Heart Rate Measurement Using a Flexible Sheet-Type Tactile Sensor

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Abstract

In recent years, nursing care facilities have faced severe labor shortages, increasing the need for technologies that reduce caregiver burden. This study aims to develop a system that measures heart rate simply by having a person sit on a chair equipped with flexible sheet-type tactile sensors installed on the seat and backrest. The system estimates heart rate from pressure fluctuations produced by subtle body movements associated with cardiac activity. By enabling non-contact and automatic monitoring, this approach can support continuous health observation in nursing environments. Implementing this system in care facilities is expected to significantly reduce caregivers' workload while improving monitoring efficiency.

Keywords: Artificial intelligence & complexity, Human-welfare robotics, Pattern recognition, Image processing, Robotics

1. Introduction

Heart rate is a key physiological indicator that reflects autonomic activity and cardiovascular condition, and it is widely used in health management, disease prevention, and safety monitoring. Changes in heart rate can signal fatigue, stress, dehydration, fever, or early signs of arrhythmia and other disorders, making continuous monitoring valuable for early risk detection. Recent studies also use heart-rate variability to estimate driver alertness, supporting technologies for detecting drowsiness or alcohol-induced impairment.

Conventional heart-rate sensors such as chest straps and optical devices offer accuracy but require physical attachment, causing discomfort, misalignment errors, and operational burdens—issues that limit their suitability for daily life, driving, or elderly care settings where non-intrusive measurement is essential.

To address these challenges, this study develops a non-wearable heart rate sensing method using a flexible sheet-type tactile sensor. By capturing minute pressure fluctuations on the seat and backrest, the system estimates heartbeats without any device attached to the body. Its ability to obtain wide-area pressure distributions enables stable measurement even with posture changes.

Integrating this technology into vehicle seats or care chairs allows users to obtain heart rate simply by sitting, contributing to drowsiness detection, alcohol impairment monitoring, and continuous health observation without burden. Thus, the proposed approach offers a socially valuable foundation for future health-management and safety-support systems.

2. Preparation

2.1. *flexible sheet-type tactile sensor*

In this study, we used the SR (Smart Rubber) sensor, a flexible sheet-type tactile sensor developed by Guo et al. (Fig. 1). The SR sensor consists of a flexible dielectric layer sandwiched between two conductive rubber sheets, and each intersection of the printed electrodes functions as an individual capacitor, as illustrated in Fig. 2. These capacitors are arranged across the plane and are referred to as cells. The detailed specifications of the sensor are summarized in the Table 1.

Fig 1

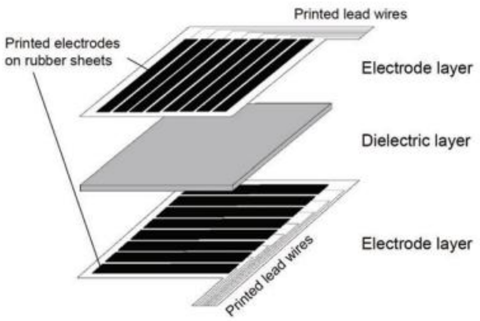

Fig 2

Table 1 Specifications of the SR sensor

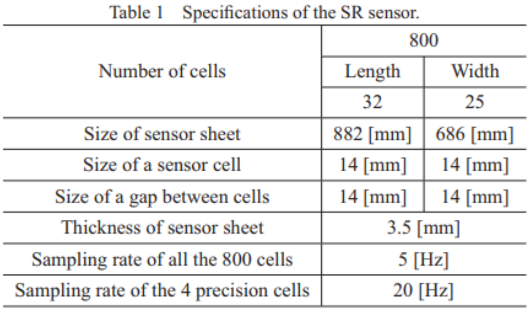

Table 1 Specifications of the SR sensor.

Number of cells	800	
	Length	Width
	32	25
Size of sensor sheet	882 [mm]	686 [mm]
Size of a sensor cell	14 [mm]	14 [mm]
Size of a gap between cells	14 [mm]	14 [mm]
Thickness of sensor sheet	3.5 [mm]	
Sampling rate of all the 800 cells	5 [Hz]	
Sampling rate of the 4 precision cells	20 [Hz]	

2.2. *Heart-rate measurement method*

Figure 3 illustrates the process of estimating heart rate from the time-series pressure data obtained by the SR sensor. First, among the cells where sufficient pressure is detected, those suitable for heart-rate measurement are selected. Signal processing is then applied to the time-series data of the selected cells to separate and extract the respiratory and cardiac components.

While respiration can be detected relatively easily, the heartbeat signal is often buried in noise, making noise suppression essential for improving accuracy. To address this, the sensor data are sampled at a rate much higher than the signal frequency and averaged to reduce noise influence. However, performing this high-precision processing on all cells would require an enormous computational load, making it difficult to maintain the sampling frequency necessary for reliable respiration and heart-rate measurement. Therefore, the high-precision processing is applied only to a subset of selected cells.

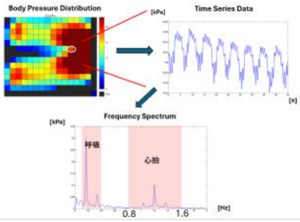

Fig 3

2.3. *Evaluation metrics for heart-rate measurement*

The signal-to-noise ratio (SNR) was used to evaluate the accuracy of the heart-rate measurement[1]. The SNR represents the ratio of the signal component to the noise component expressed in logarithmic form, and it is defined by the following equation.

$$\mathbf{SNR = 20\log_{10}（heartbeat\ signal\ /\ noise\ signal）［dB］} \quad (1)$$

Here, an FFT was applied to the pressure data obtained from the SR sensor, and the maximum spectral values in the respiratory band (0.1–0.4 Hz) and the cardiac band (1.0–1.8 Hz) were regarded as the respiratory and heartbeat components, respectively. The noise component was defined as the RMS value near 0.1 Hz, excluding the intermediate frequency range between the two bands (0.4–1.0 Hz).

Previous studies[2] have reported that heart-rate estimation errors significantly decrease when the SNR exceeds approximately 12–14 dB. Following this, the SNR was adopted as the evaluation metric in this study.

3. Heading 1 Title.

As described in Section 2.2, heart-rate measurement using the SR sensor can be performed only on a limited subset of cells, and the number of high-precision cells is restricted to four. The selection of these cells greatly affects the accuracy of heart-rate estimation. In this study, we focus on the fact that the cells in which heartbeat signals appear prominently vary depending on the sitting posture, and we propose a method to determine the high-precision cells based on the center of pressure (CoP).

First, the CoP is calculated from the pressure distribution obtained by the SR sensor. The vertical position of the CoP indicates how the contact area on the back is distributed and is used to classify the subject’s sitting posture into “shallow sitting” and “deep sitting.” Generally, shallow sitting tends to concentrate pressure on the upper back, while deep sitting tends to concentrate pressure on the lower back.

Next, for each classified posture, frequency analysis using FFT is performed on the low-resolution sampling data (5 Hz) of all cells. From the cardiac band (1.0–1.8 Hz) and noise band (0.4–1.0 Hz), the S/N ratio is computed, allowing quantitative evaluation of how effectively each cell captures the heartbeat signal.

Finally, for both shallow and deep sitting, the four cells with the highest S/N ratios are selected as the high-precision cells. This approach adapts to posture-dependent variations in the transmission pathway of heartbeat-induced vibrations and enables optimal cell selection under each condition.

By dynamically optimizing the high-precision cell selection according to the subject’s posture—rather than fixing the cell positions as in conventional methods—the proposed technique is expected to improve the stability and reproducibility of heart-rate measurement.

4. Experiment

4.1. Experimental conditions

In this study, an SR (Smart Rubber) sensor was attached to the backrest of a chair, and pressure data were collected while the subject was seated in a natural posture. The SR sensor consists of 800 cells arranged in a 32 × 25 grid, with each cell independently measuring pressure. To minimize external disturbances, all measurements were conducted in a quiet indoor environment.

Given that sitting posture affects heart-rate measurement performance, data were acquired under two conditions: *shallow sitting* and *deep sitting*. In shallow sitting, pressure tends to concentrate on the upper back, whereas in deep sitting, it tends to concentrate on the lower back. For each condition, the subject was instructed to maintain a consistent posture, and pressure data were recorded for 25.6 seconds. Measurements were repeated multiple times, and posture classification was verified using the center of pressure (CoP) computed from the pressure distribution.

From the acquired time-series data, samples were first extracted at 0.2-second intervals and formatted into 128-dimensional data representing the 25.6-second window. An FFT was then applied, and the S/N ratio for each cell was computed using the cardiac band (1.0–1.8 Hz) and noise band (0.4–1.0 Hz). Combined with CoP-based posture classification, the S/N ratios of all cells were compared to identify those suitable for heart-rate measurement under each posture.

Following previous studies, the S/N ratio was used as the evaluation metric for heart-rate measurement. An S/N ratio below 13 dB was regarded as a measurement failure, whereas values of 13 dB or higher were considered successful, serving as criteria for selecting candidate high-precision cells. The objective of this study was to determine the optimal heart-rate sensing locations by prioritizing cells with the highest S/N ratios for each sitting posture condition.

4.2. Results and Discussion

In this study, sitting posture was classified into *shallow sitting* and *deep sitting* using the center of pressure (CoP) calculated from the pressure distribution. For each posture, heart-rate measurements were performed ten times. Comparison of the CoP distributions showed that, in shallow sitting, the CoP concentrated in the lower region of the backrest ($Y \approx 17–18$), whereas in deep sitting, it shifted upward to $Y \approx 20–22$. These results indicate that the CoP effectively reflects the subject's sitting posture.

Next, for each posture class, the four cells with the highest cell scores—computed from the success rate of S/N ratio–based detection and the average S/N ratio—were selected as high-precision cells for heart-rate measurement. As a result, heartbeat detection succeeded in 4 out of 10 trials (40%) in shallow sitting and in 6 out of 10 trials (60%) in deep sitting.

The lower success rate observed in shallow sitting can be attributed to the limited contact area with the backrest. When the subject sits shallowly, the upper body does not fully lean backward, reducing the transmission of small heartbeat-induced vibrations to the sensor. Because the signals obtained by the flexible tactile sensor strongly depend on pressure fluctuations, weak contact tends to lower the S/N ratio below the threshold, leading to unstable heart-rate measurement.

In contrast, deep sitting results in a larger and more stable contact area extending to the upper back, allowing thoracic pulsations to be transmitted more effectively to the sensor, thereby improving the S/N ratio. This explains the higher measurement success rate in deep sitting. However, even in deep sitting, the success rate remained at 60%, suggesting that subtle posture variations and small body movements still influence measurement stability.

Overall, the results demonstrate that sitting posture has a significant effect on heart-rate measurement accuracy, and that selecting appropriate cells for each posture is essential. At the same time, since the success rates were not sufficiently high in either posture, further improvements in high-precision cell selection and signal preprocessing will be necessary to achieve more robust heart-rate measurement.

5. Conclusion

In this study, we investigated a method for measuring heart rate from the backrest using a flexible sheet-type tactile sensor and proposed a high-precision cell selection approach based on posture classification using the center of pressure. Sitting posture was categorized into shallow and deep sitting, and the four cells with the highest scores were selected for each posture. As a result, heart-rate measurement success rates of 40% and 60% were obtained for shallow and deep sitting, respectively.

The experimental results showed that deep sitting produced a relatively high success rate because the increased contact area with the backrest facilitated the transmission of heartbeat-induced vibrations. In contrast, shallow sitting often resulted in insufficient contact, a reduced S/N ratio, and consequently a lower success rate. These findings indicate that sitting posture has a substantial impact on heart-rate measurement performance and that selecting appropriate cells for each posture is essential for improving accuracy.

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