Design and Fabrication Methodology for Customizable, Multi-Material Prosthetic Hands for Children

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Motivation

Technological improvements in the range and efficiency of 3D printing methods have impacted medical fields related to bodily repair and customization--like dentistry and audiology--enormously, with countless breakthroughs in, for these examples, dental implants and hearing aids indebted to such techniques [1]. This same movement is now impacting the prosthetic hand industry, and could be paradigm-shifting for child prosthetics, as designs for kids tend to need frequent replacement as they grow and develop. Since 2015, several open-source platforms have introduced 3D-printed prosthetic hand devices for kids [2]. Current design and manufacturing procedures, however, require multiple parts (or components) to be printed separately and sometimes depend on complex assembly processes. Furthermore, current manufacturing procedures rarely include the creation of proper, custom-fitted harnesses by which to attach the prostheses, increasing device rejection rate [3]. In our research, we propose *a multi-material 3D printing process* that can simplify the fabrication process of a prosthetic hand by both decreasing the number of parts required to be printed, and also by custom-fitting such parts directly to the user's hand. We aim to streamline the manufacturing process and to focus on capturing emotional values of a product we build. The evolution of the prosthetics has been motivated/driven by design driven roadmapping process [4] in order to provide simplified and customized experience of adapting a prosthetic as users grow. One case study introduced in this paper exemplifies the use of multi-material 3D printing practices in a prosthetic hand for a single user [5].

Current design and fabrication method of prosthetic hands

We provide a brief overview of currently available 3D printed prosthetic hand devices that could be printed and assembled using commercial 3D printers, and expand upon research on multi-material fabrication processes used for automated creation.

3D printed prosthetic hands: Three types of open-sourced 3D printed prosthetic hands have been widely used in the "enable-tech" communities: Cyborg beast, Raptor reloaded, and Exiii. Table 1 compares three designs based on the total 3D printed parts, and the number of assembly steps required for the upper-wrist unit of the prosthetic hand.

	Cyborg beast	Raptor Reloaded	Hackerberry-Exiii
Total 3D printed parts	25	19	44
Assembly steps	24	32	66
Harness type	Solid harness with padding (Not customized)	Elastomer wrap (Partially Customized)	Solid harness with padding (Not customized)
Types of Prosthetic	Body-powered	Body-powered	Myoelectric Prosthetic

Table 1. Comparison of the number of 3D printed parts, the number of assembly steps and harness of three open-sourced 3D printed prosthetic hands. Cyborgbeast, Raptor Reloaded and Hackerberry-Exxii Removing 3D printed supports, drilling, filing, and screwing joints were counted as individual steps in assembly process.

Multi-material fabrication: 3D printing enabled multi-material fabrication by designating different materials per voxel unit. This process, pioneered in the field of bio-inspired robotics due to its compliant structure and robustness, mixes rigid and soft materials in a structure to facilitate new applications.

Proposed New Development Method

Using a user experience-driven design roadmapping approach [4], the prosthetic hands listed in Table 1 are good examples of phase 1 (aesthetics and functionality of the prosthetic hands). Our research is to enable phase 2, simplifying the services of fitting, customizing, fabricating and maintaining the prosthetic device. Fig. 1 below depicts the initial version of the design roadmap defined by our research team.

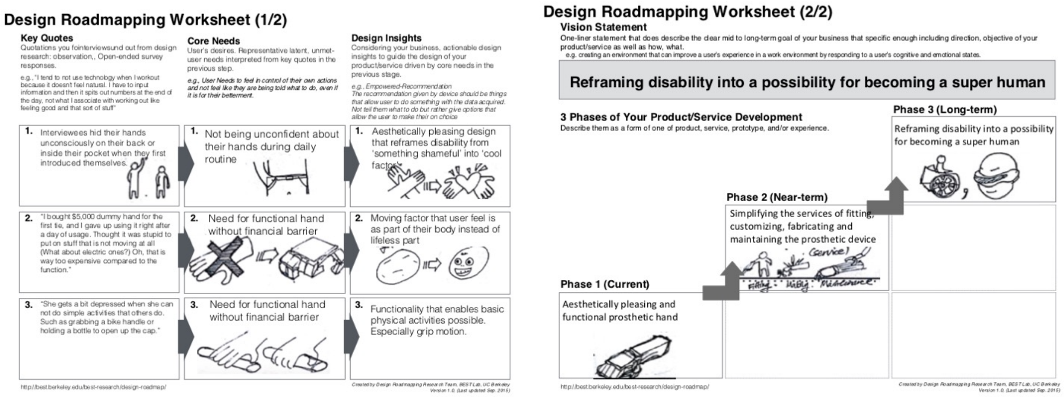

Fig. 1. Initial version of the design roadmap: Customized prosthetic hands for children

In our new approach, we designed a prosthetic hand for a user with two partial fingers on the left hand (thumb and pinky). Fig. 2 shows the prototype with a customized and flexible harness designed for our user. We used dual-extrusion printing to enable a whole prosthetic hand structure to be printed in a single print. Prototypes were built by using ultimaker 3 with dual head printing using a ThermoPlastic Elastomer (TPE) filament for flexible joints and PLA for a rigid sections. We also built our prototype using industrial grade 3D printer (Connex 260) with a mixture of Tango Black (Flexible) and Digital ABS (Solid).

Fig 2. Multi-material printing with standard 3D printer (Ultimaker 3) and industrial grade 3D printer (Objet connex 260)

Our multi-material prosthetic only requires single print, which means the 3D-printed part required for the design (above the wrist) is a single unit with a unified assembly process that only entails removing supports from the print. In the design workflow we were able to implement customized harness design through positioning flexible material in the contact area. This result demonstrates a reduced number of parts required when compared to current 3D-printed prosthetic hands, and simplified assembly process after the fabrication process.

Future Research

Current 3D-printed prosthetic hand designs, including our own, require extensive work in modeling for customization for each user with different hand shapes. Our future research will examine how to simplify the process of customizing harnesses and make modular parts that fit a wide variety of hand-shapes at less costs through optimization of product platforms.

References

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