TEST AND EVALUATION OF TEXTILE BASED STRETCH SENSORS

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ABSTRACT

This project has focused on test and evaluation of three different textile sensors. The project includes the development of sensors, the exploration of suitable measurement methods and devices and finally the evaluation of the sensors according to three different applications. Four results were given in order to characterize sensor performance and to verify the effective working ranges. Further the sensors were integrated in three applications such as force sensor, breath sensor and movement sensor in order to test the sensor functionality by application. Future research orientation has suggested by the end of the paper.

Key Words: smart textile, sensor, stretchable, testing, resistance

1. INTRODUCTION

The integration of smart materials and computing technology in textile application, so called smart textile, introduces new types of functionalities to consider in the creation of textile products. This project addresses the testing and evaluation of textile stretch sensors based on different textile techniques and applications. The ability to use different textile stretch sensors has been presented in several research projects. There are examples of both yarn based [1] and coated [2] sensors where the textile sensor changes the resistance due to stretch. Along with an increased demand on integrating textile based sensors in different applications a more extensive survey of the performance of stretch sensors and relative testing methods is necessary. An important issue to consider is that the required characteristics of the sensor is highly dependent on the end application. This survey is based on three types of applications. The first case is to sense big strain up to 40% under a continuous change of force and give response when the force is higher or lower than an undesired level by using threshold values in a controlling unit. The second is to sense small steps of elongations in order to determine small steps of movements in the material. Finally the third application case is to sense a cyclic elongation, for example a breathing sensor.

The aim of this paper is to evaluate different kind of textile based sensors by finding out the functional ranges of tested sensors. Ageing and hysteresis properties have been evaluated as well. Another aim is to find out suitable measurement methods and devices according to different performance requirement of different applications.

In order to reach the goal, two tasks were set up:

1. To find optimal conductive materials and structures of textile stretch sensors functional in different applications.
2. Such textile stretch sensors should be characteristic and tested in a suitable method, and to determine the effictive working ranges and properties.

2. METHOD

The experiment has proceeded in three steps: the development of different textile sensors, setting up three different measurement modes with two measurement methods and the final testing.

2.1 Sensor development

In sensor development six different sensors were created, table 1.

Table 1. The characteristics of tested samples

Sample code	Conductive material	Textile substrate	Textile structure	Sample test size
S1	Bekintex 50/2	PA/Lycra plain weave	woven	150mm x 15mm
S2	Beag EA1088	PA/Lycra plain weave	Woven	150mm x 15mm
S3	Bekintex 50/2	PA/PES e 1x1 rib	knitted	150mm x 15mm
S4	SheidteX 235/1x2	PA/PES e 1x1 rib	Knitted	150mm x 15mm
S5a	Carbon filled silicone	PA/Lycra plain weave	Coated	150mm x 15mm
S5b	Carbon filled silicone	PA/Lycra plain weave	Coated	115mm x 15mm

The samples were developed in different materials and different structures but in the same size. However,the last sample(S5b), with the length of 115mm was also tested in order to explore the relationship between sample length and resistance change.

2.1.1 Conductive thread based sensors

Two different textile techniques were used in the sample preparation, thread based sensors by weaving (S1,S2) and knitting (S3,S4). Different woven and knitted structures were developed and it was found that the plain weave of PA/Lycra and 1x1 rib knitted with PA / PES were the most usable samples. The samples were made by three different conductive threads with different conductivity/resistivity in order to find out the optimal conductive range for a textile stretch sensors.

Table 2. The characteristics of conductive threads

Thread code	Type	Dtex	Resistivity (Ohm/cm)
T1	Bekintex50/2	400	50
T2	BeagEA1088	180	0.2
T3	Sheildtex235/23-2ply	235/1x2	0.1

2.1.2 Carbon filled silicon coated sensor

The coated sensors (S5a, S5b) were made by coating thin layers of conductive materials on flexible textile substrates. The conductive materials were silicon filled with carbon-black particles, available from WACKER.Ltd. Since silicon is very elastic there is a good bonding to textiles and the sensor may be attached to a stretch fabrics substrates in a reliable way [3]. The textile substrates were Nylon/Lycra woven fabrics and the coating was applied by knife-over-roll method.

2.2 Measurement modes setup:

The stretch sensors were measured and evaluated based on three measurement modes:

(i) Continuous resistances change under big strain up to 40%.
An increased force was applied to the sensor. The initial resistance, resistance change under the continute increased force and the resistance when force is released were recorded and further evaluated.

(ii) Resistance change at small steps of stretching.

(iii) Resistance change when applying cyclic forces.

As a complement to these tests, hysteresis and ageing effect of performance was also evaluated.

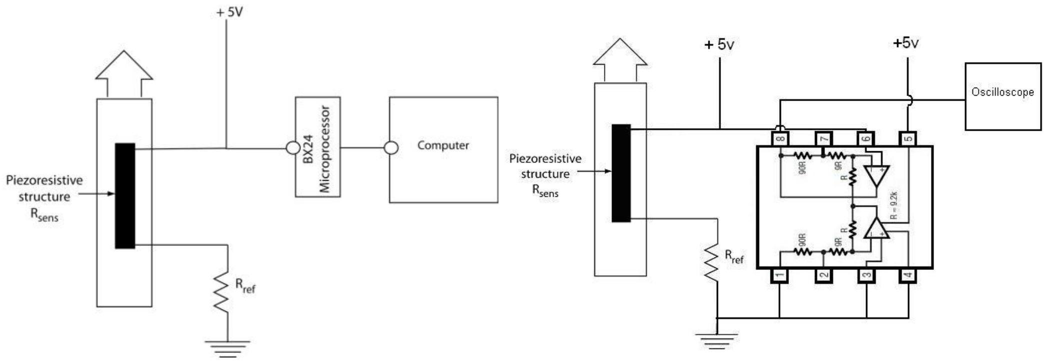
2.3 Testing methods

Two different measurement methods were used in this project.

1. Method 1 used a microprocessor connected to a computer, figure1.a. Measurements were performed with a strain tester, Zwick/Z010. The resistance was measured by a microprocessor connected to a computer. The digital output, $D_{out,}$ from microprocessor was calculated into the real output voltage,V_{out}, by the formula:

   Vout = (5 volts / 2^{10}) x D_{out}

2. In method 2 an amplifier and oscilloscope was used, figure 1b. An oscilloscope with instrumentation amplifier (LT1001) have been used in order to evaluate small changes, for example in small cyclic force testing. The output voltage (V_{out}) was conveyed into an amplifier with the amplifier gain 10 or 100 depending on the requirements, and the output signal was transferred into an oscilloscope for evaluating sensors performance.



1.a 1.b

Figure 1. Measurement set-up; by microprocessor (1.a) amplifier and oscilloscope (1.b)

In both of the measurement set-up the output voltage (V_{out}) over the reference resistor (R_{ref}) was measured and according to Ohm's Law in series circuit the sensor resistance (R_{sens}) was calculated by:

$$\frac{5 - V_{out}}{R_{sens}} \Longrightarrow R_{sens} = \frac{R_{ref}(5 - V_{out})}{V_{out}}$$

The reference resistance(R_{ref}) was determined in advance, adjusted to the sensor resistance. There are no differences in principle of there two measurement methods. However, there are pros and cros of each, table 3.

Table 3. advantages and disadvantages of microprocessor and oscilloscope methods

Method 1 Microprocessor	Method 2 Oscilloscope
+ small testing element + no additional measurement device needed +sample circuit +low cost	+ higher accuracy + fast and direct result +sensitive to small resistance change +online measurement and data processes
-lower accuracy -difficult to sense small changes -offline data process (additional work for data process)	- additional big device required (oscilloscope) - high cost

In our testing, we used method 1 to test the big strain under continuous force and the stepwise test, while the cyclic testing was made in the testing method 2.

3. RESULT

Initial results shows that the coated sensor performed best in all measurement modes. Hysteresis effect was observed in both woven and knitted yarn based sensors. However, the effect was not to big and can be overcome by the control unit according to the different applications. The result of this experiment consists of a set of sample results. Further the sensors has been integrated and used in three types of application cases.

3.1 Sample result

In thread based sensors, lower conductivity threads from Bekintex are preferred in order to have significant resistance change while stretching. The coated samples gave excellent performance in all the measurement modes and ageing did not affect the samples. The knitted sample showed good result in cyclic and part of continuous dynamic testing. Woven samples show relative random results, probably due to fabric structure which should be considered in future experiments.The most significant results are:

1. Resistance v.s length on carbon-silicon coated sensor.
   We tested two different lengths under the same continuous increased force from 2N to 4N,). The sensors was attached into the strain tester with 2N pre-load, sensors were then stretched at the force speed of 100mm/second for 15seconds. Thereafter the sensors were released at the speed of 500mm/s. Figure 2 shows an average result of 5 tests. In the best performed range, dash-square, the resistance is linear with length but the resistance change is regardless to the length (R1-R2 almost in constant). We can say, in the working range of carbon-silicon coated sensor has the characteristic of:
   $R \propto F \propto \varepsilon$, while $R/L= c$;
   R: resistance
   F: force
   ε: strain
   L: effective length

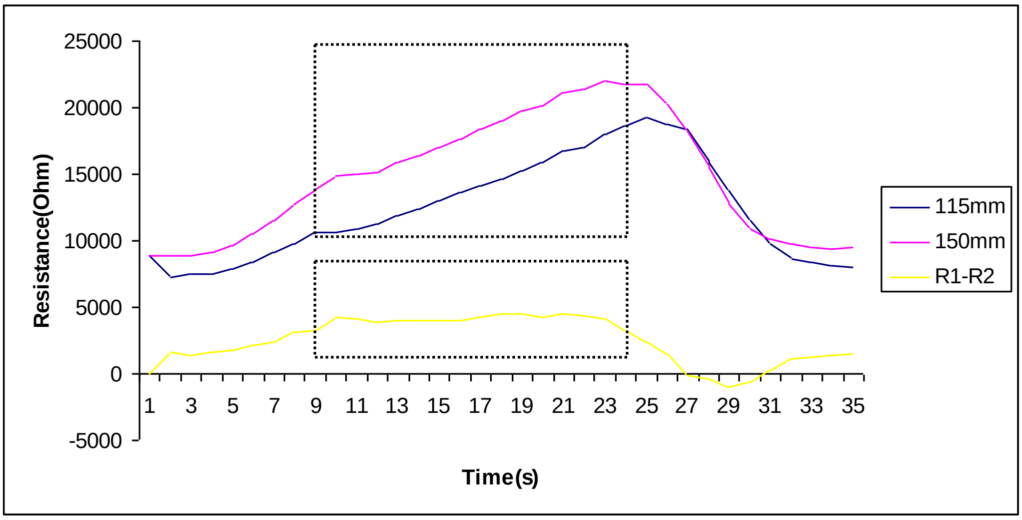


Figure 2. Resistance output under different testing length in carbon-silicon coated sensor.

2. Strain Gauge characteristic of carbon-silicon coated sensor.
   In an ideal textile stretch sensor, the sensor should have similar gauge factor as metals, around 2, or other gauge materials and constant gauge factor under different forces. Table 4 shows sensor parameters when different force are applied.

Table 4. Sensors parameter

Force(N)	6	8	10	12	14	20	30	40	50	60
Elongation(%)	16,2	20,7	23,7	25,9	27,5	32	35,7	37,1	39,1	39,2
R_0 (ohm)	8963	9768	11908	11378	11157	11027	12165	12505	13069	12655
ΔR (ohm)	21998	29463	32443	38857	38726	45466	52580	55062	53349	59265
GF	15	14	11	13	13	13	15	12	11	12

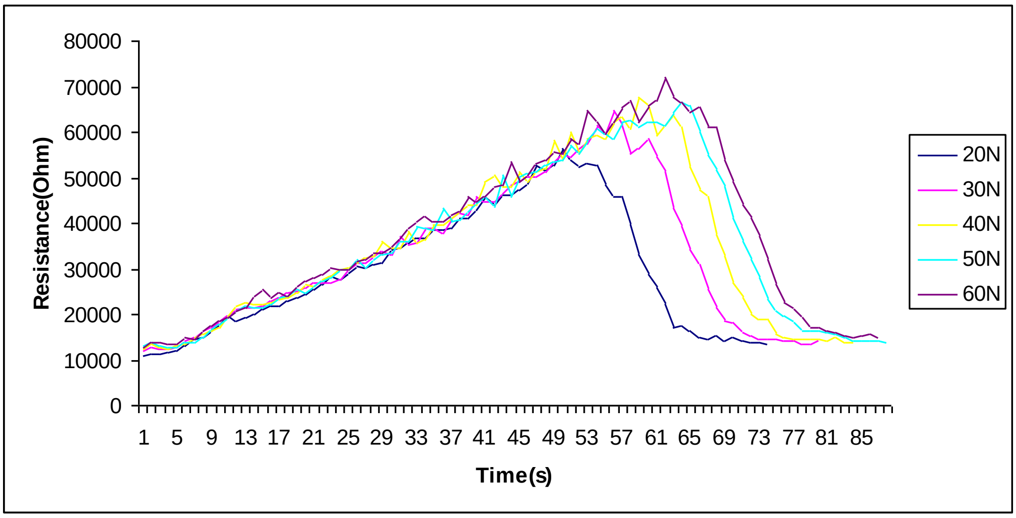


Figure 3. Resistance change under different force applied on carbon-silicon coated.

Carbon mixed Silicone coated sensor shown resistance change almost linear with force increase even up to 60N with strain of 39.2%, figure 3. In this case the sensor have a strain gauge factor around 13 while normally metallic gauge has the factor slightly higher than 2. The high gauge factor causes resistance drift in time, as we can see from table 4, the resistance in unreformed phase (R_G) were slightly incerased in different tests, this is because we were using the same sensor for testing, since resistance drift in time occurs.

3. Step-wise small force testing
   Due to high hysteresis effect on knitted and woven samples during small step changes, the step-wise testing only performed well in the coated sample. Results are shown in application case 2.

4. Small cyclic force testing
   Large cyclic force are similar as continuous force change tests, thus here, we only explored the resistance change under small and rapid cyclic force. Both coated and knitted sensors have shown good results. Figure 4 shows results of coated, knitted and woven sensor respectively.

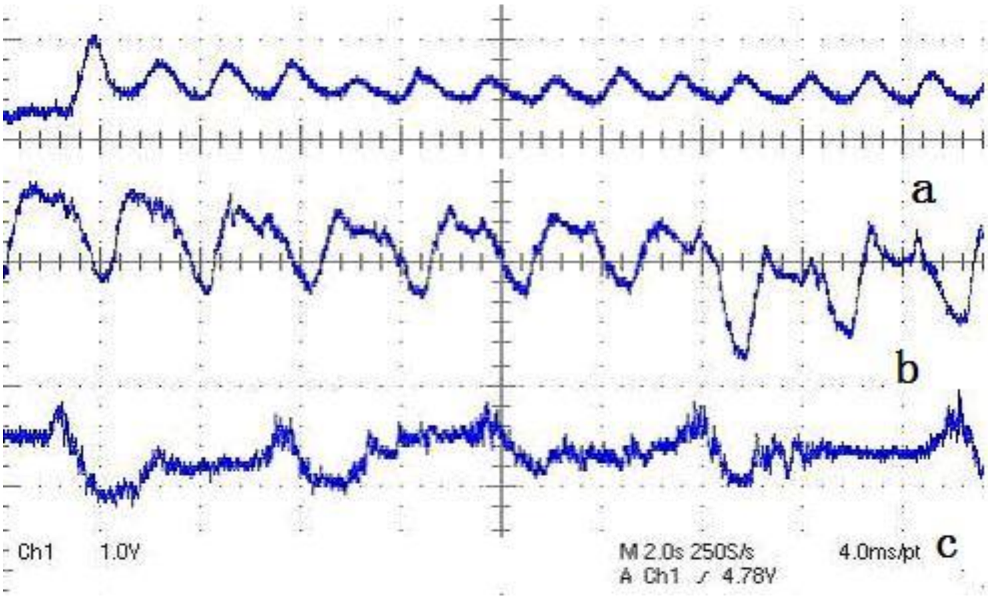


Figure 4. Cyclic testing results: coated(a), knitted(b) and woven(c) samples.

5. Ageing and hysteresis
   Ageing experiment has been done with the goal to evaluate how the resistance changes with time [5]. The samples were placed in an ageing device over 3 weeks. The same tests were done before and after ageing, during the tests, no drifts in all the sensors were found.

   Hysteresis is defined as a system whose output does not only depend on the current input but also on the history input [6]. Typical hysterisis is caused by friction and structural changes in the material. In order to verify hysteresis the sensors were stretched one hour, two hours and 12 hours before they were released. The results shows that the woven sample had almost no hysteresis effect. But unfortunately, its performance as sensor was bad. The knitted samples had hysteresis effect probably due to the knitted substrate structure itself. The coated samples on the other hand shows a reasonable hysteresis effect. It took less than 1 minute to return to 95% of initial outputs after one and two hours stretch. However, after 12 hours stretch the recovering to 95% was more than ten minutes.If the hysteresis whould be reduced, re-stretch till the full working range is always required.

3.2 Application cases

In order to further verify the sensor functionality according to the end application the coated sensors were integrated into three different application, a force sensor, a breathing sensor and a movment sensor.

3.2.1 Force sensor

In the application area where the force should be controlled within certain range, the stretch sensor is ideal. In our application test, the sensors were treated by the force 100N and 3000N, as for example in fastening strpas used in transportation. While the goods are locked-in, force on the strap is approximate 3000N, however, when the fastness is lost, the force is reduced rapidly. When the force is reduced to the standard “dangerous level”100N,the goods are considering as non-safe situation. By apply the stretch coated sensor, the system can easily sensor the huge change and used to prevent the fastness lost.

3.2.2 Breath sensor

Coated sensors are quite sensitive to small changes which maskes it even possible to sense the breathing rate. A prototype of a breath sensor has been made in order to test the breath activity. The only interested parameter in breath measurement is the resistance peaks and bottoms value, thus threshed have been set up in order to simplify the test and data process.

3.2.3 Movement sensor

There has been research on joint movement measurement and muscle activities with textile stretch sensors for some years. In some projects conductive yarn based sensor were used [7], while other projects used knitted sensor [8]. The principle of measurement the joint movement in our case are determine the stepped-wised resistance change corresponds to the joint angle change. For example, if the elbow has the stretchability of 35 to 40% which is the standards of fit in garment in textile industry. We have proven that the coated sensor has a linear resistance change with strain up to 40%. Four different steps were set without any difficulty. When the elbow is moving, the position corresponds to a certain angle.

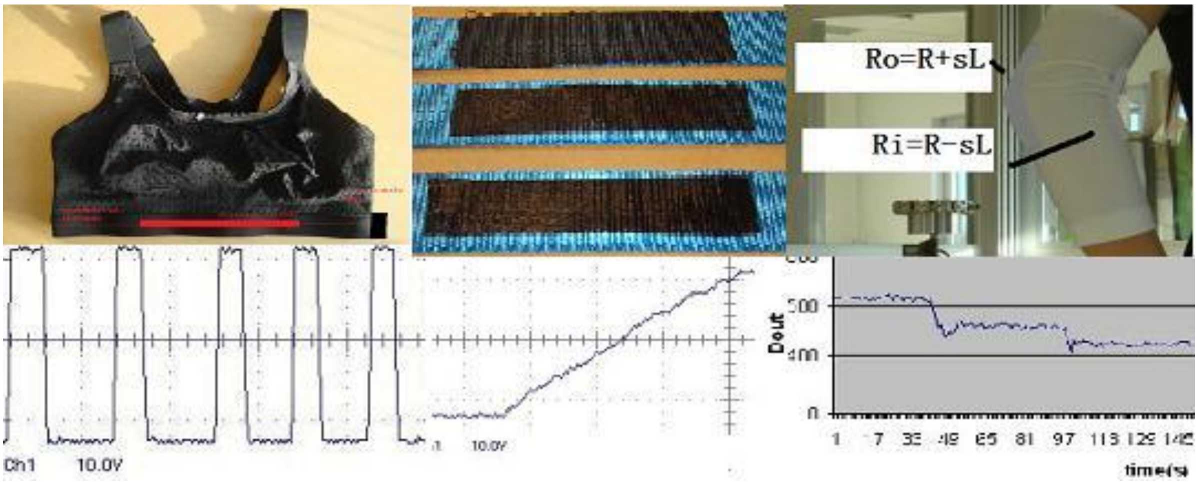


Figure 4. application examples and testing results

6. DISCUSSION

Textile stretch sensor has a trend to be widely used in the near future. Textile sensors are flexible, washable and wearable in comparison with conventional plastic or metal ones. The low cost of manufacture is another important factor which draws many industries attention. According to the results there are two major things to consider in future experiments: test standards and sensor design. Concerning test methods there are no existing test standards for textile stretch sensor yet. It is also hard to compare the characteristics of textile sensors to the conventional stretch sensors. Due to the different textile materials and implementation in different application, it is difficult to have general testing methods to all the textile sensors, which increases the complexity in the implementation of standards. More studies and experiments are required in order to develop new standards and testing devices.

In sensor design we have shown that there are several possibilites to develop textile-based sensors. There are, however, several necessary improvements to consider for future research. In this project the coated stretch senors showed the best and most reliable performance. Nevertheless threadbased stretch sensors such as knitted or woven structures are of interest since they offer an integration already in the base fabric. Both the woven and knitted samples in this experiemtns could be improved by more careful design and integration of the rather stiff conductive materials. Development of reliable strech sensing fibers and yarns is another way to improve threadbased sensors. In future we will try to improve the samples by considering the integration of condcutive yarns in woven and knitted structures. We will aslo develop coatings made of condcutive electroactive polymers in order to compare an instrisc conductuctive material with a blended one such as the carbon black silicon from Wacker.

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