A NEW APPROACH TO WEARABLE SYSTEMS: BIODESIGN BEYOND THE BOUNDARIES

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This paper presents a design framework for wearable systems. The research is focused on the development of a new design method aimed at the design of wearables. The objective is to use designer's sensibility to address wearables issues by meeting not only technological and medical requirements, but also user needs and social challenges with a human-centred approach. The research is based on an interdisciplinary approach typical of the Biodesign discipline, a nucleus of competencies in the areas of design, ergonomics, engineering and medicine. This approach has been developed with various researchers in order to better understand wearables from different perspectives. This paper describes a wearable device for physiological monitoring and training in high performance sport developed at The University of the New South Wales. The case study is used as a starting point for the development of a new design method and guidelines for wearable systems.

Keywords: Design Research Methodology, Wearable devices, Biodesign, Interdisciplinary approach.

1. INTRODUCTION

Wearables refer to a class of devices really integrated in daily life, used all the time, wherever the user goes. There is an important distinction to be made: wearable has to be actually *worn*, and not just carried or held. A wearable needs to both work and look good and be worn in the same way the user wear clothing in order to achieve the paradigm *anytime, anyplace, by anyone*.

Although there is a wide range of commercial wearable devices there are few products, which truly become ubiquitous and accomplish end-user really need.

User doesn't really understand the advantages of wearing such a device and mainly he feels uncomfortable and perceives a sense of alienation wearing it. This happens because wearables are not thin, flexible, adaptable, attractive and appropriate for housing the body yet. In order to become wearable in the same way that a t-shirt or pants are wearables, they need to be designed to be *worn on the body* [1].

The development of a wearable needs a study on placing objects on the human body with regards to mass, size, shape, mechanical properties. The reason of this research is visible in the lately technological developments: new technologies simulate body functions and strengthen the organic features. Clothing and prosthesis are instruments thanks to which body redesigns itself. From this reason the wearable should be not an overlapping structure or close architecture but an enveloping film, "a second skin" [2].

Designer has to address the big challenge to shape the technology in a desirable and acceptable way for the user. For these reasons is necessary to create a shared language thanks to which designer is able to communicate with researchers coming from the relevant areas of expertise. He has to understand the complexities of such a class of products and have the skills to talk with competence with a disparate mix of background involving ergonomics, textiles, manufacture, engineering, medicine [3]. This research

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is based on Biodesign discipline: an interdisciplinary approach to project activity based on a nucleus of multidisciplinary competencies in the specific areas of industrial design, medicine and engineering. The focus of biodesign is to introduce a technological innovation in wearable field through solutions whose effectiveness is really perceived by the human being.

Our aim is to develop an instrument that is able to support and guide the design process. It must help the designer to address wearables issues by meeting not only technological and medical requirements, but also user needs with a human-centred approach.

2. RESEARCH AIMS

This research attempts to fill the gap in wearable system project, caused by the absence of a user-oriented approach. Research objective is to identify solutions which satisfy requirements of wearability and to find solutions that meet user desires.

The word "wearability" literally means *ability* to *wear* and concerns the physical shape of wearables and their active relationship with the human form. The user desires concern the psychological dimension much important than the physical one. The hypothesis for the development of this research activity is the creation a method usable for the design of wearable devices, able to give a plus value to devices studied and developed just by professionals linked to medicine or engineering.

The design method needs to help to:

- understand the right relation between the wearables and the human body;
- localize and define the zones where put flexible form without interfering with fluid human movement;
- achieve a real integration of design and technology.

First of all a designer has to know what the user perceives as comfortable and what not. The literature shows different concepts of comfort; it can be defined as: "absence of unpleasantness or bother" or as "physical, psychological, physiological harmony between human being and the environment.The most suitable definition for the wearables is one that defines the *comfort* as "well-being", the idea for someone to feeling good in his own skin and housing.

According to Archer a design problem begins with a need, and much more with an aspirations. In this case the need to accomplish is an *"anatomically correct design"* and the aspiration is to reach a holistic comfort approach.

A wearable is a second skin for the human body, a protection shell, an housing which changes body shape. The wearables fix body silhouette inhibiting or making easier movements and postures through ergonomic and enveloping shapes.

The target is to define the interaction between the human body and the wearable object, by trying to figure out a flexible shape without interfering with human motion.

3. DESIGN METHOD FOR WEARABLE DEVICES

We developed a design method for wearable device that involves the integration of studies on wearability and the lines used by doctors in surgery.

The Institute for Complex Engineered Systems (ICES) developed a study about this topic, "Design for Wearability", by outlining a design guideline for wearable products.

In brief *wear-ability* is the physical shape of wearables and their active relationship with the human form. Besides dynamic wearability extends that definition to include the human body in motion [4].

The wearability parameters set by the Institute of Complex Engineered System (ICES) are:

- formal language: the way the different shapes blend with each others;
- size: cross section variation of human body;
- human movement: the way the form of body changes whit simple motion;
- unobtrusivity: body areas less obtrusive for wearable products.

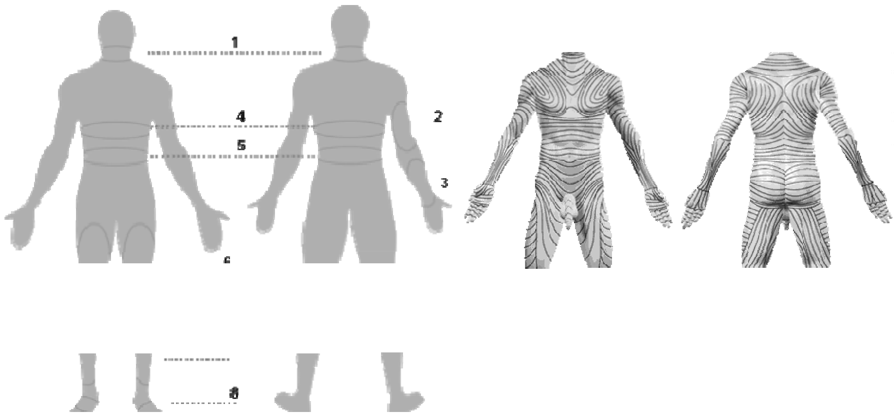

Figure 1. Ri-elaboration of unobtrusivity areas by Gemperle at al. (left) Langer's Lines (right).

They also found the most unobtrusive areas for wearable objects: collar area, rear of the upper arm, forearm, rear, side, and front ribcage, waist and hips, thigh, shin, and top of the foot (see Figure 1).

Starting from these studies we have identified a surgical theory, which provided a scientific approach to wearables. We believe that the identification of design guidelines could be improved by matching the unobtrusive areas with Langer's Lines. A Langer line, called also *cleavage lines*, is a term used in medical field to define the direction within the human skin along which the skin has the least flexibility. The direction of these lines is very important for surgical operations.

Surgeons during operation cut the body in the direction of Langer's lines, because these types of incisions generally heal better and produce less scarring (see Figure 1 - right).

In brief, our research is based on the hypothesis to achieve wearability by overlapping unobtrusive area found by Carnagie Mellon with Langer's lines.

The main idea is: use the overlapping areas to place the rigid parts of the devices and design the shape of them by following the Langers' lines.

The objective is to create a design method transferable, repeatable and usable for the design of wearable devices.

Designing a wearable system needs to address a breadth of technical, functional, physiological, social cultural and aesthetic features to be attractive, comfortable and functionally reliable. A design method that satisfies all these aspects has been developing by considering wearability aspects previous described and a design process created by Bruno Munari [5]. According to Munari design process is made up of several steps: Problem; Problem definition; Problem Components; Data collection; Data analysis; Creativity; Materials/Technology; Tests; Mock-up; Evaluation and Solution.

We propose a similarity with the design process for wearables. This approach can be used for a wearable system, creating a specific aimed method (see Figure 2).

4. A CASE STUDY

The case history here presented is "Wearable device for physiological monitoring and training in high performance sport" developed at the Biomedical Systems Laboratory (BSL) of the School of Electrical Engineering and Telecommunications of the University of the New South Wales by Prof. Branko Celler and his team.

A research staff composed by designers and PhD students in biomedical and electrical engineering developed the project undertaken by the BSL and the Biodesign Lab. The role of the designer was to set the preliminary experiments to test the performance of the system and also evaluate ergonomics and human factors, which are critical to the success of the project. In the development of such a class of product, a designer has to be a pivot, a researcher able to deal with different kind of problems and

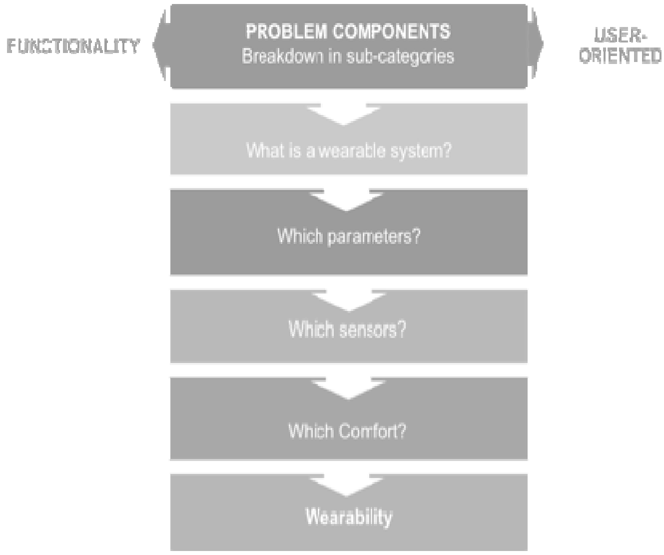

Figure 2. The steps for wearable systems.

have the competencies to talk with researchers come from different fields. Designer can make easier the cooperation amongst experts, coordinating design process among several research fields and skills.

This project shows the importance of designer cooperation in wearable systems study and in their innovative applications. This kind of devices has two classes of requirements, engineering and user-oriented one, both have the same importance. These aspects have to be complementary. Designer fills up the evident gap existing in the wearable devices, explored until now just considering the engineering qualifications.

The device is a real-time information system using a wireless transmission and biosensors, imbedded in the clothing and attached to the body, able to monitor:

- ECG and heart rate
- Step rate and energy consumption
- Respiration
- Body temperature

Following the scheme presented in Figure 2 the first step in the development of such device was to set the problem components from both functional and user-oriented point of view. The approach to design of wearables needs to create a mind map of the different aspects like measured parameters, sensors and comfort, and share it with the whole team. This phase is extremely important because the technological requirements for monitoring, generates a lot of limits for the placement of the sensors. So it is very useful to draw a body map with an overlap of unobtrusivity area, Langer's lines and sensor's area position.

In order to achieve the requirements of functionality and comfort of the product, the various professional figures involved in the project, worked closely together to decide on many design strategies to achieve the desired outcomes. The monitoring system for measuring of signals is made up of: silver chloride electrodes for skin bio-impedance used for both ECG signal and respiration frequency, electrodes to inject a high frequency current and to capture the voltage variation caused by thoracic impedance change, a tri-axial accelerometer for the step rate and a thermistor for body temperature.

From functional point of view one of the most important problems to face was to understand in detail the electrochemical properties of the sensors connected to the human body and to design circuitry that is safe, reliable and able to perform well even under the most adverse conditions of strenuous exercise

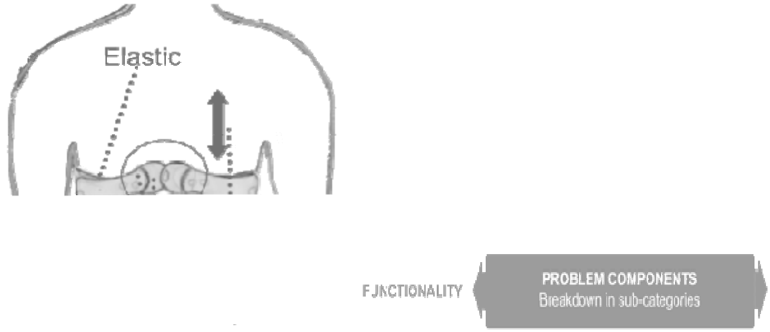

Figure 3. Functional Requirements.

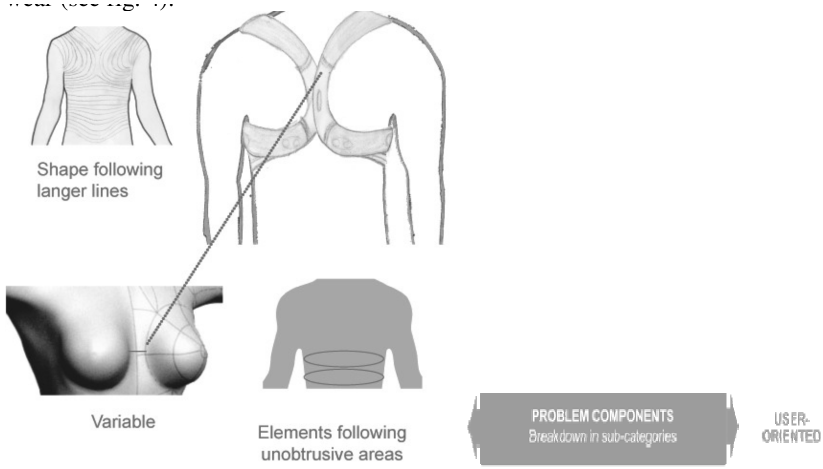

Figure 4. Wearability Studies.

(see Figure 3). The sensors had to be in contact with the skin because the more they are close to the body the more they are able to get a good signal. Another challenge was to design a device that is easily adaptable to the different body sizes, is unobtrusive and aesthetically pleasant and is comfortable to wear (see Figure 4).

At this point it is indispensable use designer's skills in human-centred approach to find user needs and desires. In the case of wearables, unlike traditional industrial design products, the proper functioning of the device is closely related to the interface body. For these reasons is necessary to match wearability studies and observation techniques.

5. THE METHODOLOGICAL APPROACH

After setting the problem components designer collected and analysed the data and conceived the idea. The concept was a top for the women and a t-shirt for the men with the sensors embedded and a box containing the electronics and the battery.

The following phases were the tests, the realization of mock-up and the evaluation ones. Wearable includes different factors of wear-ability, so in order to better understand them and design a comfortable device the research involved a test on a similar product and on a mock-up. The similar product tested was the *Polar Belt*: a heart rate, speed and distance monitoring equipment.

Besides a mock-up with the sensor on the front and a rigid part on the back was realized.

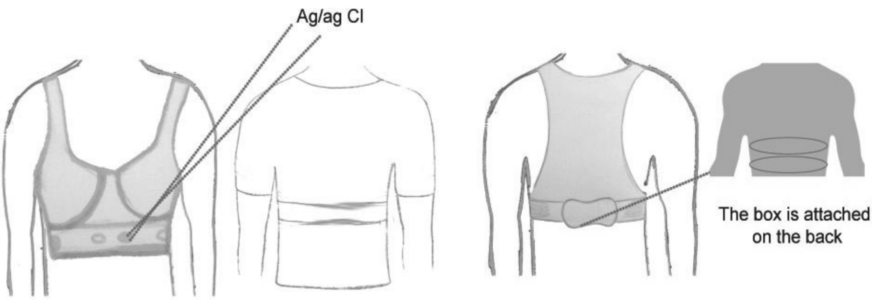

Figure 5. Sketches of first concept. Front on the left and back on the right.

Figure 6. Belt mock-up.

Thirty people were asked to wear polar belt and the mock-up during running thinking about the factors set for comfort dimension. Statements representing the comfort dimension were:

- Attachment: perception of device on the body
- Harm: the level the device hurt the skin
- Movement: perception of device moving around the chest
- Respiration affection
- Skin sweating

The results of the test were used in addiction with the parameters of ICES and Langer lines, for the design of wearable device. The shape of device was born by overlapping the unobtrusive areas (those with relatively the same size across body and larger in surface areas) and the Langer's lines, (showed in Figure 5) considering the requirements and the needs of users. The result obtained is a top for the women and a t-shirt for the men divided in 3 parts:

- Bra/t-shirt
- A belt containing the electrodes
- A box

6. CONCLUSIONS

The described project highlights the necessity to have a fit design method. Besides Munari method and the merging of wearability guidelines with Langer lines, other approaches might be investigated in order to improve "a fit design method".

An interesting approach comes from Tim Brown, the chief of Ideo design. He developed the idea of design thinking that is "*a creative human-centered discovery process followed by iterative cycles*" [6].

According to this definition design process is metaphorically considered as a spaces-system and not a series of steps (see Figure 8):

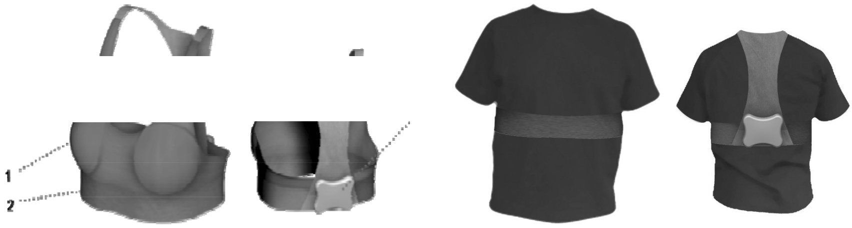

Figure 7. Final solution for woman.

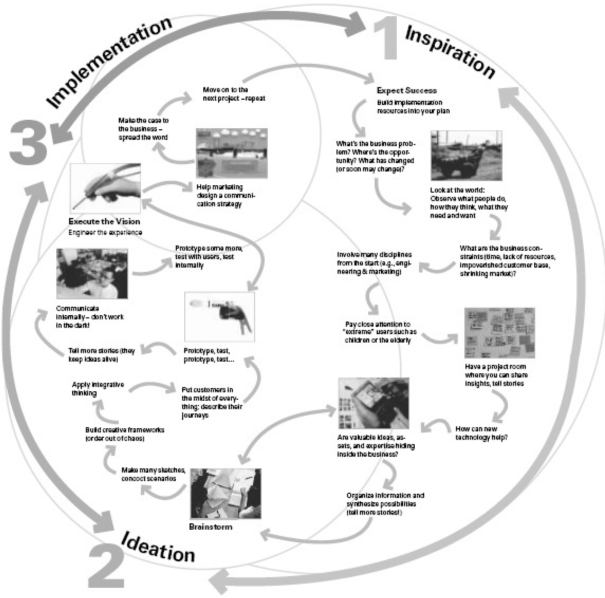

Figure 8. IDEO design process.

- Ispiration: where does the idea come from?
- Ideation: generation, development analysis
- Implementation: focus on the market

A consideration concerning the ideation needs to be pointed out [7]. According to Nigel Cross the ideation is made up of four basic cognitive operations that are necessary in order to deal with any kind of problem space (see Figure 9):

– generation;
– exploration;
– comparison;
– selection.

Summarizing '*design thinking'* is an approach that uses the designer's sensibility and methods for problem solving to meet people's needs in a technologically feasible and commercially viable way. In other words, design thinking is *human-centered innovation."*

All those approaches used in the design process are really useful in the development of a method for wearable device cause consider user needs, and all the aspects connected to the product.

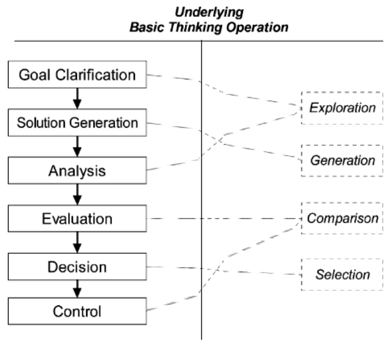

Figure 9. Scheme taken from Dorst, K and Cross, N 'Creativity in the design process: co-evolution of problem–solution' Design Studies, Vol 22.

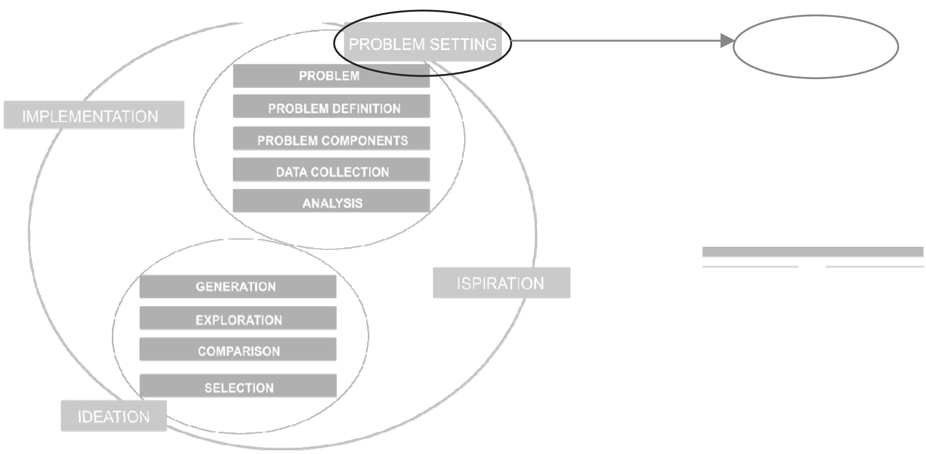

Figure 10. Design method for wearables.

For this reason an experimental method that is the result of a combination between the different approaches such as design thinking, and Munari method as well, could be developed (see Figure 10).

A wearable device needs a new process that crosses the existing ones, demands a disciplinary team, from a mix of different backgrounds, to embrace a collective awareness of new technologies, research methods and design techniques. The case study here described shows an approach to the design of wearables different from the technological one but still needs to be more focused on the user needs. Our objective is to provide a new method and develop guidelines resulting from the combination of different approaches. In order to validate this method, it is currently used on other case studies: a device for fire fighters and a glove for elderly rehabilitation. Further the results will be showed in order to stress in a better way the effectiveness of the method.

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