Switching from Traditional Medical Applications to Mobile Devices: Cardiac and Cochlear Implants

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Abstract. Designing HCI in a medical context is not trivial. It needs to provide patients and medical experts with essential information for the tasks to be performed while ensuring the safety of operations. In this paper, we tackle this issue focused on the HCI requirements and expectations revealed by the use of mobile devices (Smartphone for patients/Tablet for specialists) on the assistance of cochlear or cardiac implanted patients. To illustrate the feasibility of our research work, we report several experiments and evaluations attempting to guarantee the safety of operations on adjusting cochlear implants and supporting the monitoring of patients with cardiac implants. This work is carried out as part of an academic and industrial research project.

Keywords: Human Computer Interaction, IT and Healthcare, Mobile and Medical Applications, Medical Data Visualization.

1 Introduction

In the last decade, technological enhancement increasingly motivates medical domain to discover new ways to improve the quality of healthcare. By means of adapted information systems and exploiting new visualization techniques, patients and medical professionals are progressively better supported and assisted [1,2]. Indeed, visualization techniques in this domain extends to a variety of application cases, such a consulting an EHR (Electronic Health Record) [3], providing a diagnosis [4] or monitoring patients with chronic pathologies [5].

However, designing the HCI in the medical domain is not trivial. This is particularly due to the significance of providing essential information to the intended tasks for a given user (i.e. practitioners, specialists, patients…), meeting clarity and ease of use criteria (depending on type of user, for example a disabled patient) [6], guaranteeing safety of operations and ensuring trustable data discovering.

The study that we conduct in this paper refers to the HCI challenges revealed by the future generation of medical implants (cochlear and cardiac) and implying the migration of medical applications to mobile devices. More specifically, we are interested in two main issues: one related to the specificities of patients with cochlear and cardiac implant interacting through a Smartphone (i.e. visualization choice, available functionalities…) and another one concerning the visualization requirements of specialists to easily correlate medical data by using a Tablet. In both cases, the

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rapidity of execution, safety of operations and the confidence on the applications must be guaranteed. For this paper, our solutions are described in terms of safety of operations and its impact on the HCI design and development.

The rest of the paper is organized as follows. Section 2 describes the specificities and HCI challenges of our study cases: cardiac monitoring and cochlear implant adjustment. Section 3 details our approach and finally, we conclude in Section 4.

2 Monitoring and Assisting Implanted Patients: Cochlear and Cardiac Visualization Requirements

In the following paragraphs, we describe the specificities of the traditional procedures for cochlear adjustment and cardiac monitoring. Together, we underline their resulting evolution and its consequences on the HCI design and implementation.

2.1 Adjusting Cochlear Implants: Patients and Medical Experts

Cochlear implants are intended for profound deafness or hard-of-hearing people from infants to elderly[1]. An implant is mainly composed of two parts: an inner part and an outer part (prosthesis) (Figure 1a). The inner part is implanted by a surgical procedure and it is composed by several electrodes (currently 24 electrodes) connected directly to the patient's auditory nerve. The prosthesis sits behind the ear and requires a battery and a processor to correctly process sound signals and convert them into electric impulses. These two parts are connected by magnetization and a transceiver system through the skin.

(a) (b)

Fig. 1. Cochlear implant and implant adjusting

A cochlear implant is adjusted by an audiologist with a fitting software (on PC, Figure 1b). Audiologist sets several parameters like the minimum and maximum band frequency threshold for each electrode. Also, the audiologist (with patients) can create and set programs matching four different listening situations. These programs enable the patient to dynamically adjust the settings of the implant (i.e. transition from silent to noisy environment) and are accessible via few buttons placed on the prosthesis. Actions performed over these buttons, involve an immediate adaptation of the implant.

[1] http://www.nidcd.nih.gov/Pages/default.aspx

2.2 Monitoring Patients with Cardiac Implants

The monitoring of patients implanted with Cardiovascular Electronic Implantable Devices (CEIDs) like defibrillators or pacemakers (Figure 2a) implies a continuous monitoring and regulation of the heart activity and by transmitting electrical impulses to stimulate it, only if it is necessary. Such a monitoring can be performed at specialized clinics, by transferring data to the specialist, initiated by the device or by the patient (remote monitoring), or even by the combination of both monitoring modes. Traditionally, portable defibrillators are developed to analyze data from cardiac implants and interact with. Recently, labs monitoring and recording systems (over a PC, Figure 2b) are used to analyze heart activity and other associated parameters (i.e. blood pressure).

The heart activity or cardiac signal analysis is specially based on an Electrocardiogram (ECG). The ECG is a measurement of the electrical activity of the hearth and is traditionally represented or traced over 12-lead, where each lead points to a specific part of the hearth (Figure 2c).

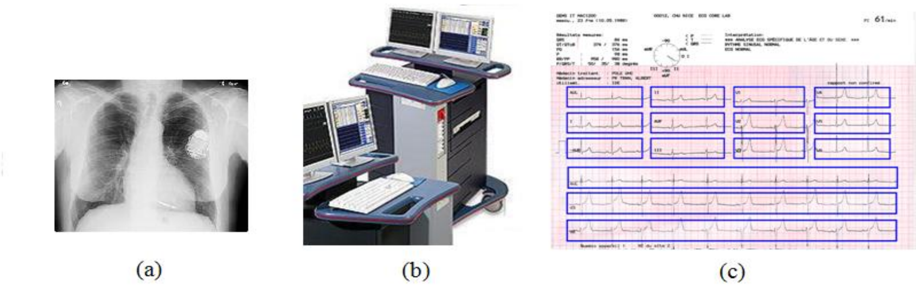


Fig. 2. Cardiac implant and ECG representation

When the specialist analyzes the ECG, he/she examines the size and length of each part of the ECG. Indeed, the size and length variations of each lead may be significant to determine a problem with a specific part of the heart. In a monitoring context, the ECG can be discovered in different ways, for example by performing a random or programmed recording of the heart's electrical activity as well as recording only when a given situation occurs (i.e. arrhythmia, blood pressure variations, etc.).

2.3 Cochlear and Cardiac Implants: New Visualization Challenges

Until now, most of the medical applications are deployed on PCs or on dedicated medical equipment; their interfaces are developed as user-friendly environments, with icons and menus, images or multimedia. More recently, Web 2.0 technologies have offered patients and healthcare professionals with more interactive and attractive graphical interfaces for displaying medical information such as patient's medication control, consultations boards, etc. Further, thanks to mobile devices patient information can be also integrated with medical sensors such as ECG, glucose, temperature, etc [5,7]. Applications for remotely monitor patients with chronic diseases [5] are focus on simple but very specific data (i.e. heart rate) often associated with a timestamp and representing patient's behavior. Besides, applications assisting diagnosis through medical imagining manipulate more complex data which are processed and discovered by features like zoom, scale, color, 3D... [4] and where a migration to mobile devices is not already conceived.

The evolution of cochlear and cardiac implants requires adapted visualization design over new interaction devices such as mobile devices. In both cases, our goal is to provide patients and experts with HCI ensuring the quality required for such applications: in any case we should not compromise patients' safety.

The new generation of cochlear implants deals with issues related to the disappearance of the prosthesis and the migration of the adjusting software (PC) to mobile devices. As a result, patients would be capable to adjust their implant via a Smartphone and the audiologists will switch over Tablets in order to achieve cochlear setting. Besides, the future generation of CEIDs addresses new challenges related to the accessibility, autonomy and performance, aiming to better assist and support patients and specialists. For example: patients will be able to visualize their heart condition and the implant status on their personal Smartphone and specialists will have the possibility to interact with an electronic ECG through a Tablet.

3 Towards Medical Mobile Applications: Patient and Specialists Oriented Visualizations

Switching traditional applications for cochlear and cardiac implants to mobile devices requires adequate visualization solutions while ensuring the safety of operations in terms of patients' safety and quality of healthcare. For the cochlear implant adjustment as well as for the cardiac monitoring, the richness of information to be transmitted to medical specialists can be summarized in *correlated data visualization* for a given task. For example, adjusting a cochlear implant requires a simultaneous visualization and interaction with the implanted electrodes, and for cardiac monitoring, several visualizations of *EVi* values (in real-time or in periods of time) are required to isolate possible malfunctions and provide better diagnostic (Figure 2c).

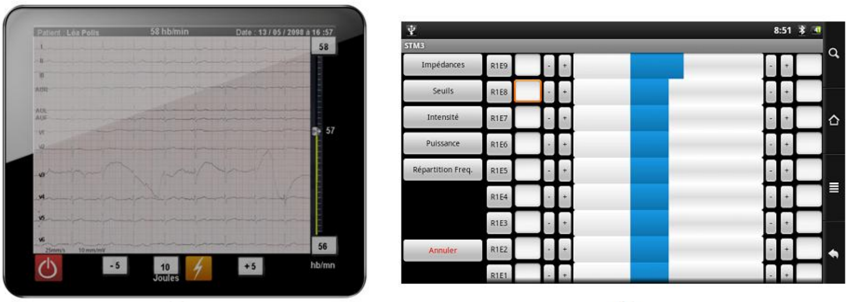
For both cases, the new visualizations and interactions should be based on the existing correlated data visualizations and which have been proven through the years by the medical domain. Such visualizations ensure implants adjustment and diagnostic without compromise patients' safety and thus, migrating to a mobile device like a Tablet, must preserve such visualizations which specialists are used to interact with. Also, in order to avoid inconsistencies, we have to take into account aspects like device's screen size (17" for a PC to 10" for a Tablet) and the diversity of interactions (mouse for a PC to tactile functions for a Tablet).

Switching to mobile devices opens also new interaction perspectives for patients. Actually, the operations are constrained by the current medical equipment: the prosthesis enabling to adjust listening profiles and the alert button for the cardiac implanted devices. Our survey of users' requirements conducted through patient interviews reveals their concern about to maintain a limited interface on the mobile phone. In fact, they estimate that traditional interfaces may frustrate patients who ask for more interaction functionalities. However, considering the *safety of operations* as a fundamental requirement, it is important to define the interactions and visualizations adaptable to the patient requirements but in agreement with medical procedures. In the rest of this section, we describe several solutions provided to satisfy the application requirements.

3.1 Correlated Data Visualizations for Specialists

In this paragraph, we detail our prototype proposal oriented to medical specialists and targeting Tablets as medical support equipment.

For a specialist, two main factors are essentials: rapidity of execution and the safety of operations. Until now, there are not specific visualization techniques that allow user to improve their rapidity of execution as this strongly depends on the sequence of tasks to be performed. However, inspired on [4] we provide an approach basing the visualization on three main aspects: *support navigability in the main tasks*, *facilitate data reading and changes*, and if necessary *provide access to secondary tasks*(i.e. patient records consulting). In the description of our prototypes, we particularly focus on the data reading and their changes by using views illustrating the visualizations of correlation data adapted to the main tasks to perform.



(a) (b)

Fig. 3. Prototype for an ECG view and for a Cochlear implant adjustment

These prototypes (Figure 3) have been defined according to the existing PC-based HMI and are intended for audiologists who carry out the cochlear implants adjustment and for cardiologists who examine the condition of a patient with a cardiac implant. They have been tested by domain experts and incorporate the first feedbacks regarding the safety of operations. In both cases, our evaluations were performed with three testers: two experts on (cardiac/cochlear) implants and one specialist (cardiologist/audiologist).

The evaluation was characterized by three phases: (i) Overview of the scenario (i.e. you must adjust the implant of M. Dupont according to the pathologies indications and the type of implant in accordance with several associated medical guidelines), (ii) task achievement (i.e. observing the user in the sequence of performed tasks), and (iii) feedback (questionary about the strengths and weaknesses of the prototype). Due to the lack of space we only detail in this paper the evaluation and results obtained for the cardiac monitoring study case.

Evaluation and Results: The first model (Figure 3a) provides a real-time display of an ECG and tests only the representation of the data correlations by simulation of transmitted data.

During the patient examination or diagnosis, the specialist can traditionnally act on the implant by providing heart-shocks or stopping the implant operation when necessary. Our view is thus complemented by actuators that perform emergency settings. Testers feedback contributed to select the adapted colors and organize the prototype visualization. They prefer a classic ECG at the center with the available operations be performed around it. Together, tests hightlight the necessity to provide cardiologist with secondary tasks like *zoom* or *markers* enabling to focus or isolate segments of the ECG and compare the measures differently to the traditional (cf. Figure 2c).

The difficulties concerning the migration to mobile devices are essentially related to the relevance of the information displayed, especially considering the screen size limitation. Also, the real-time management requires easily browse the graph (if necessary) by moving tactilely. The zoom areas identification requires extensive reliability and confidence testing. This is part of our work in progress.

3.2 Visualizations for Patients: Ensuring Safety of Operations

This paragraph introduces our prototype proposal oriented to implanted patients and targeting Smartphone as medical support equipment (Figure 4).

Fig. 4. Prototypes for implanted patients (Cochlear and Cardiac implants)

For patients, two main factors are necessary: simplicity of usage and the safety of operations. Indeed, the specificities of the selected device to interact with their implants arises new usage perspectives which must be approved by the medical specialists in order to guarantee patients' safety. Beyond the well known security issues (e.g. user authentication and data privacy) not covered in this paper, it is necessary to provide an adequate level of functionalities adapted to the pathology in question. Furthermore, studies have also shown that providing adapted tools for patients and their families, we obtain better results both for patients' health condition as for clinical procedures [8].

These prototypes have been defined according to a cross analysis of the user requirements and the medical constraints addressed to a panel of patients and the concerned experts of implants. Such prototypes were tested (according to the same evaluation phases than for specialists, see Section 3.1) over two experts of each domain and by several patients chosen by the experts themselves. They have incorporated the first feedbacks regarding the safety of operations. For example, in order to reassure patient (for both use cases), we provide a feature enabling the patient to call a specialists when a doubt or problem arise. The scope of this paragraph tackles only the description of the cochlear implant prototype (Figure 4b,c,d).

Evaluation and Results. The prototypes proposed in Figure 4b,c,d expand the possibilities of cochlear adjustment for patients. For example, on the current generation of implants, the only way to interact with is by the four buttons placed on the prosthesis. Such specificity is ergonomically compatible with the hardware constraint (implant's size and area accessible by the patient). Also, it is possible to modify or adjust listening profiles during the visits to the specialist.

In particular, switching to a mobile device lifts the limit of the number of embedded listening profiles. Thus, in order to better assist patient in their regular life, it is important to provide the possibility to easily change their current listening profile and/or adjust several parameters (i.e. volume o noise) several times per day.

As a result, our prototype privilege a task menu based on a Dashboard including icons and a sequence of screens adapted to the usage frequency. Considering this design, the patient is allowed to change (anytime, anywhere) his/her current listening profile among those programmed by the specialist. Such profiles are represented with standard icons (Figure 4b) where the current profile is indicated by a red border. Together, a summary of the settable profile parameters and functionalities (i.e. volume, noise, lower, frequencies…) to adjust the implant is also provided (Figure 4c and Figure 4d). These parameters are strictly supervised by specialists during the configuration stage. Actually, medical experts must validate the available functions and ensure safe and controlled percentage thresholds adapted to the patient pathology and needs.

After evaluation, patients highlighted the comfort and accessibility of cochlear adjustment by using a mobile device. In fact, cochlear adjustment becoming more discreet with a Smartphone motivates them to use it more frequently and probably being in better listening conditions. Also, in order to provide faster profile changing, we suggested the use of GPS for Smartphones. For example, automatically switch to "office" or "home" listening profile according to their location. However, practitioners are concerned about the automatic listening profile adaptation; they estimate this function as a dangerous for patient safety and recommend rather provide suggestions such as*:"It seems you are in a noisy place. Consider to activate your outside profile if necessary".* This new feature will be tested soon.

4 Conclusion

In this paper, we have highlighted the HCI challenges related to the specificities of the future generation of cochlear and cardiac implants being monitored and managed through mobile devices. In this study, we emphasized the importance to guarantee safety of operations in particular for patient's care and safety. For specialists, the migration to mobile devices implies a strictly respect of safety criteria based and especially guided by the current medical software on PC. However, for the patients switching to a new device holds new needs and expectations that involve a thoughtful approach to provide adapted functionalities while respecting safety criteria.

For these first prototypes, we made design choices concerning visualization and task organizations accordingly. Such design has been evaluated and validated by potential users. The current proposal still needs further validation steps before it can be completely accepted.

Our ongoing work address also issues such a compare the impact of new interactions, for example switching from mouse to tactile functions, especially considering specialists requirements (rapidity of execution and reliability on implant data). Also, we plan to perform more scalable tests of our prototypes under limited time and delicate operations. Such tests should enable the estimation of the confidence and safety level of the prototypes.

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