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Respiratory Sensor Measuring Capacitance Constructed Across Skin

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Abstract

A capacitive respiratory sensor is studied. The frequency response shows the nearly pure capacitance characteristics and indicates the sensing mechanism based on the skin thickness change with the reasonable consistence. The bellyband-type sensor wear realizes the stable sensing with the comfortable fit.

1. Introduction

The respiratory rate is one of the important vital signs. Its monitoring helps to figure out the progression of illness [1, 2]. The respiratory rate is also useful in sleep studies, sport training, etc. Despite such high importance, this vital sign is considered as the most neglected one [2].

The spirometer is the common device for measuring the respiratory rate [1]. The mask and the tube are tethered to the air flow sensor. They often disturb the subjects' natural condition. Scilingo et al. [3] and Paradiso et al. [4] showed piezoresistive fabric sensors. The inner garment must be always tightly fit around the body. We have proposed a capacitive sensing technique. The capacitive method is advantageous without requiring the physical pressure. A sensor garment is realized by fixing electrodes inside [5]. Figure 1 shows one example. The periodic signal corresponds to the respiration. Although the signal similar to the respiration cycle is observed, the mechanism was not clear.

In this study, the sensing mechanism is first investigated from the frequency characteristics of the signal. Based on the finding that the change of the skin condition due to the respiration is the signal origin, a wearable sensor is demonstrated with the improved stability.

2. Mechanism Investigation

The electrodes as shown in the inset of Fig. 2 are pasted on the skin using the elastic tape (3M, Multipore Sports Lite Elastic Tape). The electrode is the conductive textiles (flexible textile SFE-DEV-10070 combined with MK-KTN260) connected with the cable (AWG22). The subject takes the deep breathing. After the inhalation or the exhalation, the subject keeps the condition measuring the frequency response. Figure 2 shows the typical signals at inhaled and exhaled conditions. The impedance magnitude decreases linearly against the frequency. The phase is about -90° at the frequency below 1MHz. The signal is nearly pure capacitance whose impedance is expressed as $Z=1/j\omega C$. The phase increases at the higher frequency, which can be explained by the inductance of the cable. So, the capacitance itself changes with

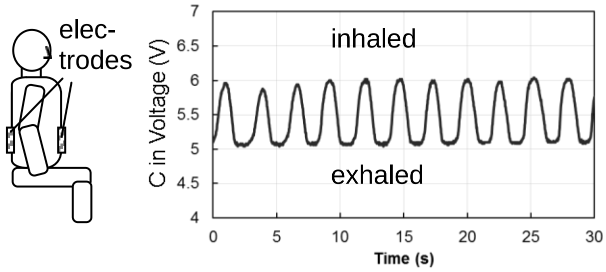

Fig. 1: The hand-made capacitance sensor signal using the electrodes (conductive textile of DW-372N) at the abdomen and backside. The output voltage increases when the capacitance increases.

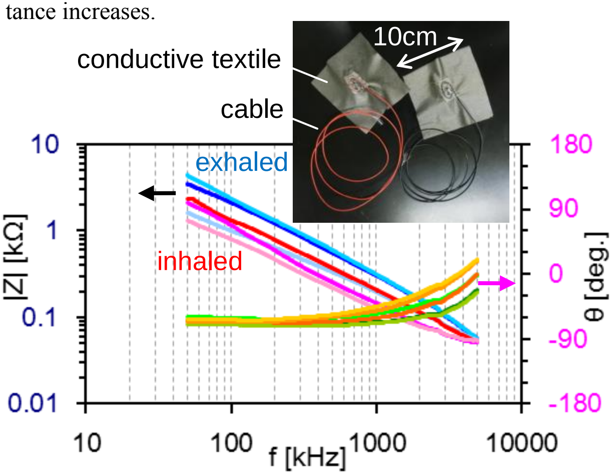

Fig. 2: Typical frequency response of the sensor signal. The electrodes are pasted on the chest center. The response is almost same when the electrode is pasted on the abdomen. The applied voltage amplitude for sensing is 1V.

the respiration. At the inhalation, the impedance decreases. This means the capacitance increases. The signal distribution is mainly caused by the change of the subject's posture.

Based on the fact that the inside body is the electrolyte having the low resistance, the capacitance will be generated at the skin surface. Figure 3(a) shows the typical model of the skin tissue. The capacitance will consist between two electrodes. One is the conductive textile outside. Another is the inside electrolyte. Figure 2(b) shows the case under the exhalation. The skin will shrink as the body volume decreases. The gap between the electrodes is considered to increase. The capacitance decreases, and the impedance increases. Figure 3(c) shows the case under the inhalation. The gap between electrodes decreases, so the capacitance increases, ant the impedance decreases.

Figure 4 shows the capacitance as the function of the

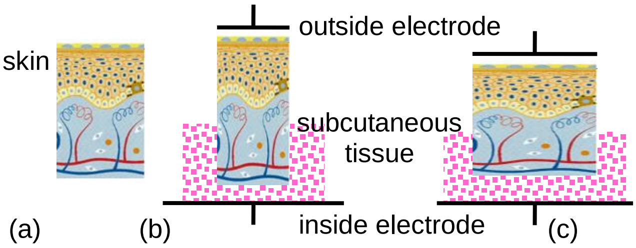

Fig. 3: (a) Typical skin structure. The model of the electrodes consisting the capacitance across the skin at (b) the exhaled and (c) the inhaled conditions.

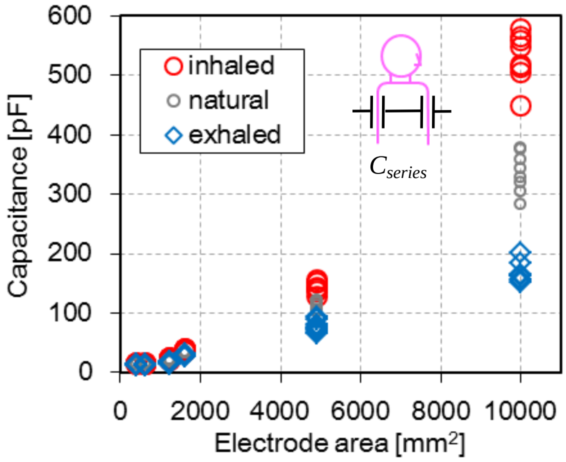

Fig. 4: The capacitance as the function of the electrode area. Two electrodes are pasted on the abdomen. The measurement frequency is 700kHz.

electrode area. The subject keeps the inhaled, natural, and exhaled conditions. The capacitance decreases when the electrode area decreases. This decrease saturates below 1000mm^2. The fringe field is considered to be major inside the capacitance. The model in Fig. 3 bases on the skin thickness of the gap between the electrodes. The fringe field generally becomes obvious when the electrode span is comparable with the gap. 1000mm^2 electrode has the span of about 32mm. The capacitance value in Fig. 4 will be the total of two same capacitances connected in series.

$$C_{series} = \frac{\varepsilon_0 \varepsilon_r Area}{2Gap} \quad (1)$$

The relative permittivity ε_r is supposed to be 80, the value of the water. Supposing the area of 10000mm^2 and the capacitance of 350pF, Eq. (1) estimates the gap to be 10mm. Although this value is relatively large compared to that of the skin structure (1.5-4mm), this is reasonable counting the subcutaneous tissue below the skin. Other data from the thinner man indicates the smaller gap value of 5mm.

3. Demonstration of Stable Sensing

Figure 4 shows the data when the electrode is pasted on the right chest. The convex position on the human body is found to stabilize the electrode condition. The signal shows the clear difference between the inhaled and the exhaled conditions. The sensor wear is prepared sawing two conductive textile electrodes. The inset of Fig. 6 shows such

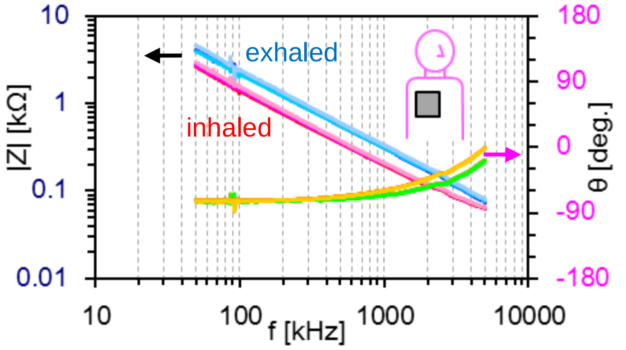

Fig. 5: Frequency response of the signal. The electrodes are pasted on the right chest and its back. The shielding cover wear is also found to be effective for stabilizing the signal.

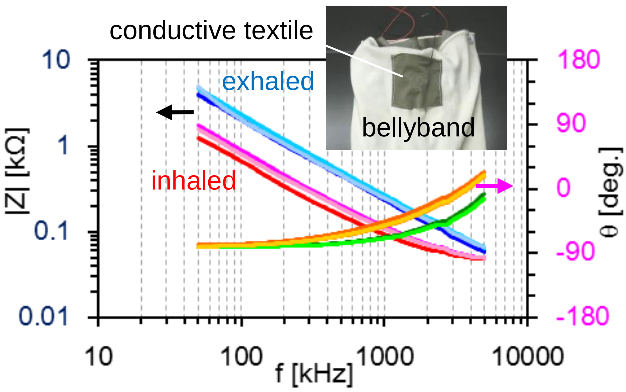

Fig. 6: Signals when the electrodes are fit on the chest center and its back using the bellyband with the shielding cover.

wear with the textile fixed inside the bellyband obtained from the market. The outside is the shielding cover of the conductive textile. Although the electrode is placed at the concave position at the chest center without using the pasting tape, the signal is stable with the comfortable fit with the body.

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