Poster Abstract: In-Ear Thermometer: Wearable Real-time Core Body Temperature Monitoring

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ABSTRACT

Core body temperature is an important indicator of medical treatment. Sudden changes in core body temperature can be a precursor to neurodegenerative diseases such as Parkinson's disease. These diseases have the potential to strike at any time, therefore, long-term monitoring of core body temperature and alerting to sudden changes in temperature become important. In this paper, we designed an in-ear thermometer to monitor the core body temperature with the help of smartphone.

CCS CONCEPTS

• **Human-centered computing → Ubiquitous and mobile computing systems and tools**.

KEYWORDS

Smart Health, Thermometer, Mobile, Wearable, Core Body Temperature, Temperature Monitoring

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1 INTRODUCTION

There are approximately 930,000 patients with Parkinson's disease in the United States, and this number will increase to 1,238,000 by 2030 [2]. Muscle tremors caused by Parkinson's disease can lead to behavioral problems and risks of falling [4]. In order to prevent this from happening, it is important to continuously monitor core body temperature[5, 6], as a Parkinson's onset is accompanied by an increase in core body temperature which can be used as an early warning. Therefore, patients can ask for help to release symptom in time.

Current body temperature solutions are dominated by the one-time body surface thermometer, such as digital thermometers and forehead thermometers. Compared with core body temperature, the surface temperature is easily affected by the environment. Moreover, these solutions are not suitable for a long-term and unobtrusive application. As a result, a continuous and wearable core body thermometer is demanded.

Figure 1: In-Ear Thermometer can monitor the core body temperature by sensing the inside of the auricle.

We propose In-Ear thermometer, as shown in Fig. 1, using an infrared sensor to sense tympanic membrane in the ear via a 3D printed skin-friendly lightweight wearable device. Specifically, the infrared energy emitted by the capillaries in the tympanic membrane is focused on the photodetection module of the infrared sensor and is converted into an electrical signal. Then, a Bluetooth low energy module on the wearable device then sends the data to a smartphone, and a mobile app analyzes the temperature data and provides warnings of sudden changes in core body temperature. Finally, long-term core body temperature monitoring is performed.

2 BACKGROUND

2.1 Core Body Temperature

Core body temperature (CBT) is the temperature of the internal environment of the body. Different from the surface body temperature, the core body temperature is not easily influenced by the ambient temperature Therefore, it can better reflect the changes inside the body. Current methods for measuring core body temperature are: rectal measurement, oral measurement and axillary measurement [3]. These methods causes inconvenience to user, in addition. the temperature data cannot be continuously obtained in real time.

2.2 CBT and neurodegenerative diseases

The CBT in Brain is primarily a result of mitochondrial oxidative chemical reaction. However, neurodegenerative diseases such as Parkinson's disease cause abnormalities in mitochondrial oxidative metabolism. Therefore the ability to stable brain temperature is impaired by Parkinson's disease[5].

3 SYSTEM DESIGN

We designed our system as shown in Fig. 2. The system enables long-term CBT monitoring through two part: *In-Ear Thermometer Device* and *In-Ear Thermometer App*.

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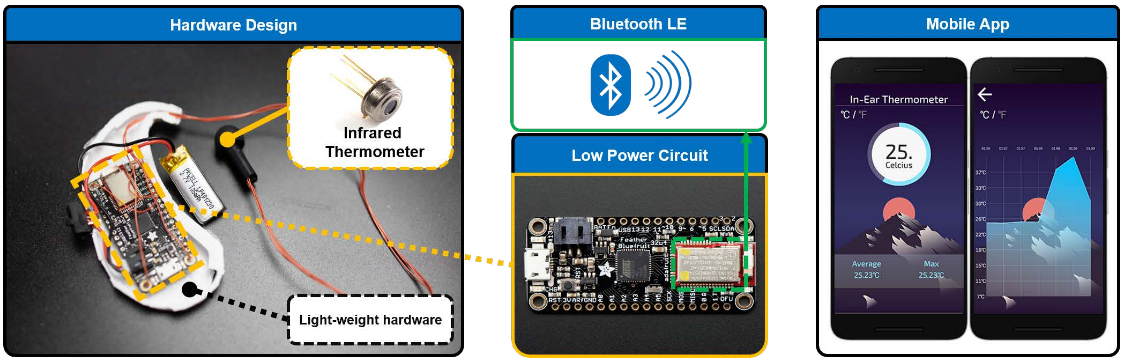

Figure 2: The overview of In-Ear Thermometer.

3.1 In-Ear Thermometer Device

As the In-Ear thermometer is designed to be a long-term wearable device, we have three specific hardware design considerations in terms of the *portability*: 1) **Size**. We use the smallest Arduino (Adafruit Feather 32u4 Bluefruit) as the motherboard. The dimension is 51 mm x 23 mm x 8 mm, which is about the size of a dollar coin; 2) **Weight**. We use a light-weight 3D printed shell to reduce the weight of the device, the ergonomic design is followed to improve long-term wear comfort. the net weight of the device is 18g; 3) **Battery Life**. A 105 mAh battery is used that is able to support the device for more than a day of stable operation with as little weight as possible.

3.2 In-Ear Thermometer App

Usability is crucial when developing the mobile app to help users of all ages, especially the patients of Parkinson's disease. Therefore, we leverage smartphone and implement a mobile application to collect the temperature data from the In-Ear thermometer. After an intuitive one-time pairing process, the application is able to monitor CBT detected by thermometer in real time. In addition, the In-Ear thermometer app alerts when a change in intracranial temperature occurs. The alert threshold for a temperature change is an increase in temperature of 0.3 degrees Celsius within five minutes [5]. The alarm is given by the vibration and sound of the phone.

4 EVALUATION

Setup: To evaluate the performance of In-Ear thermometer under different conditions such as indoors and outdoors, doing exercise and sleeping. We recruit 8 subjects (age: 24 ± 6). Human subjects involved in the experiment was approved by the institutional review board (IRB). During the experiments, participants are asked to perform three activities, i.e., running, sit-in, and sleeping, while wearing the In-Ear thermometer. At the same time, the CBT data is collected and recorded by a smartphone. As a controlled experiment, we use a conventional thermometer [1] to collect the temperature inside the auricle at the same time as ground truth.

Results: As shown in Fig. 3, the In-Ear thermometer successfully records the temperature change continuously of the subject from 11 am to 2 pm. In the exercise phase, the measured data is 0.15 °C lower than ground truth. The reason may be the increase in humidity in the auricle due to sweat secreted by the body during exercise. The range of error is ± 0.16 °C. The correlation is 0.9438. The average accuracy of different subjects is above 99%. Results prove that In-Ear thermometer' can monitor intracranial CBT continuously.

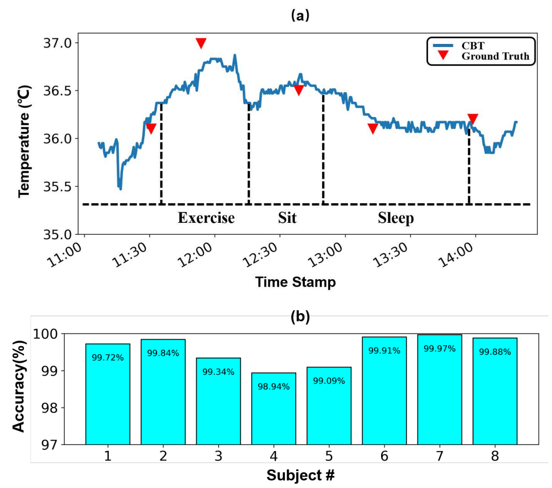

Figure 3: In-Ear thermometer performance evaluation. (a) In-Ear thermometer measured temperature in various conditions; (b) In-Ear thermometer accuracy across subjects.

5 CONCLUSION

In this work, we design and develop a prototype of an In-Ear thermometer as well as an smartphone app to support the device. This technology can be used to monitor the temperature of patients with Parkinson's disease and alert before muscle tremors. The future work will be making the device smaller and more intelligent, and integrate the system with other smart-health sensing technologies to monitor more body information such as blood pressure, blood oxygen to achieve better smart health services.

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