Multimodal Wearable System for Motor Rehabilitation - Design Perspective and Development

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Abstract. Wearables can ease the transition towards personalized medicine, bringing healthcare to anyone, anytime and anywhere. For wearable devices, human factors are essential; from conception to subsequent design phase. Current solutions are cumbersome and, despite they are designed according to standardized guidelines, they are developed for skilled users (physicians or engineers), without taking into consideration the real actors who will use and wear them: the patients. This paper aims to describe the application of a new methodology for integrating design and technology requirements in the development of wearable systems.

Keywords: Wearable devices · Pervasive healthcare · Human-centered design

1 Introduction

Population ageing is leading society to rethink and reshaping the healthcare system, bringing care and rehabilitation directly into patient's home, in order to reduce healthcare costs.

Nowadays, wearable devices can offer not intrusive ecological solutions for monitoring people anywhere. Wearable devices can ease the transition from today medicine to a more personalized one, for healthcare to anyone, anytime and anywhere by removing location, time and other restraints, while increasing its coverage, customization and quality [1]. Considering devices which are wearables, the human factors are essential in the entire development process; from conception to subsequent design and finally to the test and production phase.

This paper aims to analyze the different design requirements of a wearable system for personalizing rehabilitation at home, in order to define and apply a new design methodology for developing a modular textile sensing platform suitable to fit a wide range of people. The research outcome is the implementation of a multimodal wearable system for motor rehabilitation based on co-design

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methodology and User-Centred Design principles (e.g. wearability, usability and acceptability) following all the requirements and indications which come from the User Research process.

2 Design Methodology for Wearable

2.1 User-Centered Design

User-Centred Design (UCD) is an approach commonly used to develop products and solutions by involving human perspective (the users) in all the steps of the process [2].

UCD does not simply force to considers desires, wants and needs of the users, but targets the studies to satisfy needs onto two different levels: functional and emotional.

In order to better investigate the functional and emotional level, UCD defines three general principles:

- *Collaboration*: all the user are involved in all the process.
- *Empathy*: deeply understand desires and motivation which drive the users.
- *Experimentation*: hypothesize and verify this hypothesis experimenting with the users.

These three principles need to be approached using five different interactive stages schematized in Fig. 1.

- Planning: drawing up the entire design process in order to guide developers and users interaction.
- Context of use: collecting information about the intended user (user characteristics, tasks, equipment, interaction, physical and social environment);
- Usage requirements: extracting task which the user perform or should perform while using the product/system;
- Design: developing a first draft of the product/system by means of prototypes;
- Evaluation: involving the user with the prototype in order to understand the strengths and weaknesses of the products/system and re-calibrate the development step.

For each of these stages, Maguire et al. [3] underline specific design methods in order to collect qualitative and quantitative data. Nevertheless, the design methods to be used are strictly related to the product/system topology and purpose. Wearable devices and systems require an ad-hoc method which includes both user and technological aspects, also analyzing connectivity, data analysis and data management aspects.

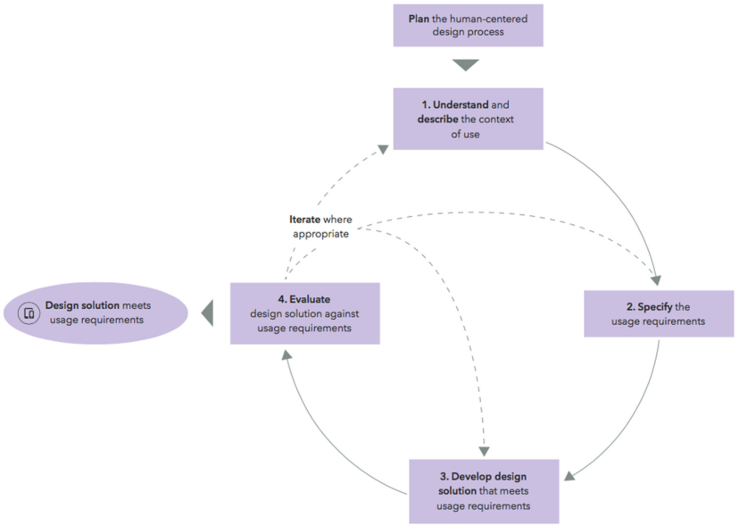

Fig. 1. User-centered design process study (ISO/TC 159/SC 4 Ergonomics of human-system interaction [4]

2.2 Octopus Methodology

One of the first try in wearable design methodology is Octopus presented by Martin et al. [5].

Octopus methodology is the result of an ad-hoc study which involved different disciplinary actors intending to create an optimal strategy for motion capture (MoCap) wearable product development. Figure 2 shows the representation of the MoCap wearable product/system structure and its ecosystem. Octopus consists into three main areas:

- context: strictly related to UCD first two stages; in this area, environment and users are analysed to extract characteristics and needs both from the technical and emotional sphere.
- device: it consists of the study and development of the material part of the project. Here it is the evaluation of technological aspects, the prototyping and the evaluation of the product/system.
- software: it is the "fluid" part of the product/system, but often the most valuable. It consists of all the algorithm for data analysis and the program for data visualization.

Designing wearable involves different disciplinary actors from medical to engineer and designer. Design methodology for wearable needs to include all these subjects in order to optimize the product/system not only for the user but also for all the actors which intervene in the use of the system, even if only marginally. This is especially true for medical wearable systems in which the

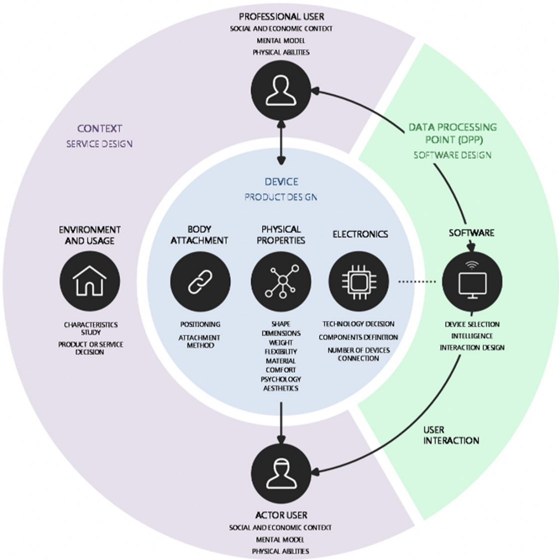

Fig. 2. The Octopus methodology [5]

actors related to the use are both patient, physicians and also relatives. Aiming to create a more personalised medicine, removing location, time and other restraints, modern wearable system make use of transmission technologies and internet connection that allow the sharing f medical data and the constant connection with the physician. Moreover, these technologies add some degrees of complexity to the system which, although on the one hand increase the performance of the system [6], on the other it can cause a decrease in usability due to a lack of interaction and experience evaluation. These two main factors have been found during focus groups, during which some subjects highlighted difficulties of daily used connected equipment, due to loss of connection or lack of status feedback. For this reason, Octopus methodology, developed for MoCap wearable product/service design, is not enough and needs and add-ons.

3 Evolving Design Methodology and In-Vivo Application

This paper is based on the project Multimodal Wearable (MW), funded by "Centro Protesi" INAIL, one of the research centres of the National Institute for Insurance against Accidents at Work.

The project goal is the design of a wearable system for monitoring and evaluating motor rehabilitation activities in post-stroke patients, with the aim of reintegrating them into the work environment. The core strength of the project is the migration from the classic hospital rehabilitation, to a more personal and personalized at-home rehabilitation, with the aim to improve both the well-being and effectiveness of the treatment.

One of the most import parts of the project has been the design methodology development. Starting from Octopus methodology, MW project evolves it, based on information gathered through focus groups and interviews, adding two other main areas: the communication and the human factor. The evolved methodology has then five main areas:

- users and environment;
- wearable device/s;
- communication and network
- software;
- human factor;

All of these areas, as described below, has been studied by means of specific tools, in order to extract information that have been then applied for the development of the system. Next paragraphs summarise the application of these tools.

3.1 User/s and Environment

Wearable itself define a piece of technology which are in close contact with the user's body. For this reason, it seems quite easy to define the context of the study of a system like this, but this applies only to simple commercial devices such as fitness trackers, which do not deal with medical data. Wearable contextualized within telemedicine or pervasive health (in terms of medicine for everyone, regardless of geo-location, timing and personalizing), the context of the study and any servitization became more complex due to the presence of multiple actors which operates with the product/system. For a multi-modal wearable system for motor rehabilitation, two types of users can be defined: professional users and everyday users. Each of these types can contain different sub-categories of users. In order to study all the users and actors, the environment variables and their interaction, the most used methods, suggested by the handbook of human-centred design [2] are Personas and Scenarios. The definition of personas and scenarios allow for the first technologies skimming and the definition of all the users/actors. Thanks to the concrete application of these methods, our approach for wearable devices allow to define two main actors typology:

- Expert or Professional users: who does not directly use the system, but it is involved in the prescription, configuration and installation (e.g. physicians, health workers, engineers...).
- Common users: who really use the system but also relatives which can help using it.

3.2 Wearable Device/s

After defining users' types and environment, one of the following steps is the definition of technology. Technologies are strictly related to the interaction with the user and for this reason, choosing which technology to put in place is related to user studies. Ones of the best methods for collecting this information are the focus groups and questionnaires [2]. Applying the method, three design interactions were carried out:

1. two focus groups with all the actors (30 peoples) found during the context study, followed by an ad-hoc paper questionnaire administered of the end-users;
2. design and technical analysis followed by a validation of "fake products" with a panel of users;
3. prototyping and final standardised questionnaires (SUS - QUIS) for acceptability and usability study.

Information gathered by means of focus groups and questionnaires is then used for selecting both proper technologies and interaction methods. In the in-vivo application of the methodology, we divided the technological study into two parts: wearable devices development and smart garment.

Wearable devices development consist in the design of electronics, enclosure and connection with the smart garments; smart garment consists in the design of the garments (based on activities to be analyzed), connection with electronics and embedded sensors. Figure 3 shows the output obtained from the information collected during the activities described above.

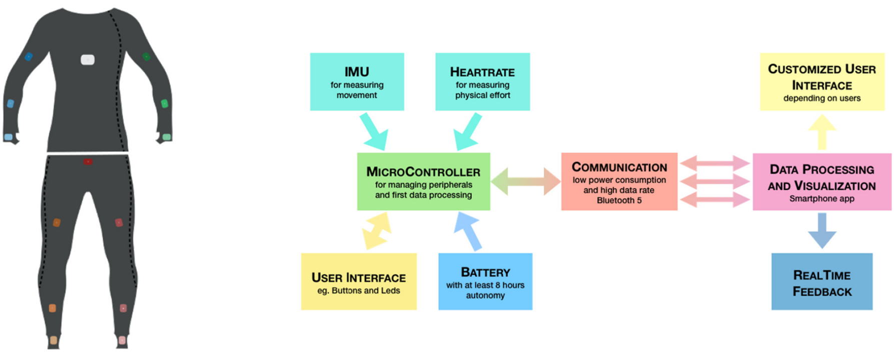

Fig. 3. On the left, the sensorised suit structure: the colored squares are the wearable devices; on the right, block diagram of the wearable device

3.3 Communication and Network

Figure 3 shows the block diagram of the wearable device. It consists of nine main parts: from the micro-controller to battery management circuit. Ones of the most important parts of the system, related to how user interact with the product, are the communication part and the networking part. The communication encapsulates all the aspects related to user communication of system state, alert, error and data. A product usually implement displays, LEDs, sound, but also wireless communication which allow for product interaction by means of other instrumentation (e.g. personal computer, smartphone...). Moreover, wireless communication can be also used for data communication and recording, both with other wearable device or smartphone/tablet, without user intervention. Although the user is very often marginally involved in the design of these aspects, due to the fact that they are seen as unrelated to the actual use of the system, it is important to consider the analysis of user data and user's feedback in the technological development. In fact, the choice of the technological component and the communication standard can largely influence the usability of the entire system, as underlined by Yaakop et al. [7] who study the usability of Bluetooth 5 technology in the IoT field.

The in-vivo application of this methodology, thanks to information collected from engineers and users during the first phase of the focus group, sees these two parts composed by:

- Communication: devices show status and error by means of one multi-color LED. The only input methods is instead a button (which include the previous LED). Data are shown on the smartphone and tablet. A most accurate status visualization and error management can be done using the smartphone application.
- Network: multiple devices are connected to the same smartphone or tablet via Bluetooth 5. This allows for high speed and compliance, without compromising the normal use of the system forcing the user to long and tedious connection procedures.

3.4 Software

Another fundamental part of a wearable system is the software. Software means both the data collection and processing component (the algorithms), and the part of the graphic interface and visualization. User takes part especially in the design of the front-end graphical interface. This is the most sensitive point of the whole system: it is the one with which the user will interact most. For this reason, it is very important to design a stable, minimal and understandable UI: Nielsen heuristics [8] are good practice for this. In our in-vivo application, the software has been tested with users by means of an A/B test [9].

3.5 Human Factor

The human factor for wearable devices and system is essential both in terms of wearable device size and position. Size of the devices are highly dependent on the technologies used and the battery; smaller is better, in terms of wearability but too small dimensions can cause usability issue. Moreover, the position of sensors on the human body can cause discomfort under multiple aspects, as described by Zeagler [11]. For this aspect, our in-vivo solution takes into consideration both Zeagler consideration but also biomechanical aspects, studying the best positioning that can optimize both wearability and the biomechanical model performances.

4 Conclusion

The promising application of an expanded octopus methodology for the wearable device allows obtaining a system with a good level of acceptance by the users. In-vivo application of the methodology allows developing a new multi-modal suit composed by a sensorised suit and 14 wireless sensors. The results emerged from the qualitative analysis (interviews with users) show that the system has excellent approval ratings from all the actors involved in the rehabilitation process: from users to caregivers and clinicians. The design process, based both on Octopus and User Centred Design, has a continuous iteration between users and designer in order to create an high-level product/system. The next step will be the standardization of the described method and its application to a big scale production wearable system.

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