3D functional sport prostheses

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***Abstract*— 3D printing techniques are making rapid improvements, especially in the medical field, where many people are requesting prosthetic devices that are customized in design and function. This is happening especially in sports to facilitate access for the disabled, providing more affordable devices suitable for those who want to play sports without having Olympic ambitions. In this study we present some 3D printed sport devices, for swimming and cycling, developed by the Io Do Una Mano Association, the official Italian chapter of e-Nable. Each device presented has been customized for specific disabilities and is based on different requests.**

Keywords— prostheses, sport devices, 3D printing, e-Nable

I. Introduction

Over the last years, significant developments have occurred in 3D printing of upper limb prostheses. Across the world people are designing and printing new devices that easily fit a human arm [1].

In December 2012, Ivan Owen, an artist and designer from the United States, in collaboration with Richard Van As, a South African woodworker who had lost fingers in an accident, made the first prosthetic hand through 3D printing technology with the support of the MakerBot company: the Robohand [2]. Early the following year, the makers made their model available to the world, laying the groundwork for what in July 2013 became the global community e-NABLE. The community has grown into an international movement of tinkerers, engineers, 3D-printing enthusiasts, occupational therapists, university professors, designers, parents, families, artists, students, teachers, and people who have developed 3D-printed prostheses [3]. Several models of upper limb prostheses, for both hand and trans-radial amputations, have been developed, and numerous chapters have been established around the world. The Italian chapter of e-NABLE, Io Do Una Mano (I Lend A Hand) [4], was born in 2020.

3D-printing has several advantages compared with other manufacturing techniques [5,6]:

- Possibility to design parts with highly complex geometries;
- Custom Design easy to personalize with desired shape, size and color;
- Low cost and quick process from idea to final product for the user [1].

From the invention of 3D printing, there have been many innovations not only from a technological perspective but also in the materials. Today, there are many different materials available, supplied in the form of powders, filaments, etc., depending on the features and properties required by each specific application. These characteristics make 3D printing suitable not only for prostheses replacing hands but also for developing devices specifically designed to enable people with physical disabilities to play different sports.

There is a large amount of evidence that participation in sports is important for both physical and mental well-being [7]. Engaging in sports has helped amputees improving their physical condition and overall well-being [8,9] and it is not only a way to keep fit and active but also a means to interact with others. Increasing levels of sports participation can help to build social contacts and develop friendships [10].

Currently, the availability of specialized sport prostheses for those missing totally or partially the upper limbs is limited [10]. TRS is an example of a company that does produce sports devices for people with upper limb deficiencies or amputation [11], but their small-scale production often results in relatively high costs. In addition, not all sports are covered, meaning that some users may need to consider abandoning their preferred activity if no suitable device is available [10]. Thus, there is still the goal to facilitate access to sports activities for the disabled, designing devices suitable for those who want to play sports without having Olympic ambitions that are more affordable.

In this context, the Io Do Una Mano Association aims to help people, particularly children, with congenital or acquired upper limb deficiencies by modeling, 3D printing, and distributing free customized devices. Io Do Una Mano builds mechanical and totally custom-made devices, to best suit both the body and the preferences of the children, who can, in the design phase, personalize the device by adding their name, taking inspiration from their favorite superhero or cartoon, and choosing their favorite colors.

The aim of this study is to present different sports devices that are produced based on the needs of users with different upper-limb disabilities.

II. Functional sport prostheses

The use of prostheses in sports activities can help reinforcing the muscles of the residual limb and lead to a more symmetrical use of the body, thus improving quality of life. The following are examples of sports devices that have been fully designed and 3D printed by Io Do Una Mano. All the devices were 3D printed using different materials according to different models and applications. Generally, the following plastics are used for these types of prostheses: ABS (Acrylonitrile Butadiene Styrene), PLA (Polylactic Acid) and TPU (Thermoplastic Polyurethane, a flexible material). In our case, we used specific materials, produced by the company LATI 3D [12] for each application. The cost for the maker who produces such devices is around 50-100 euros. As mentioned above, however, such devices are totally free for those who request them.

A. Swimming

The absence of a hand and/or a forearm, which produce major propulsive forces in swimming [13], determines an imbalance that can cause (1) intracyclic fluctuations in swimming speed [14] and (2) the development of compensation strategies to maintain stable repetitions of the overall arm swimming cycle [15]. For these reasons, we decided to build a 3D printed, low-cost and versatile swimming prosthesis. The design of the prosthesis consists of

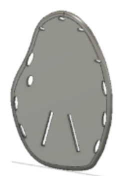

Fig. 1 Example of swimming device

(a) (b)

Fig. 2 Disability below the elbow (a) and example of non-binding model (b)

a paddle with straps that can be adapted to different amputations and different arm sizes (Figure 1).

For each type of swimming style, the hand maintains a relaxed position, but at the same time remains closed to make greater use of friction with the water.

For this reason, the paddle shape and material were selected to attain a tool that resembled as closely as possible the operation that the close hand has during the swimming operation so as not to fatigue the person using it but at the same time increase the mobility of the users in the water.

For this swimming device, the material used is a plastic that has a small degree of flexibility; we used a polypropylene-based material with an antibacterial additive. It is suitable for applications in aggressive environments, such as swimming pool water. It resists attack by hydrocarbons, strong acids and bases, and peak temperatures up to 100°C.

B. *Cycling*

Upper limb amputees use their prosthesis to grip the handlebar, to steer and operate the gears and brakes.

We have made three different models for different types of amputations and needs:

1. *Non-binding model:* The first model is for people who have an arm disability below the elbow (Figure 2a). We have made a model that consists of a support where people can insert their stump, that attaches to the handlebar. This tool is fixed, i.e. by design it does not have the possibility to rotate or move up and down, which would decrease stability. By inserting the stump inside the support, the user can easily control the movements of the handlebar (Figure 2b).
2. *Binding model:* This second model is also for people with an arm disability below the elbow. Compared with the previous model, this model is more binding. It consists of an attachment to the handlebar (Fig. 3A) inside which, through a spherical system, a funnel is wedged (Fig. 3B). The recipient fits the stump inside this funnel and, thanks to the spherical system, turns the bicycle by rotating the handlebar.
3. *Handlebar transposition*: The last device was designed and customized for a specific disability, a missing forearm (Figure 4a), i.e. for people with hand, wrist and elbow joints, but no forearm. Without a prosthetic device, the person was forced to assume a strongly asymmetrical position to grasp the handlebar; this is uncomfortable and it can lead to secondary complications. Therefore, we developed a custom-designed tool that on the side of the missing body part translated toward the person the handle to grip (Figure 4b). The elongated parts are printed completely flat, and only later twisted, via thermoforming. This was decided to avoid an excessive use of supports during the printing process and to have a better orientation of the layers, thanks to the superposition of parallel planes with no points of fragility.

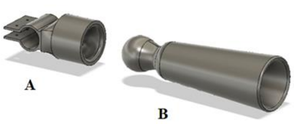

Fig. 3 Example of binding model

(a) (b)

Fig. 4 Example of disability, where the forearm is missing (a) and example of handlebar transposition device (b)

As material, for the bicycle devices we used a PLA stabilized to hydrolysis and UV attack, thus suitable for outdoor environments. This material, when cook the printed piece at 100°C for 15 minutes, crystallize thus achieving superior mechanical strength and temperature resistance up to 100°C (under direct sunlight it would not deform, as standard PLA would). Usually, when printing a classic PLA, the overlap of the different layers of material often remains clearly visible, both to the eye and to the touch with also the consequent presence of pores between the different layers. Using this type of material provides the possibility of obtaining a better aesthetics since it hides the layers.

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