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Integration of User Centered Design in the Development of Health Monitoring System for Elderly*

Guifeng Jia, Jie Zhou, Pan Yang, Chengyu Lin, Xia Cao, Hua Hu, and Gangmin Ning

Abstract— **This paper presents a health monitoring system by incorporating the approach of user centered design (UCD) for enhancing system usability for the elderly. The system is designed for monitoring cardiovascular diseases (CVD) related physiological signals including electrocardiogram (ECG), pulse wave (PW) and body weight (BW). Ease of use and non-obtrusiveness are two key requirements for design criteria. Our health monitoring system is designed on three levels: personal medical device layer, mobile application layer and remote central service layer. A chair-based apparatus was built for physiological signal acquisition and a mobile application was developed for data delivery and health management. Finally, usability evaluation was conducted and the system efficiency was quantitatively analyzed by system usability scale (SUS). The results demonstrate that the performance of the system is acceptable for the elderly and the UCD principle is helpful for health system design.**

I. Introduction

Cardiovascular diseases, which include heart attacks, stroke, hypertension and heart failure, are the leading causes of morbidity and mortality in elderly population [1]. Abnormalities in various physiological signals like electrocardiograph (ECG), blood pressure (BP), body weight (BW) and pulse wave (PW) associate directly with CVD [2]. It is widely recognized that a health system for daily monitoring these indices at home benefits CVD suffers. However, for ordinary users, in particularly for aged people, the usability of a health monitoring system is critical, which is identified as mainly obstacle in health care [3]. Thus, a health monitoring system with proper usability in keeping with the elderly requirements is highly demanded.

To ensure the usability for elderly, this work employs UCD approach to develop the health monitoring system. UCD is defined as a framework for a design process that increases the usability and acceptance of a system [4]. It typically runs in an iterative cycle with stages of understand, study, design, build and evaluate [5]. Our system provides an end-to-end solution for health monitoring and consists of three levels: personal medical device layer, mobile application layer and remote central service layer. The personal medical device is used for acquisition of physiological signals such as BW, ECG and PW. The intermediate layer is used for physiological data collection, representation, storage, delivery and preliminary analysis. The remote central server is developed for deep analysis and health management.

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Gangmin Ning, Guifeng Jia, Jie Zhou Pan Yang and Chengyu Lin are with the Department of Biomedical Engineering, Zhejiang University, Hangzhou, China. (Corresponding author: Gangmin Ning, phone: +86-0571-87951091; e−mail: gmning@zju.edu.cn).

Xia Cao and Hua Hu are with the School of Computer Science & Technology, Hangzhou Dianzi University, Hangzhou, China

II. System Design

The procedures of the system design are on the basis of UCD iterative cycle and contain five stages which are illustrated in Fig. 1. The initial stage is "understand". Each procedure is described as follows.

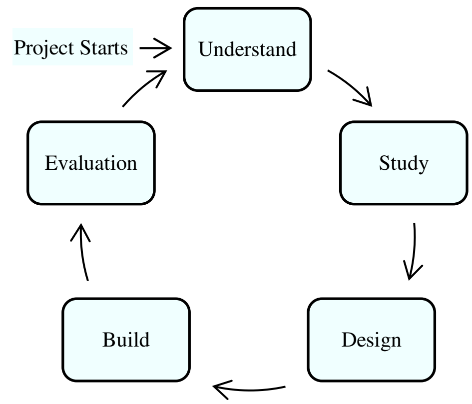


Fig. 1.The procedures of health mintoring system design

A. *Understand: eliciting the users' requirements*

The "understand" is the initial stage to elicit users' requirements and specify the context of use. It needs to contact with intended users directly for collecting thoughts and to find out what requirements from users should be implemented in the system design. Questionnaire is a popular approach to obtain user information and aspiration for their responses to a set of targeted questions [6]. Thus, questionnaire was adopted for eliciting the requirements of the elderly. Twelve questions were designed in the questionnaire, which were divide into two sections. The first section was used to find out the elderly conditions including healthy status, activities of daily living, education levels, as well as living surroundings. The second section was about users' requirements to investigate which properties of a monitoring system the elderly are most need. The candidate options in the questionnaire include ease of use, non-obtrusiveness, extrinsic feature and reliability.

The survey was carried out in communities. Finally, we received thirteen effective responses. The age of the responders ranges from 57 to 75 and the average age is 67.1. The statistical results of survey are listed in Table I. It is found out that the elderly people have low education level. A high proportion of them suffer from chronic disease and the most prevalent is hypertension. A key outcome is that the 'ease of use' and 'non- obtrusiveness' are the striking features which

TABLE I. STATISTICAL RESULT OF THE QUESTIONNAIRES

Attributes	Categories	Numbers	Proportion
Education levels	Primary education	6	46.2%
	Middle education	6	46.2%
	College education	1	7.6%
Requirements	Ease of use	10	76.9%
	Non-obtrusiveness	7	53.8%
	Reliability	5	38.4%
	Extrinsic feature	2	15.4%

the elderly most concerned for health monitoring system. These two features received 76.9% and 53.8% positive responders respectively. Consequently, the work trended to focus on the issues what those two features specific implicate and how to integrate them into the health monitoring system.

B. *Study: fleshing out details of the user's requirements*

This stage involves fleshing out details of how to meet these particular requirements.

1) Ease of use in health monitoring system

To achieve ease of use, it is essential to figure out what potential obstacles encountered by the elders during manipulating the system and how to overcome these obstacles. In the light of the investigation results, we found that knowledge barriers, daily behavior disability and poor manipulating skill of electronic equipments hindered the use of health monitoring system for elders. To overcome those obstacles, three criteria were introduced for system design:

- Automation in system configuration and operation.
- Redundancy design for data representation by visualization and color-coding in interaction.
- Display in a large font (at least 16pt) for easy reading.

2) Non-obtrusiveness on users

Non-obtrusiveness means that devices should not impose unnecessary awareness on users. Three criteria are figured out to decrease the measuring impact on daily activity:

- System should be in similar infrastructures with existing home devices, which users are familiar with.
- The interaction with the system should be integrated into user's daily activity.
- The attachments on users, for instance, measuring electrodes, should be minimized.

This stage provides a deep understanding of the concerns of elderly related to capacity, daily life, surroundings and etc. Finally, a set of design criteria was summed up for following process.

C. *Design*

This stage is to accomplish the objectives of functions and users' requirements. The diagram of the system design is illustrated in Fig. 2.

1) Personal medical device

The assignment of personal medical devices is for acquisition of ECG, BW and PW. In terms of technology, it involved embedded system, sensors, signal processing, wireless communication and etc. Obeying to the non-obtrusiveness criteria, the physiological measuring system is embedded in an armchair. The technical design is introduced in details. The electronic system is made up of four components: micro control unit (MCU), signals processing parts, sensors and Bluetooth communication module. For easy to accessible and consistent with the elderly usage, ECG signal is acquired by three electrodes, which are placed on the chair armrests. Body weight signal is obtained by four piezoelectric transducers on the chair legs and measured by a Wheatstone bridge. For PW data, a pressure sensor is adopted to measure pulse wave from fingers.

2) Mobile application design

The mobile application is used for signal collection, data representation, storage and wireless communication. For flexibility, it is constructed on personal mobile devices, like smart phone and tablet PC. The event-driven mechanism is applied for actualizing the automatic functions of the system, which is crucial for elder users. An event is a notable activity that indicates what users want to do. In other words, the application function is not driven by trivial and complicated operation but by the triggers fired on incoming events relevant to users' aspiration or action. A group of intelligent strategies for software application is given in Table II.

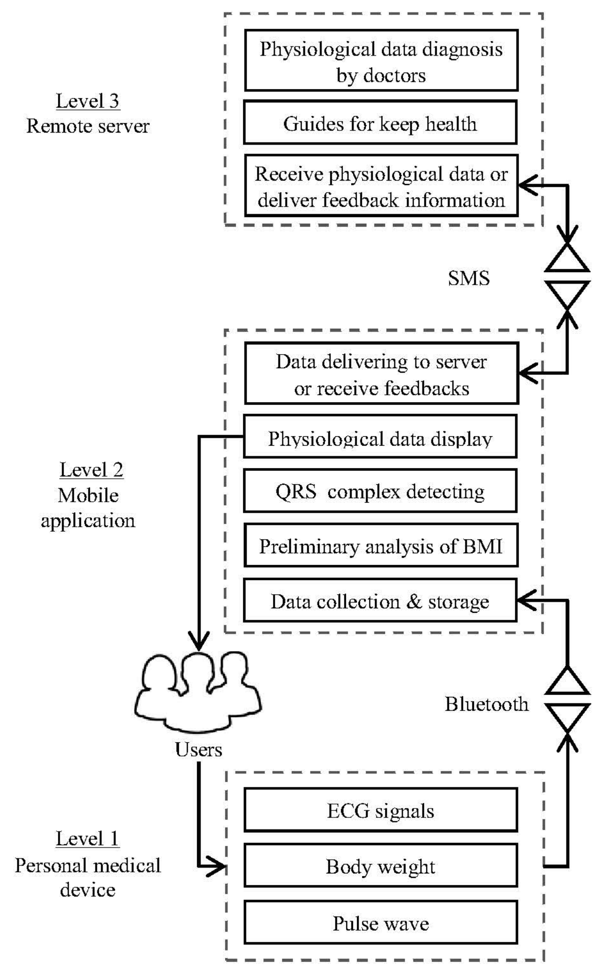


Fig. 2. The structure of the health monitoring system

TABLE II. THE DEFINITION OF EVENTS AND ACTIONS

Events	Automatic action
Application activated	Enable local Bluetooth communication; Search nearby medical device;
Medical device found	Identify the type of medical device; Build a link with the device; Listen to the Bluetooth link;
Receive data	Represent received physiological data; Save data in local database; Send data to the remote central server by SMS;
Software exit	Disconnect the link; Disable local Bluetooth communication;

The techniques of data visualization and color-coding are used for physiological data representation. The continuous time signals such as ECG and PW are represented by curve drawing, while discrete data like daily BW are illustrated by line graph. This is intuitive to become aware of variation tendency. Furthermore, color-coding is also adopted for indicating health conditions. Meanwhile, received data are saved in local SQLite database. Bluetooth communication is used for data transmission with personal medical device and short message service (SMS) is adopted for communication with remote central server. The mobile application serves as a personal health management tool and is also responsible for data transfer.

3) Remote central server design

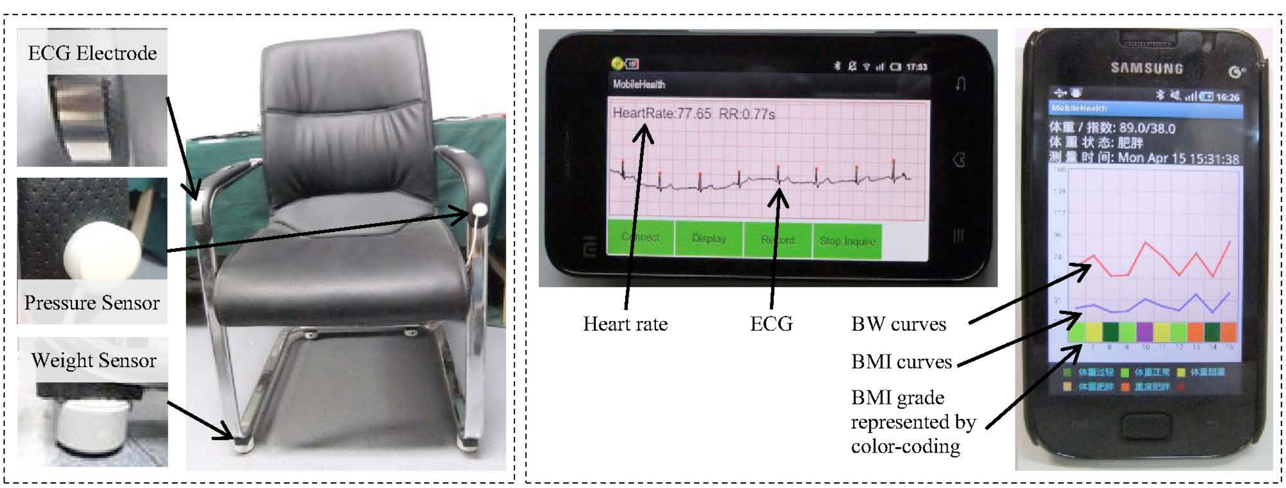
The remote central server is a website that provides secondary health management solution. It is designed as three main components: a web service for health data collection, a web interface for the doctors to diagnose and manage users' health condition, and a mechanism for health information feedback to users.

III. RESULTS OF SYSTEM CONSTRUCTION

This section is related to the "build" stage. In this stage, a chair- based apparatus was built to collect ECG signal, body weight and pulse wave. The outlook of the apparatus is shown in Fig. 3(a). The electronic units consist of four parts: sensors, signal pre-processing, MCU and Bluetooth communication. The MCU adopted is MSP430F149. A Bluetooth version 2.0 module delivers physiological data. Three electrodes are embedded in the chair arms. Two of them for ECG signal acquisition are placed on the right armrest and one for right-leg driven is placed on the left. The pulse wave sensor is installed on the left armrest. The sampling frequency of ECG and PW is 250Hz. The piezoelectric transducers are installed on the bottom of legs. During measuring, the user's feet should keep leaving ground for seconds to obtain actual BW reading.

For mobile application layer, two versions of software of Android operating system were developed for smart phone and tablet PC. In accordance with the design, all functions were actualized completely by Java applications. Android OS version is 1.6 or later. The ECG measurement interface and BW analysis interface are shown in Fig. 3(b).

The central sever is supported by Internet Information Services (IIS) server and SQL server. The web application was programmed by C#. The central sever contain a SMS communication module which is used for receiving data from users and sending feedback information to the mobile application.



(a) Personal health monitoring apparatus

(b) Mobile application for phone version

Fig. 3. The prototype of the health monitoring system

IV. Evaluation

Evaluation is the last process of development lifecycle to assess the quality of initial prototype [7]. There are various techniques available for evaluating an interactive system. In this work, the approach of user testing was employed. In addition, system usability scale (SUS) was introduced as a measure of system usability. First, we developed a customized SUS on the basis of paradigm [8]. The customized SUS contains 10 questions about the users' assessments and opinions about the monitoring system. Each question was rated on a scale of 1 to 5 score based on the strength of agreement. The final computed score ranges from 0 to 100, which are direct proportional to system usability and users' satisfaction. According to the SUS method, the performance of usability is ranked into five categories by the score, as 'Poor' (< 38), 'Ok' (38-52), 'Good' (52-73.5), 'Excellent' (73.5-85), and 'Best' (85-100). The acceptable usability of SUS score is regarded as above 70 [9]. After a series of users' tests, the SUS score of our system is 72.5. It indicates that the usability of our health monitoring system is acceptable and the system achieved a good performance for elderly.

V. Conclusion

This study presented a health monitoring system for elders in home use to monitor CVD related physiological signals. UCD principle was employed to guide the system design for competent system usability for target users. Consequently, through the development procedure, diverse capacities of the elderly have been identified and main requirements were elicited by investigation. Meanwhile, a set of criteria was generated for system design and development. A complete prototype of the system was constructed and its usability was evaluated by SUS. The results demonstrate that the proposed health monitoring system succeeded in accomplishing design tasks and the UCD principle is helpful for health care system design.

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