Respiration and Heartbeat Signal Measurement with A Highly Sensitive PVDF Piezoelectric Film Sensor

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ABSTRACT

A highly sensitive sensor for monitoring the respiration status of subjects using artificial respiration devices and screening tests for sleep apnea syndrome (SAS) of public transportation drivers was developed using a very simple poly-vinylidene difluoride (PVDF) piezoelectric film. A charge amplifier and a band elimination filter which were required for accurate respiration sensing were also developed. By using the sensor developed, it was also possible to measure the heartbeat signals due to its excellent sensitivity. The respiration and heartbeat signals could be separated cleanly by applying low-pass and band-pass digital filters with the appropriate cut-off frequencies. Furthermore, a wireless monitoring system was also developed so that the respiration and the heartbeat activities could be monitored from mobile devices such as smartphones, tablets or laptop computers.

KEYWORDS

PVDF, piezoelectric film, respiration, heartbeat, sensor, wireless monitoring

1 INTRODUCTION

Medical failures such as the malfunction of artificial respiration devices can cause critical situations for patients. People who take care of these patients always have to pay a great deal of attention to confirm if they are breathing properly. Therefore, a device which can accurately measure the respiration activity was needed. Also, in recent years, it has been recognized that people who have sleep apnea syndrome have a risk of drowsy driving which could result in serious traffic accidents [1, 2]. Therefore, the SAS screening test is now mandatory for many of the public transportation drivers and long-distance truck drivers. For this purpose, as well, an accurate respiration monitoring device is needed.

Respiration status can be detected through a combination of air flow sensor masks and other sensors such as a pulse oximeter. However, the air flow sensor masks have a drawback in their discomfort to the patient due to mounting. Also these masks can lead to measurement errors by deviation in the contours of the face from person to person. Furthermore, the pulse oximeter measures the heartbeat rate and oxygen saturation (SpO_2) of the blood but not respiration activity directly [3, 4]. Although apnea can be inferred from a decrease in the SpO_2 level, there is always some time-delay in relation to the apnea. For these reasons, the development of a new respiration sensor that can measure respiration status accurately has been in demand for many years.

In this work, a very sensitive respiration sensor was newly developed using a very simple poly-vinylidene difluoride (PVDF) piezoelectric film. Because of its very high sensitivity the new respiration sensor could also measure heartbeat signals. The respiration and heartbeat signals could be easily separated by using digital frequency filters. In addition, a wireless system that enables the respiration and heartbeat signals to be monitored from a mobile device was also developed.

2 DEVELOPMENT OF A VERY SENSITIVE RESPIRATION SENSOR

2.1 Piezoelectric Film Used for Respiration Sensor

Figure 1 shows the PVDF piezoelectric film (DT2-028K/L, Tokyo Sensor Co. Ltd.) used for development of the respiration sensor in this

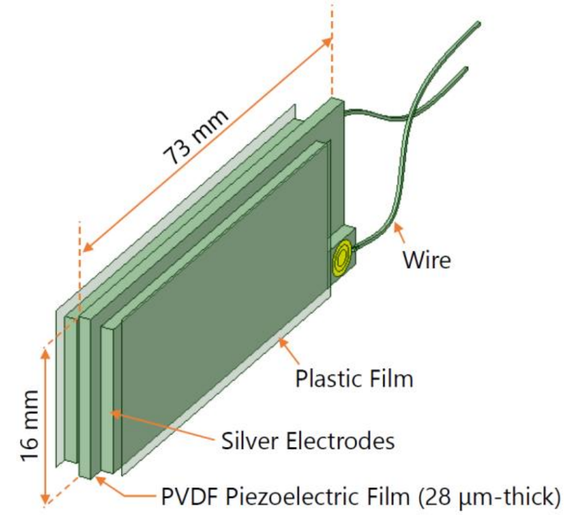

Figure 1. Schematic of PVDF piezoelectric film (DT2-028K/L, Tokyo Sensor Co. Ltd.) used for development of the respiration sensor.

study. The thickness and the area of the PVDF piezoelectric film are 28 µm and 16 mm × 73 mm, respectively. Both faces of the PVDF piezoelectric film are covered by silver electrodes with an area of 12 mm × 62 mm, and the electrodes are physically protected and electrically isolated by plastic film. The piezoelectric film generates electrical charge signals in proportion to the mechanical stress or strain making it suitable for respiration sensors because of its high sensitivity. It generates very large signals even when only slightly moved [5].

Respiration sensors using PVDF piezoelectric films have already been developed and put into practical use. However, conventional PVDF respiration sensors are mounted with a non-elastic band, as shown in Fig. 2 (a), tightly around the abdomen so there is no slack around the chest. This strongly limits the size change in the chest cavity that occurs during normal breathing and also makes the belt prone to slippage and can cause further patient discomfort. Furthermore, this type of configuration leads to only small changes in shape of the piezoelectric film which results in relatively small output signals. Therefore, it is very difficult to measure respiration activities accurately by itself. In order to measure respiration more properly, it is necessary to

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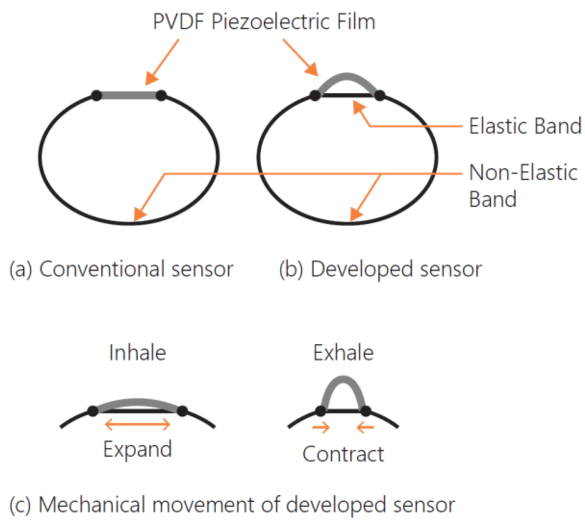

Figure 2. (a) Structure of the conventional respiration sensor using piezoelectric film. (b) New structure of the respiration sensor developed in this study. (c) Mechanical movement of the sensor developed following respiration (inhale and exhale) activities.

combine the data with multiple other sensors that also cannot precisely measure breathing alone. Therefore, in order to enhance the magnitude of the output signals from the PVDF piezoelectric film, the structure shown in Fig. 2 (b) was developed so that a larger deflection change in the PVDF piezoelectric film would occur. To follow the change in thoracic circumference due to breathing, a short elastic section that expands and contracts with breathing was added to the conventional static band. To this elastic section, the PVDF piezoelectric film was attached. The attached PVDF piezoelectric film is bent into a flexing arch. This elastic section to which the film is attached allows for a reduction of the restriction of the thorax changes during breathing of the patient and better fit comfort was also observed. This concentrates the changes in thoracic expansion and contraction to the elastic section shown in Fig. 2 (c). With a larger change in the deflection of the PVDF piezoelectric film, the output signal was also increased and it became possible to more accurately measure respiration activity.

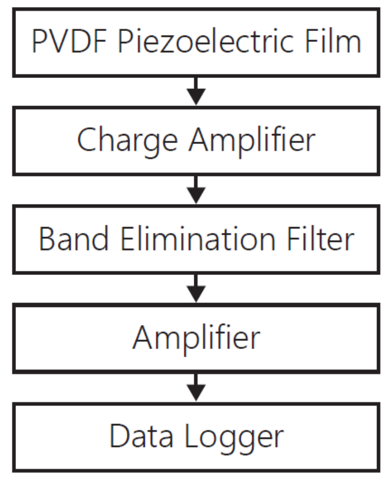

Figure 3. Block diagram of the measurement circuit for the respiration sensor.

2.2 Measurement Circuit

Figure 3 shows a block diagram of the measurement circuit used for the respiration sensor. The PVDF piezoelectric film was connected to a charge amplifier so that the charge generated in the PVDF piezoelectric film was accumulated with time and converted to voltage signals. The charge amplifier was designed to accept both positive and negative charge signals from the PVDF piezoelectric film but to output only positive voltage signals in the range from 0 V to the DC power supply voltage, typically 3 V. In order to suppress the AC 60 Hz noise from the AC/DC power-supply, the output signal from the charge amplifier is fed into a band elimination filter. A high Q-factor band elimination filter using a twin T-type band elimination filter and an OP amplifier with positive feedback circuit was employed. The filtered signals are amplified by a factor of 500 through an amplifier and recorded by a data logger.

3 MEASUREMENT OF RESPIRATION SIGNALS

3.1 Output signals from the respiration sensor

Figure 4 shows a picture of the respiration sensor and the measurement circuit worn

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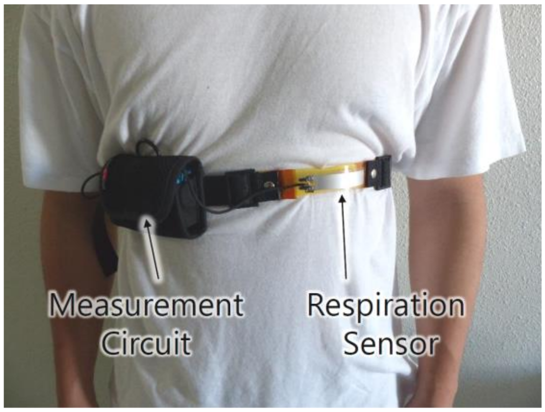

Figure 4. The respiration sensor and the measurement circuit worn by a subject (Male, 22 year-old).

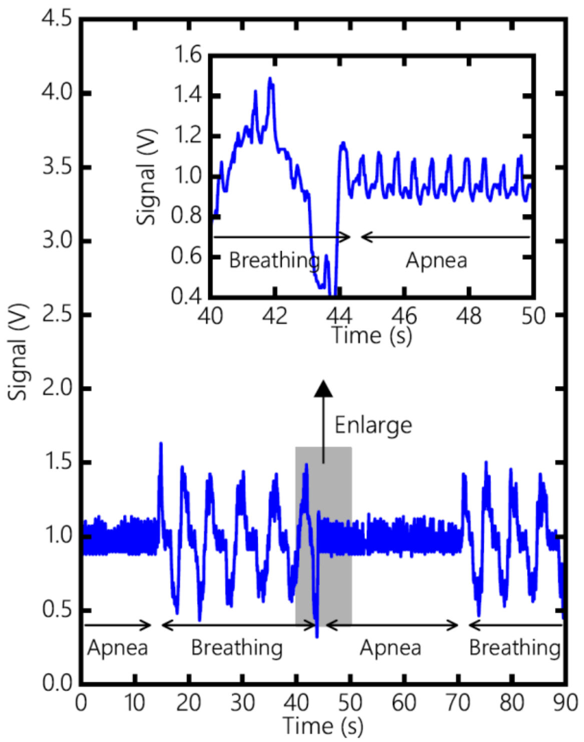

Figure 5. The Output signals of the respiration sensor recorded by the data logger. The waveform baseline is at 1.0 V. The respiration status (ventilation or apnea) is clearly distinguishable as large positive and negative peaks appear while the subject is breathing. The inset shows an enlarged waveform between 40 and 50 s. Small peaks are confirmed to be the heartbeat signals of the subject.

around the chest of a subject (Male, 22 years old). The output signals of the respiration sensor were recorded using a data logger while the subject repeated breathing and cessation every 30 s. Figure 5 shows the output signals measured for 90 s. The baseline of the waveform is at about 1.0 V. The large positive and negative peaks are clearly observed periodically approximately every 2 s only when the subject is breathing. Therefore, these large peaks can be attributed to the respiration activities of the subject. The positive and the negative peaks correspond to inhaling and the exhaling, respectively. The amplitude of both positive and negative respiration peaks a larger than 0.5 V which is roughly 1000 times stronger than those measured by a conventional respiration sensor using piezoelectric film. Thus, by modifying the structure of the PVDF piezoelectric film sensor, the sensitivity of the sensor was greatly improved. In addition, by looking at the waveform carefully, one can notice that there is another set of periodic peaks with relatively small amplitude as shown in the inset of Fig. 5. These small peaks appear more frequently than the respiration signals and this was confirmed to be the heartbeat of the subject through a comparison with the heartrate waveform from a pulse oximeter. By using the newly developed respiration sensor, both the respiration and heartbeat signals can be measured at the same time.

3.2 Separation of Respiration and Heartbeat Signals by Using Software Frequency Filters

Since the data measured by the respiration sensor contains both the respiration and heartbeat signals, an attempt for separating these two signals was made using a software filter. The original waveform data shown in Fig. 6 (a) was processed with a software low-pass filter (5th-order Butterworth filter) with a cut-off frequency of 1 Hz so that the higher frequency components including the heartbeat signals were eliminated. The respiration signals are more clearly seen after the signal processing as shown in Fig. 6 (b). On the other hand, a digital band-pass filter (5th-order Butterworth filter) was also applied to the original waveform so that the heartbeat signals were

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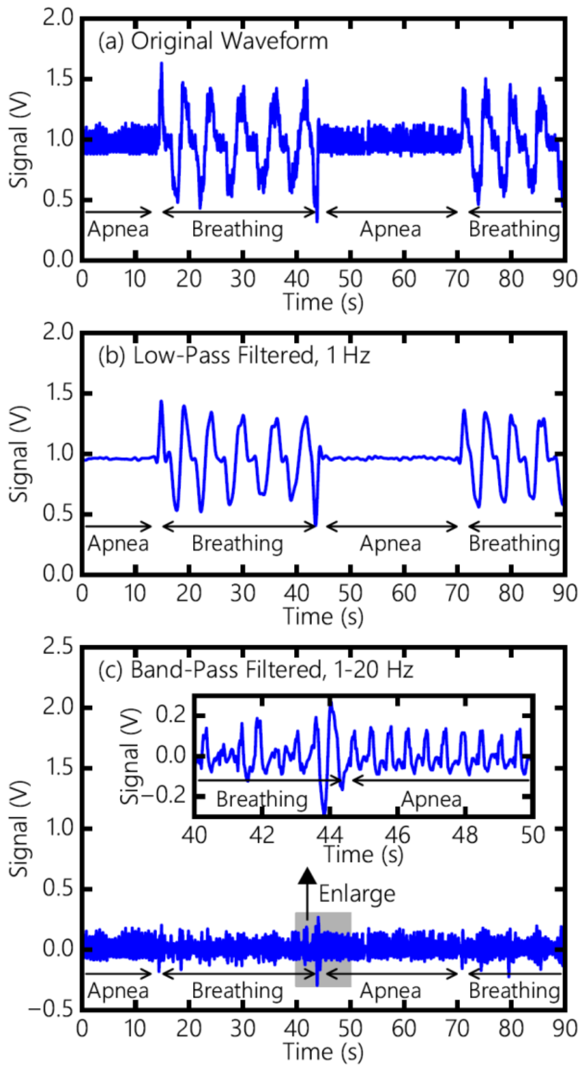

Figure 6. (a) The output signals (original waveform) of the respiration sensor recorded by the data logger. where the waveform baseline is at 1.0 V. (b) The waveform processed by a digital low-pass filter (5th-order Butterworth filter) with a cut-off frequency of 1 Hz. The respiration signals are much more clear than the original waveform. (c) The waveform processed by a digital high-pass filter (5th-order Butterworth filter) with a cut-off frequency of 2 Hz. The inset of (c) shows an enlarged waveform between 40 and 50 s. The heartbeat signals can be recognized clearly.

exclusively extracted as shown in Fig. 6 (c). The lower and the upper cut-off frequencies are 1 and 20 Hz, respectively. Since both of the respiration and the heartbeat signals are very clear after the filtering, further real-time digital data analysis such as judging the respiration

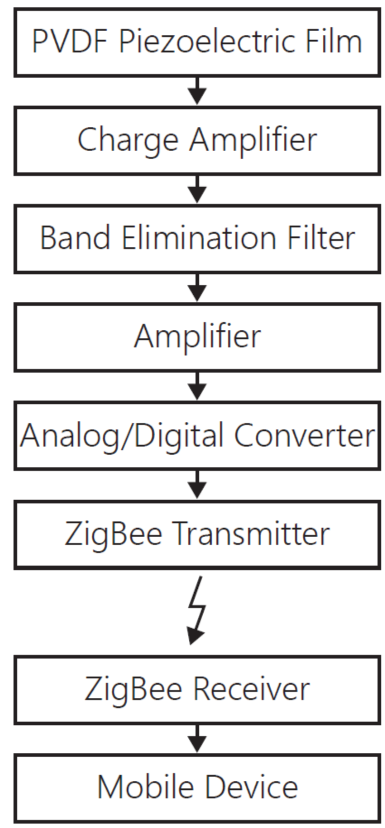

Figure 7. Block diagram of wireless monitoring system for the respiration sensor.

status (breathing/apnea) and heart rate is now possible.

4 WIRELESS MONITORING SYSTEM USING MOBILE DEVICES

For more practical use of the respiration sensors, a wireless monitoring system was also developed. Figure 7 shows a block diagram of the system. The output signal of the charge amplifier is processed by the band elimination filter and the amplifier as same as the previous one, but the output signal of the amplifier is fed into a ZigBee wireless module (TWE-Lite DIP, Mono Wireless Inc.) which is also equipped with an analog-to-digital converter. Thus the analog waveform signal is converted to digital forms and transmitted using the ZigBee protocol. The transmitted data is received by another ZigBee module (ToCoStick, Mono

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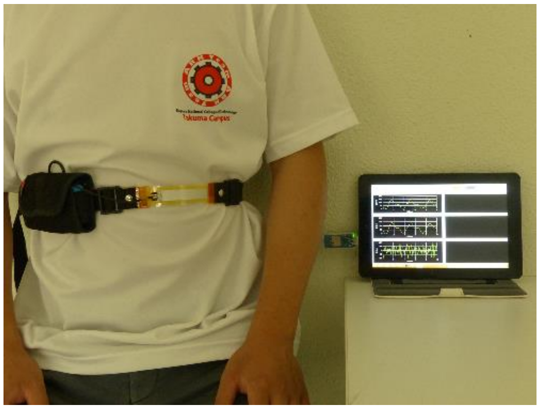

Figure 8. The wireless monitoring system for the respiration sensor. The respiration and the heartbeat waveforms are displayed on the tablet computer.

Wireless Inc.) which can be connected to mobile devices such as smartphones, tablets or laptop computers. The received data is processed using software filters as previously described and consequently the respiration and the heartbeat signals are shown on the screen of the mobile devices as shown in Fig. 8.

5 CONCLUSION

A highly sensitive respiration sensor was developed using PVDF piezoelectric film. A charge amplifier and a band elimination filter which were required for accurate respiration sensing were also developed. By using the respiration sensor developed, it was also possible to measure heartbeat signals because of its very high sensitivity. The respiration and heartbeat signals could be separated clearly by applying low-pass and band-pass software filters with appropriate cut-off frequencies. Furthermore, a wireless monitoring system was also developed so that the respiration and heartbeat signals can be monitored from mobile devices such as smartphones, tablets or laptop computers. The respiration sensor and the wireless monitoring system developed can be used for SAS screening tests and monitoring the respiration status of the people who are on artificial respiration devices.

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