Preliminary Guidelines to Build a Wearable Health Monitoring System for Patients: Focusing on a Wearable Device with a Wig

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Abstract. We have previously developed a wearable health monitoring system embedded in a wig. In this paper we introduce our system and derive preliminary guidelines to build such wearable devices for healthcare purposes. The major goal of the system is to monitor and detect falling in addition to measuring heart rate, body temperature, and current location of a patient who is wearing the device, and send text messages to pre-configured recipients in emergency. Preliminary guidelines were developed using a focused group interview with healthcare experts, which include form factor, wearing area, motivation, target, and additional functions. We are currently in the process of developing an improved device based on the derived insights.

Keywords: Wearable systems · Connected healthcare · Fall detection

1 Introduction

Wearable health monitoring systems have been under the spotlight recently, especially among the research community and the health industry. The market size of wearable healthcare is estimated to be approximately 2 billion dollars and is expected to reach 41 billion dollars by 2020. [3, 5] However, many existing products and services have not been successful in the market.

In this paper we summarize our previously developed wearable device, embedded in a wig, which is focused on healthcare for patients. The wig form has at least two advantages. First, the wig has a larger surface area that can be attached to the skin, compared to other wearable devices such as smart watches. As a result, the wig form factor can incorporate more sensors than traditional devices can. Second, a wig is considered as a personal accessory that enhances the wearer's appearance. It is also perceived as a fashion accessory, which fits well with the needs of the wearable devices market that sets a high value on fashion. Further, the wig is naturally a good form factor that makes the device completely transparent, both to wearers and observers. That is the major motivation that we develop a health monitoring system using the wig form

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factor. We also built preliminary guidelines for developing such a system by interviewing healthcare experts.

2 Related Work

This section compares the differences between another wig-formed wearable device and our system, and then addresses diverse efforts to develop fall detection systems.

2.1 Smart Wig

Tobita and Kuzi conducted a research on a wearable device using a wig [7]. They suggested certain advantages of using a smart wig and some potential examples in their paper. Tobita and Kuzi introduced two key functions, navigation and presentation, as applications of the wig-formed wearable device. While their analysis identified two important functions and advantages of the smart wig, it did not focus on healthcare.

2.2 Fall Detection System

A fall is unintentional and happens against one's own intentions. Technically a fall refers to one's sudden change of position to the ground/floor or a lower position compared to a primary position [6]. Existing fall detection solutions mainly employ two major mechanisms for the fall detection. The first mechanism analyzes acceleration to detect falls. Lindemann et al. [4] integrated two bi-axial accelerometers into a hearing aid housing. They used three trigger thresholds for acceleration and velocity to detect falls. The other mechanism utilizes both acceleration and body orientation information to detect falls. Bourke and Lyons [1] developed a threshold-based fall-detection algorithm using a bi-axial gyroscope located in the sternum. They measured angular velocity, angular acceleration, and change in trunk angle to detect falls. Fall-detection algorithms have been implemented using various forms. However, wig-formed devices have rarely been employed to implement fall detection systems.

3 Design and Approach

3.1 System Architecture

The goal of our system is to monitor patients' specific physical states (specifically falling), as well as physiological data (e.g., heart rate and body temperature), and situational information (e.g., current location). Our system has also capability of sending text messages to pre-configured recipients such as the patients' family members, nurses, and doctors in emergency. As shown in Fig. 1(a), the system consists of three parts: input module (which collects data from patients), Micro-Controller Unit (MCU, which processes and communicates with a smartphone application), and output module (which rings an alarm with a buzzer and LED). As shown in Fig. 1(b),

(a) (b)

Fig. 1. (a) Our system consists of three parts (Input module, MCU, and Output module, which communicates with a smartphone application via Bluetooth). (b) Prototype using a wig.

we developed a prototype using a wig, in which an integrated circuit board having various sensors, modules, and battery is attached to the inside of a wig.

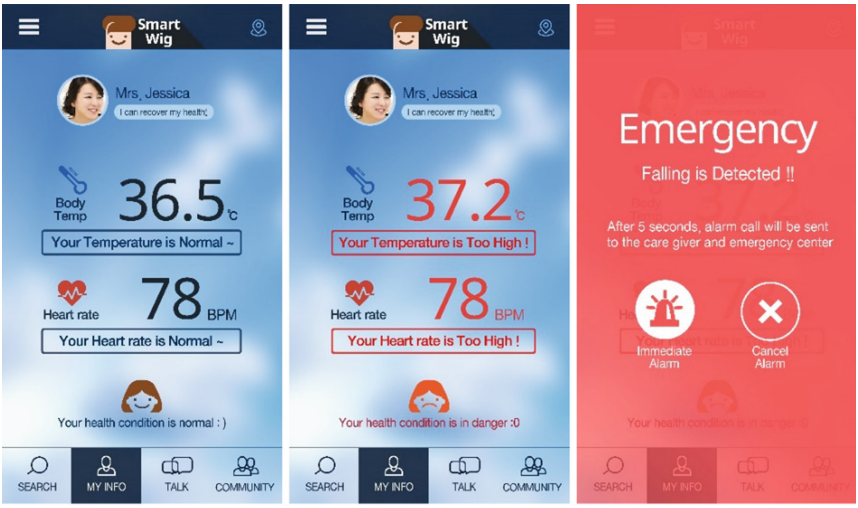
The validity of the fall-detection algorithm in our system has been shown in our previous paper [2]. The primary targets of our system are patients who suffer from physical deterioration and hair loss induced by chemotherapy. We measured the acceleration and the change in trunk angle using a tri-axis accelerometer to detect falls. Our fall detection solution could distinguish four different stages related to falls: normal, dynamic transition, analogous falling, and falling.

3.2 Application

We developed an Android application (See Fig. 2), which is wirelessly connected to the hardware systems and has two functionalities: monitoring the patient's state and emergency alarm. The application displays the patient's physiological data as shown in Fig. 2 (a), highlighting abnormal data in red when undesirable situations occur (Fig. 2(b)). When the undesirable situations continue for more than 5 s, a pop-up alarm appears as shown in Fig. 2(c). A text message including the patient's current location is send to pre-configured recipients automatically unless the patient chooses "Immediate Alarm" or "Cancel Alarm" within 5 s.

4 Interview with Healthcare Experts

After developing the prototype, we conducted a focused group interview with three healthcare experts at the cancer department in Samsung Medical Center in order to validate the practicality of our prototype. The healthcare experts include the head of cancer education division, a medical researcher, and a senior registered nurse. Through the interview with them, we could identify several primary considerations for developing wearable healthcare devices such as form factor, wearing area, motivation, target, and additional functions. The results of the interview are as follows.



(a) (b) (c)

Fig. 2. Android application working with the proposed wearable device

Form Factor All the experts agreed that patients may be uncomfortable with the wig. It is primarily because patients may use the wig only occasionally, especially in social settings. According to them, patients would prefer using scarves or hats rather than wigs. Therefore, the use of wigs may not be practical.

Wearing Area When we asked about the appropriate area for wearing such a device, the healthcare experts stated that head is hardly suitable for patients because they don't frequently wear even a hat. They instead suggested that arms (e.g., a watch or a wrist band) or waist (e.g., abdominal binder) would be more suitable as wearing areas for such devices since patients are used to wearing devices in those areas.

Motivation As wearable devices for healthcare require the user's constant wearing to collect data, it is important to keep users motivated to wear the device constantly. People generally do not have a strong motivation for healthcare. Appropriate and timely feedback (e.g., visualized statistics) can be of help to give motivation to the user.

Target The healthcare experts suggested that the major target users of such systems should be medical staffs since their opinions are more influential than patients. They unanimously agreed that such a device that is specially devised to prevent falling is greatly useful because "falling" is a critical issue for patients in (and out of) the hospital.

Additional Functions The experts also suggested several specialized functions for the system such as fall prevention by prediction. For example, the system can prevent a fall by providing an alarm when the common patterns of typical falls are detected or monitored from the analysis of the data relating to the patient's body balance.

In sum, the interview helped us create the following preliminary guidelines to build a healthcare wearable system for monitoring the states of patients. First, the wig-formed device is not recommended because of the rarity of patients with hair loss and its use of discomfort. Second, arm or waist, which is more conventional areas for health monitoring, is recommended as the area for wearing such devices. Third, at the prototype development stage, medical requirements should outweigh usability improvement since the target users would be mostly medical staffs. Fourth, additional features such as "prevention of falls by prediction" would be necessary.

5 Conclusions and Future Work

In this paper we recapitulated a healthcare wearable device in the form of a wig [2], and suggested preliminary guidelines to develop a wearable health monitoring system based on the results of a focused group interview with healthcare experts. These methods helped us derive the primary considerations for such systems: form factor, wearing area, motivation, target, and additional functions.

We are currently developing and testing a small pouch-shaped device that can be attached to either arm or waist. Its primary target users are medical staffs and patients as presented in the preliminary guidelines. In future we plan to conduct a study to evaluate our system in two cases: falls and normal daily activities.

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