

# ‘Disappearing Sensor’-Textile Based Sensor for Monitoring Breathing

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**Abstract**— Textile based sensors were developed and used for remote monitoring of breathing. The breathing is simulated by using a new *cyclic tester* device. In the simulated a cyclic force is applied along the length of the textile sensor. However due to the morphology of human body, in real situation the sensor is not only under stretching but also under a certain degree of bending. A prototype garment with the sensor situated on the chest area was made. The prototype was worn by 10 persons, and breathing was recorded as the persons were sitting still, walking and jogging. Deep breathing in the supine position and breathing with a method called *athletic breathing* were used to evaluate the sensor. A testing circuit and a Labview program were made for preliminary test. The sensor is wearable, washable and comfortable. Sensor construction is totally ‘disappearing’ and visualize as printed pattern onto the surface of garment.

Keywords-wearable; sensor; textile; breathing; testing; device.

## I. INTRODUCTION

Wearable technologies, such as textile based sensors and electrodes used for physiological and medical diagnosis evaluation have been rapidly grown during the last decade. The application of wearable technologies and devices can be grouped into 3 categories: wellness, healthcare and security/prevention [1]. The current trends in wellness and healthcare lead to the development of a new market for personal healthcare that can be defined as ‘products and services to improve the health status and the personal performance outside institutional points-of-care’ [2], that means, textile based sensors and electrodes integrated into a system are expected to be able to support the monitoring of personal activity during daily life and ensure the early detection of abnormal conditions and prevention of its serious consequences. In the last few years, innovated wearable sensors based on conductive yarn [3], optical fiber [4] and conductive polymer [5] able to measuring body physiologic signals have been constructed, such as breathing rate [3] and ECG signals [6]. Different types of garments have been sensorized, for example as gloves [7] to detect hand posture, as pants [8]

to record lower body activity and as shirts [9] to monitor heart rate.

The interpretation of spontaneous breathing pattern plays an important role for the early detection and the prevention of serious illness, such as asthma, sleeping apnea, bronchitis, lung cancer and so forth [10]. Apart from mouthpiece measurement, which measures the volume change of lung, there are usually three different kinds of techniques for breath monitoring: magnetometer, strain gauge and inductance plethysmograph. The magnetometer measures the thoracic diameter change during breathing, strain gauges assess thoracic circumference and the plethysmography records the thoracic cross-sectional area information. However, these devices are applied professionally and usually with built-in software and hardware, which is neither necessary nor suitable for early detection outside institutional points-of-care. Wearable technology allows designing and producing a set of sensing elements hidden in normal garments by using the electrically conductive textile structure or functional coating. This new technology enables a remote monitoring of people’s daily life without limitation of their normal activities.

In this paper, a prototype garment for breathing monitoring was designed and realized, it consists of two elastic conductive coated straps located on the chest and abdomen. Conductive threads functioning as transmission wires were integrated by piping. An attachable unit containing all electronic components and a wireless data transmission device (Bluetooth) was designed to be placed on the back waist of the garment. This garment is comfortable and washable; sensors are visualized as the printed patterns. The sensor located on the chest was tested on 10 subjects with a combination of machine simulation tests. The testing results for the sensor located above the abdomen are not reported in this paper.

## II. MATERIALS AND METHODS

Two prototypes were made for testing. A strap (Fig.1) was made for the machine simulation testing and a garment was produced for the real breathing testing on the human body. The sensing units on both prototypes were made by conductive coating. A conductive silicone with brand name *ELASTOSIL®* LR 3162 from Wacker was used. The textile substrate was a PA/Lycra woven fabric;

this fabric has good elasticity and recoverability, which guarantees a good sensor sensibility. The application of the conductive layer was done by the knife-over-roll [11] laboratory coating method. The size of the whole testing strap was 100 mm × 2.5 mm, while the effective coated area was 100 mm × 10 mm. For the prototype garment, two conductive straps were coated on the chest and the abdomen positions. Conductive threads with brand name *SHIELDEX*® from Statex connected the coated straps and functioned as data transmission wires. The conductive thread was braided onto cotton yarns and then piped along the seam line (The green lines in Fig.2) into the garment construction.

For the machine simulation, a coated strap was connected to the *cyclic tester* (See Fig. 1) in order to apply repeated mechanical extension and deformation to the sensor. A pre-stretch of 2 mm was first applied before testing in order to simulate the situation of wearing a close-fitting shirt. An electrical circuit was built to record the resistance change of the sensor along with its mechanical deformation. Two crocodile clips and ordinary electrical wires were used as the interface and transmission wires (Fig. 1). The signal was collected with a DAQ (data-acquisition device) from National Instruments, and a Labview program was developed for online monitoring and recording the breathing pattern in the form of an electrical signal. In the real case, the signal will be recorded by a microprocessor and transmitted through Bluetooth to a PDA or PC for further processing. Normal breath, deep breath, hyperventilation and sleeping apnea condition were simulated by adjusting machine speed and extension position.

For a real breathing testing, the signal was collected by an attachable control unit located at the back of the garment (Fig. 3). All components except the attachable control unit are flexible, washable and comfortable to wear. As shown in Fig. 2, the sensors have an appearance as printed patterns, giving a feeling like an ordinary garment while wearing. Prototype testing has been made with 10 subjects, whose breathing patterns were recorded during sitting still, walking and jogging. The subjects also did deep breathing in a supine position and *athletic breathing* during running. A so called *athletic breathing* is a special breathing method using by some professional runners, especially for long distance runners. During running the runners manage their breathing in a special way that they repeat performing 3 inhalations and 3 exhalations instead of 1 inhalation and 1 exhalation when breathing usually. The subjects rested a minimum of 3 minutes prior to recording the breathing pattern for 1 minute.

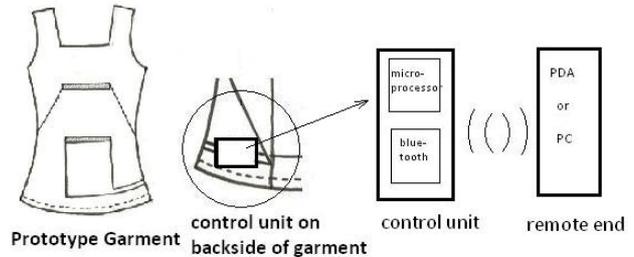


Figure 1. Coated straps on cyclic tester (top left).

Figure 2. A prototype consists of two sensors and the data transmission lines. (top right).

Figure 3. Block diagram of the testing system. (bottom).

### III. RESULTS

#### A. Machine simulation testing results

For this study, a new device called *cyclic tester* was developed in order to apply a cyclic force to the textile breathing sensor. Different speed and elongation were applied to the sensor to simulate normal breathing, deep breathing, hyperventilation and apneas.

##### 1) Normal breathing simulation

The average change of thoracic circumference is 8 mm for an adult, while the average breathing rate is 18 breath/ min. The inhaling time as a ratio of total breathing cycle time is around 0.42 [12]. By calculation, the machine has been set up to have the speeds of 5.67 mm/s and 4.23 mm/s for extension and return, respectively. In Fig. 4 a typical machine simulated result of normal breathing can be seen. The peak of each cycle can be clearly seen; there is a delay of each cycle trip, therefore, only 13 cycles were produced by the device.

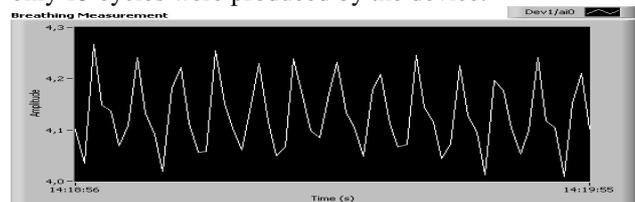


Figure 4. Machine simulation of normal breathing. X-axis indicates the time in real time scale. Y-axis indicates the voltage (resistance) change caused by stretching and recovering.

##### 2) Deep breathing simulation

Deep breathing gives a change of 21 mm of thoracic circumference in average. A healthy deep breathing takes longer time than normal breathing. The simulated inhalation speed was set to 8.27 mm/s and the exhalation speed was set to 6.07 mm/s as a consequence.

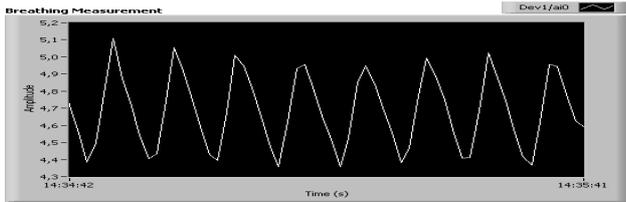


Figure 5. Machine simulation of deep breathing. X-axis indicates the time in real time scale. Y-axis indicates the voltage (resistance) change causes by stretching and recovering.

Simulated deep breathing gave a more uniform breathing pattern per cycle, 8.5 cycles were produced by the cyclic tester.

### 3) Hyperventilation simulation

Hyperventilation (or over-breathing) is the state of breathing faster and/or deeper than normal. [13]. Hyperventilation is a symptom of certain diseases, such as apnea or asthma.

To simulate the faster and deeper breathing, the elongation, which indicated thoracic circumference change, was set to 21 mm, the speeds were 49 mm/s and 37 mm/s for inhalation and exhalation respectively. As can be seen in Fig. 6, although the patterns were not uniform for each cycle, the peaks were still clearly distinguished; and the breathing rate can therefore be indicated by the sensor.

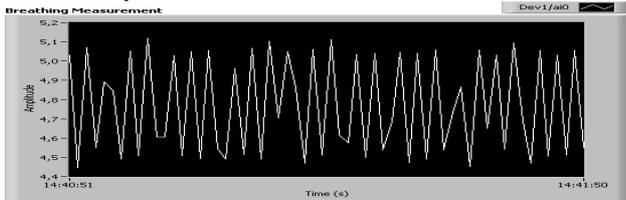


Figure 6. Machine simulation of hyperventilation. X-axis indicates the time in real time scale. Y-axis indicates the voltage (resistance) change causes by stretching and recovering.

### 4) Sleeping apnea simulation

Sleep apnea is a sleep disorder by abnormal pauses in breathing; each pause in breathing is called an apnea [14]. This becomes a life-threatening problem when the pause is prolonged. A pause of 10 seconds during sleeping should be diagnosed. In order to simulate apnea, the cyclic tester was set up to have a lower cyclic rate at 16 cycles per minute, which corresponds to the normal breathing rate during sleep. The simulated inhalation speed was set to 5 mm/s, while the speed was set to 3.7 mm/s during the simulated exhale phase. In addition, deep breathing and hyperventilation were also simulated within one test cycle. Fig. 7 illustrates a combination of four types of breathing movements including one apnea (10 seconds of pause).

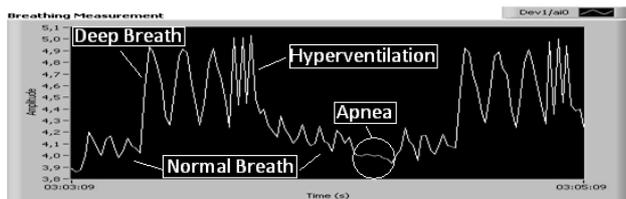
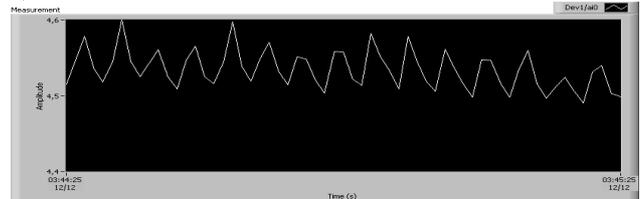


Figure 7. Machine simulation of normal breathing during sleep. Deep breathing, hyperventilation and one apnea. X-axis indicates the time in real time scale. Y-axis indicates the voltage (resistance) change causes by stretching and recovering.

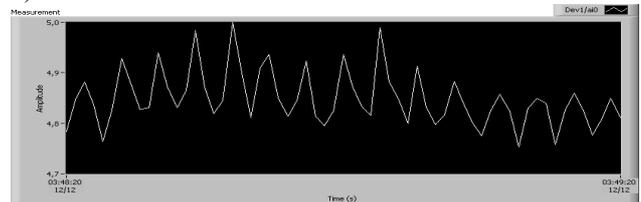
## B. Real breath testing results

In the machine simulations, the deformation of the sensor strap was in one dimension, however, in the real breathing situation both stretching and bending along the chest occurs. In order to study this, a prototype garment was tested by ten subjects and their breathing patterns were recorded during sitting still, walking and jogging. In addition, deep breathing on supine position and *athletic breathing* were studied. These five breathing patterns selected in our studies represent a variation of breathing that a person may perform during daily life. As we can see in Fig. 8, the signal detected from the wearable sensor (subject no.5) can be clearly distinguished between the different activities performed. The sensor could register both the frequency change and the amplitude change that occur during testing. For example, as can be seen by comparing fig. 8 d) and fig. 8 e), the frequency of deep breathing in a supine position is clearly lower than the frequency of deep breathing during running, and the sensor resolves this in a satisfactory way. The amplitude in fig. 8 a) is smaller than in fig. 8 b) and fig. 8 c), indicating that during walking and jogging, the subject breathing was deeper.

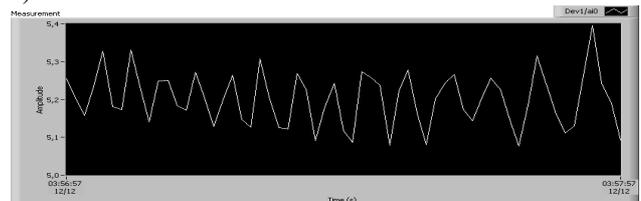
a).



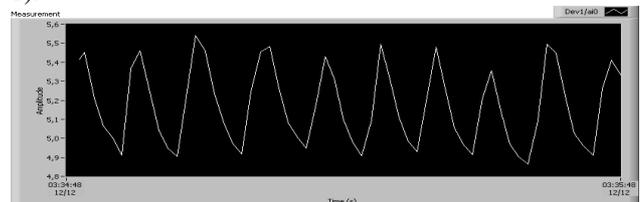
b).



c).



d).



e).

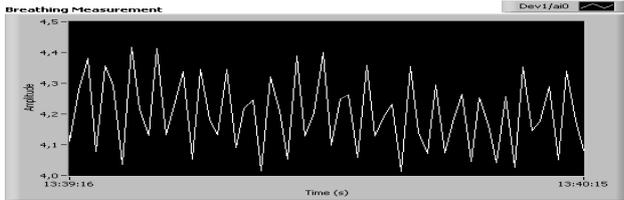


Figure 8. The result of breathing pattern (subject no. 5), a) sitting still, b) walking, c) jogging, d) deep breathing, e) athletic running

All subjects performed the five different breathing styles. During testing, the breathing rate was counted by subjects themselves as a comparison to the frequency result recorded by sensors. There is a high agreement of sensor recorded data and the counted data on breathing cycles. Fig. 9, however, gave a result of standard deviation of individual testing for five breathing styles. The highest deviation could be seen for walking and jogging, this is because the individual subject has a different breathing method. This can be avoided by using a trained breathing method, shown in Fig.8 c); the standard deviation of *athletic method* is much smaller than jogging.

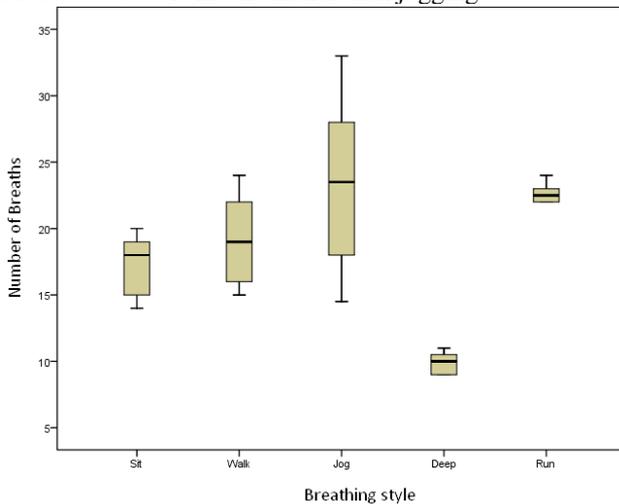


Figure 9. Breathing rate of different breathing style and the standard deviation.

Therefore, we can conclude that the prototype garment performed in a very good manner and that it can sense and record the person's breathing during normal daily activities. The sleeping apnea simulation also indicates there is a potential application for using this sensor in diagnosing and treating this order. It should also be noticed that the prototype garment did not cause any restriction of body movement during testing.

#### IV. CONCLUSIONS AND FUTURE WORKS

The results obtained from this study show that the coated sensors combined with the conductive thread make it possible to construct a simple wearable garment system, which measures and monitors the breathing. The entire garment were made by textile materials and methods, therefore, it is soft, flexible and comfortable to wear.

Except for the attachable control unit, the system is fully washable. The coated sensor and the conductive thread almost gave no addition feeling during wearing. With an improved design, the sensor could be totally incorporated in the textile structure and become a part of an ordinary printed pattern on the garment.

In the future work, we will test the prototype with the sensor placed on the abdomen position. In addition, we will compare the developed sensor to an ordinary breathing sensor.

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