Knitted Wearable Stretch Sensor for Breathing Monitoring Application

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ABSTRACT

Wearable technologies have been rapidly growing during the last decade. One of the most developed applications is the physiological and medical evaluation by using textile based sensors and electrodes. Sensors integrated into such 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 such as sleep apnea which is a sleeping disorder phenomenon .Complete garment knitting is a one-step process, which enables to integrate the textile based sensor into a garment directly in the knitting process. The objective with this project was to design a weft knitted stretch sensor of different conductive yarns and structures. The performance of the sensors was evaluated by measuring the electrical resistance changes in the knitted structure as a function of elongation with a self-built *cyclic tester*. In addition, a prototype garment made by flat knitting machine has been made in order to evaluate the sensor performance as a breathing rate indicator.

KEYWORDS

Medical textiles, Seamless knitting, Complete garment, Conductive yarns, Stretch sensor

INTRODUCTION

During the past few years many successful attempts have been made to achieve a sustainable and functional combination between textile and sensors to make a wearable health monitoring system for patients [9]. In these attempts a certain interest has been diverted towards measuring the breathing rate of human beings whether they are patients with sleep disorders, athletes or even children who need special care outside the institutions of medical treatment. In the last decade smart textiles are associated and have been working with healthcare to incorporate some smart techniques in this field. Attempts have been made by using certain sensors with conductive polymer or optical fibers to measure physiological signals such as temperature, ECG and breathing in a human body [1][2]. For this purpose different sensors made out of textile have been developed such as gloves for hand movement, shirts for measuring heart rate [5]. Knitted stretch sensors are among them which can be used to monitor the breathing rate of a human being. Early sensors used for breathing monitoring were normally biomedical sensors such as in LifeShirt and Smart Shirt which caused inconvenience in wearing [9]. Similar past work also include the use of piezoresisitive sensors along with fabric electrodes for firemen under the European project “Proetex” [8].The stretch sensors made from weft knitting have the advantage of being stretchable and comfortable to wear and at the same time are washable. The one-step process used in knitting can lead to seamless garments and increase productivity [3]. There are many advantages of making a product by seamless knitting which in other words is also known as the one step-process for knitting. The first and foremost advantage of doing a one-step process is that there is no post cut process involved and post sew process is limited to minimum [3]. The flatbed knitting machine allows the process-ability of fibers which are stiff, brittle or conductive such as Bekinox, Shieldex etc. which can cause buildup of static charges in the machine. These fibers also require special low tension setting to minimize the breakage in the yarn. The ability to make complicated structures in one single process using computer aided designs and with consistent quality are advantages of using a flat-bed knitting machine for this purpose. All of this and it also helps in being eco-friendly by less wastage of material. The garment made by knitting is certainly comfortable, soft and body fit [7]. The structure recovery compared to weaving [3]. The knitting machine used for the purpose is Stoll CMS 330 TC.

There are numerous materials and knitting structures which can be used for stretch sensors. In this paper, section 2 illustrates the choice of materials and structure followed with the testing method, section 3 gives the results from the tests. A prototype made by flat knitted is shown in section 4, while the results concluded in section 5.

MATERIALS AND METHODS

Sample Preparation

In this project following yarns were considered. The properties of the yarns are given in table 1 and the microscopic pictures are shown in figure 1.

Conductive yarn	Thickness	Resistance Ω/m
Copper Stainless Steel	0.05mm	105
Beakart	Nm 50/2 ×4	300
Statex Shieldex	235 34×2	35
Bekinox	Nm 9.1	70

Table 1: conductive yarns used in this project and their properties.

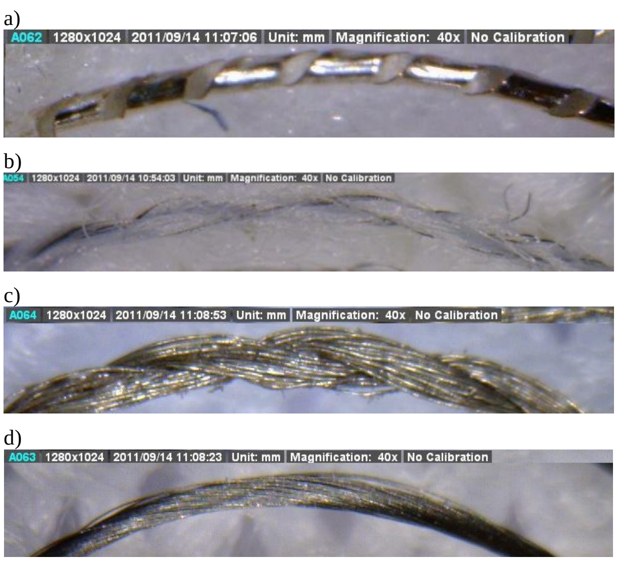

Figure 1: microscope picture of yarns used in this project. a). Cooper Stainless Steel metal yarn; b). Beakart yarn; c). Statex Shieldex yarn; d). Bekinox yarn.

Structurally these stretch sensors are in rectangular pattern having a fraction of conductive yarns in them with the longest side along the direction of knitting as shown in provided by knitting is also elastic as well as it has good elastic

Figure 2. Out of these yarns each yarn was used in making four different structures of knitting, namely: Plain Jersey (used as reference), 1×1 Rib, Interlock and Floating (fig.3). It is of importance that the structure used can show clear distinction between breathe in and breathe out and we know that the double face fabrics show less pronounced distinction [4]. For general purposes the base yarn for all the samples was PES.

Figure 2: knitted stretchable sensor made by conductive yarn.

Figure 3: microscope picture of different structures, Plain Jersey (up left); 1x1 rib (up right); Interlock (bottom left) and Floating (bottom right).

Sample Evaluation

Each yarn with the respective four structures was put to test in a self-built cyclic tester. This device was specially built by one of our lab members. The most important function of this device is to imitate the breathing pattern of human being at different rates so, it can be used to simulate breathing during sitting, standing, running and sleeping by varying the speed and the elongation of the device. This device stretches the fabric sensor sample between two arbitrary points at variable speed. The device can perform different elongation while using different speeds of up to 50mm/s for stretching.

Cyclic tester is operated together with a device called Keithley which is used to measure resistance of the sample. With the help of LabVIEW™ program, Keithley can automatically record a graph between resistance and time, by varying the time of the stretching in the cyclic tester different graphs can be obtained. Both these devices are connected together through software and the whole setup is shown in Figure 4.

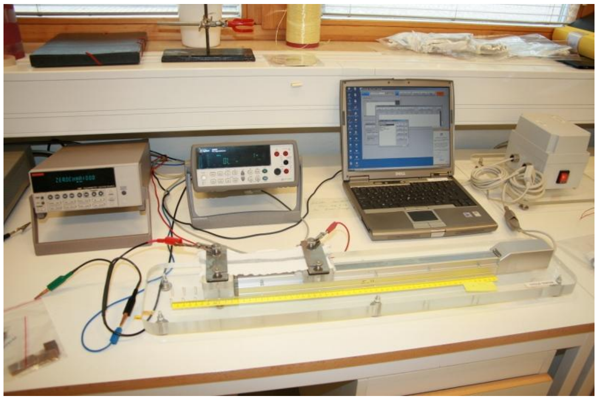

Figure 4. Cyclic tester along with attached sample sensor, Keithley and software

Sensor samples of dimension 20cm×5cm were produced for analysis. Elongation of 5% was used to imitate breathing at normal rate and stretching speed of 20mm/s was used. For each sample 20 cycles of breathing were recorded. The cycles can easily be counted from the graph once the setting for elongation is kept within 1 second. By performing this method repeatedly for all the present samples and comparing their results we were able to filter out the 2 less functional conductive yarns namely Shieldex and Bekinox and all of its structures, the reason being breathing sensor is no application for the highly conductive yarns, which makes it even more cost effective by using low cost conductive yarns with high resistance values. This was the first step to find out the conductive yarn with acceptable resistance values.

The next step was to determine the optimal structure out of the four proposed structures. The aim is to find the structure that is best suitable to be used as sensors i.e. the difference in resistance between stretching of sensor can be easily recorded and perceived. Normally two run for each sample were performed to rule out any unwanted deviations, as the knitted structure would perform differently each time it is stretched and it is difficult to predict the structural changes in knitted structure.

Prototype Garment

In complete garment production the entire garment is ready-made directly in the flat knitting machine. The different parts of the garment are knitted in the right shape and knitted together with the trimmings, pockets and other accessories. The advantages with this technique are many, no waste of material such as cut-loss in the cutting process and no expensive post-knit processes such as sewing or cutting [3] [7]. This is particularly useful when the price of the yarn is high, as often is the case with technical fibers as for example conductive yarns. All yarn in the garment comes from the same yarn cones, which enables higher quality and reduces problems with yarn from different dye lots. Due to seamless technology, the garment could both fit perfectly and be comfortable to wear. Three separate tubes are knitted, one for the body part and two for the sleeves. The sleeves and body are knitted and formed to the right shape and dimension and then joined together at the shoulder part of the garment. Because of lack of time the prototype was knitted as separate panels, cut and sewn together to a garment. The basic structure of the prototype was full rib combined with interlock structure over two feeders in the conductive parts. Intarsia technique was used to lead in the conductive yarn to form the rectangular sensors as shown in Figure 5. In particularly sensitive areas of the knitting process it is an impending risk of yarn breakage, but it is possible to reduce the speed of the machine. In this case, it was done when the conductive yarn was knitted into the garment. We believe that it is entirely possible to produce this product in one piece to gain all advantages of the complete garment technology described above.

Figure 5. Prototype garment made by flat knitting machine.

RESULT

After investigating we can say that highly conductive yarns such as Bekinox having resistance of 35Ω/m are not among the best possible yarns for breathing sensors as they can sometime give insignificant changes in resistance during inhalation and exhalation, which can be tricky to measure.

Graphs conceived by PET and Beakart stretch sensors are shown in Figure 6. In all the cases the elongation is kept up to 5%, while the stretching speed is 20mm/sec. In each graph the peaks show the relaxation of the sample i.e. breathe out and lower peaks show the breath in. Complete cycle can be easily seen in the graph (fig.6). A0 (relax state) and B0 (stretched state) represent the initial resistance of the sensor while A1 (relaxed state) and B1 (stretched state) represent the final resistance of the sensor. ΔA and ΔB indicate the differences between A1 and A0, and B1 and B0. In ideal care, A0 and B0 should equal to A1 and B1 respectively (ΔA = ΔB= 0), which indicate there is no hysteresis in the sensor. However, in reality, especially when textile structure involved in, hysteresis exists in all cases [8]. Therefore, we prefer to have a sensor which has constant change in resistance against elongation (B-A= constant) as an alternative. As we can see from figure 5, the interlock structure perform best (ΔA = ΔB), and both 1x1 rib and floating has bigger ΔB than ΔA. Another important character of sensor is the resistance in stretched state (B) should always smaller than the resistance in relaxed state (A), if so we can setup a threshold value of the sensor to record the cycles. Both interlock and floating structure fulfill this requirement, while sensor with 1x1 rib structure is beyond the requirement (A1>B0).

As a conclusion, out of the four structures the most practicable structure which stands out for using in sensory garments for breathing are floating and interlock. This is because the 1x1 ribbed structures has only one set of loops going in front and back of the structure which makes the structure more elastic and loose compared the two sets of loops in interlock which are present in both sides of the fabric resulting in a dense and heavy fabric with higher elastic recovery. However, in floating structure the missed loops result in irregular results as shown in figure 6.

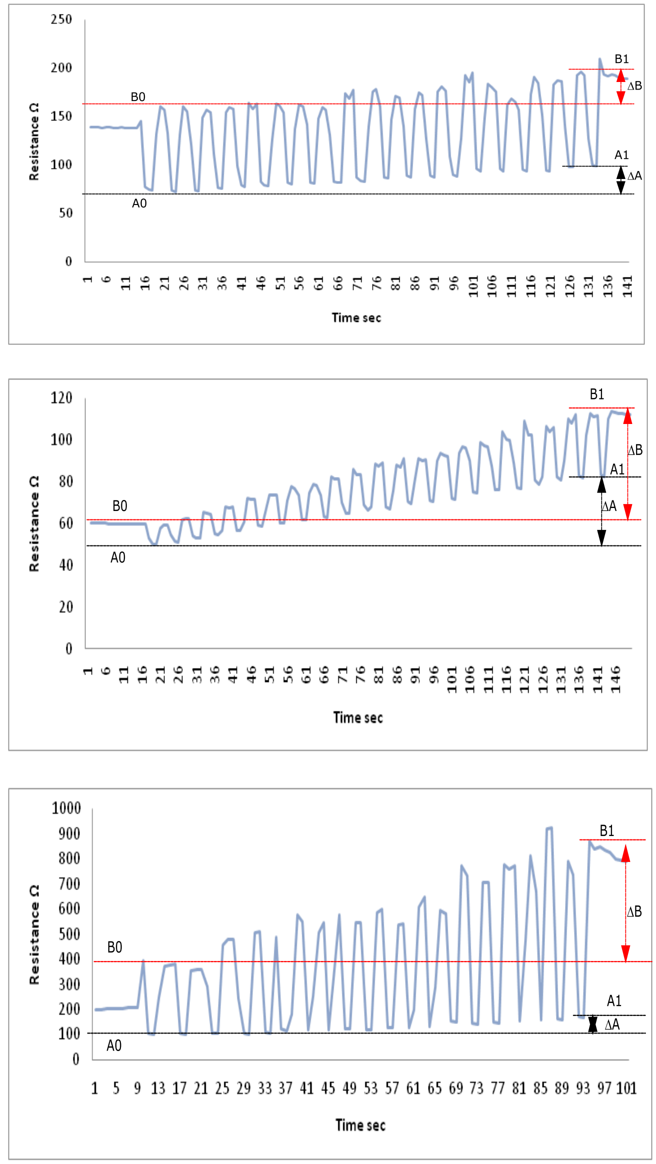

Figure 6. Resistance shown as a function of time for PET/Beakart with stretching speed of 20mm/sec, top: interlock, middle: 1x1rib, bottom: floating.

Prototype garment for breathing monitoring

Prototype garment has been utilized as a breathing monitoring shirt. The prototype garment has been tested on one health subject. During her nature breathing, the electrical signal has been recorded and the transfer through Bluetooth into a laptop, the signal collected and processed by a LabVIEW program. Signals from both sensors placed at the position of chest and abdomen were readable but not stable enough for long time monitoring, this is because the knitted loops in the garment was not compact enough to ensure a good sensitivity of both sensors. The next prototype should focus on improving the elasticity of the basic structure. This can be achieve by increasing the stitch density / decreasing the stitch length and by using Lycra yarn instead of PES as the base. Another improvement for better sensitivity is by using elastic conductive yarns.

CONCLUSION

The achievement of this work is that now we are sure that textile knitted sensors has the potential to be used for monitoring breathing of patients in their daily life without inhibiting their daily routine. This sample along with the transmitter can easily be used to record and transmit data to a computer which can compile the data and produce a graph to monitor the breath of a patient, athlete child who needs special care outside the boundaries of a medical institution. This sensor is without the transmitter is completely washable and comfortable to wear with high resiliency even after long measuring times.

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