Garment-Based Monitoring of Respiration Rate Using a Foam Pressure Sensor

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Abstract

Comfortable body monitoring is crucial to many wearable devices. However, many traditional sensors impede wearability by their physical structure or functional requirements. This paper presents the application of a novel garment-integrated foam-based pressure sensor used for monitoring the wearer's respiration rate. The sensor was evaluated in a torso garment during a 10-minute treadmill test. Results were accurate within one breath per minute, as compared to a standard airflow breathing test.

1. Introduction

Conducting polymers have recently offered the wearable computing community a soft, comfortable new alternative to traditional sensing technologies. In previous work [1], the development of a foam-based pressure sensor of this type has been described. This type of sensor is particularly appealing for its wearability benefits, but it introduces a different set of compromises. Its application to various types of body monitoring has been described in previous works [2, 3].

Respiration rate is closely linked to a variety of physical responses: activity rate, stress, emotional activity, and many medical conditions [4,5]. In a clinical setting, respiration is often measured using a pneumotachograph (airflow monitor), which measures the volume of inhaled and exhaled air passing through a tube per unit time.

Other, less precise means are often used when wearability, rather than detail, is the objective. Measuring the expansion and contraction of the ribcage (through respiratory inductive plethysmograph sensors) instead of the flow of air through the mouth is a more wearable solution. While this method is effective and provides a fair amount of tidal breathing volume information, it is known to be susceptible to movement noise [5], and it requires the user to don a special device to measure respiration.

Polypyrrole (PPy) coated foam sensors provide an inexpensive means of measuring similar stimuli. Their extremely low cost and ease of integration with fabrics prevents the necessity of having only one sensor [1]. The PPy foam sensor used here measures chest expansion in a slightly different way than prior studies [6]: rather than coating an extensible structure with PPy and using the expansion of the chest to stretch the sensor, the foam sensor is integrated into a non-extensible garment, and the expansion of the chest serves to compress the foam structure between the body and the garment. The garment itself is used to house the sensor, removing the need to don an additional device. This presents a less intrusive, inexpensive alternative to existing respiration monitors.

The test garment used in this study was a woman's sleeveless, collared shirt, described in [2].

2. Methodology

Two 10-minute treadmill tests were performed with one subject. For both tests, the subject donned the prototype garment, and a standard clinical breathing monitor (Vmax229, SensorMedics). This monitor consisted of head-mounted breathing apparatus used to monitor airflow and gas contents, and a software package used to determine breaths per minute, breath volume, and gas composition.

Breathing rate (breaths per minute or BPM) was recorded by the airflow monitor while the resistance values from the foam-based sensor was recorded in two ways. In the first test, data was collected by a constant current digital multi-meter (HP, Leixlip, Ireland). Data was collected at a rate of 1 sample per second. In the second test, data was collected wirelessly through one Mica2 Mote (Crossbow Technologies) [7], at a rate of 5 samples per second.

The test structure was as follows: two minutes of baseline stationary breathing, followed by approximately 8 min of increasing speed—from walking to jogging to running.

Figure 2: Prototype garment

As the airflow software package offered only BPM rates, similar calculations were performed on the foam resistance values recorded in both cases. BPM rates were calculated for each minute over the 10-minute test period.

3. Results and Discussion

The breathing rate recorded from the foam sensor was very similar to that recorded from the airflow sensor. Indeed, the foam data gathered via wireless Mote never differed from the airflow data by more than 1 breath per minute, with a correlation coefficient of 0.99 and a standard error of 0.62 for the foam-based sensor compared to the benchmark airflow prediction. The wired multi-meter data was slightly less precise, with a correlation coefficient of 0.95 and a standard error of 1.59. This is most likely due to a loss of precision resulting from the reduced sampling rate on the multi-meter. (More detailed results graphs shown in poster presentation).

This response was recorded despite the varied vigorous physical activity of the subject, which has previously impacted the response gathered from a garment-integrated sensor of this type [3], and has been known to effect the response of other chest-mounted measurement devices [5].

The wireless connection created by the Mica2 Mote appeared to have no effect on the accuracy of the BPM measurement; in fact its increased sampling rate resulted in improved accuracy over the wired alternative, due to its higher sampling rate.

The sensor itself requires some force to be exerted against the expanding ribcage during respiration, in order for the sensor to be compressed sufficiently to register a response. However, the chest constriction caused by a closely fitting, non-extensible chest strap did not appear to cause the subject discomfort, even during heavy breathing. This is perhaps because the amount of force required to compress the sensor is small, and therefore the chest strap did not need to be extremely tight.

4. Conclusion

The work presented in this paper represents part of a broader research programme as part of the Adaptive Information Cluster (www.adaptiveinformation.net). Our working hypothesis has been that this sensor technology is well adapted to wearable computing applications, from a comfort viewpoint, and that it provides a level of accuracy and reliability that is appropriate to a number of practical applications. This hypothesis has been validated in the breathing rate test described in this paper.

In summary a reliable breathing rate was recorded during a standard exercise test, from a foam pressure sensor integrated into a closely fitted torso garment. Vigorous activity appeared to have no impact on the accuracy of the recorded respiration rate, as compared to the rate recorded by a standard airflow measurement. The foam sensor represents a non-invasive, comfortable means of gathering this type of data without impacting the user's other physical activity or general comfort.

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