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A Chair-type Interface for Long-term and Ambient Vital Sensing

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***Abstract*— We investigate a novel type of interface that enables long-term vital sensing through noninvasive direct-contact vital sign detection and observation of body motion and feedback of health conditions through an illuminated display. Although various types of vital sign measuring equipment are currently commercially available, their complexity and inconvenient user interfaces coupled with human reluctance to continue long-term use discourage their daily use. Consequently, in this research we propose a method for involuntary measurement of vital signs of a user who is relaxing in a normal living environment. This study also investigates physical and physiological activity regarding body motion. In addition, a trend analysis is also performed with the help of past data automatically stored after each session.**

I. INTRODUCTION

The number of people diagnosed or at risk of contracting diseases such as cancer, cardiac disease, or cerebrovascular disease is increasing. As we know, these diseases are largely caused by lifestyle. Meanwhile, there has been an increasing interest in home health checks and care. In recent years, the existence of numerous health measuring systems with different types of data formats (for example, instantaneous blood pressure and time-averaged pulse rate) has led to the suggestion [1] that the communication protocol of personal health care devices be standardized internationally. In practical use, there is a novel type of room called the “intelligence toilet” [2]. This toilet room is equipped with four measurement machines with which the user can check his or her own health level.

In recent years, there have been a number of studies on smart houses and ambient rooms, which are designed to measure daily human activities. Although various types of personal vital sign measuring equipment are currently commercially available, their complexity and inconvenient user interfaces coupled with human reluctance to continue long-term use discourage their daily use. The main causes discouraging such continuous measurement include the limitation of body movement required for accurate measurement and the need to make measurements at a specific time of day since vital signs differ throughout the day. The measurement of blood pressure, which requires maintaining a specific posture during measurement and performing regular measurements every morning, can be taken as a typical example. This problem disturbs vital sensing for long-term in-home health monitoring.

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In research related to home health care, Yamakoshi [3] [4] suggested an unconscious automated physiological monitoring system. This system, involving an intelligent environment with physiological sensors, is a large system contained within the house, incorporated into, for example, the bed space, Japanese bath, or bathroom. Although such a huge system is effective for managed buildings such as hospitals, it would be difficult to install and maintain in a domestic environment; therefore, personal home health care needs a more compact and simple system.

In this paper, we propose a novel concept called “ambient vital sensing.” This concept is based on the involuntary measurement of vital signs and the measurement of posture of a user relaxing in a normal living environment. Vital sign trend analysis is also performed with the help of past data automatically stored after each session. In addition, feedback provided to the user serves to motivate the user to play a more active role in personal health management.

We have been developing a chair-type interface because, given the considerable noise caused by body movement in daily life, sitting on a chair serves to minimize this. This chair-type interface is equipped with physiological sensors, which are noninvasive direct-connect physical sensors, and the user only has to sit on the chair to get measurements. This interface then automatically measures vital signs and body motion simultaneously without the need to attach additional personal health care measuring devices. In addition, this chair provides feedback of the user’s health condition through an illuminated display.

II. SYSTEM CONFIGURATION

Fig. 1 [5] shows the human antebrachial region. Because we select a situation in which the user sits on a chair, we expect certain physiological parameters in the antebrachial region to provide an anatomical point of view [6]. The presence of large capillary blood vessels allows us to obtain four parameters from this region: blood pressure, photoplethysmography (PPG), an electrocardiogram (ECG), and percutaneous oxygen saturation (SpO_2). In addition we expect to calculate pulse wave velocity (PWV) by using PPG and the ECG. Since traditional measurement methods that require restraints are counterproductive, we attempt to use noninvasive direct-contact vital monitoring. However, traditional measurement methods are not applied to this system. We therefore developed a novel type of vital sensing module for the situation in which the user sits on the chair. In addition, we investigate color-based feedback as a means to motivate users though visualizing their health condition.

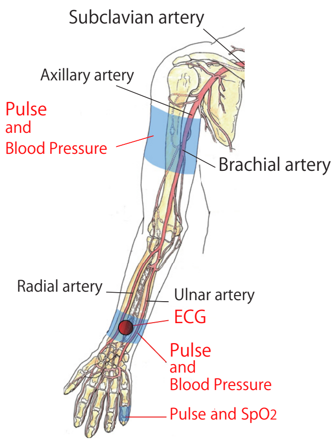

Fig. 1. Anatomical chart of the antebrachial region.

Fig. 2. Chair-type interface.

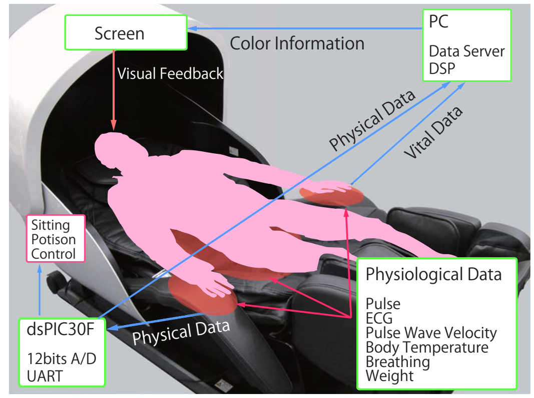

Fig. 3. Chair-type interface system.

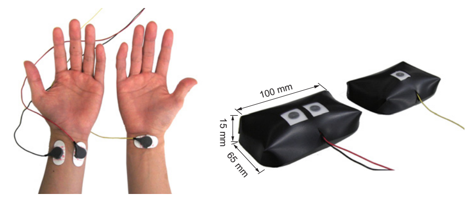

Fig. 4. (Left) Traditional ECG measurement device. (Right) Trial write-rest-type device.

A. Chair-type interface configuration

Figs. 2 and 3 show an overview of the developed interface. The chair used is a massage chair (Osim Family Co., Ltd.). Although each traditional measurement device can measure one kind of vital sign, our chair-type interface can measure several types of vital signs simultaneously. The system detects the user sitting on the chair by a physiological sensor. The backrest of the chair is adjustable to provide a comfortable position for measurement. The user touches the sensing module by this interface and the system then measures all the physiological vital signs simultaneously. Finally, when the measurement is finished, the system displays a specific color as the result of vital sign analyses.

B. Sensor configuration

For making measurements as natural as possible, we installed two physiological sensors and two physical sensors. The physiological sensors are PPG sensors that combine an LED with a photodiode (PD) on the chair near the left-hand fingertips and ECG sensors made of two electrodes on each wrist rest. We used a two-channel physiological wireless sensor (BAQT-0001, Bio Signal Co., Ltd.), which can measure both ECG and PPG simultaneously, and the data are acquired through a 10-bit A/D converter operating at 500 [Hz]. Figs. 4 and 5 show an example of the device for the traditional method of ECG measurement and the trial method involving sitting on the chair. This trial method induces the user to touch the physiological sensor and measures vital signs by using the user's own arm weight. The physical sensors are two pressure sensors (Kinotext trial, Nitt Co., Ltd.) on each arm and two axis acceleration sensors (KXM52-1050, Kionix, Inc.) placed within the chair near the fingertips of the right and left hands. Pressure sensor data, which have a range of 0 to 25 [kPa], are acquired from 54 (6 columns $\times$ 9 rows) points at a rate of 40 [Hz] and the acceleration sensor signals are acquired through a 12-bit A/D converter operating at 1 [kHz].

III. SYSTEM EVALUATION FOR A NOVEL TYPE OF PHYSIOLOGICAL MODULE

Although almost all vital sensing is sensitive to noise generated by body movement, considering the usability, we propose a novel method of nonrestrained vital sensing. To find the potential vital sign that can be measured by direct connect only, it is necessary to analyze the accuracy of this method. Both PPG and ECG are known to be measured noninvasively and PWV, which indicates the hardening of blood vessels, is calculated from the time difference between rising edges of the PPG and the ECG (Δt) and the length between the heart and the left-hand fingertips (L). This can be expressed in an equation as

$$\mathrm{PWV} = L/\Delta t \tag{1}$$

1) Method: Subjects. Two healthy subjects (two males, of ages 23 and 22 years).

Materials. Synchronized PPG and ECG data were taken using the new chair-embedded system and PWV data were taken using a medical device (from PWV/ABI, Omron Healthcare Co., Ltd.).

Tasks. The subjects were asked to sit in the chair system

Fig. 5. Using the trial device.

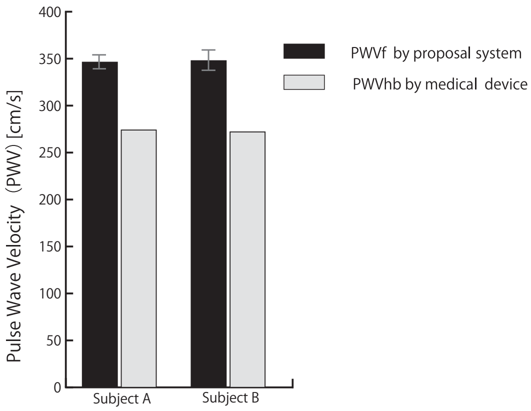

Fig. 6. Comparison between $\mathrm{PWV_f}$ and $\mathrm{PWV_{hb}}$.

for about 30 [s]. The data were recorded and diagnosed twice with a medical device by a medical doctor for $\mathrm{PWV_{hb}}$, which is the pulse wave velocity measured between the heart and the upper arm. This $\mathrm{PWV_{hb}}$ value is used as a reference.

Analysis. After recording data with the new system, an average of ten $\mathrm{PWV(PWV_f)}$ values is calculated by PPG and ECG.

2) Results: Fig. 6 shows the result of $\mathrm{PWV_f}$, its standard deviation, and $\mathrm{PWV_{hb}}$. There was a difference of about 70 [cm/s] between $\mathrm{PWV_f}$ and $\mathrm{PWV_{hb}}$. PWV depends on the square root of the inside diameter of the artery [6]. Because the diameter becomes small from the shoulder to the wrist, the mean of the diameter between the heart and the finger is smaller than between the heart and the upper arm. Thus $\mathrm{PWV_f}$ value larger than a $\mathrm{PWV_{hb}}$ one is acceptable. In addition, because the difference between $\mathrm{PWV_f}$ and $\mathrm{PWV_{hb}}$ values was similar for each subject, our proposed nonrestrained measurement has a good potential for measuring ECG, PPG, and PWV.

3) Problems: The accuracy of the data depends on the quality of contact between the sensor and the arm as well as body movement and we need to evaluate the large number of subjects.

IV. PHYSIOLOGICAL AND PHYSICAL SENSING

We propose improving this system by introducing a physiological sensor and a physical sensor together. Furthermore, the physical sensor monitors the user's body movement or posture and the quality of contact between the sensor and the arm, and the system is embedded with a knowledge base to determine whether or not the data are stable. When the user is stable, which is determined by physical data, this system starts to measure physiological data to compensate for any

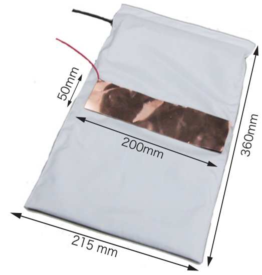

Fig. 7. Multiple sensor for ECG and pressure.

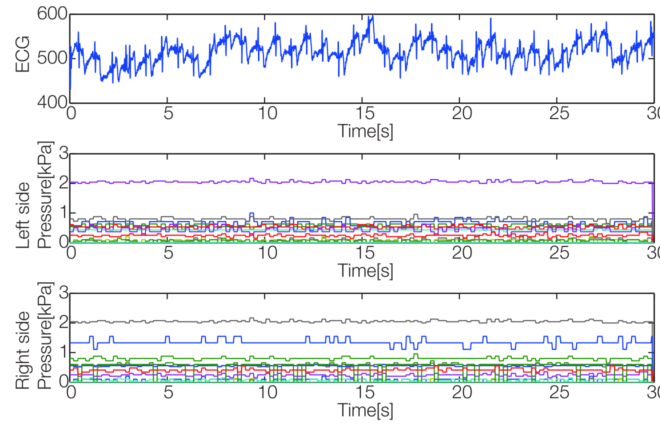

Fig. 8. Readings with an electrode size of $200 \times 50\ \mathrm{mm}^2$.

unexpected noise in the measurement.

A. Improved device with ECG compatibility

Fig. 7 shows part of a multiple sensor for measuring ECG and pressure sensing. This multiple sensor is combined similarly to the previous pressure sensor with a 50 [mm] $\times$ 200 [mm] copper sheet being substituted for the previous electrode as in Fig. 4. The ECG, which is sensed by the copper sheet, is acquired through a 12-bit A/D converter operating at 100 [Hz]. This multiple sensor is put on the armrest of the chair and the ECG and the pressure between the sensor and the user's arm are measured simultaneously.

B. System evaluation

Traditionally, ECG is measured by using clip-type or cupule-type attachments, because it is important to have a good connection between the body and the electrode. However, in our method, the ECG sensors are held in place by using the user's own arm weight. Therefore, to find adequate electrode locations on the arm and to find the corresponding pressure from the arm weight during sitting, it is necessary to measure both ECG and pressure simultaneously.

1) Method: Subjects. Two healthy subjects (two males, of ages 23 and 24 years).

Materials. The multiple sensor is on the armrest, as was the previous pressure sensor and copper sheet electrode for the ECG. The other 50[mm] side of the copper sheet is set with the subject's elbow.

Tasks. The subject sits on the chair for about 30 [s] for each recording, and measurements are taken at seven different parts of the arm. The electrode is sequentially masked

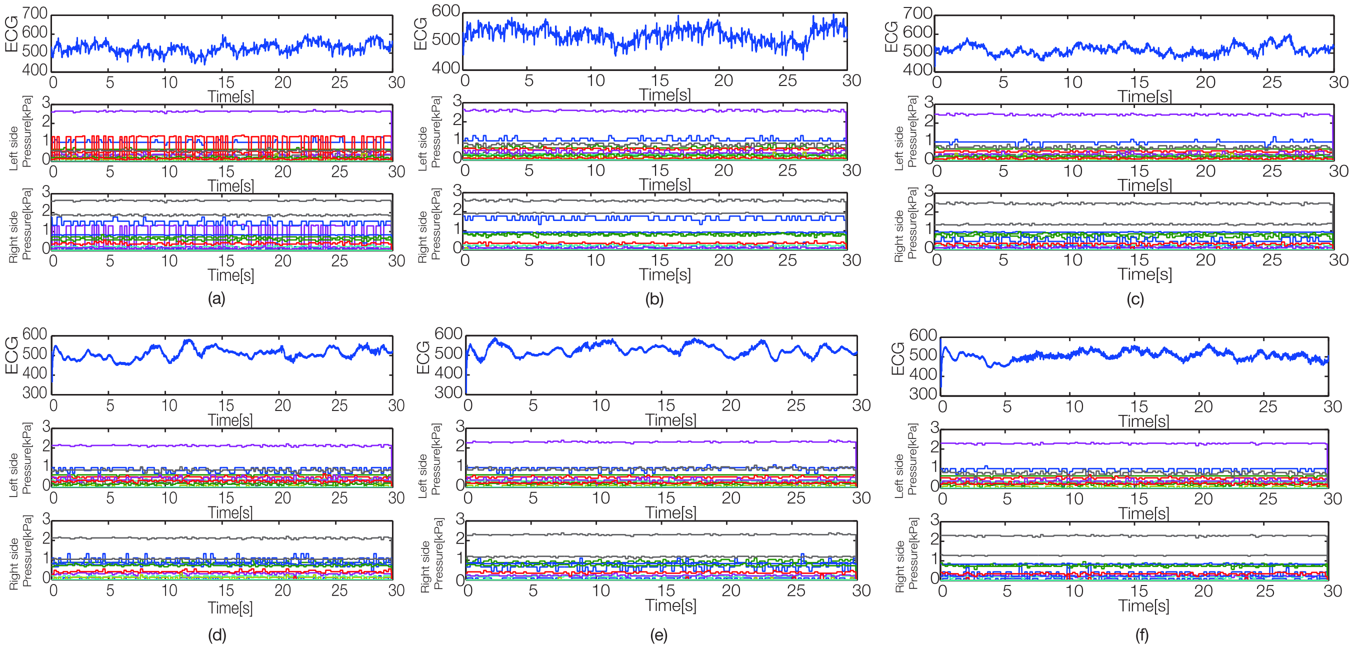

Fig. 9. Readings taken from the wrist with an electrode size of (a) $150 \times 50[\mathrm{mm}^2]$, (b) $100 \times 50[\mathrm{mm}^2]$, (c) $50 \times 50[\mathrm{mm}^2]$.Readings taken from the elbow with an electrode size of (d) $150 \times 50[\mathrm{mm}^2]$, (e) $100 \times 50[\mathrm{mm}^2]$, (f) $50 \times 50[\mathrm{mm}^2]$.

from the elbow side or the wrist side, with exposed sizes from elbow or wrist of $150[\mathrm{mm}] \times 50[\mathrm{mm}]$, $100[\mathrm{mm}] \times 50[\mathrm{mm}]$, and $50[\mathrm{mm}] \times 50[\mathrm{mm}]$ (and a nonmasked size of $200[\mathrm{mm}] \times 50[\mathrm{mm}]$).

2) Results and discussion: Figs. 8–9 show the results of one subject's ECG and pressure against time. Both subjects showed a similar trend. Figs. 8–9 indicate that the elbow pressure is more than 2 [kPa] and on other points it is less than 1.5 [kPa]. Nevertheless, the ECG R wave was successfully recorded by the copper sheet on the side of the wrist (Figs. 9-(a)–9-(f)). So, from these results, it can be confirmed that the ECG R wave can be observed at the wrist when the elbow pressure is more than 2 [kPa] and the electrode is larger than 150 [mm] $\times$ 50 [mm], though the relationship between the specific part of the arm and ECG detection is uncertain.

V. CONCLUSIONS

In this paper, we proposed a novel concept called "ambient vital sensing." Given the amount of measurement noise that can enter from body movement, we developed a chair-type interface, as very little body movement is associated with sitting. We verified the successful detection of vital signs through a noninvasive direct-contact interface and verified that PWV can be calculated from synchronized PPG and ECG measurements using this system. However, direct-contact vital sensing has the problem of being sensitive to noise caused by body movements.

Further, we proposed a multiple sensing device with physiological and physical sensors. User bodily movement and the quality of contact between the sensor and the body are monitored by a physical sensor, which is used to determine whether or not the physiological sensing data are stable. We investigated the relationship between location and pressure for measuring an ECG by one's own arm weight. We showed that the ECG R wave can be confirmed from the wrist when the elbow pressure is more than 2 [kPa] and the electrode is larger than 150 [mm] $\times$ 50 [mm], though the relationship between specific front arm area and ECG R-wave detection is uncertain. For long-term vital sensing in daily life, human–machine interaction in several sitting situations (e.g., with the user watching TV, reading a book, or relaxing) must be considered in future systems, and the relationship between physiological and physical data must be made clear. In addition to vital sensing, it is important to provide feedback of the user's health condition to encourage continuous usage of the system.

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