From robots to humans: prosthetics for All

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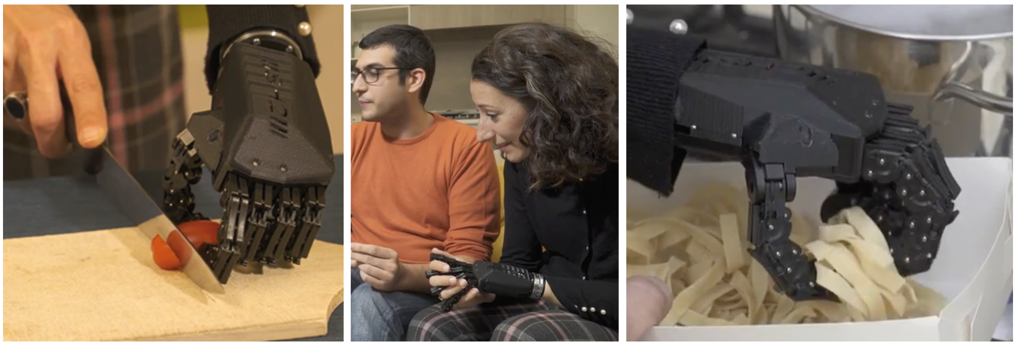
ABSTRACT

SoftHand is a novel robotic hand combining the principles of soft robotics and postural human synergies to achieve a simple and effective implementation of the human functional and structural anthropomorphism in prosthetics aids. Originally developed for the industry by the Italian Institute of Technology and the "E. Piaggio" Research Center of University of Pisa, the SoftHand is becoming a prosthesis thanks to SoftPro, a H2020 research project. Thirty prosthetic users are currently testing it in 4 academic and rehabilitation centres around the world, to improve design, dexterity, and fitness to myoelectric prosthetic users. The latest design of the hand is smaller and lighter while keeping its merits: simplicity, due to the presence of one only motor; compliance, strength and robustness, thanks to its intrinsic softness and its human-like (19 degrees of freedom) architecture. The team involves a designer - who is also a tester - to improve design by considering also its social and aesthetic impact. Sustainability is a core issue of this research to present the market a robotic prosthetic hand with an affordable price; this goal has important socio-economical aspects. The paper will analyse market scenarios and competitors. The integration of contaminations coming from the Design and Humanities in the research flow is fundamental to explore the relationship between prosthetic appearance and social sustainability, which already achieve novel and unique self-interaction capabilities.
Key Words: soft robotics; prosthetics; myoelectric hands; social sustainability.

1. INTRODUCTION

Originally developed for the industry by the Italian Institute of Technology and the "E. Piaggio" Research Center of University of Pisa, the Pisa/IIT SoftHand is a simple, robust and effective robot hand, which combines the modern technology of soft robotics with a bio-inspired joint design and the neuromorphic principle of sensory motor synergies, and is able to achieve an adaptable and gentle grasp, together with advanced manipulation capabilities. The simplicity of its mechanical structure is ascribed to the use of only one motor, which nonetheless, is able to activate the whole hand. This is possible thanks to a distributed transmission system – namely a tendon - that runs through all the fingers and that is wrapped around and winded up by the motor. Often, robotic hands with many degrees of freedom (DoF) are controlled by diverse motors, the Pisa/IIT SoftHand has 19 degrees of freedom (as the human hand), but the use of only one motor keeps the hand very light and robust. Moreover, its tendon-based transmission system lets the fingers to adapt to different shapes while creating an interdependency between the phalanxes, in line with the concept of human hand synergies. The hand system designed is very robust and its biomorphic joint design allows perfect recovery after large deformations and even disarticulation. **In ultimate analysis that studies in human synergies led to a design which simplifies the handling of 19 degrees of freedom and guarantees, at the same time, an affordable technology**. As mentioned before, the idea at the core of the Pisa/IIT SoftHand, i.e. soft synergies, comes from a theory in natural motor control which interprets part of the complexity of the motions of the human hand as the result of two opposing principles: on one side the coordinated (i.e. synergetic) motions that our nervous system command to the hand, and on the other its physical and elastic (i.e. soft) interaction with the environment. The application of these principles in a robot system makes the SoftHand capable of grasp a great variety of objects despite its single degree of actuation.



[Figure 1] The SoftHand adaptable and gentle grasp. In the middle, its self-interactions feature exploited.

Simplicity, robustness, lightness and effectiveness make the Pisa/IIT SoftHand ideal for both humanoid robotics and industrial application[1]. Moreover, a commercial version of the hand, the qbsofthand, is produced by a spinoff of University of Pisa and IIT. Literature is available on this topic (Catalano et al. 2016), devoted mainly to engineers' research community. The original Pisa/IIT SoftHand is released as an open hardware project under the umbrella of the Natural Machine Motion Initiative (Della Santina, 2017). Despite the apparent distance that separates prosthetics from industrial automation, the same characteristics that make the SoftHand innovative and versatile in factories, render it potentially disruptive in prosthetic application. So, thanks to the European Commission H2020 project named "SoftPro", currently the hand is designed smaller and lighter and integrated with convectional controllers for prosthesis (surface electromyographic sensors - sEMG). Usually, active prosthetic hands are controlled by one or two sEMG sensors: a solution that perfectly fit the Pisa/IIT SoftHand system with its two input requirements: the opening and the closing commands. A novel prosthetic hand borns: the SoftHand Pro (Godfrey 2018).

2. MARKET SCENARIO

One of the key issues in developing a prosthetic hand is related to its possible position on the market. Concerning this aspect, one of the emerging strengths of SoftHand Pro is its economic sustainability due to the relative electro mechanical simplicity of its architecture. To complete this analysis, it is necessary to define a preliminary market state of the art. Few robotic hand prostheses are available worldwide and are owned mostly by few leader companies (van der Riet et al. 2013); the most important are Michelangelo, BeBionic and MYO hand owned by Otto Bock; iLimb owned by Touch Bionics (now a part of Ossur). Few other hands occupy a very little percentage of the market, Taska hand (from Australia) is an example. Each hand has its own market, defined by specific user's needs that are reflected in imaginaries described trough specific marketing activities. Otto Bock's most advanced robotic myoelectric hand is

[1] A proof of this is that the University of Pisa team was finalist at the Amazon Picking Challenge.

Michelangelo. It has two motors: the thumb, index and middle fingers are actively driven, while other fingers follow passively. Michelangelo has three position modes, offering 7 grip types. Michelangelo comes with a clear glove or a natural pale rose (human-like) silicone glove[2]. In Otto Bock's website real-life stories videos refer to keywords such as *new normal, positive attitude, do things people love to do, life grateful, passionate*. **Bebionic** hand (Otto Bock) has individual motors in each finger that allow to move the hand and grip in a natural, coordinated way. It has up to 14 programmable grip patterns and proportional speed control for each finger that gives precision control over delicate tasks[3]. Bebionic is, most of the times, portrayed without a glove, even if cosmetic gloves are available in black, white or in flesh tones. Emerging keywords are: *this is every day for me, bebionic is part of me, allow me to be the person I want to be, embrace the everyday*. **MYO Hand** (Otto Bock) is the oldest hand in the Otto Bock fleet (originally designed in the Sixties); it has a tridigital grasp actively controlled by EMG sensors, covered with a human-like glove. It is simple and strong, can be opened with a quick real time reaction; it has one motor and six control[4]. Other keywords related to this hand are: *quick reflexes, secure hold, grasping objects, different sizes, flexible in application*. **iLimb** (Ossur) is a robotic hand with five motors, two degrees of freedom per finger and four controls modes, with up to 36 different(customizable) grips available. It has different finishing, such as black, transparent and flesh tones gloves. Emerging keywords are: *inspiring*, *things I love to do double handed, simple controlled, total control via app*[5]. **Taska** hand has 10 joints, it is waterproof without the need of a covering glove, is black and finished using a combination of different materials. It's presented in a very forceful and assertive way. Key features are: *robust, waterproof, flexible and dexterous*. The users also can also use controls placed on the back of the hand[6].

[Table 2.1] *Myoelectric robotic hands comparison.*

	Size	Motors	DoF	Weight	Cost*
Otto Bock Michelangelo	Male (7 3/4)	2	6	420 g	Approx. 25.000 €
Otto Bock BeBionic 3	Medium (length 195 mm)	5	11	500-570 g	Approx. 15.000 €
Otto Bock MYO Hand	7 3/4	1	2	460 g	Approx. 8.000 €
Ossur iLimb	Small (length 180 mm)	5	11	450-615 g	from 12.000€ to 33.000€
Taska hand	8 ¼ (length 181 mm)	n.a.	10	616 g	n.a.
SoftHand Pro	Length 180 mm	1	19	290g+70g (wrist)	*8.000 € estimated*

* Estimated costs referred to the hand (no glove, wrist, etc) for the Italian market, excluded tax.

Table 2.1 summarizes the main features of the previous described hands (extrapolated also from Belter et al., 2013) comparing them to the SoftHand Pro. In this scenario, SofHand Pro stands up for its lightness, and accessible market costs. This could generate a market positioning that is not covered by any other product at the moment: **a new idea of affordable high technology hand prosthesis**. In terms of economic accessibility, SoftHand Pro could be compared only with the MYO Hand - that has the majority of the market in Italy – but that is not comparable in terms of intrinsic technology. Moreover, SoftHand Pro features traits that, at the moment, are not present on the market, such as robustness (Catalano et al. 2016) and soft and deformable fingers, that make the hand unique in terms of self-interaction and grasp possibilities.

3. DESIGN OF UPPER LIMB PROSTHESES: A FRAMEWORK

In anthropology and sociology*, disability* is often perceived as a concrete form of *otherness*. The disabled person perceives himself as "something else", mutilated in relation to a normal standard (Saradjian et al. 2008). Traditionally, the Stereotype Content Model about disabled people's group elicits disrespect for a perceived lack of competence (Fiske et al., 2002). Moreover, this approach targets a paternalistic prejudice and lets pity emerge (Fiske et al., 2002). Murphy (2017) states that disabled people remain blocked in a sort of *liminality phase*: they are not healthy but, at the same time, are not ill. As a consequence, they are not excluded from society but not perfectly integrated either.

Disability can be understood as a cultural issue, able to guarantee social inclusion or favour the raising a *stigma*, as described by Goffman (1963). This makes upper limb robotic prosthetic design a complex issue that invest technical and technological aspects with critical subtended social consequences. To enhance design, dexterity, and fitness to myoelectric prosthetic use, the SoftHand Pro is being tested in laboratory and with final users. Different experiments are

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[2] Information from official website: https://www.ottobockus.com/prosthetics/upper-limb-prosthetics/solutionoverview/michelangelo-prosthetic-hand/ (accessed 30/01/2019). The motto is: "Fascinated with Michelangelo. Perfect use of precision technology".

[3] Information and texts are taken from the official website: https://www.ottobockus.com/prosthetics/upper-limbprosthetics/solution-overview/bebionic-hand/ (accessed 30/01/2019). The motto on the website homepage is: "The world's most lifelike bionic hand". "Comfortable, intuitive and precise, bebionic continues to transform the lives and abilities of amputees around the world. From helping them perform simple tasks like tying their shoelaces, to giving them back their control and pride."

[4] In the main page of the SVO Hand official website is written a motto: "Grasp, hold, and be active".

[5] Text from official website: http://www.touchbionics.com/users-families/touch-bionics-difference. Their motto is: "precision. power. intelligent motion".

[6] The homepage video closes with a phrase "practical and useful device that will enable you to simply do more".

settled up to improve on diverse aspects: single parts and whole systems, mechanical and control issues[7], usability, dexterity, and fitting are all being experimented with final users[8].

The rest of this paper will focus on covering and finishing aspects as they are related to both aesthetics and hermeneutic issues, strongly related to the idea of social sustainability. Indeed, the hand research team involves a designer - who is also a tester - to improve the finishing concept design by considering also its **aesthetic and social impact**. The integration of contaminations coming from the **Design and Humanities in the research flow, is fundamental to explore the relationship between prosthetic appearance and social sustainability**, which already leverages on novel and unique self-interaction capabilities thanks to the adopted soft robotic approach.

Since no design literature is substantially available about the aesthetic and hermeneutic issues in prosthetic user satisfaction, a preliminary research was conducted on available studies, focusing - in particular - on the relation between users and their prosthesis and their social interactions. Interesting papers were found in the field of Biomedical Engineering and Rehabilitation area. The main issues emerging from the research in these fields, are factors associated with **prosthesis acceptance or abandonment**, **prostheses rejection rates** and **psychosocial wellbeing** related to prosthesis use. Some important statements emerge: Saradjian et al. (2008) observe that people's hands and arms are not only particularly important functionally, but socially as well. They are used for expression, communication and affection, with hands considered to be the second most individual and personal part of the human anatomy after the face, as already published by Ham and Cotton (1991) and Baumgartner (2001). Users describe an external shame and use the prostheses as a defensive behaviour to conceal their amputation as such they consider prostheses as an important help to manage **social interactions** (Saradjian et al. 2008).

Prostheses impact also in restoring the **body image** and improve functioning in a cosmetically acceptable way (Saradjian et al. 2008). Murray (2004) delineated two different approaches within the **prosthesis's embodiment experience**: those who have a strong emotional connection to it, experiencing the prosthesis as part of their body and those who merely intend it as a functional tool, no matter what it looks like.

Anthropomorphism is a raising issue, strongly related to social interaction, ensuring the prosthesis user to present himself in public, concealing his diversity. Often, the idea of normality is one of the first objectives to be achieved for the disabled people. Pullin (2009) - from a Design discipline point of view - reinforces this idea pointing out that in prosthetic limbs design field there are often two main approaches: the realistic and the functional one. The first is defined through the focus on human likeness, through the use of materials such as PVC and silicone and colours similar to the human skin. The second, the functional one, has its priority in functionality beyond appearance.

4. A DICHOTOMY BETWEEN A MIMETIC *vs* NON-MIMETIC APPROACH

Often people experience a sort of repulsion against something that appears very similar to human (intended as life-like), but also is recognizable as alien. This phenomenon known as the Uncanny Valley in the research field of Engineering and Informatics helps in defining the idea of dichotomy between a mimetic and a non-mimetic approach in the finishing design for upper limb prostheses. Masahiro Mori, in the Seventies, proposed a model of relation between human likeness and people's comfort level: in general, more human-looking artefacts are perceived as more agreeable (comfort level), but this trend interrupts until testers experience artefacts that look so similar to humans that make them appear eerie, creepy (discomfort level). In his analysis Mori mentions directly prosthetic hands. Experiments let emerge that a natural look combined with an artificial feeling creates eeriness. This sensation is amplified by movements (such as unnatural dynamic dimension) and by other sensory aspects (tactile, such as material softness and temperature; or audible noises). This could lead to feelings related to fear and disgust. Other factors that could affect eeriness are proportions deviation from the human beauty standards, or colours and textures that evoke the idea of death. Poliakoff et al. (2013) let emerge that passive human-like cosmetic prostheses cause a non-familiar feeling and eeriness, while mechanical hands without any mimetic covering are considered less eerie.

Also, the state of art in upper limb prosthetic design can be divided in two different approaches: one oriented toward a mimetic, human-like design and another one that tends toward a non-mimetic design. It is possible to intend these tensions as opposing, as a dichotomy, as an issue that could be also managed by the design discipline. In these terms, the scenario of lower limb prosthetics has some interesting examples. The dichotomy between mimetic and non-mimetic approach seems to be partially overcome in prostheses for sport. Notorious examples are those such as the one worn by famous athletes as Oscar Pistorius or Aimee Mullins. In these kind of lower limb prostheses, design has found a form of conciliation between the formal aspects of technology (non-mimetic aspects) and the need of relation with the human body and its proportions (mimetic aspects). These prostheses transform the user's figure

[7] More literature can be found in Softpro project website (www.softpro.eu – accessed 12/02/2019) and in EU project's partners repositories.

[8] Users are currently testing the robotic hand in academic and rehabilitation centers around the world, such as: Mayo Clinic (Rochester), Shirley Ryan Ability Lab (Chicago), Hannover Medical School (Hannover), ETHZ (Zurich), Azienda USL Toscana (Massa). Tools adopted, among others are: Resnik 2013, AM-ULA; Hermansson 2005, ACMC; Light 2002, SHSAP; Bray 2001, AMPS.

substituting the lower limb full mass with an elegant shapely gesture. Moriggi and Nicoletti (2009) confirm the social acceptance of these kind of prostheses keeping in relation aesthetics of prosthetics, technology and society[9].
Keeping in mind that lower limbs do not represent a social interaction medium as important as hands, we ask the question: is it possible to search a mimetic vs non-mimetic dichotomy solution able to create acceptance and satisfaction in upper limb prosthetic users, comfort in social interactions and a society culture able to favour social integration? **How can the designer's role be exploited - in complementarity with that of the engineers - to favor the cultural change towards a positive social acceptance of robotic prostheses?**

5. DISCUSSION: THE PROJECT'S DUALISM BETWEEN (DE)SIGN AND CULTURE

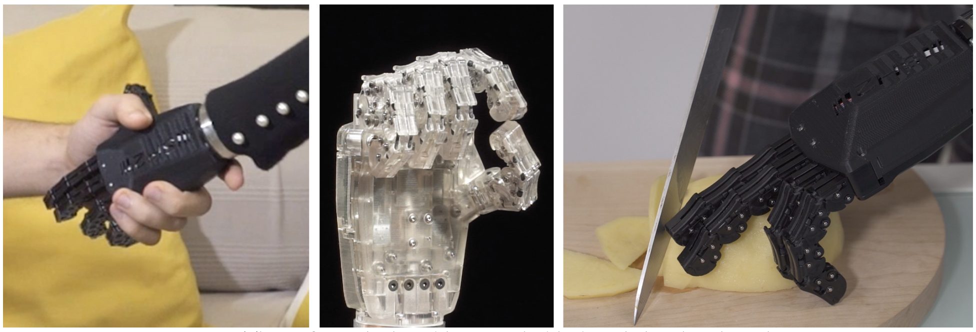
In the design community, it is traditionally welcome the idea that "objects have their own life, [...] in the sense that they reinforce social practices just as social practices reinforce them" (Molotch 2005). Also Miller (1987) rightly argues that while we shape things, things are shaping us. These ideas let emerge and assume the **consolidated bi-directional relation between individuals and objects/tools** (prostheses included!). While Miller (1987) underlines it from a cognitive and functional point of view, Molotch (2005) focuses on the (sociological) cultural point of view. So, prostheses - as all manufactured products – could be considered as composed by a tangible part – the (de)sign - and a cultural part (intangible). Both engineers and designers act on the tangible aspects of a product, designing its *materic* and formal characteristics that are experienced through perception. As Levi and Rognoli (2005) sum up, designers can manage the *significant potential of materials*. On the other hand, **design actions can be interpreted as cultural actions, mediated by perception**, understood as the way a concept is elaborated in human mind and then applied to mental reference frames (Pisano 1987). Rognoli (2005) links strongly the material expressive and sensorial dimension with the "*human's mind power in symbolizing*" that determines a reference culture and is objectified through perception. So, it is possible to assume that designers act on the sensorial level (through the "materic aspects" of the project), also by managing and redirecting perceptions towards aesthetic and functional values that contribute in qualifying a positive culture of a product. In the design community this project dualism has been often identified and theorised: the tension between **Form and Function** or the one between **Arts and Science** constitute basic principles. Moreover, looking at Humanities, Semiotics naturally balance these two elements: *signifier* and *meaning*. Van Onck (1994) affirm that a sign could not refer manifestly only to itself, but it constitutes an emotion's forecast. Continuing this design literature excursus, Pisano (1987) confirms these two aspects of the project, describing human-environment interactions. On one side there are *Physical interactions* (dimensions, shape and surfaces) and *Sensory interactions* (related to human senses, as sight, hearing and touch, with all the implications of their physiological apparatus). While on the other side there are described *Informational interactions* (as the conscious phase of perception) and *Cultural interactions* (referred to hierarchies of values and models, emerged from the accumulation of human experiences along its anthropological, social, generational and individual history).
Lastly, for the purpose of this paper it is very interesting to consider what is defined as the iceberg model of the ergonomic research which identifies different aspects of a project and places them on a pyramid with a submerged part, the metaphor of the iceberg. The visible (and tangible) part refers to *usability,* while the submerged part (intangible) refer to *pleasantness* that includes, among others, needs, desires, aspirations, emotions, dreams and attitudes. Pleasantness - investigated mostly by Human Factors studies can - in turn - be defined as social, psychological, ideological or physiological, according to the typology of involvement (Jordan 1999). Trough decades, design literature referred to these two different aspects of a project, the more tangible one, that designers could affect, and the less tangible one that is possible to generate thanks to the interaction with users (culture).

6. CONCLUSIONS

The previous theoretical analysis reveals the need of more in-depth studies where the design discipline could offer specific skills and tools to manage these emerging issues in designing upper limb prostheses. The design discipline could act as a process facilitator (Manzini in Rizzo 2009), offering specific tools to handle more intangible consequences implied in the design of innovative upper limb robotic prostheses. More and more frequently, designers are called to manage these aspects and use participative tools to brief and inform the design process, based on the User Centered Design approach. This approach could handle and inform the design process about the complex interactions emerged from this paper, using *qualitative and contextualized tools,* such as interviews, design probes, and more (Fossati 2018) in: (1) dashing the social contexts of prosthetic users; (2) deepening users' needs, desires and expectations about prosthetic design, in line with the concept of pleasantness (Jordan 1999) and intending the

[9] About the Pistorius case, Nicoletti defines it as the case that "has overthrown the ignominious prejudice of the amputee, transforming the impairment into a heroic virtue". The images of these athletes have travelled around the world, exalting the heroic aspects and leading to the idea of Superhumans, as presented for the promotion of the 2012 Summer Paralympics in London.

prosthesis is an intimate extension of the body (Biddiss et al. 2007). This kind of research could merge and deepen also researches about self-interaction and the *body image* theories; (3) deepening and conducting field research about social acceptance. Starting from the idea that an upper limb loss could no more concealed, but inspired by technology, the finishing/covering design aspects are being investigated in experiments by the IIT and Pisa design teams. Figures show the hand *naked*, without any finishing. Two different product concepts are currently being developed: one that looks at the mimetic prosthesis finishing design and a *meta-mimetic* one. Engineers and designers are currently testing the hand looking for better grasping, applying an empirical ergonomic approach to ameliorate usability. To improve grasp efficiency, preliminary findings suggest improving grip and increase contact surfaces between the hand and different objects. Moreover, usability is also intended to guarantee users safety, decreasing the user's postural compensatory movements. To this aim the prosthesis has to be considered as a part of a larger complex system which includes also the human body, the environment, real life objects and typical tasks. These experiments are intended to generate design guidelines for the covering/finishing design. On the other hand, to deepen the aesthetic perception of prostheses in society (non-disabled people, users or potential users) we developed a quali-quantitative survey composed of prostheses images (visual stimuli) and includes questions about feelings and emotions (differential semantic approach referred to adjectives used in the Uncanny Valley Model and the Stereotype Content Model).



[Figure 2] The SoftHand adaptable grasp, in black and clear hand version.

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