

Suitability of conductive knit fabric for sensing human breathing

Aliaa A. Mohamed^{1*}, Mohamed M. Ezzat², Z. M. Abdel Megeid², Ahmed Saeed³

¹Faculty of Women Ain Shams University, Textile and Clothing, Cairo, Egypt

²National Research Center, Textile Research Division, Dokki, Cairo, Egypt

³Electronics, Communications and Computer engineering, Helwan University, Cairo, Egypt

Abstract:

This paper studies the suitability of conductive knit fabric in order to produce a reliable breathing sensor. Conductive single jersey knit fabrics was manufactured from silver coated nylon yarn with different production parameters (stitch type (ST)- combination ratio (CR) and number of wales (NW)). A cyclic tester was built to simulate the breathing mechanism of a human being and to explore the influence of these parameters on the electric resistance. The results show that there is a significant effect on the resistance value by the difference in ST and CR, while the width of the sample doesn't show a significant effect. The best sample suited for breathing sensor is the one with increase in width (NW), less CR and normal stitch.

Key words: conductive fabric- breathing sensor- combination ratio –stitch type.

1. Introduction:

Conductive yarn when integrated or embedded in a textile fabric it possesses some electric properties to the fabric. This fabric can be used in different application including textile pressure sensor(**Coyle, et al., 2010**) (**Meyer, et al., 2010**) (**Rothmaier, et al., 2008**), anti-electrostatic textiles (Cheng, Ueng, & Dixon, 2001), electromagnetic shielding sensor (**Ceken, et al., 2012**)(**Perumalraj & Narayanan, 2014**) and breathing sensor.

Noury et al measured the respiration frequency by using an inductive sensor formed in sinusoidal pattern. (**Noury, et al., 2004**). Merrit and Paradiso et al, produced a piezoresistive breathing sensor by using carbon-loaded rubber (**Paradiso, et al., 2005**), (**Merrit, 2008**). While, Zieba and Frydrysiask studied the electric resistance of knitting as well as weaving textiles integrated with conductive yarn. They stated that conductive polymer yarn and optical fibers can be useful in designing breathing senor(**Zięba & Frydrysiak, 2006**). Moreover, a textile digital sensor named “E-vital wear” was developed. This device was applied for measuring the human physiological signal including respiration monitoring(**Yang, et al., 2008**).

Many authors tend to explore the influence of conductive knitting fabric production parameters on electric and mechanical properties(**Li L. , et al., 2009**),(**Li, Liwen et al., 2009**)**(Guo, et al., 2013)****(Ehrmann, et al., 2010)****(Qureshi, et al., 2011)** (**Atalay , et al., 2013**)**(Atalay, et al, 2015)****(Liu , et al., 2016)****(LiuSu et al., 2016)****(Wang, et al., 2014)****(Zhang, et al., 2005)**.

* Corresponding author: ziz.alya@gmail.com

Li et al, (**Li, Liwen et al., 2009**) studied different knitting structure with silver coated conductive yarn to measure the confining pressure and electric resistance and in order to test the electric properties of conductive knitted fabric an electric model of 1X1 rib fabric was introduced. Guo and Berglin measured the resistance change and strain gauge properties of woven- knitted and coated textile based sensor(**Guo & Berglin, 2009**). While Ehrmann et al, study the electric resistance of polyester yarn containing a small amount of stainless steel wires to be used as a knitted breathing sensor (**Ehrmann, et al., 2010**)

Furthermore, the knitted loop structure was studied and a hexagonal model was developed to analyze the relationship between the electric resistance and load applied to the knitted conductive fabric in a unidirectional (**Zhang, et al., 2005**)as well as biaxial direction(**Wang, et al., 2014**). In order to compute the electric resistance of conductive knitting fabric, an empirical equation model was developed.

In 2011 Qureshi et al, studied different types of conductive yarns with four knitting structures (plain jersey, 1x1 rib, interlock and float) to design a knitting stretch sensor and interlock structure was selected for the sensor (**Qureshi, et al., 2011**), While Ehrmann et al, (**Ehrmann, et al., 2010**), examine the reliability of knitted elongation sensor developed form different conductive yarns, stitch size and knitting structure, results showed that full cardigan with medium size is better suited for use as stretching sensor. Another study was carried out in order to explore the effect of contact pressure of knitted strain sensor on the electric resistance. (**Atalay, et al., 2013**). In order to produce a knitted strain sensor a comparative study was conducted on the plain and interlock knitted structures using different conductive yarns, the successful strain sensor was realized in this study is the sensor with a series of single conductive courses within the interlock structure using Ag coated Nylon yarn(**Atalay, et al., 2015**).

Recently, the effect of float stitch(**Liu , et al., 2016**) and tuck stitch(**Lui, Su et al., 2016**)on the performance of electric functionof conductive knitted structure was studied.

This paper focuses on the study of the combination ratio of conductive yarn to non-conductive one with other knitting production parameters as well as the speed of contraction/ relaxation mechanism of fabric which could simulate breathing of human body at chest circumference. It can be a part of a cloth attached or applied on chest for monitoring breathing status.

2. Materials and Methods

2.1. Materials:

The conductive yarn used is Silver coated Polyamide (Nylon) Fiber (Ag/ Nylon); yarn count 70 denier ratio of silver to Nylon is 20% - 80 %. The non-conductive yarn is nylon/ elastomeric yarn with yarn count 70 denier. The yarn has elasticity property which is highly recommended for producing the breathing sensor and nylon is well known with its high resilience

and good durability. Furthermore, the yarn count is almost the same compared to Ag/ Nylon, so it can be easily calculate the ratio of the yarn in the samples produced.

2.2. Method:

All samples were produced on a flat knitting machine gauge 12 and fabricated in single jersey structure with fixed number of course / piece (50). Table 1 shows the parameters levels used in this work.

Table 1 parameters carried out for the work

Parameters	1	2
• Stitch type	Normal	Float
• No. of wales / piece	180	360
• Yarn combination ratio; C* : N-C** yarn	1:3	2:2

* C : conductive yarn

* N-C yarn: non-conductive yarn

- Dimensional measurement

The width and length of the samples were measured, for each sample five measurements were taken and the values tabulated so as to estimate the mean value (see Table2).

Table 2 the average width and length of the samples in (cm).

Sample no.	SL * (cm)	SW* (cm)
1	6.5	18.6
2	9.3	8.0
3	6.4	39.0
4	10.3	15.2
5	6.7	18.5
6	10.8	7.4
7	6.2	37.9
8	10.1	15.1

SL: Sample length – SW: Sample width

- Electrical resistance measurement:

In order to measure the electric resistance in the produced sensor knitted fabrics during the contraction/ relaxation mechanism; which simulates the human breathing, a cyclic tester was built (see Fig.1) which connected to a microcontroller to calculate the resistance. Two different breathing modes: sitting and walking were applied on the sensor knitted samples shown in Table 3, the modes are varied in speed and time delay between cycles with 5% stretching of the original length, 20 cycles were chosen to be close to the normal breathing rate for adults: 16-20 per minute (Charbek & Christensen, 2015).

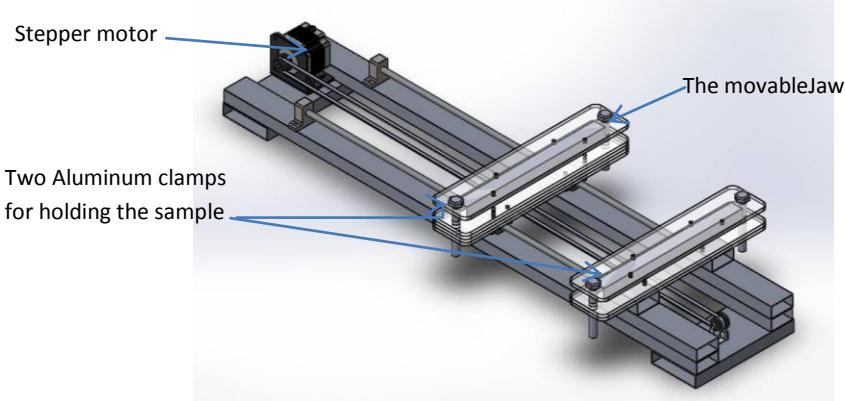


Figure 1 schematic design of cyclic tester

Table 3 different type of modes to simulate different breathing conditions

Mode type	Speed mm/sec	Time delay Sec.
1- Sitting	12.5	0.7
2- Walking	15	0.4

- Analysis of variance was carried out to define the main effect of the studied parameters on the resistivity and of the produced conductive samples as well as the difference of resistance along the cycles.

3. Results and Discussion

3.1. Influence of studied parameters on the electric resistance:

Samples specification and the results of the mean values of the electric resistance and ΔR of sitting mode (SM) and walking mode (WM) are present in Table (4). The speed was varied to evaluate the performance of the knitting sensor; the results clear that the speed values are very close to each other as a result one speed (SM) was chosen to represent the charts for the study. Figure 2 show the graph plotted between resistance and time / second for the whole samples, from the Figure it can be seen that samples no.3, 4 and 7 has a reliable and uniform pattern with clear Hi/Lo peaks. The high peak in the graph represents the breath out as well as the relaxing state and the low peak shows the breath in. The high peak and the low peak together represent one cycle. When calculate the difference in resistance (ΔR), shown in table 4. Sample no.3 shows the highest ΔR values (1.02 and 1.1Ω) for SM and WM, respectively. While sample no. 4 and 7 recorded 0.3 and 0.7Ω , respectively for both modes. For a breathing sensor performance it is preferable that the ΔR is high so as to detect and monitor the breathing pattern easily (contraction and relaxation of a human chest) (Qureshi, et al., 2011). The rest of the samples have undesirable pattern and the range of the resistance value is unstable along the cycles as clear from Fig. 2.

Table 4 samples specs., resistance and ΔR values of the 2 speed modes

sample no.	ST	NW	CR	Sitting		walking	
				R/ Ω	$\Delta R/\Omega$	R/ Ω	$\Delta R/\Omega$
1	N	180	1: 3	5.76	0.60	5.99	0.72
2	F	180	1: 3	2.26	0.16	2.26	0.17
3	N	360	1:3	7.79	1.02	7.91	1.10
4	F	360	1:3	3.42	0.27	3.38	0.29
5	N	180	2:2	2.49	0.37	2.43	0.34
6	F	180	2:2	1.77	0.07	1.80	0.07
7	N	360	2:2	3.75	0.67	3.76	0.68
8	F	360	2:2	1.86	0.11	1.84	0.10

ST: stitch type
N: Normal F: Float
NW: No. wales/ piece CR: combination ratio
 ΔR : Difference in resistance
R: Electric resistance

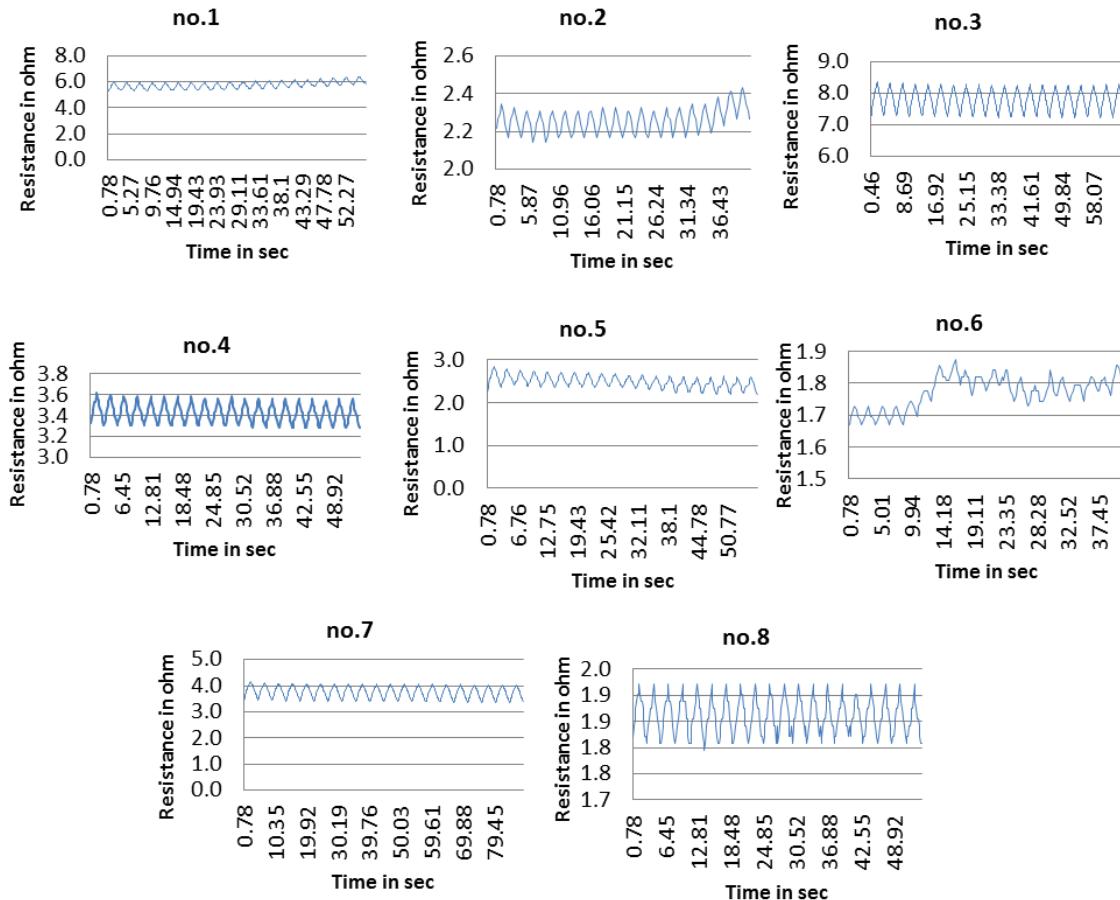


Figure 2Relationship between resistance and time (in seconds) for the whole samples in the setting mode

The effect of different parameters on the electric resistance are shown in Figures 3 and 4, the Figures present the relationship between resistance and stretching, the knitted sensor fabric for samples with NW (no. of wales) 180 and 360, respectively. Figure 3 shows samples of

NW=180, it can be seen that there are 2 bars of normal single jersey (NSJ) different in combination ratio (CR) 1:3 and 2:2 respectively, the sample of CR 1:3 show high resistance value (5.76Ω) than the ones of CR 2:2 (2.49Ω) while, the 2 bars of float single jersey (FSJ) different in CR 1:3 and 2:2 respectively. The sample of CR 1:3 shows slightly higher resistance value (2.26Ω) than the sample with CR 2:2 (1.7Ω), when comparing it with the NSJ both gives low resistance.

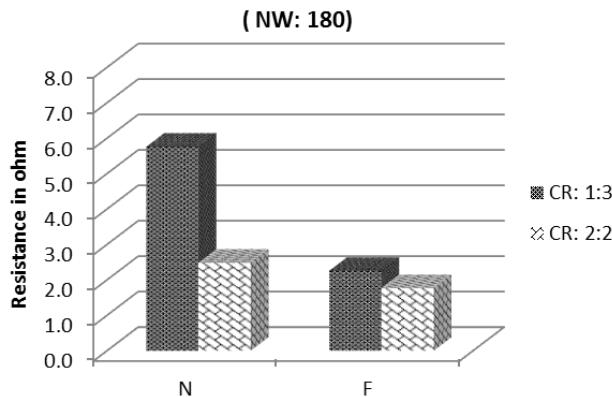


Figure 3 Relationship between resistance and 5% stretching of SJ fabric in 20cycles for samples of NW is 180 of N and F stitch and different CR.

Figure 4 represent samples of NW=360, it can be noticed that there are 2 bars for SJN samples different in CR 1:3 and 2:2 respectively, the sample of CR 1:3 is higher in resistance (7.79Ω) than the CR 2:2 (3.75Ω) on the other hand, the 2 bars of FSJ are different in CR 1:3 and 2:2, respectively. The sample of CR 1:3 show higher resistance value (3.42Ω) than the sample with CR 2:2 (1.86Ω), when comparing with the SJN both gives low resistance values. From the previous charts, it can be seen that even though samples of NW=360 show higher resistance value compared with samples of NW=180, the ANOVA results indicated insignificant (P value is 0.2) for SM and WM. Furthermore, the results of the analysis of variance for SM and WM, indicates that there is a significant effect on the resistance when changing the ST (P value is 0.024 and 0.034) and CR (P value is 0.027 and 0.037) SM and WM, respectively.

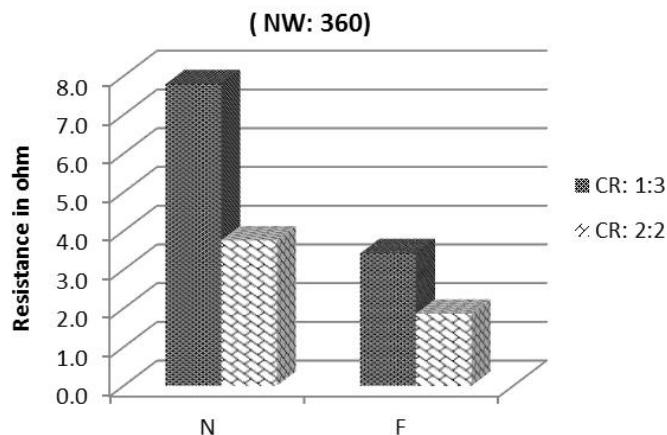


Figure 4 Relationship between resistance and 5% stretching of SJ fabric in 20cycles for samples of NW is 360 of N and F stitch and different CR.

3.2. Influence of studied parameters on the resistance difference (ΔR):

Figure 5 and 6 presents the effect of the different parameters on ΔR . The Figures show the relationship between the ΔR and stretching of knitted sensor samples with NW (no. of wales) 180 and 360, respectively.

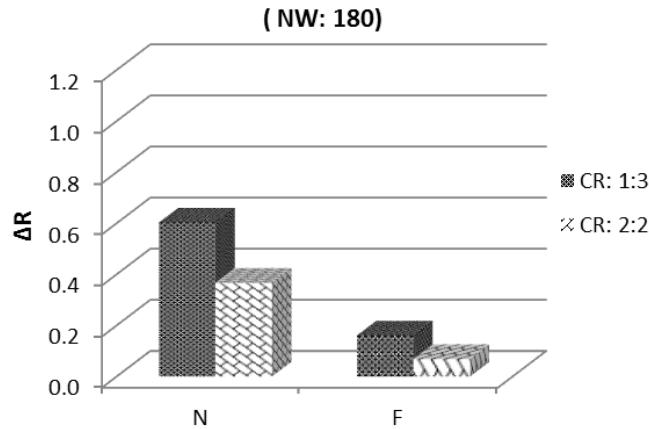


Figure 5 Relationship between ΔR and 5% stretching of SJ fabric in 20cycles for samples of NW is 180 of N and F stitch and different CR.

Figure 5 shows samples of NW=180, from the Fig. there are 2 bars of normal single jersey (NSJ) different in CR 1:3 and 2:2, respectively, it can be noticed that sample of CR 1:3 is higher in ΔR (0.60Ω) than the ones of CR 2:2 (0.37Ω) on the other hand, the 2 bars of float single jersey (FSJ) different in CR 1:3 and 2:2, respectively. Sample of CR 1:3 has slightly higher ΔR (0.16Ω) than the sample with CR 2:2 (0.07Ω), when comparing it with the NST both gives low ΔR .

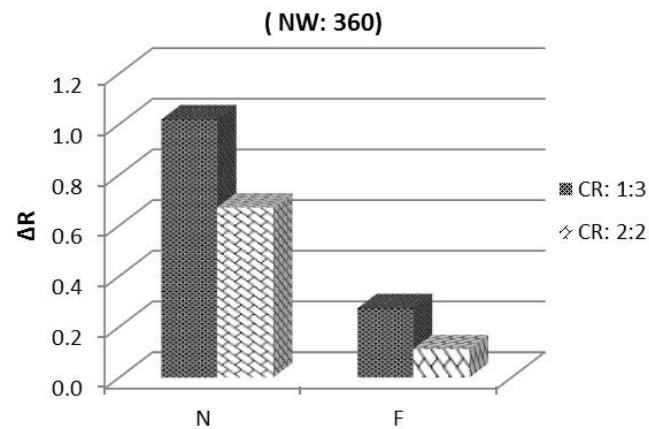


Figure 6 Relationship between ΔR and 5% stretching of SJ fabric in 20cycles for samples of NW is 360 of N and F stitch and different CR.

Figure 6 shows samples of NW=360 from the Fig. there are 2 bars of NSJ different in CR 1:3 and 2:2 respectively, it can be noticed that sample of CR 1:3 has higher value in ΔR (1.02Ω) than CR 2:2 (0.67Ω) on the other hand, the 2 bars of FSJ different in CR 1:3 and 2:2, respectively. Sample of CR 1:3 show higher ΔR (0.27Ω) than sample with CR 2:2 (0.11Ω) but both gives low ΔR .

when compared with the SJN. From the previous charts, it can be observed that samples of NW=360 show higher ΔR compared with samples of NW=180, and samples with less number of conductive yarns shows increase in ΔR . Moreover, The results conducted from the variance of analysis shows highly significant in ST ($P = 0.004, 0.005$) in sitting and walking modes respectively while it shows significant effect on the other two parameters NW and CR ($P=0.065, 0.089$) and ($P=0.073, 0.049$) in sitting and walking modes respectively.

4. Conclusion

- The performance of the electric resistance was studied and it was found that there is a significant effect for ST and CR, while the width of the sample doesn't show a significant effect on the resistance value.
- Normal stitch shows high resistance values than the float one.
- The accuracy of the discrimination of breathing cycle improved by the increase in the ΔR .
- The ΔR is highly affected by the change of ST and also shows influence by the change in NW and CR.
- The increase in NW show increase in ΔR .
- The speedvariation shows no effect on the electric resistance and ΔR values.
- The results showed that SJ knit fabric with less number of conductive yarns and high NW can be applied as a breathing sensor.
- The authors suggest further investigation to be applied on other knit structures such as Rib and interlock in order to examine its reliability as a breathing sensor.

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الملخص باللغة العربية

ملائمة قماش التريكو الموصى للكهرباء لاستشعار تنفس الإنسان

علياء عبد العزيز محمد¹- محمد عز بقحمند²- زينب محمد عبد المجيد²- احمد سعيد³

¹جامعة عين شمس-كلية البناء-قسم الاقتصاد المنزلى (ملابس ونسيج)

²قسم الملابس و التريكو - المركز القومى للبحوث

³هندسة إلكترونيات و اتصالات - جامعة حلوان

هذا البحث يقوم بدراسة مدى ملائمة قماش التريكو المصنوع من خيوط موصولة للكهرباء من أجل إنتاج قماش يتنفس ويتشعر التنفس يمكن الاعتماد عليه. تم إنتاج قماش جيري من خيوط النايلون المطلية بالفضة Ag coated Nylon والنايلون المخلوط بلوكر Nylon/Elastomeric. هذه الأقمشة مختلفة في الإنتاج من حيث (نوع الغرزة ST) - نسبة الخيوط الموصولة للكهرباء و الخيوط غير الموصولة (CR) و عدد الصوف في العينة (NW) (عرض العينة). تم تصميم جهاز (cyclic tester) لمحاكاة آلية التنفس للإنسان، ودراسة بعض العوامل التي تأثر على مقاومة الكهربائية. وأظهرت النتائج أن هناك تأثير كبير على قيمة المقاومة من قبل نوع الغرزة (ST) و نسبة الخيوط الموصولة للكهرباء و الخيوط غير الموصولة (CR)، في حين اختلاف عرض العينة لم يكن له تأثير كبير. أفضل عينة مناسبة لاستشعار التنفس هي العينة التي بها أقل نسبة للخيوط الموصولة للكهرباء و تحتوي على الغرزة العادية و التي لها عدد أكبر من الصوف.