additionally, Brachïum plans on medically licensing our prostheses as a type 2 medical device through Health Canada to commence the distribution of the arm. Eventually, we also intend to have the production and delivery of the prostheses subsidized by fundraising campaigns to help distribute them in an effort to improve the quality of life for those in need. Our end goal is to turn Brachïum into a licensed worldwide NGO focused on lowering the disparity in the healthcare system through custom engineered low-cost medical devices.

This plan was created while carefully considering our manufacturing process thus far. When planning out future steps, it is critical for us to understand the minutiae that have to be taken into account in the design process. Considering the functionality of the product while limiting size, weight and other complexities were crucial in our goal to ultimately lower production time and material cost. With these constraints, it will be crucial to continuously research and develop creative modifications in future iterations of the prosthesis, especially as the global healthcare industry continues to evolve.

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References

1. Ku I, Lee GK, Park CY, Lee J, Jeong E. Clinical outcomes of a low-cost single-channel myoelectric-interface three-dimensional hand prosthesis. *Arch Plast Surg*. 2019;46(4):303–10. Available from doi:10.5999/aps.2018.01375.
2. IRPP. *Poverty dynamics among vulnerable groups in Canada* [Internet]. Available from: https://irpp.org/research-studies/poverty-dynamics-among-vulnerable-groups-in-canada/ [cited 2021 Sep 17].
3. Government of Canada SC. *The association between skills and low income* [Internet]. 2016 [cited 2021 Sep 17]. Available from: https://www150.statcan.gc.ca/n1/pub/75-006-x/2016001/article/14322-eng.htm BBDCD241ABPQ/1?accountid=13631 [cited 2021 Sep 17].
4. Koprnicky J, Šafka J, Ackermann M. Using of 3D printing technology in low cost prosthetics. MSF. 2018;919:199-206. Available from doi:/10.4028/www.scientific.net/MSF.919.199.
5. Argueta-Diaz V, Spitzfaden CJ, Basso D, Ayers HL. Evaluation of a low cost prosthetic hand controlled by surface EMG sensors and vibrotactile feedback. International Journal for Service Learning in Engineering. 2018;13(2):69-78. Available from doi:10.24908/ijsle.v13i2.12816.
6. Advancer Technologies. 3-lead muscle/electromyography sensor for microcontroller applications [Internet]. 2016. Available from: https://github.com/AdvancerTechnologies/MyoWare_MuscleSensor/raw/master/Documents/AT-04-001.pdf
7. C O'Neill. An advanced, low cost prosthetic arm. 2014 IEEE SENSORS. 2014;494-498. Available from doi:10.1109/ICSENS.2014.6985043.
8. Mercer JA, Bezodis N, DeLion D, Zachry T, Rubley MD. EMG sensor location: Does it influence the ability to detect differences in muscle contraction conditions? *J Electromyogr Kinesiol.* 2006 Apr;16(2):198–204. Available from doi:10.1016/j.jelekin.2005.07.002.
9. Schweitzer W, Thali MJ, Egger D. Case-study of a user-driven prosthetic arm design: bionic hand versus customized body-powered technology in a highly demanding work environment. Journal of NeuroEngineering and Rehabilitation. 2018 Jan 3;15(1):1. Available from doi:10.1186/s12984-017-0340-0
10. Salem FHA, Mohamed KS, Mohamed SBK, El Gehani AA. The Development of Body-Powered Prosthetic Hand Controlled by EMG Signals Using DSP Processor with Virtual Prosthesis Implementation. Conference Papers in Science. 2013 Jun 16. Available from doi:10.1155/2013/598945

Photographs and/or Images

Computer-Aided Design (CAD) Models

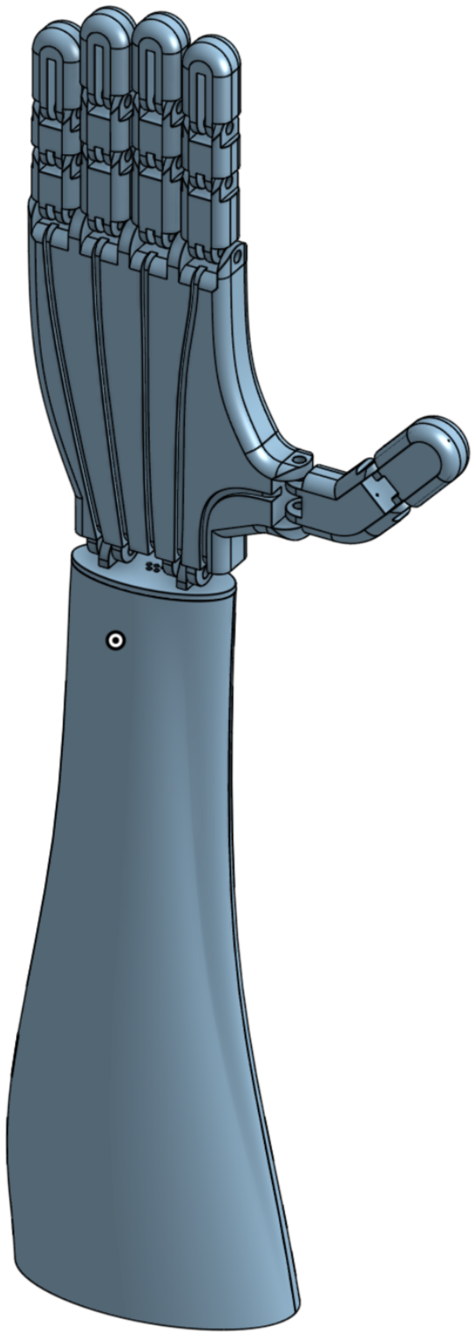

Figure 1. Isometric view of transradial prosthesis prototype (full forearm and hand)

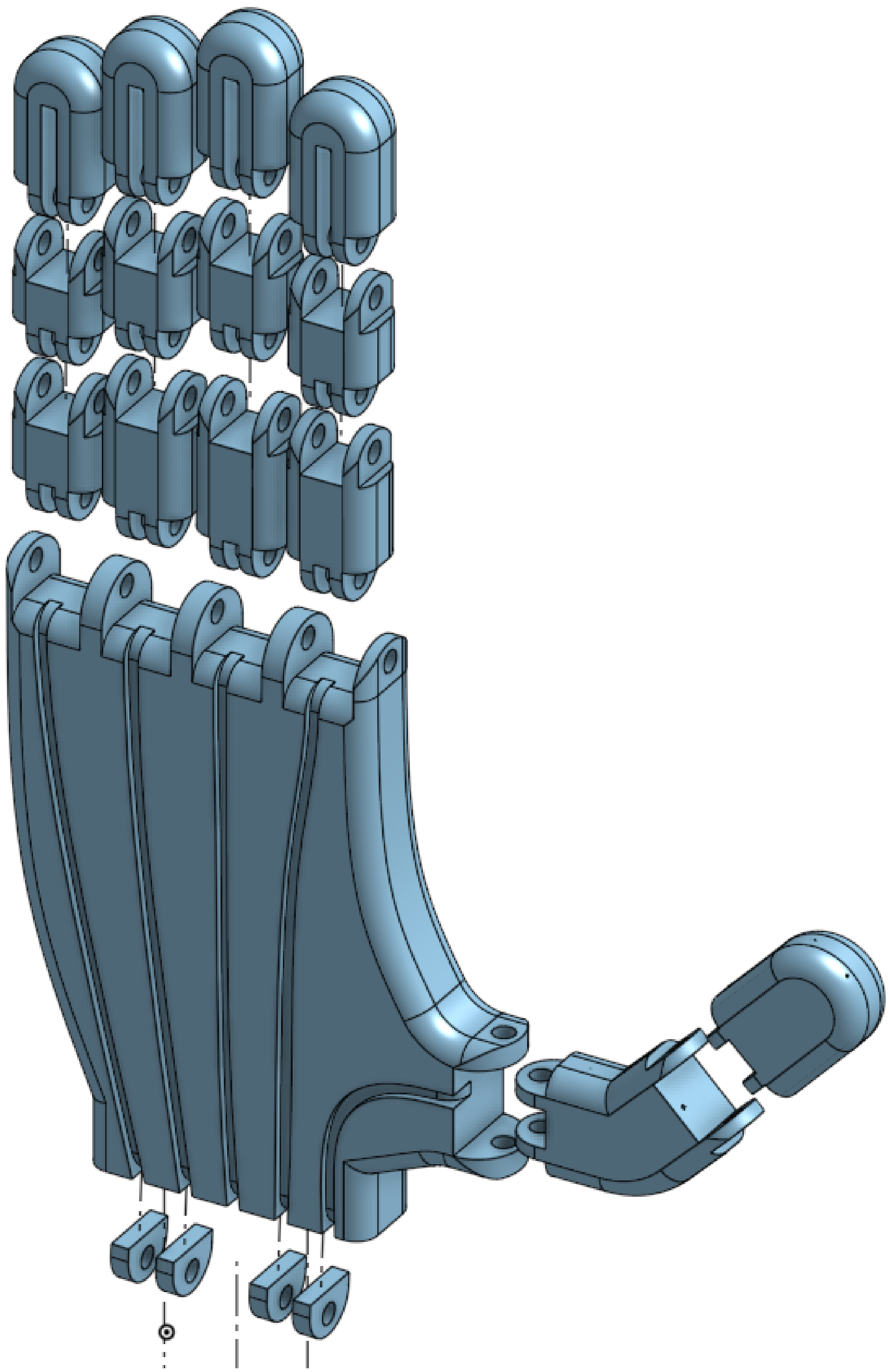

Figure 2. Exploded, dorsal view of transradial prosthesis prototype (hand)

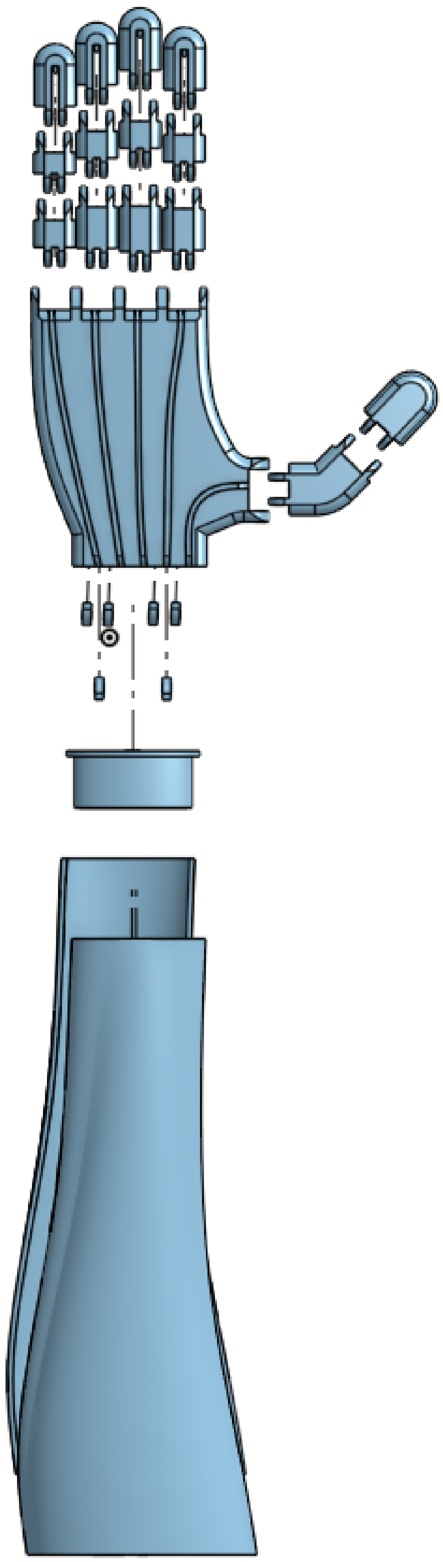

Figure 3. Exploded, palmar view of transradial prosthesis prototype (full forearm and hand)

Assembled Model

Figure 4. Deconstructed model of electrical and mechanical components (full forearm and hand)