Habdil - Development of an adaptive and affordable partial hand prosthesis using 3D printing

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Abstract. This paper introduces the design and development of an adaptive hand prosthesis that incorporates flexible materials and advanced sensors to improve user functionality and comfort. This prosthesis is designed for individuals with partial hand amputations, enabling better control and ergonomic integration with the natural hand anatomy. The methodology used for the design, simulation, and validation of the prototype is presented, as well as preliminary tests carried out in controlled environments.

Keywords: Prosthesis, ergonomics, design, disability, amputation, finger, partial, modular, 3D printing, rehabilitation, prototype, mechanical, flexible mechanism.

1 Problem Description

1.1 A Subsection Sample

In Mexico, out of approximately 128.5 million inhabitants, 9.25 million people have some form of disability, 17.3% of whom experience difficulties in moving or using their arms or hands. In Jalisco, which has a population of 8.82 million, around 96,333 people face challenges with arm or hand mobility, according to INEGI reports [1].

Current upper limb prostheses are often expensive, complex, and poorly adapted to users, particularly in cases of partial hand amputations. While full-arm prostheses have been extensively developed, solutions for partial hand amputations remain limited, especially in terms of functionality and affordability. Additionally, 31% of Jalisco's population lacks access to medical services [2], further restricting their ability to obtain advanced prosthetic technology and participate in rehabilitation programs.

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There is a pressing need for affordable and customizable solutions, such as a modular partial hand prosthesis that offers optimal user support, enabling them to perform daily tasks and reintegrate into the workforce, ultimately improving their quality of life.

Figure 1. Population aged 5 years and over with disabilities, by activity with difficulty and by sex, 2023)

It refers to people who have the answer "He does it with great difficulty" or "He cannot do it" in each of the activities for which the question is asked. Note: The sum of the percentages by sex is greater than 100 because a person could report difficulty in more than one activity. The percentage is calculated with respect to the total population with disabilities for each sex. Source: INEGI. National Survey of Demographic Dynamics (ENADID), 2023. Database. National Statistical and Geographic Information System (SNIEG). Information of National Interest (IIN). [1].

1.2 Concept

The partial prosthesis is designed to operate in two modes: a purely mechanical mode that requires no power and a hybrid mode activated by electromyography (EMG) sensors, allowing for more natural control that enhances the user's independence. This system promotes intuitive and adaptive control, making the prosthesis more user-friendly.

The goal is to develop a customizable, adaptable, and easily adjustable prosthesis featuring modular components, such as interchangeable and durable attachments. This flexibility enables the prosthesis to be tailored to users with varying degrees of finger loss.

The design is inspired by the assembly of 3D-printed components integrated into a fabric or leather base, ensuring that the device can be easily worn and removed. This concept draws from the ergonomics and functionality of medieval bracers or gauntlets. The goal is to create a customizable, adaptable, and easily adjustable prosthesis featuring modular components, such as interchangeable and durable attachments. This flexibility allows the prosthesis to be tailored to users with varying degrees of finger loss.

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The proposed prosthesis aims to significantly enhance the quality of life for individuals with disabilities. This functional and affordable solution addresses the need for assistive devices that are not only cost-effective but also adaptable to different anatomies and work environments.

Its intuitive design, which combines myoelectric sensors with mechanical control, enables users to perform daily activities and participate in professional settings with greater autonomy, fostering both social and economic reintegration.

The project's open-source approach enhances accessibility by allowing healthcare professionals, engineers, and organizations to collaborate on improving and customizing the design for specific regional and individual needs. This initiative democratizes access to medical technology while also encouraging continuous innovation and scalable solutions to address the challenges of prosthetic accessibility in underserved communities.

1.3 Market competition:

Arm prostheses in Mexico range in price from 10,000 to 500,000 Mexican pesos or more, depending on the model and functionality. More advanced and sophisticated prostheses tend to be significantly more expensive, while simpler, more basic models are generally more affordable [3].

There are several companies in Mexico specializing in upper limb prosthetics, but most focus on transulnar or full-arm amputations. In contrast, finger prostheses are primarily aesthetic, offering limited movement and load-bearing capacity.

1.4 Product differentiation

The primary mission of this product is to enhance user self-sufficiency by providing a functional and adaptable solution that restores mobility and dexterity for essential daily activities. By offering a combination of mechanical and myoelectric control, this prosthesis allows users to perform routine tasks with greater ease and confidence.

Additionally, the design aims to facilitate workforce integration, empowering individuals with partial hand amputations to engage in professional environments and skilled labor without the limitations imposed by traditional prosthetic devices. By promoting greater autonomy and independence, this prosthesis contributes to improving users' overall quality of life, enabling them to fully participate in social, economic, and personal development activities.

1.5 Sustainable Development Goals (SDGs)

This project aims to meet some of the Sustainable Development Goals in the following ways:

SDG 3: Health and Well-being: The project has the potential to improve the quality of life of people with partial amputations by providing them with a functional tool that restores motor skills and promotes their physical and psychological well-being.
SDG 9: Industry, Innovation and Infrastructure: It incorporates electromyography sensors and 3D printing to promote research and development of accessible and customizable prostheses.
SDG 10: Reduced Inequalities: Offering an accessible and functional prosthetic solution can help reduce inequalities by empowering people with disabilities, allowing them to fully participate in society and the labor market.
SDG 12: Responsible Production and Consumption: Promotes the efficient use of resources and reduces environmental impact with sustainable materials and additive manufacturing.
SDG 17: Partnerships to Achieve the Goals: A project of this nature allows for collaborations between researchers, designers, engineers and health professionals, strengthening alliances for innovation and inclusive development.

1.6 Reduction to practice

Currently, a prototype of the prosthesis has been developed using a public domain model as a template [4]. A custom socket was added by editing it with Blender software, using the scanned stump as a reference and guide to ensure a precise fit for the user (Fig. 2). 3D printing has proven to be highly efficient in terms of material usage. The solid parts are made of PET-G, which exhibits remarkable resistance to wear and tear, even after more than a year of use. The joints in the wrist and phalanges were printed with TPU, allowing the prototype to incorporate a compliant mechanism activated by wrist flexion. This feature enhances the ability to grip large objects, such as glasses, bottles, and boxes, and facilitates holding items that require the support of both hands.

The only component that requires regular maintenance is the fishing line (hemp), which acts as tendons and needs to be replaced approximately every two months due to wear. One of the main challenges to address is properly sizing the anatomical proportions to ensure the device does not exceed the dimensions of the user's hand. Another key objective is to enable finger articulation, allowing for individual movement, which is currently being evaluated for practicality using the author as a test subject.

These tests include validating ergonomics, assessing the functionality of the hybrid system (mechanical and myoelectric), and evaluating ease of use. The 3D-printed components have demonstrated a good balance between cost and durability, while the integration of EMG sensors has enabled basic motor control testing. Initial iterations have focused on optimizing the design's adaptability to anatomical differences and everyday tasks, yielding promising results in terms of comfort and control. Additionally, efforts are underway to improve documentation and refine the design, facilitating the replication of the model within communities of interest.

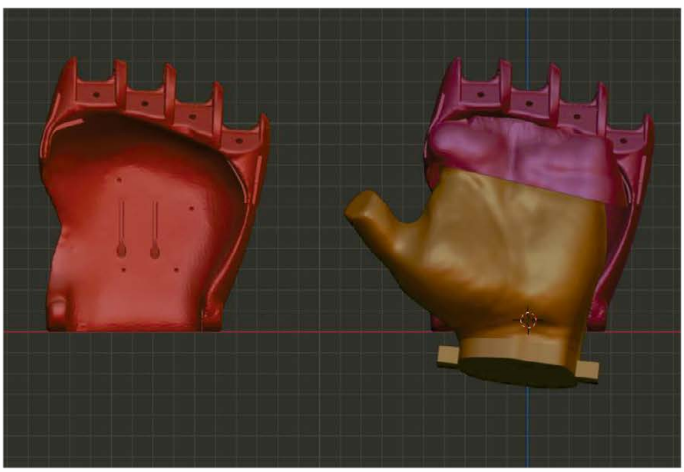

Fig. 2 Screenshot of the unedited open source model next to the version with the socket and the scan from the test subject user.

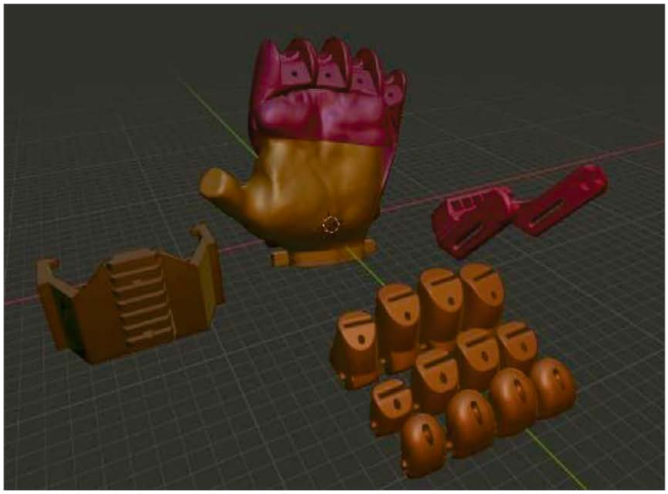

Fig. 3 Screenshot of all the prototype parts in Blender.

Fig. 4 Photo of the prototype in use based on the test subject.

1.7 Pathway to implementation

1. Strategic collaborations: With the support of the Inventors Laboratory, CyberTIM-Lab, BioTimLab (from CUCEI UdeG) and the Innovation Laboratory (LIN) of the Zapopan government, there are facilities where there is advice, linkage and various equipment, specialized equipment for manufacturing (3D printers, laser cutters, etc.)

and testing of the device. These alliances will also facilitate clinical validation with real users.

2. Design optimization: Based on current tests, we will continue to iterate on the design to improve its functionality, comfort and efficiency in manufac-turing.

3. Accreditation and testing: Through strategic collaborations with institutions that promote community support, tests will be carried out with different users who meet the user profile to validate the effectiveness and impact of the project.

4. Distribution and accessibility: Publishing the design as open source will ensure that communities, professionals and institutions can access the project and adapt it to their needs.

1.8 Conclusion.

A design that enables users to experience the seamless functionality of a tool, as effortlessly and discreetly as putting on a glove, represents a significant step toward fostering the reintegration of individuals with functional diversity into various aspects of daily life. Often, these individuals face challenges not only in physical functionality but also in societal perceptions that can lead to exclusion from certain activities. By prioritizing comfort, accessibility, and intuitive usability, such a device has the potential to break down barriers and redefine the relationship between assistive technology and personal empowerment. Furthermore, with the correct implementations, this innovation serves as a crucial bridge between rehabilitation technology and bioengineering, demonstrating how advancements in material science, sensor integration, and ergonomic design can converge to create solutions that are not only functional but also enhance the user's overall quality of life. Beyond its technical merits, this approach highlights the importance of human-centered design in medical and assistive technologies, emphasizing that true progress in the field comes not just from improving mechanical efficiency but from fostering dignity, independence, and social inclusion.

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