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Proposed Design for Adjustability: Body Powered Prosthetic Hand

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Abstract

This paper proposes the integration of the adjustability concept when designing for humans into an existing body-powered prosthetic hand especially designed for the Symbrachydactyly abnormality population. Adjustability would accommodate a range of changes in hand size resulting from hand growth, especially at early stages of age. This accommodation would reduce frequent prosthetic hand changes and associated burdens. The proposed design is based on splitting the palm of an existing design by e-NABLE and using three connecting pieces of three different sizes to join the split palm. The connecting pieces sizes are based on the sizing guide by Unlimbited Phoenix to allow for changing the prosthetic hand size. The developed design must be inspected for functionality and comfort, while satisfying adjustability requirements due to hand size increases. The integration of adjustability into the design of a body-powered prosthetic hand for the Symbrachydactyly population would characterize a significant advancement in personalized prosthetic solutions. The proposed design exemplifies a thoughtful engineering solution tailored to meet the unique needs of its users. This research emphasizes the importance of user-centered design in prosthetic development, paving the way for more adaptable and sustainable solutions that empower individuals with limb differences to lead more active and fulfilling lives.

Keywords
Adjustability, Designing for Humans, Prosthetic Hand and Symbrachydactyly.

1. Introduction
Congenital upper limb anomalies are prevalent worldwide. Additionally, around 2 million people worldwide live with upper limb amputations due to various causes such as accidents, diseases, and military conflicts. According to the World Health Organization, approximately 1 in 1,000 babies are born with hand deformities. Such a prevalence emphasizes the need for advanced prosthetics. The human hand is one of the most significant and complex human organs and functionally essential for work and leisure. It functionally interfaces with the surrounding environment more than any other anatomical unit. Full or partial loss of functionality of a hand or both hands reduces the capability of performing work and other daily activities, leading to lower quality of life and job loss.

One type of partial hand functionality loss is called brachydactyly which is a birth defect resulting in short fingers. A subgroup of those with this defect have what is called Symbrachydactyly. This is a rare congenital hand condition with a morbidity of 1 out of 32,000 births. This condition is where the hand fingers are abnormally short and conjoined. Symbrachydactyly has three levels of severity: 1) short finger symbrachydactyly, 2) monodactylous/bidactylous symbrachydactyly, and 3) adactylous/peromelic symbrachydactyly.

Scientists in the field of prosthetics have been actively developing substitutes for lost hands. These substitutes can substitute functionally and cosmetically original natural hands. Those substitutes may restore some natural hands' functions and aesthetics. Three types of prosthetic hands are available, namely: 1) passive or cosmetic hands, 2) Myoelectric hand prostheses, and 3) body-powered prosthetic hands.

The body-powered prosthetic hand, which is the focus of this research, uses a harness system attached to the forearm that enables the wearer to manipulate the prosthetic hand by flexing their short-conjoined fingers to control mechanically the grip action of the prosthetic hand by pulling the cables. The advantages of the body-powered prosthesis are their low or no maintenance requirements, less training time, and low affordable price, making them an ideal choice for symbrachydactyly and partial hand amputations in general.

According to the World Health Organization (WHO), only 1 in 10 people in need has access to assistive products, including prostheses and orthoses, because of their high cost and lack of awareness, availability, trained personnel, policy and financing. Efforts aligned with WHO's global initiative, "Global cooperation on assistive technology" (GATE), to improve access to high-quality, affordable assistive products, are a necessity. Any contribution to the development of assistive products, including prostheses and orthoses, for making them available to everyone who needs them.

The current prosthetics do not adapt to the child population's normal growth, requiring frequent visits to health care providers for adjustments or replacements, which may cause abandonment. Accordingly, this paper proposes an adjustable design for the body-powered prosthetic hand specific to the Symbrachydactyly population to accommodate a broad range of ages from 3 to 16 years, to cut down on costs associated with frequent size changes. The adjustability concept is integrated into an existing body-powered prosthetic hand to accommodate a range of sizes of hands with Symbrachydactyly abnormalities.

The original design used in this research is the "Unlimbited Phoenix Hand" by e-NABLE. People from all over the world can use and 3D-print their prosthetic hands from this online community. The designs are created by e-NABLE volunteers to help people with upper limb amputation, and they design for 3D-Printing which manufactures complex details at low cost. The Unlimbited Phoenix design is provided with a sizing guide sheet to help the user decide on the 3D printing scale. This ranges from 100% (base size at the age of 3 years) scaled up to 145% (at the age of 16 years) and is determined by the width of the palm and the length from the finger to the half of the forearm. The sizing guide has 10 sizes with a 5% difference between each two consecutive sizes. The design consists of seven components: 1) Thermo-formed gauntlet, 2) Palm, 3) Distal phalanges, 4) Proximal phalanges, 5) Tensioner block, 6) Pins, and 7) Caps, as presented in Figure 1.

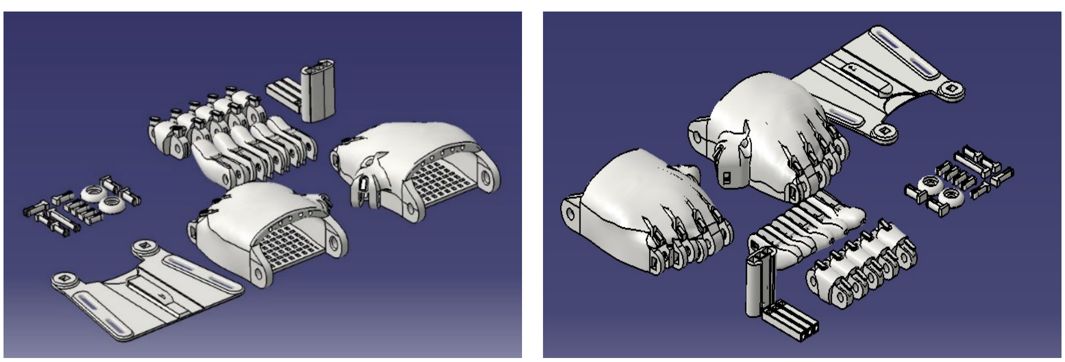


Figure 1. Prosthetic hand components

2. Methods

The proposed design is based on splitting the palm of the original design by e-NABLE and using three connecting pieces to allow for changing the size of the prosthetic hand to reduce the need for changing the whole prosthetic hand during its projected lifetime Figure 2.

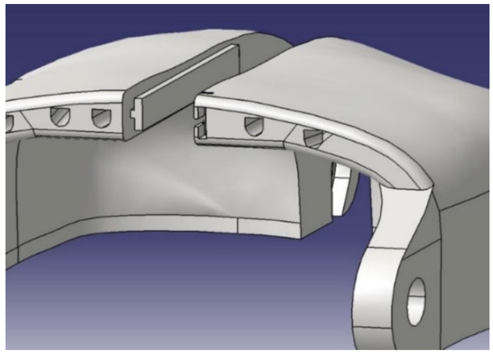


Figure 2. Split palm of the original design

Additionally, it reduces the need to conduct excessive measurements. The connecting parts have three different sizes based on the sizing guide by Unlimbited Phoenix. This originally had 10 different prosthetic hand sizes. These 10 sizes were divided into three ranges: 1) 100% to 115%, 2) 115% to 130%, and 3) 130% to 145%. This resulted in 3 different sizes of the connecting part as presented in Figures 3, 4, 5 and 6. Each connecting part is a T-beam combined with a T-slot to assure a secure and durable connection of the two separate parts of the hand. The three parts have the same length and width of 39 mm and 6.2 mm respectively. This is to comply with the original size of the split palm part of the prosthetic hand. The heights of the three connecting parts, which add width to the split palm incrementally, are 2.76 mm, 5.52 mm, and 8.28 mm respectively. These values correspond to a 15% increase in palm width each. Figure 6 illustrates the lock part to prevent adjustability parts from disassembling. The proposed design provides adjustability to the width of the prosthetic hand. In addition, the palm length is the maximum size to serve all users within the range of widths. The fingers size and the gauntlet size are the average size for each range. The lower fixed layer of the palm (from the original design) is replaced with Velcro to hold the bottom of the hand while the width changes.

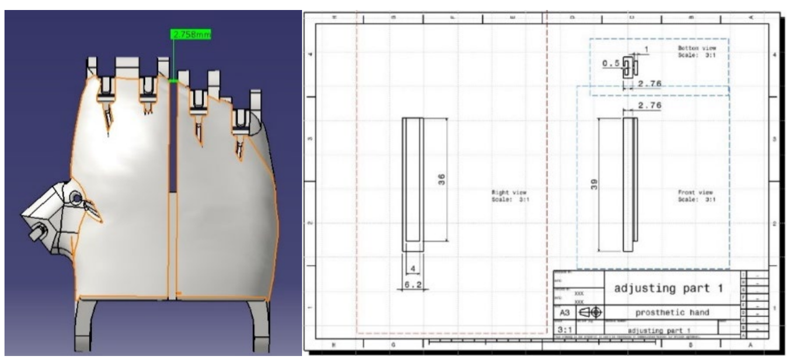


Figure 3. Joining part 1

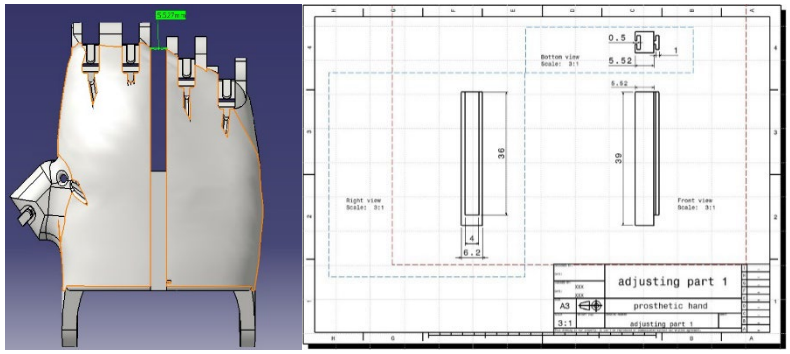


Figure 4. Joining part 2

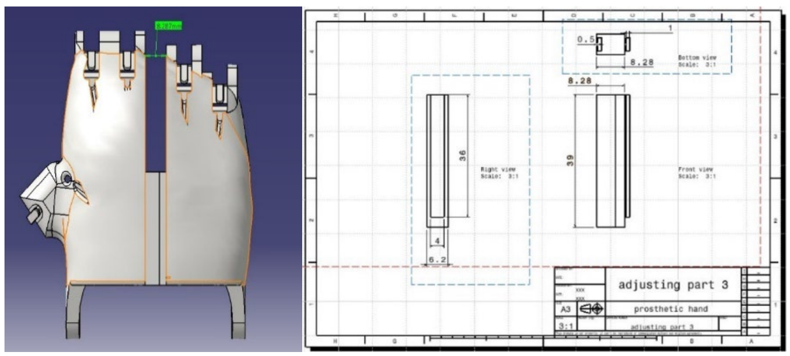


Figure 5. Joining part 3

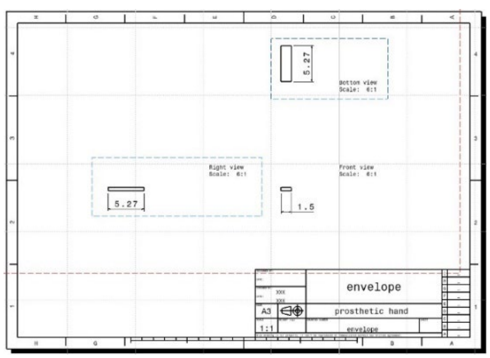
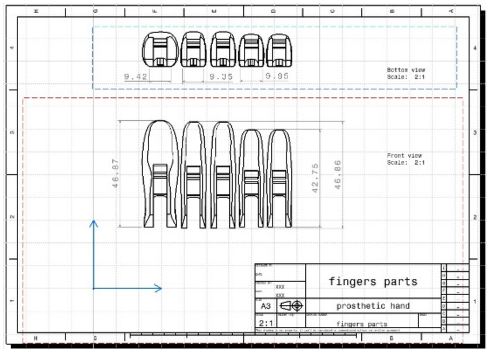


Figure 6. Lock part

Figure 7 demonstrates the five fingers associated with the first size of the connecting part (which adds 15% to the original width). The size of these fingers is 107.5% of the base prosthetic hand size, which is the average size at the first adjustability stage. Both the binky and index fingers have the same length and width, while both the middle and ring fingers have the same length and width.



Figures 7. The prosthetic hand five fingers

Figure 8 demonstrates the gauntlet that aligns with the forearm to assure hand stability and hold the tensioner while using it. Figure 9 demonstrates the location to attach Velcro to both the right and left sides of the split palm to assure fixation. Velcro replaces a rigid bottom layer of the original size palm to accommodate the adjustability features.

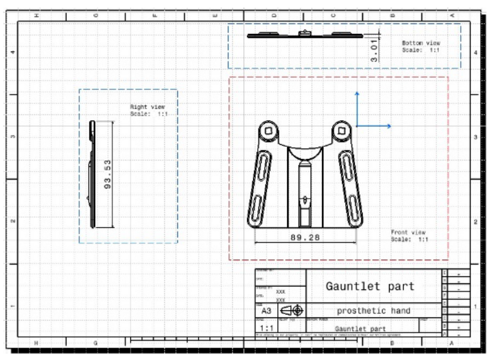


Figure 8. The gauntlet

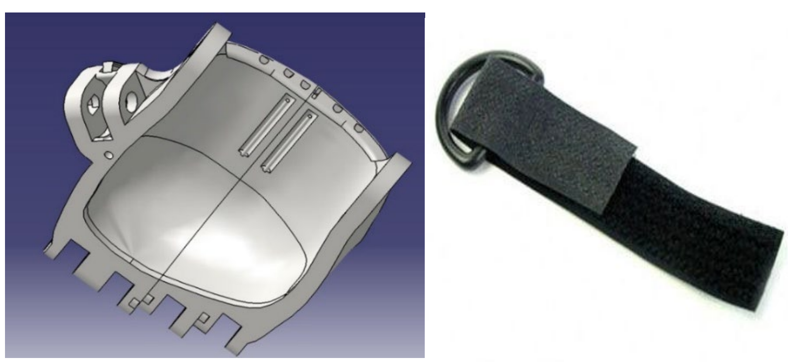


Figure 9. Prosthetic hand five fingers

Figure 10 demonstrates the tensioner block used for holding the connecting nylon cords and adjusting the tension in these connecting cords. The gauntlet slot is where this part is installed.

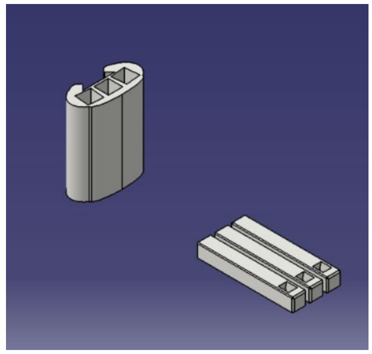
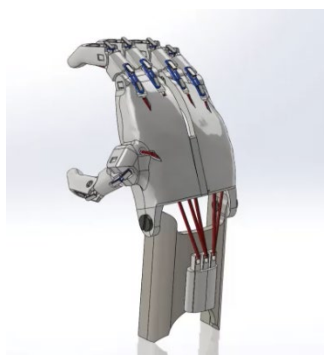


Figure 10. Tensioner block

Figure 11 demonstrates the 3D-view of the fully assembled prosthetic hand as an initial idea that this new design is applicable.



Figures 11. Fully assembled prosthetic hand

Having developed the adjustable design, it should be examined for functionality and comfort as the original design. In addition, it should satisfy the adjustability requirements due to the increase in hand size. As part of the testing methodology, objective and subjective assessment should be undertaken to validate that the proposed design is functional as expected.

3. Conclusion

The integration of adjustability into the design of a body-powered prosthetic hand for the Symbrachydactyly population would characterize a significant advancement in personalized prosthetic solutions. By accommodating variations in hand size that occur during critical growth phases, this innovative approach would alleviate the logistical and emotional burdens associated with frequent prosthetic changes. The proposed design exemplifies a thoughtful engineering solution tailored to meet the unique needs of its users. Future work should focus on rigorous testing to ensure that the design meets essential functionality and comfort standards while fulfilling its adjustability requirements. This research emphasizes the importance of user-centered design in prosthetic development, paving the way for more adaptable and sustainable solutions that empower individuals with limb differences to lead more active and fulfilling lives. Ultimately, the success of this initiative could serve as a proposal for future prosthetic designs across various applications, encouraging further innovation in creating adaptable, responsive, and user-friendly devices.

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Biography

Tamer M. Khalaf is an Assistant Professor with the Department of Industrial Engineering, King Saud University, Riyadh, KSA. He earned B.S. in Mechanical Engineering from Al-Azhar University, Cairo, Egypt, in 1994, an M.S. degree in Industrial Engineering from the University of Louisville, Louisville, KY, in 2004 and a Ph.D. in Industrial Engineering from the University of Louisville, Louisville, KY, in 2007. From 1994 to 2000, he was a Teaching Assistant with Al-Azhar University and from 2000 to 2007, he was a Research Assistant with the Center for Industrial Ergonomics, University of Louisville. From 2008 to 2011, he was an Assistant Professor with the Department of Mechanical Engineering, Al-Azhar University, Cairo, Egypt. Since 2011, he has been an His research interests include human responses to both physical and mental workload, human performance, workplace design, work environment design and design for disability.