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Investigation of 3d Printing Techniques for Fabrication of Customised Prosthetic Limbs

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Abstract

Losing a limb can lead to profound emotional and functional challenges for those affected. For many users of upper limb prosthetics, finding a balance between comfort and appearance is crucial. By precisely replicating the size and shape of an amputated limb using 3-D printing and silicone casting, this article seeks to introduce a more efficient way to prosthetic creation. In order to accomplish this, we first scanned the CT scans of the patient's unaffected and affected arms. Then, using computer-aided design software, we created the socket and prosthetic arm geometry based on the mirrored shape of the unaffected arm. A child's psychosocial development can be significantly impacted by having access to a prosthetic device. Unfortunately, a lot of kids have trouble getting gadgets that are both aesthetically pleasing and useful because of things like expensive prices, insurance restrictions, the availability of medical care, and worries about usability and longevity.

Keywords: Prosthesis, Durability, Amputated Arm, Socket.

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Introduction

Traditional methods for creating prosthetic sockets mainly involve casting, modifying, and laminating, and they can indeed produce comfortable sockets in a reasonable timeframe. However, feedback from patients has consistently pointed out that discomfort is a major reason for dissatisfaction and even abandonment of prostheses. Amputees often find themselves making multiple trips to specialist clinics because of the plaster casting process, and they can wait anywhere from 2 to 5 weeks to get their socket (Colombo et al., 2010) . A study involving 935 individuals in the U.S. with significant upper and lower limb amputations revealed that, on average, amputees visit clinics about nine times a year. Typically, there's no physical or digital record kept of the cast, and even small manual adjustments can greatly affect how well the socket fits (Sengeh, 2012). This means those plaster molds can't be saved for future reference, leaving little room for correcting any mistakes. If there are irreversible errors, the entire manufacturing process has to start over, which means the patient has to return to the clinic, adding to the inconvenience for everyone involved. From a clinical perspective, replacing a socket involves a lot of labor, takes considerable time, and offers limited financial benefits. When it comes to creating products with a 3D printer, there are certain key parameters that need to be in place to ensure high-quality results in a timely manner. Understanding the various process parameters in 3D printing can really help manage the factors that influence the quality of the final product. The insights gained from analyzing these parameters can serve as a valuable reference for future 3D printing projects, ultimately speeding up the production process. That's why having an optimization method is crucial for identifying the best parameters to achieve quality products in the least amount of time. Some popular optimization techniques include Design of Experiments (DoE) methods like Taguchi, Response Surface Methodology (RSM), Fractional Factorial Design, and Full Factorial Design, along with other algorithm-based approaches. DoE is particularly favored by researchers for designing experiments in the lab, thanks to its reliability. The three core components of DoE are factors, levels, and responses (Jin et al., 2015).

In the past ten years, we've witnessed a remarkable surge in interest surrounding digital manufacturing techniques. In the prosthetics industry, technologies like 3D printing and scanning have become revolutionary. We can now accurately capture the size and shape of residual limbs and existing sockets using 3D scanners, some of which are even reasonably priced, such as smartphone scanning. This eliminates the need for dirty plaster casts and mold disposal. Additionally, a valuable digital record of a patient's limb can be created by saving both the original scans and any later digital adjustments (Sharma, 2014).

The ability to share 3D design models online has sparked a vibrant maker community around the world. After a carpenter lost three fingers in a terrible accident in 2011, there was a global effort to help him regain some of his lost dexterity. In 2012, the world's first 3D-printed upper-extremity prosthesis was made by carpenter Richard Van As and mechanical special effects artist Ivan Owen. They released the designs in an open-source format so that the maker community around the world may duplicate and enhance their creations. As seen in Figure 1, this novel, body-powered gadget used the residual limb's wrist movement to cause a coordinated contraction of the fingers.

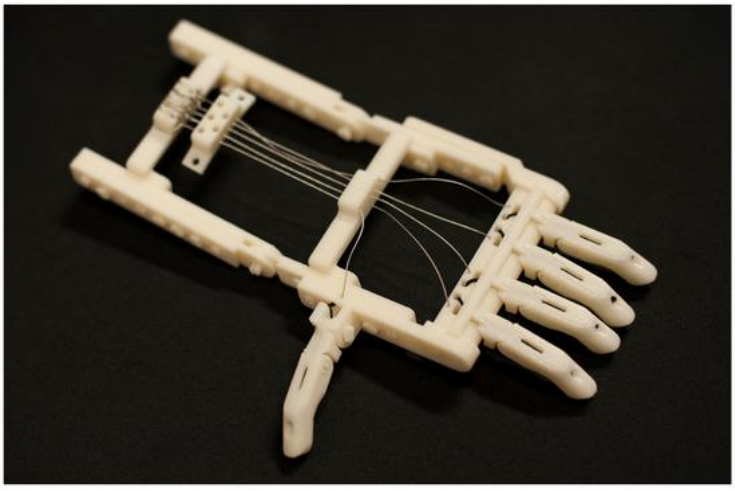

Fig. 1: The Robo hand Assistive Device, First Made Available for 3D Printing Globally

Literature Review

When it comes to helping patients with lower limb motor disabilities, we choose a specific type of robotic device tailored to their rehabilitation needs based on their condition. For instance, if we look at stroke patients, we can categorize their recovery into two main phases: the flaccid stage and the spastic stage. Each of these stages requires a different focus during rehabilitation. In the flaccid stage, the patient's muscles are relaxed, and they lack the ability to move their limbs actively. Here, the goal is to strengthen the muscles and prevent atrophy. As we move into the spastic stage, muscle tension increases, and spasticity starts to set in. This is when we incorporate exercises that involve joint movement and response. Activities like standing, walking, and weight-bearing exercises are essential to manage spasticity and improve the patient's walking pattern. As recovery progresses, we see the emergence of active movement patterns, which we continue to strengthen through balance, coordination, speed training, and walking exercises, all aimed at establishing a normal movement pattern. To effectively support patients in their rehabilitation journey, the lower limb rehabilitation robot must offer a variety of modes, including different movements, training techniques, working postures, and user-friendly interactions (Zuniga et al., 2015).

The way we classify rehabilitation training methods can actually be expanded to include categories like gait, running, ground, foot, and static, especially when we consider how affected individuals interact with the devices designed for their recovery. Additionally, rehabilitation exoskeletons can be divided into active, passive, and resistance modes based on the various training methods available. For patients with paralysis, relying solely on one type of sports training system or approach often falls short of meeting their evolving rehabilitation needs. Without a tailored approach, achieving the best outcomes during rehabilitation can be quite challenging. It's crucial to choose the right training method based on each patient's exercise capabilities and recovery status, or to tweak different parameters within the same method to ensure a smooth interaction between the human and computer systems (Zuniga et al., 2015). Moreover, rehabilitation robots designed for lower limbs are quite distinct from regular industrial robots. Since these rehabilitation robots operate in the same space as the patient, there's a dynamic interplay between the training mechanism and the patient's lower limbs, making it a complex system characterized by multiple variables, strong coupling, and nonlinear dynamics.

Methodology

Study selection

We carefully went through the resulting articles to weed out any duplicates, which we then removed. The articles that were left were further evaluated by four reviewers, who examined their titles and abstracts to determine which ones should be excluded based on specific criteria:

1. A foreign language, such as one that is not English or Dutch;

2. Intended for usage in nations with upper-middle-class to high-income levels;

3. Nonhuman subjects, such as objects, plants, and animals;

4. A partial prosthesis, such as splints, fingers, etc.

5. Nonlimb prostheses, such as orthoses, arthroplasty, replantation, implants, and surgery;

(Studies focusing on the embedded electrical design in a prosthesis [i.e. the component of the sensor placed on the main circuit board], rather than the design of the prosthesis itself]) The primary result is an electromyographic circuit (sensor).;

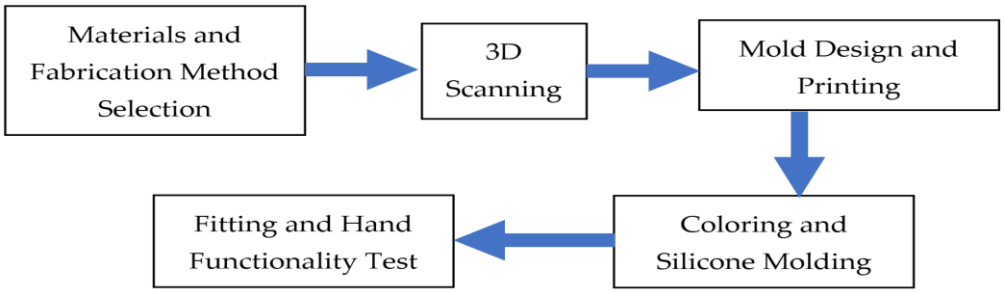

Fig. 2: Design framework

Data retrieval

The assigned author pulled together the information, which was then double-checked by a second author. If there were any disagreements, a third author stepped in to help discuss things until everyone reached an agreement. It also covered aspects like the country where the study took place, costs, weight, the name of the prosthesis, the techniques used, as well as any limitations or advantages, failure rates, and overall satisfaction (Fan et al., 2015, Herbert et al., 2005).

Data analysis

We took a close look at various studies on 3D printing to provide a comprehensive overview of how it's being used in low- and middle-income countries for limb prostheses, focusing on the results. We organized the data according to the type of prosthesis, and when we found similar data, we combined it for a clearer picture.

Results and Discussion

The hybrid manipulator we're proposing is designed to assist with upper limb rehabilitation for patients recovering from a stroke. It features four degrees of freedom, which allows it to perform a variety of movements. Essentially, this hybrid robot combines two parallel manipulators that work together in a series. You can see the section of the workspace for the lower parallel manipulator during the elbow flexion-extension motion illustrated in Figure 2.

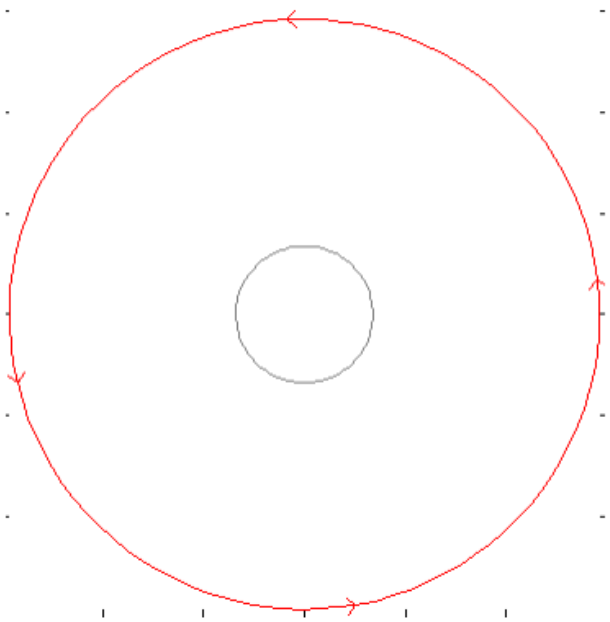

Fig. 3: Workspace for Extension Motions in XY-Plane

The two circles overlap one another, creating an intersection that defines a specific area in the xy-plane. This overlapping section represents the workspace for the robot as it carries out its elbow flexion-extension motion.

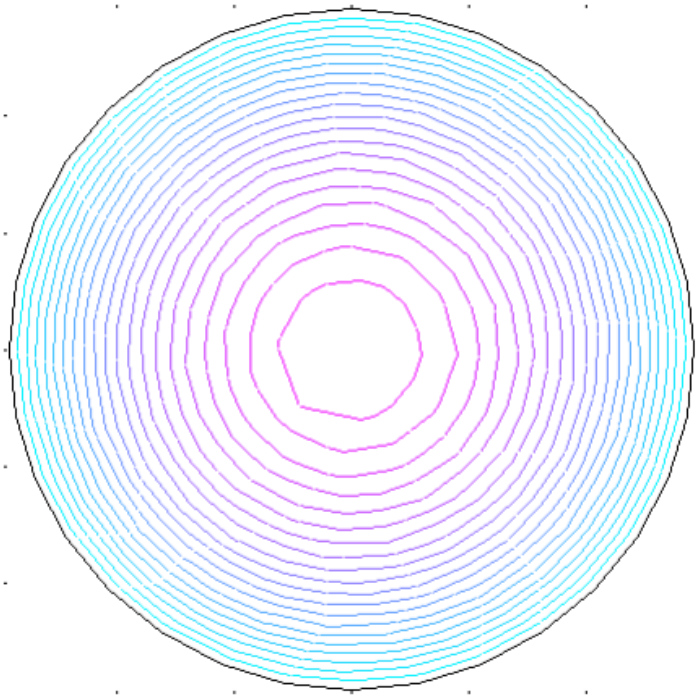

Fig. 4: Section of the Workspace for Motion to Elbow Supination Motions in XY-Plane

The range of motion achieved for elbow movements is quite impressive, but the robot's wrist motions leave a lot to be desired and definitely need some improvement. That's why we're proposing the use of the Bennett mechanism as an upper parallel manipulator in the hybrid structure.

Conclusion

Prosthetic devices will become a commonplace aspect of amputees' lives due to affordability. Future prosthetic arms may be equipped with characteristics that improve social interactions as technology advances and costs decrease. Consider some of the earliest prostheses that were made to let people feel and be touched. These devices had tactile sensors or simulated realistic warmth and softness. Future generations of 3D-printed prosthetic limbs will be able to integrate these cutting-edge characteristics thanks to the existing designs. The utilization of collaborative design and 3D printing processes appears to have a bright future, as quick developments result in improved user experiences. But much more needs to be done, particularly in the areas of clinical evaluations and power supply. We may make a substantial contribution to the field and determine if these electromyographic 3D-printed bionic limbs are ready for broader usage by developing and putting into practice novel clinical evaluations for them, complete with unambiguous outcome measures. Converting these technologies into useful applications will require constant efforts to verify and assess both performance and design.

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