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The Role of Wearable Monitor for Healthcare

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Abstract. Wearable monitor for healthcare was proposed in the late 1990s. Physiological monitoring in daily life has considerable potential for preventing and predicting diseases, without significant discomfort or inconvenience to the user. Over the past 25 years, wearable monitoring systems have been developed for health monitoring in daily life. In this presentation we will 1) review the devices used in wearable monitoring, including home use and clinical practice; 2) consider the evidence for their benefit in terms of healthcare outcomes; and 3) discuss long-term data collection and analysis using Big Data techniques. Furthermore, issues relating to the popularization of these devices are discussed, including regulation and business models. There are many promising devices available for wearable healthcare monitoring, and we propose ideas to popularize these devices.

Introduction

Wearable monitor for healthcare was proposed in the late 1990s. Physiological monitoring in daily life has considerable potential for preventing and predicting diseases, without significant discomfort or inconvenience to the user. Over the past 25 years, wearable monitoring systems have been developed for health monitoring in daily life.

There are several kinds of wearable sensors in the market. Most common is inertial sensor and pulse sensors. However, we found not so many evidences in the point of healthcare.In this presentation, we reviewed our finding of inertial sensors, pulse sensor and thermometer. Secondly the evidence are considered and them further development are discussed.

Scenario of future healthcare

Future healthcare will be a simple, unawareness and invisible system with minimum disturbing wearable sensing. In the home, unawareness and invisible sensing is preferred. However, in the field we use wearable sensors. Then data are collected and analyze further evaluation of health. Data collection makes not only continuous monitoring but appropriate intervention to the client and patients. Current system is a physician driven tele-medicine, tele-care, home healthcare. Decisions are making by physicians. Although GPs have responsibility of their patients and clinical practice, face to face diagnosis is important, computer-based diagnosis and intervention need more time to contact the patients. Towards the elderly society, elderly used to quite often contact to the physicians. However, physicians are busy and contact limited person. We proposed computer-based expert system with medical professionals included physicians. The expert system automatically generates alerts based on comparisons with predetermined threshold values. When alerts are issued, a health professional calls the client and conducts a clinical evaluation. Based on the findings, the health professional judges the client's health status and decides whether a visit from a clinician is warranted or if a caregiver should be called. In this system we included wearable sensors included pulse rate monitor, inertial sensor and thermometer shown in Fig. 1. The role of wearable sensors is discussed.

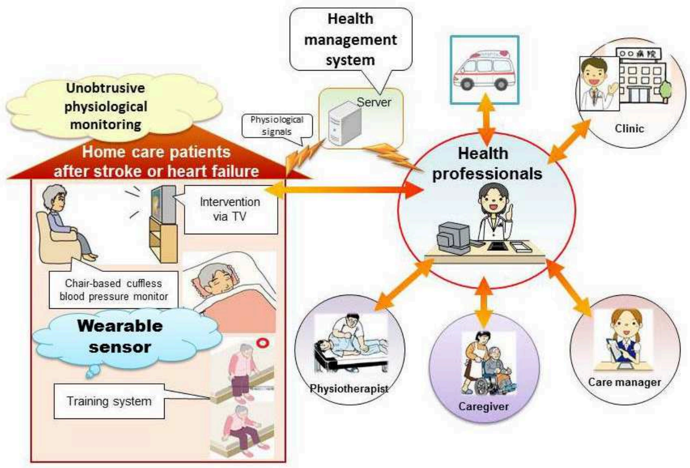

Figure 1 Overview of the system

Wearable sensors

1.Pulse rate sensor

There are too many pulse rate monitor, especially for exercise in the market [1]. Both pulse rate and strength of exercise is important factor during exercise. We have also developed pulse rate monitor with green reflected photo-plethysmpgraphy. Using green light instead of infrared light prevents motion artifact during exercise but still problem to use as a long-term monitoring shown in Fig.2.[2].

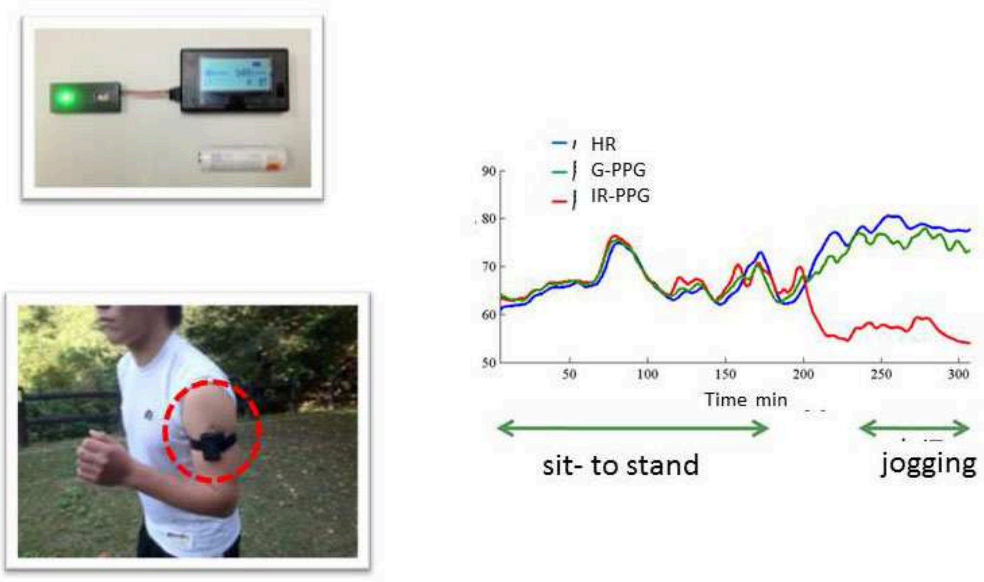

Figure 2 Reflected PPG signal during rest and exercise

2. Cuff less blood pressure monitor

Recently, cuffless blood pressure monitor has been proposed. Basic principle is pulse wave velocity (PWV). The pulse wave velocity is related to the stiffness of arterial blood vessel.. The stiffness of blood is generally described by the Moens-Korteweg equation. PWV has been shown to predict cardiovascular and other diseases.

$$\mathrm{PWV}=\sqrt{\frac{Eh}{2r\rho}} \qquad (1)$$

where E=Young's modulus of elasticity of wall material, h=wall thickness of vessel, r=inside radius of vessel and ρ=density of blood).

A more useful version of this equation is the Bramwell and Hill equation, which relates PWV to distensibility:

$$\text{PWV}=\sqrt{\frac{\Delta PV}{\Delta V\rho}}=\sqrt{\frac{1}{\rho D}} \tag{2}$$

where $\Delta PV/\Delta V$=relative volume elasticity of vessel segment, ρ=density of blood, and D=distensibility.

The technique of pulse wave velocity is valid and reproducible, and has been widely applied in both normal volunteers and patients in the research setting. The principle is relatively simple and the technique can be learned fairly easily. Moreover, outcome data show that pulse wave velocity is an independent predictor of cardiovascular risk in hypertensive patients.

The system consists of photo-plethymography (PPG) and electrocardiography (ECG). The pulse wave velocity based on the R wave of the ECG and the associated peak of the pulse wave is related to the blood pressure (BP). If we know the calibrated BP, calibrated systolic blood pressure (SBP_{CAL}), and calibrated pulse transit time (PTT_{CAL}) at SBP_{CAL}, the estimated systolic (SBP_{EST}) and diastolic (DBP_{EST}) blood pressures are defined as

$$\text{SBP}_{EST}=SBP_{CAL}-\frac{2}{\gamma PTT_{CAL}}-\Delta PTT\ \ (\Delta PTT=PTT_{MEAS}-PTT_{CAL} \tag{3}$$

$$\text{DPB}_{EST}=SBP_{CAL}-\frac{2}{\gamma PPT_{CAL}}\Delta PTT-(SBP_{CAL}-DBP_{CAL})(\frac{PTT_{CAL}}{PTT})^2 \tag{4}$$

where PTT is pulse transiti time and an inverse function of PWV, γ is the peripheral resistance, and ΔPTT is the difference between the obtained PTT_{MEAS} and PTT_{CAL} [3,4].

Figure 3 show the priciple of blood pressure estiamtioin during biking.

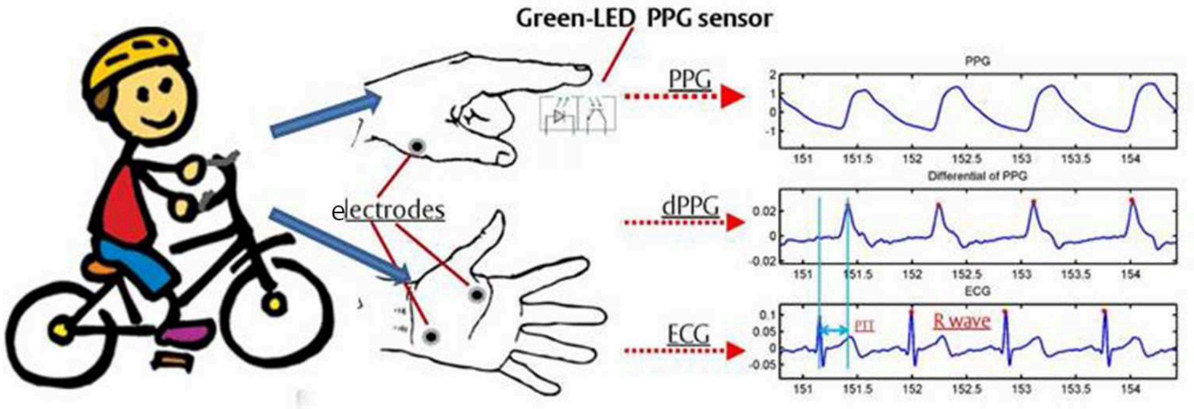

Figure 3 The principle of continuous monitoring of blood pressure by pulse transit time

For the long term evaluation of BP by cuffless blood pressure estiamation, the attachment of PPG must be considered.

3. Motion sensor for fall risk assessment

The wearable motion sensor can be divided into four parts; sensor, amplifier, transmitter and data processing part. The sensor consists of 3D (antero posterior, medio lateral and vertical axis) accelerometers and three 1D gyro sensors for roll, yaw, and pitch axes. The measured signal then was amplified using amplifier. The accelerometer sensor could measure three axes of acceleration with sensitivity range of ±2g with a sensitivity of 600mv/g and ±4g with a sensitivity of 400mv/g by selection for examinar. Three gyro sensor required with sensitivity range of 0.67mv/deg/s to measure three axes. In data processing part, amplified signals then were converted from analog to digital signal using microcontroller installed. The digitized information then transmitted in the data processing unit to the PC via the transmission section using Bluetooth. Using more than one motion sensor required a synchronization to ensure that the data measured at the same time between those sensors. The signal from the sensor unit was recorded by a 100Hz sampling. The continuous recording could be made 13 hours with lithium battery (3.7 V 740 mAh). The dimensions are 55 x 52 x 18 mm and weights 55 g shown in Fig.3. We can monitor when and how the elderly falls. The acceleration threshold

(2m/s^{2}was predetermined. When the acceleration detected above threshold, the data before 8 s and after 2 s were stored with time. The 16 epochs could be stored.

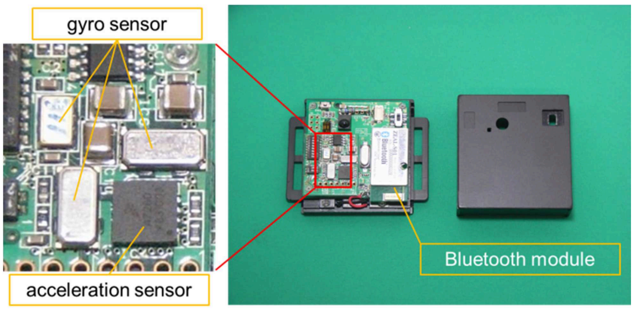

Figure 4 Wearable motion sensor

4. Thermometer

To develop a wearable Deep Body thermometer (DBT), the dual heat-flux method (DHFM) has been used. DHFM, which is a relatively new method that calculates the DBT based on the heat flux inside a probe, was originally proposed by Kitamura *et al.* [5]. The double heat path inside the probe enables calculation of the DBT by the temperature sensors. A substrate material with four embedded temperature sensors comprises the core of the probe. The substrate material has physical properties similar to those of skin and, when attached to the skin, most of the heat flow from the core body due to the difference between the DBT and the skin temperature will flow into the substrate material. Additionally, under a heat isolation peripheral boundary condition, heat will flow longitudinally. Since the two heat paths (T_1–T_3, T_2–T_4) are locate transversely close to each other, the thermal resistors in the skin layer of the two heat paths are the same, and thus the DBT can be calculated from the measurements of the four sensors (T_1–T_4) using the equation below, where k (= R_1/R_2) is the ratio of heat resistors inside the probes within the two heat paths. Figure 5(a) shows the location of temperature sensors based on deep body temperature estimation.

$$T_d = T_1 + \frac{(T_1 - T_2)(T_1 - T_3)}{k(T_2 - T_4) - (T_1 - T_2)} \tag{5}$$

The prototype of this device provided measurements with a difference of less than 0.1°C compared to the reference thermometer. However, a urethane sponge cover must be used. Huang et al. improved this method by means of theoretical simulation and experimental validation. Removal of the external heater markedly reduces the power consumption of the device and thus facilitates its use as a wearable sensor. We have tested the basic performance of this device in practical terms [6] (Fig.5 (b)).

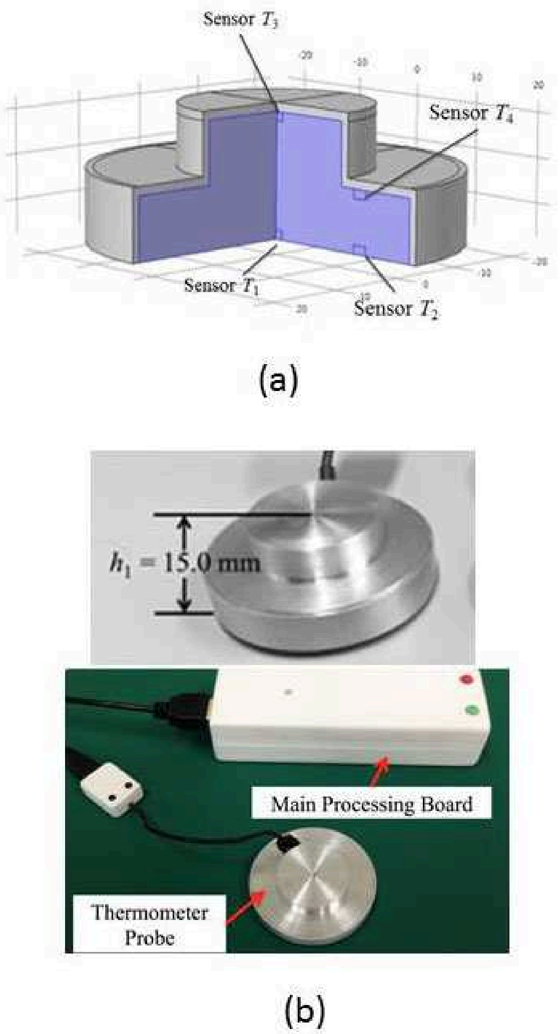

Figure 5 Dual heat-flux deep body thermometer monitor. a) Measurement sites of temperature for Dual heat-flex deep body thermometer, b) Prototype of deep body thermometer

System Evaluation

In preliminary studies, we performed exercise with bicycle ergometer. A younger subject aged 20, male, participated experiment with 50 W load and hot environment. The Institution's Ethical Review Board approved all experimental procedures involving human subject. We have obtained written informed consent from a subject. Figure 6 show an example of time course of deep body temperature changes as well as blood pressure and pulse rate.

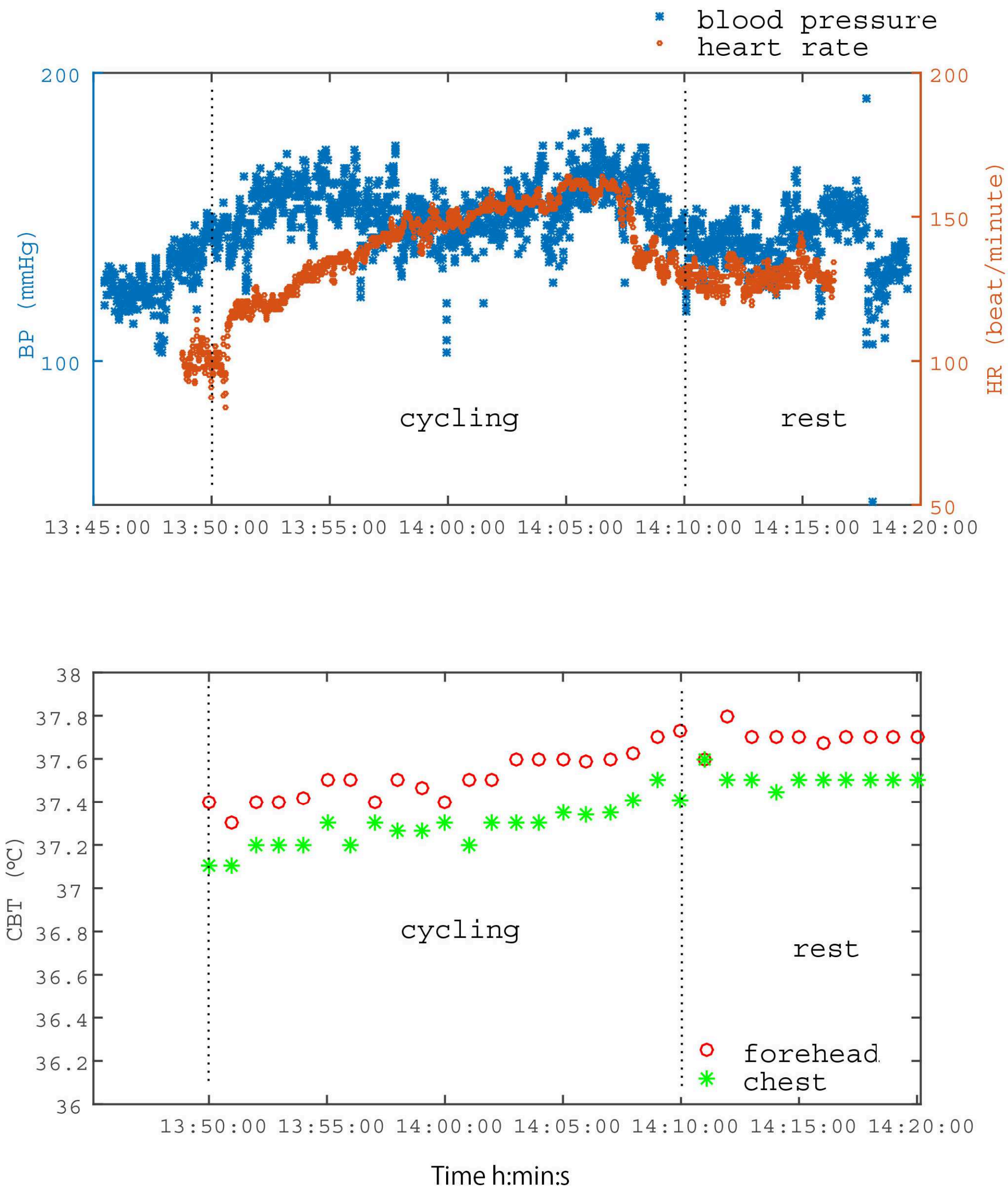

Figure 6 An example of home healthcare system during exercise

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Summary

We have proposed a new wearable technology of healthcare that involves monitoring physiological parameters to improve team-based healthcare.

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