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Feasibility Study on Fabric-Sheet Unified Sensing Electrode for Non-Contact In-Bed Measurements of ECG, Body Proximity and Respiratory Movement †

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Abstract: In a recent article, we have reported that a fabric-sheet unified sensing electrode (FUSE) can detect electrocardiogram (ECG), body proximity at the chest and abdomen (BPx_{chest}, BPx_{abd}) and respiratory movement at the abdomen (RM_{abd}) via worn clothes and bedsheet simultaneously from recumbent human subject. We conducted feasibility study involving 21 subjects to assess the influence of individual difference on this FUSE system. Results revealed that individual difference of physical constitution had little impact on both accuracies of ECG R wave and RM_{abd} under the current FUSE configuration, but had some influence on the voltage changes in BPx_{chest} and BPx_{abd} caused by postural change. We deemed to revise some dimensions of the FUSE to avoid individual threshold setting for sitting up detection.

Keywords: individual difference; feasibility study; fabric-sheet unified electrode (FUSE); capacitive electrocardiography (cECG); body proximity (BPx); respiratory movement (RM); home monitoring; non-contact measurement

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1. Introduction

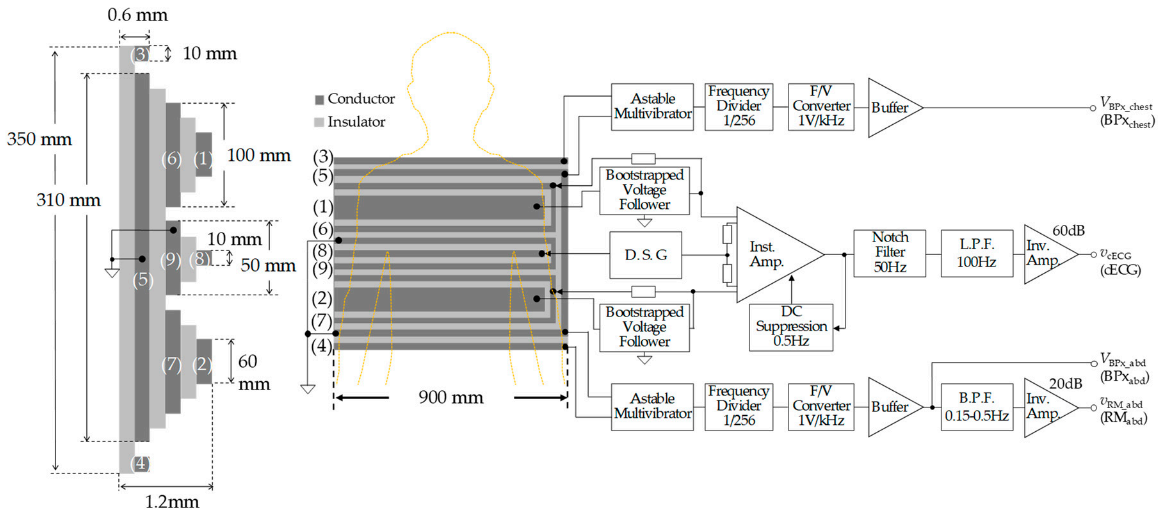
With the rapid population aging [1], and the progress of information and communication technology, physiological and behavioral signals are considered to be monitored at home in the near future. Vital monitoring at home is considered to play an important role in both preventive daily healthcare and in-hospital care. In a recent research report, a fabric-sheet unified sensing electrode (FUSE) can detect electrocardiogram (ECG), body proximity at the chest and abdomen (BPx_{chest}, BPx_{abd}) and respiratory movement (RM) via worn clothes and bedsheet simultaneously from recumbent human subject [2]. In the article, however, verification of principle of the system and fundamental evaluation were only done. In the current research, we conduct feasibility study involving increased subjects to assess the influence of individual difference on this FUSE system.

2. Materials and Methods

2.1. Fabric-Sheet Unified Sensing Electrode (FUSE)

The FUSE can simultaneously measure capacitive electrocardiogram (cECG), BPx_{chest}, BPx_{abd}, and respiratory movement at the abdomen (RM_{abd}) signals. The FUSE is laid under the bed sheet and the back of the lying subject. To prevent sleep disturbance due to night sweat, the FUSE is constructed from breathable materials (conductive fabric of porous copper thin film and insulating fabric; see

Figure 1). The detection circuit is basically similar to the conventional system. In addition, a driven seat ground (DSG) circuit [3] was introduced to suppress common mode noise.



(**a**) (**b**)

Figure 1. The measuring system used in this study. (**a**) Cross-sectional side-view configuration of the FUSE. (**b**) Top-view configuration of the FUSE and block diagram of the measuring system.

2.2. Simultaneous Measurements of cECG, BPx_{chest}, BPx_{abd} and RM_{abd} at Rest and Sit-up Motion

The content of experiment was approved by the Human Life Ethic Committee of Tokyo Denki University. All subjects provided informed consent prior to participation in our experiments. We measured the cECG, BPx_{chest}, BPx_{abd}, and RM_{abd} signals simultaneously totally 31 times from 9 males and 12 females (BMI: 16.0 to 29.0 kg/m^2). Subjects were asked to keep supine posture and breathing at 30 breaths / minute (rpm) using the metronome on the bed for 5 minutes. Subjects were then asked to sit up. Reference electrocardiogram signal (ECG_{ref}) was simultaneously measured by a commercially available wireless telemetry type electrocardiograph (i.e., BN-RSPEC, BIOPAC Systems, Goleta, CA, USA) and disposable electrodes (i.e., F-150S, Nihon Kohden, Tokyo, Japan). Reference RM_{abd} signal (RM_{ref}) simultaneously measured by a belt type respiratory transducer of the same telemetry type (i.e., BN-RESP-XDCR, BIOPAC Systems, Goleta, CA, USA). For evaluation, commercially available analysis software (i.e., AcqKnowledge 4.1, BIOPAC Systems, Goleta, CA, USA) was used. Five minutes of rest state was set as an analysis section of the cECG and RM_{abd} signals. The cECG and ECG_{ref} signals were preprocessed by smoothed by the 20-point window, filtered through a digital high-pass filter (infinite impulse response filter, f_c = 10 Hz) and differential processing, respectively. The each ECG were detected the R wave by the peak detection function of the software and calculated R-R intervals (RRIs). Detection was performed when the time difference between the RRI of each ECG was ±5 ms or less, and the detection accuracy of each was calculated. RM_{abd} and RM_{ref} signals were preprocessed by filtered twice through a digital band-pass filter (infinite impulse response filter, f_c = 0.15–0.5 Hz). Discrete RM_{abd} cycles in each RM_{abd} signals were automatically detected by software with threshold processing [4], and detection accuracy of each RM_{abd} was calculated. Detection of the sit-up motion was calculated from the voltage change of BPx_{chest} and BPx_{abd} signals (ΔBPx_{chest}, ΔBPx_{abd}) before and after sit-up motion.

3. Results and Discussion

Table 1 shows the maximum value (Max), the minimum value (Min), the mean value (MN) and standard deviation (SD) of the accuracies of cECG R wave and RM_{abd} signals, and each ΔBPx. Figure 2 shows representative simultaneous measured waveforms of BPx_{chest}, BPx_{abd}, cECG, ECG_{ref}, RM_{abd} and RM_{ref} signals including sit-up motion. Detection accuracy of cECG R wave exceeded 90% in all subjects. The average value of detection accuracy in RM_{abd} signal was 91.9%. The ΔBPx due to the sit-up motion varied from 0.2 to 4.0 V in ΔBPx_{chest} and from 0.2 to 6.0 V in ΔBPx_{abd}. Measurement of cECG signal were stable in all subjects. On average, the detection accuracy of the RM_{abd} signals exceeded 90%. Individual difference was confirmed in ΔBPx_{chest}, and ΔBPx_{abd} due to sit-up motion. It was inferred that this is due to the difference in bonding position between the electrode and the body due to the difference in physique. It is considered that examination of electrode size is necessary to reduce the influence of difference in body size.

Table 1. Max, Min, MN and SD of the accuracies of cECG R wave and RM_{abd} signals, and each ΔBPx.

	accuracy of cECG R wave (%)	**accuracy of RM_{abd} (%)**	**ΔBPx_{chest} (V)**	**ΔBPx_{adb} (V)**
Max	100.0	100.0	4.0	6.0
Min	92.5	40.3	0.2	0.2
MN ± SD	97.8 ± 2.2	91.9 ± 12.9	2.1 ± 1.0	3.0 ± 1.6

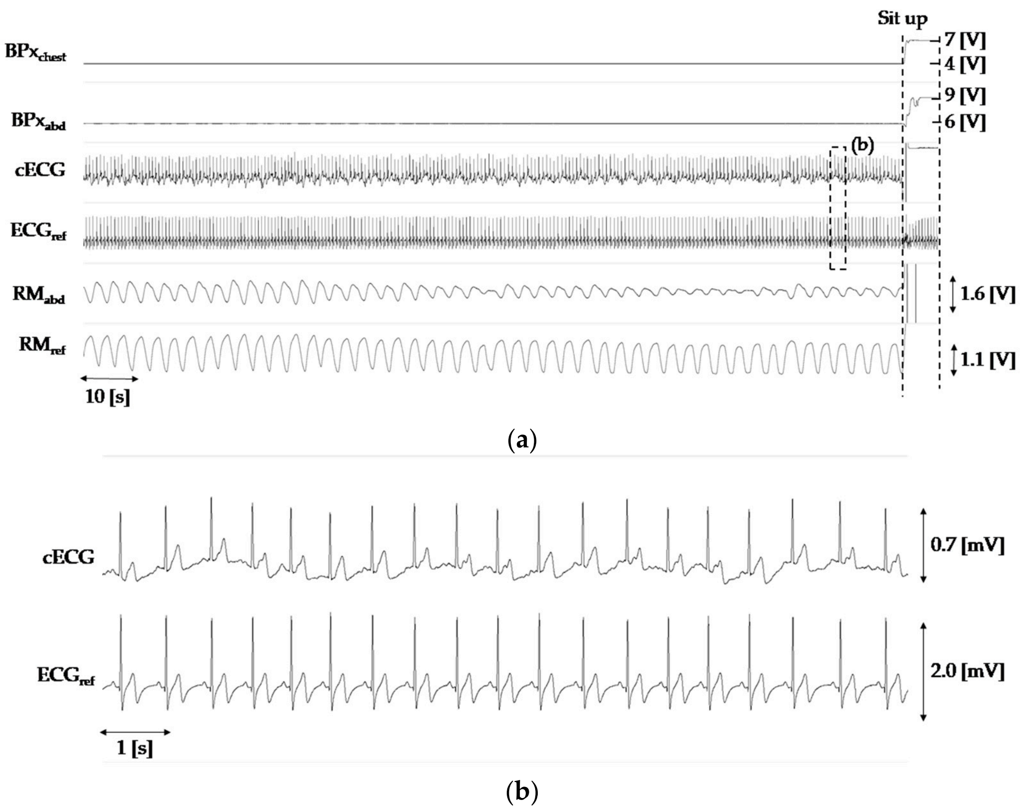


Figure 2. Representative measurements including sit-up motion. (**a**) Discriminative recordings of BPx_{chest}, BPx_{abd}, cECG, ECG_{ref}, RM_{abd} and RM_{ref} signals measured simultaneously by the FUSE. cECG waveform was smoothed by the 20-point window. (**b**) Enlarged example of cECG and ECG_{ref} waveforms for the segment enclosed by dotted line in (**a**).

4. Conclusions

Feasibility study was conducted to evaluate the influence of the individual difference on the FUSE. Totally 31 measurements were done for 9 males and 12 females (BMI: 16.0 to 29.0 kg/m^2). Individual difference of physical constitution had little impact on both accuracies of cECG R wave and RM_{abd} under the current FUSE configuration, but had some influence on the BPx_{chest} and BPx_{abd} caused by sit-up motion. Therefore, we deemed to revise some dimensions of the current FUSE to avoid individual threshold setting for detecting sit-up motion.

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