Inclusive Design of Wearable Smart Objects for Older Users: Design Principles for Combining Technical Constraints and Human Factors

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Abstract. The purpose of this article is to propose an evaluation of integration principles between constraints resulting from the choice of technologies to be used on devices, and human needs deriving from the needs analysis of the elderly, in the field of wearable smart objects design for self-sufficient and non-self-sufficient users. The authors will describe this process according to the state of progress of HABITAT project.

Keywords: Inclusive Design · Wearable devices · Wearable technologies
Smart object · Design for elderly people · Healthy aging · Internet of Things

1 Introduction

The continuous growth of average age of the world population, and the consequent increase of the percentage of elderly in our society, created an enlargement of the demand for goods and services related to healthcare and safety issues[1].

The continuous increase of costs related to chronic diseases and the pressure to which public budgets are subjected, are just some of the challenges that welfare systems will have to face all over the world in the next years. In this scenario, digital technology can put itself at the service of health issues by supporting it both in the

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progress of knowledge and by making possible paradigms of support for medical care H24 anywhere-anytime, especially for the most fragile and in need of support categories, just like the elderly [1]. In the debate on the Internet of Things, the scientific community starts to question what effects and positive impacts can have on people who need assistance and daily help [2]; some researches are nowadays focusing on Health Iot, a network of devices connected to each other to collect, record, analyze and share health data [3].

Wearable devices stand out in this sector, which incorporate advanced technologies and can provide solutions of effectiveness and efficiency concerning certain challenges that health systems have to face.

Wearable devices conceived around the last twenty years aimed to help on solving that problems related to safety, but with huge limitations: the first products were substantially “wearable buttons” to ask for help, they were unaesthetic and above all stigmatizing for people wearing them, causing them embarrassment to wear it in public; secondly, they weren’t predictive and didn’t have the same accuracy as the current available detection systems that are able to anticipate emergencies before they happen; thirdly, they didn’t have the ability to communicate “autonomously” a danger.

2 Case Study

In this paper the authors will describe some aspects of a research project they are working on, that is focused on Inclusive Design for the elderly; the project is named HABITAT, it is funded under the program POR-FESR 2014–2020 of Regione Emilia Romagna, Italy, and it aims to design and test a platform based on Internet of Things for the realization of environments that are assistive, flexible and adaptive for the care of the elderly in their home environment.

Among the various smart objects designed, there are in particular two wearable devices conceived to detect the elder’s habits interpreting data collected throughout the day, that will be combined to allow a reading of behaviors protracted over time, so as to make a further long-term evaluation possible on both motor (i.e. The elder performs the same paths but at a lower speed and with more difficulty in the movements) and cognitive decline (i.e. the elder often does the same route without having a goal).

3 Supported Thesis

The aim of the paper is to demonstrate that the chosen design methodology allows to combine the available technologies with the design requirements expressed by the users.

3.1 Wearable 1

The first wearable device deals with indoor localization of users in their living environment, with the aim of monitoring the elder’s behavior: the amount of ground covered and the relative time it takes to walk it, in order to evaluate any possible decline in motor skills; the actual position, in case the individual needs to be located; the user's immobility, to hypothesize danger and set an alarm; etc.

For the indoor localization of elderly, disabled people, or persons with any form of senile dementia (i.e. Alzheimer's Disease), a reader able to control in real-time multiple active tags has been designed, developed, and tested.

The technology that has been exploited to achieve this goal is the Radio-Frequency IDentification (RFID), widely spread in the last decades, but still in development nowadays; it exploits the communication via the propagation of electromagnetic waves at radio-frequency between two different entities: a tag, that can be active or passive depending on whether or not it is supplied by batteries, and a reader, that remotely queries the tags for the purpose of identification, automatic memorization…

In the framework of the HABITAT Project, a compact and hand-held RFID reader, named RID (the acronym of Remotely Identify and Detect) [4] has been used for this aim: the operating frequency of this prototype is 2.45 GHz, belonging to the ISM (Industrial, Scientific and Medical) Radio Band covering from 2.4 GHz to 2.4835 GHz, and its main working principles are based on the Monopulse radar and beam-steering techniques; this last technology, in particular, allows to perform an horizontal, or azimuth, scanning that enables to obtain an accurate estimation of the angular position of the tagged entity (Fig. 1).

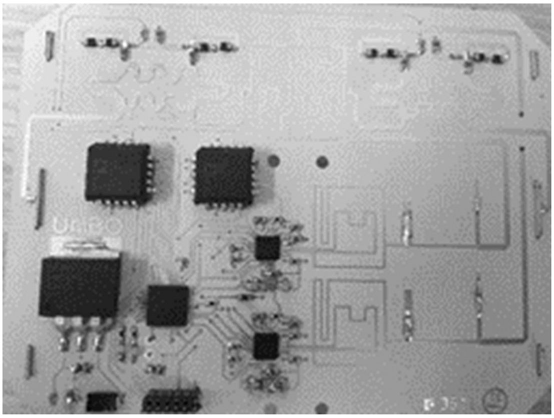

Fig. 1. Layout of the reader circuitry.

The radar is based on an array of two flag-type dipole antennas [5], able to create, through proper feeding, two different radiation patterns (known as Sum Σ, in-phase feeding, and Difference Δ, out-of-phase feeding), whose a-posteriori combination is able to guarantee an appropriate figure of merit (MPR – Maximum Power Ratio) at each angle, revealing the precise angular position of the tag at a certain time [4].

As explained before, this smart object allows the angular detection of the tags; the distance, that would obviously provide a further essential information to process the data and to correctly localize a person in a room, is estimated making use of the maximum RSSI (Received Signal Strength Indicator, i.e. the power values received at the reader from each tag) at the Σ Channel: the usage of a simple formula taking into account both the value of a reference RSSI (at 1 m) and a path-loss model to simply characterize the involved radio channel, allows an almost real-time recover of the information. The room under evaluation has been also divided into three calibration zones: the different radiation patterns of Sum and Difference at the borders and the different radio conditions have been considered for all of them [6].

Fig. 2. Segmentation of the office scenario under test in three zones of calibration.

The wearable RFID active tags use a patch antenna at the frequency of 2.45 GHz: this choice is based on the fact that, due to the presence of the ground plane in the antenna layout itself, it intrinsically isolates the antenna performance from the body and thus can be easily worn without being influenced by the human body, and vice versa. Both the reader and the tags are equipped with Texas Instruments (TI) MSP430 microcontroller and a TI CC2500 transceiver (two for the reader, one for each channel); the circuitry used for the tags derives directly from the TI eZ430-RF2500 Development Tool. The substrate of the antenna (dimensions: 50 × 50 mm, with a thickness of about 0.65 mm) is made of typical RF materials: several choices can be made such as Taconic RF 60-A, Rogers 4360G2, or FR4 (Fig. 3).

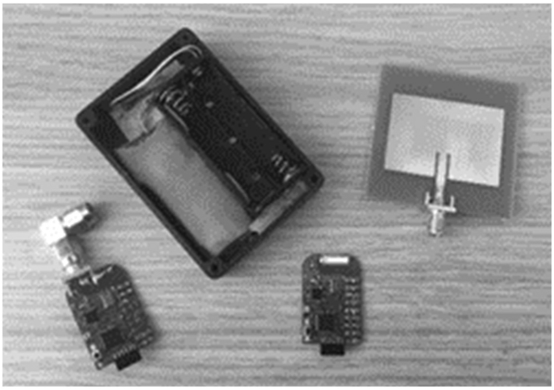

Fig. 3. Active tags, circuitries, and FR4 patch antenna used in the tests for wearable RFID tags.

3.2 Wearable 2

The second wearable designed within HABITAT, is a device capable of quantitative and qualitative analysis of the elderly indoor and outdoor movement, thanks to an inertial platform (IMU) which is inserted in the object itself. Also this device will provide useful information for the assessment of the health and activity status of the person.

Wearable systems for activity monitoring comprise various types of sensors, transmission modules and processing capabilities and they promise to change the future of personal care. Personal wearable systems need to satisfy a great diversity of criteria and constraints. These include small weight and size, privacy and security of personal data, unobtrusiveness, ease of use, low cost, reliability and low power consumption. Designing such a system can be a challenging task since there are often conflicting requirements that have to be considered from the designers. In addition, although there are already many different solutions on the market for activity monitoring, few of them are designed having elderly users in mind.

It is not always necessary to design a new piece of hardware; today's smartphone not only serves as computing and communication device, but it also embed a rich set of sensors, such as an accelerometer, a magnetometer, a gyroscope, a GPS, a microphone, and a camera. The high computing power, together with multiple connectivity and sensing options is enabling new applications across a wide variety of domains, such as healthcare[2], social networks, safety, environmental monitoring[3], and transportation[4]. Therefore an activity monitor could just be designed as a smartphone or smartwatch app.

The most widespread and utilised sensor for designing an activity monitor is the accelerometer. Uni- and multi-axial accelerometers: actigraphs[5] are commonly used in sleep medicine and clinical research to assess patients' motor behavior. Actigraphs are small watch-like devices worn on the wrist to log limb movements but can also be attached on the ankle or waist; they basically record the presence or absence of motor activity and its intensity. Pedometers, attached to the patients' ankle or waist, are also based on an accelerometer and on a step/peak detection algorithm.[6] The application of inertial sensors fixed on the patient's lower back allows the analysis of individual

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mobility patterns as an indication of the patients' motor behavior[7,8]. Advanced signal processing and feature extraction methods can be applied when the sensing unit is fixed on the lower back in order to assess specific characteristics of balance, gait, postural transfers, and turns. Depending on the specific motor tasks of interest, activity classification algorithms can benefit from the readings of a gyroscope and/or a magnetometer in terms of reliability and information content; the combination of an accelerometer, a gyroscope, and a magnetometer is called Inertial Measurement Unit (IMU).

4 Methodological Process

The entire Habitat project has followed a User Centered approach [7] to design smart objects and the system that governs them, so users have played a fundamental role both during the definition phase of the requirements [8] and during the experimentation phase of the various design solutions hypothesized.

The applied methodology was aimed at optimizing the combination between constrains deriving from the technological choices and requirements derived from the analysis of the needs carried out with users. The phases of the design process applied for the definition of the wearable smart objects project, were the following:

4.1 Definition of Primary Users, Secondary Users and Stakeholders, and Analysis of the Relative Needs Concerning the Design of the Two Wearable Devices Within the Project HABITAT

The needs analysis has been carried out in different steps [9]: at the beginning were collected many contributes using surveys, direct interviews, focus groups… than information were elaborated in order to obtain brief statements that could express the requirements desumed by the different categories of users involved in the project. These statements were classified depending on the user that expressed them, on the field they were related to and on the relevance they had for the design of wearable smart objects.

4.2 Definition of Constrains Deriving from the Technologies Developed by the Partners of the Habitat Project, and Individuation of the Features of Smart Wearables to Be Designed

Wearable1: Regarding the RFID reader, the steering of the electronic beam is able to detect and localize tagged users in a scanning zone going from −45° to 45° (Fig. 2) with respect to the direction orthogonal to the reader plane. Several measurement campaigns in different indoor environments have been carried out and it has been

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demonstrated that the major localization errors belong to border regions (up to 30% of percentage error on the absolute position). For these reasons, it would be preferable to install the reader in a corner of a room, in order to ensure that almost every part of the room will be covered.

Obviously, a setup of the room adopting two or more cooperating readers would be desirable, to enhance the indoor localization accuracy, as the reader-tag distance increase. Moreover, in this way, a possible hiding of the tag's antenna from one reader's view (i.e. caused by human blockage) should be balanced by the presence of the other one.

With regard to the vertical placement of the RID, for typical indoor localization of human beings, it's recommended to locate it between 160 and 180 cm of height: this could prevent or minimize the effects of humane blockage or other unwanted interferences.

However, as regards the wearable tag's constraints, the fact that the antenna has a shielding plane is of great importance for the aim of wearability and coexistence with nearby human bodies: for that reason, the choice for the tag's antenna has fallen upon a planar patch.

After several trials, also some feasible positions of the active tags have been selected: on chest as a pendant, on the shoulders, or in a cap on the head.

Wearable 2: Information collected by the Habitat infrastructure are locally processed and displayed on the wall-mounted touchscreen in a summary report.

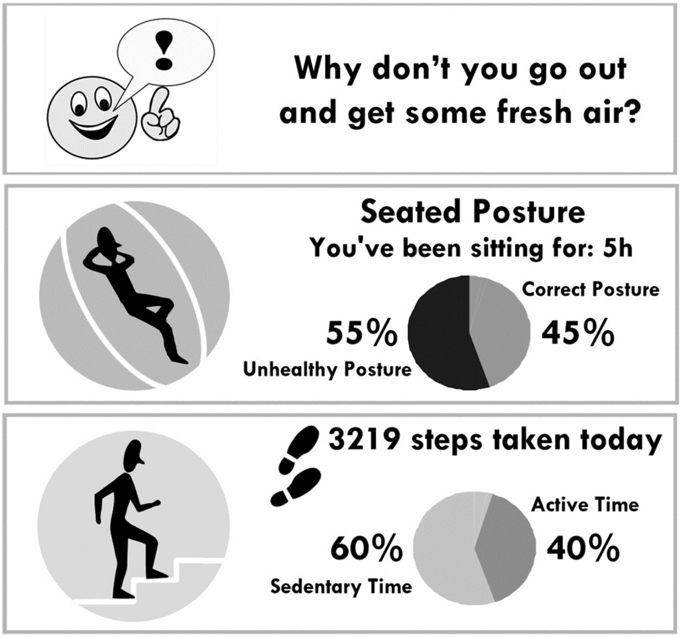

Fig. 4. Summary report of the Habitat system. The report includes statistics about room occupancy, physical activity, and sedentary behavior. It also provide personalized tips and suggestions for the user.

Information about physical activity consists of the number of steps, the sedentary time, and the active time. Although this information could be derived with very simple wrist or waist worn actigraphs, the wearable sensor is placed on the lower back by means of an elastic case waist belt. This placement allows the estimate of a rich set of features for the assessment of the quality and quantity of postural transitions and gait bouts. The algorithms embedded into the wearable sensor automatically identify lying, sedentary, active, and walking bouts along with the movement intensity [10]. For each waking bout the algorithm automatically detects turns while walking and segments each walking interval into straight-path walking episodes and turns [11]. A set of advanced gaits and turning features is extracted such as step duration and variability, gait coordination [12], gait regularity, gait symmetry [13], gait smoothness [14, 15], turning peak velocity, turning mean velocity, turning angle, turning smoothness [16], and number of steps for turning (Fig. 4).

Those advanced features are of clinical interest and can be used to monitor both the physical capacity and the physical performance of the user and hence predict functional decline. Even though advanced features are not shown to the user they are used by the system for personalizing feedbacks, messages, and the user experience in general.

4.3 Application of the Quality Function Deployment, for the Definition of Project Priorities and Hierarchy of Most Important Needs to Be Met, and Interpretation of Its Results

The QFD [17] is a tool that helps to design products and services starting from a hierarchy of users' and customers' needs. It helps to decide the performance due to items or services to be designed and allows having feedback on the consistency of project proposals and starting objectives. The inputs of the QFD are the "Needs," that are defined to reflect users' necessities and the "Features", that are measurable performances of the object to be designed. Both needs and features are put in correlation through a matrix chart, which helps designers to evaluate the degree of relationship. Starting from hierarchy resulting from expressed evaluations, it will be than decided how to design products or services. In this project QFD helped to combine issues related to quality (emotions and necessities of selected categories of users), with issues related to quantity (measurable features of the smart objects to be designed regarding both design and technologies), designers had the role of applying these results to the design of wearable devices.

4.4 Design and Construction of the First Rough Prototypes

Designers hypothesized different solutions for both wearable devices, then they chose the ones considered more appropriate for the achievement of the objectives established in the preceding phases.

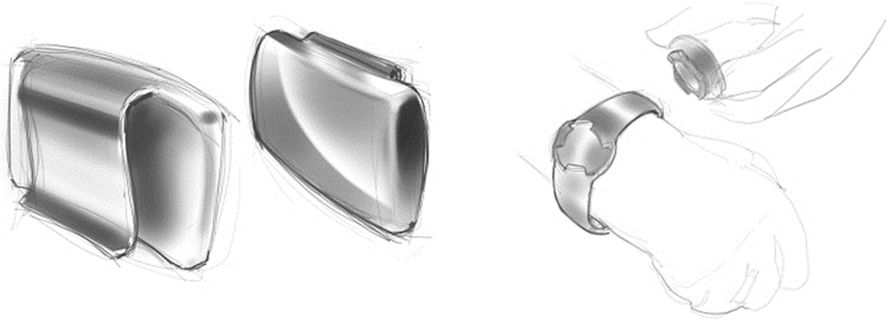

Fig. 5. Sketches of Wearable1

Fig. 6. Sketches of Wearable2

The first prototypes had the function to make possible an evaluation of usability by older people, so wearables have been realized with poor and cheap materials, just to make possible a simulation of usage and to evaluate dimensions, shapes, colors and psychological impact for the user (Fig. 5 and 6).

4.5 Testing of Prototypes with the Same Users that Were Involved in the Initial Analysis and Development of Test Results for the Improvement of Wearables' Design

The rough prototypes have been tested by primary users, both self-sufficient and not self-sufficient elderly, to collect feedback aimed at evaluating the usability of the smart objects. A meeting was organized between designers and users in a day center usually visited by the elderly; the testing phase concerned both the use of devices and the interface connected to them. Users have been subjected to the various developed solutions, instructions related to the usage were minimized just to assess how the use could be intuitive and not related to previous knowledge. At the end of the test phase, information gathered through observation, direct questions and shots of the elderly in action was elaborated to understand which strategies were most effective for the implementation of natural and physical interfaces. The results of the test phase were then translated into the design of precisely objects and interfaces that were an evolution of the previous project, which would allow an increase in the level of usability without compromising the technical choices derived from the use of the technologies described above.

5 Results

The iterative process typical of User Centered Design [7] allowed designers to improve the design of the two wearables by having a feedback of users for the different hypothesized versions, and to optimize the functioning of technological components used in the project. The design process passed through several stages, each of them more complex and efficient compared to the previous ones, each stage corresponded to an evolution of the design of the two wearable devices.

6 Conclusions

The QFD, a tool created to encourage listening to the user's voice, and collaboration between designers of different disciplines within the Japanese industries, proved to be an effective tool for the user centered management of multidisciplinary research design projects. In the project described in the paper, the technological constraints identified by the team of engineers, were assumed as invariants in the definition of the concept, based on the needs analysis developed by the designer team. All the data collected in the various phases and in the co-design workshops were used to identify the configurable features, and to define their importance in relation to the needs, producing shared project specification, enriched by the different skills of the team.

User Centered Design allows not only to direct project results to a humanly significant outcome, but also to harmonize multidisciplinary skills in an effective synergistic design research development process.

The wearable devices project illustrated in the article reached the final phase. The definitive prototypes are under construction and will soon be officially presented and tested for the verification of obtaining a TRL 5 level.

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