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Nonintrusive Measurement of Biological Signals for Ubiquitous Healthcare

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***Abstract*—In order to monitor biological signals during our daily lives for ubiquitous healthcare, nonintrusive biological signal monitoring methods have been developed. Without contacting sensors and connecting wires to the subjects, the biological signals are monitored using specially designed methods. ECG is measured using capacitive coupling over clothes and PPG is measured nonintrusively during ordinary activities. Blood pressure is also estimated from ECG and PPG by calculating pulse arrival time (PAT). These methods can be applied to evaluate the health levels of subjects without intervening in their ordinary daily activities.**

I. Introduction

With the increasing interest for health and quality of life, the need for monitoring health level in daily life is growing. Medical services that have previously been restricted to hospitals mainly for treatment of diseases can be extended spatially out of hospital and into people's homes to support our daily healthcare. Ubiquitous health monitoring (u-Health monitoring), which can monitor subject's health status without restriction on location and time, is required to perform health monitoring in our ordinary daily lives.

While long-term measurements of biological signals in our daily lives are necessary for u-Health monitoring, it is important that these measurements should not intrude on the daily lives of subjects. The nonintrusive measurement is purposing to monitor health-related information continuously without interrupting the subject's ordinary daily activities and without requiring additional operations or cooperation for signal measurements. Even signals should be monitored without the subject's awareness on the measurements. Thus, we can get a daily record of a subject's health status user-transparently, and we can apply the method for a longer time without any inconvenience to subjects. To meet these requirements of non-intrusiveness and user transparent operation, methods that measure biological signals with sensors installed in daily using home equipments, such as toilet seats, chairs and beds, have been studied. Even though the signals can be monitored by these methods are now restricted to several situations, these methods are promising for u-Health monitoring according to their maximized non-intrusive characteristics. I review several nonintrusive monitoring methods that can be used effectively for u-Health monitoring.

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II. Heart Activity Monitoring

Even though electrocardiogram (ECG) is highly informative and widely used in hospital to evaluate the performances of cardio vascular system, attaching electrodes to exposed skin limits their application in our daily activities. To monitor heart activities in nonintrusive ways alternative sensors and methods have been developed.

A. Ballistocardiogram

Ballistocardiogram (BCG) is the vital sign caused by the mechanical movement of the heart. Several type sensors have been developed to record BCG nonintrusively.

Phonocardiogram sensor was applied on an air mattress or water mattress to record BCG [1]. Polyvinylidene fluoride (PVDF) sensors have been adopted in the form of a two-dimensional array [2]. Multimodal optic sensors [3] and Electro-Mechanical Films (EMFi) sensors [4] have also been used. Static-Charge-Sensitive Bed (SCSB) monitoring was introduced for measuring the change of static charge caused by the movement of respiration [5]. To solve the saturation problem in air mattress sensor system, balancing tube was used [6]. Method using loadcells was developed for nonintrusive cardiac activity monitoring specially for sleep duration [7]. Four loadcells are installed at the bottom of the bed legs to detect force changes at each leg of the bed. With appropriate filtering, movement, weight changes and respiration as well as BCG can be separated from measured composite signal.

B. Capacitively coupled ECG

BCG has own limitation due to its mechanical characteristics of signal in contrast to the electrical nature of ECG. To record electrical behavior of the heart non-intrusively, without contacting electrodes directly on exposed skin, ECG recording method using capacitive coupling was suggested [8]. In this method, an ECG is measured through capacitive connection of body and electrode as shown in Fig. 1, even while the subject wears clothes. To enhance performances, Lim et al. suggested use of active electrodes with embedded preamps [9]. Two active electrodes pick up electrical potentials through capacitance established between electrodes and body surfaces. Another wide conductive sheet is used as a ground also by capacitive coupling during the measurement. Thus, the system is totally

separated from the body.

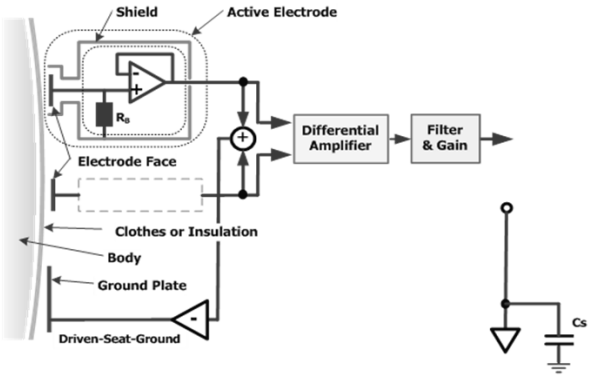

Fig. 1. ECG measurement using capacitively coupled electrodes composed of two active electrodes and a capacitive ground totally separated from body.

The quality of a measured ECG strongly depends on coupling capacitance. Even though capacitance is increasing by enlarging the electrode size or reducing the gap between body surface and electrode, it is not easy to obtain reasonable coupling capacitance in a practical situation. Because thickening the clothes reduces capacitance and deteriorates the quality of measured signals, intelligent methods that can establish required coupling capacitance should be devised. High input impedance of the preamplifier can minimize the impedance effect of clothes and driven capacitive ground successively increases the quality of measured signals. Also, this measurement can be implemented in wearable type as a belt.

III. Respiration Monitoring

Respiration is another vital sign and it should be monitored continuously to evaluate progress in some symptoms like apnea. By recording the accompanying air flow, chest or abdomen movements, different types of sensors are being used for monitoring respiration. Also, some methods are suggested to monitor respiration nonintrusively. Mechanical dynamics of lung during respiration affects the heart movement, and its effect is usually involved in BCG or ECG. With appropriate filtering, respiration can be separated from non-intrusively recorded BCG or ECG without using extra sensors for respiration recording.

IV. Photoplethysmogram Recording

A photoplethysmogram (PPG) also provides critical physiological information of blood oxygen saturation, heart rate and respiration. Because it is noninvasive, easy to obtain, and cost-effective, it has been widely employed in health monitoring [10]. While heart rate and respiration can be monitored by a PPG alone, a PPG is also used in combination with an ECG for estimating beat-to-beat blood pressure by calculating pulse arrival time.

Wearable systems that enable continuous, unobtrusive, 24-hs PPG measurement were developed for heart rate and respiration monitoring. Ring type sensor [11] and earpiece sensor [12] were developed for ambulatory monitoring purpose. A pillow has been used for nonintrusive heart rate and respiration monitoring by PPG measurement during sleep [13]. Similarly, the feasibility of nonintrusive PPG measurements for car drivers [14], computer users [15], and on toilet seat [16] were suggested. These studies show good prospects for nonintrusively recording of daily PPG measurements at home and in the office, and even for ambulatory monitoring.

Recently, a new method that allows PPG measurement through clothes was introduced [17]. Clothes can be thought as another light-absorbing medium, such as tissues or a venous blood pool. The basic concept of PPG measurement, which relies on the Beer-Lambert law, can be extended to include the clothes layer while measuring a PPG over clothes. This recent innovation is expected to expand the scope of nonintrusive PPG measurement to home settings such as a chair or a bed.

V. Blood Pressure Estimation

Blood pressure is one of the most important vital sign representing directly the status of cardiovascular system, and it is most widely measured in hospital and at home. While noninvasive blood pressure (NIBP) monitors are widely used at home, they are not suitable enough to monitor day-to-day variations in blood pressure without active cooperation of subjects in the measurement process.

Although there have been some trials to measure blood pressure nonintrusively [18], the method using pulse arrival time (PAT) draws the greatest attention. Even though the PAT method does not physically measure blood pressure, it can estimate blood pressure with reasonable accuracy.

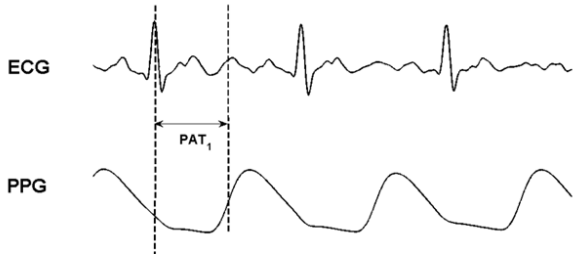

Fig. 2. Pulse arrival time (PAT) to estimate blood pressure by calculating the time difference between R-peak of ECG and maximum slope point of PPG.

PAT is usually calculated as the time difference between the R-peak of an ECG and a specific feature point of a PPG, as shown in Fig. 2. It has been shown that PAT and blood pressure are closely correlated and especially systolic blood pressure (SBP) is highly correlated with PAT [19]-[22]. Thus, if we can measure PAT nonintrusively, we can estimate blood pressure nonintrusively. Table 1 shows some possible combination of nonintrusive signals for PAT or PAT

equivalent difference measurement.

While the accuracy of SBP estimation is high enough, the accuracy of DBP estimation using the PAT is still lower than SBP. To improve DBP estimation accuracy, supplementing parameters are required. Heart rate and duration from maximum derivative point to dicrotic peak (TDB) in the PPG signal, reflecting arterial stiffness, have resulted in an improved correlation [23].

TABLE I
POSSIBLE COMBINATION OF SIGNALS FOR PAT CALCULATION.

1st signal	2nd signal
CC-ECG	PPG over clothes on chair PPG over clothes on bed PPG on toilet seat PPG on PC mouse BCG by air cushion on chair BCG by load cells on bed.
BCG	PPG over clothes on chair PPG on PC mouse

Although there is general correlation between blood pressure and PAT, this correlation is higher for intrapersonal relationships than for interpersonal relationships. Estimation results can be enhanced by personally tailoring the estimation equation for each subject.

Technology leading to nonintrusive estimation of blood pressure is promising. Because blood pressure has an important role in diagnosis of disease and in health management, nonintrusive blood pressure measurement is very important for the successful application of ubiquitous health monitoring in daily lives.

VI. CONCLUSION

For long term measurement of biological signals in our daily lives without interrupting our ordinary activities, non-intrusive and subject transparent measurements are important for practical application. To meet these requirements for u-Health monitoring, nonintrusive methods for biological signal measurements have been developed. This method can combine various pieces of home equipments, such as beds, chairs, computer mice, toilet seats and belts for measuring ECG, respiration, PPG and blood pressure.

In future studies, nonintrusive sensors will be diversified and measurement space will be extended to all living space for u-Health monitoring.

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