Suitability of Conductive Knit Fabric for Sensing Human Breathing

Aliaa Abdel Aziz Mohamed – Lecturer, Hebatullah A. A. Abdel-Hamed, Enas A. H. El-Okda,
Home Economics Department - Textile and Clothes
Women's Faculty - Ain Shams University
Cairo, Egypt

Mohamed M. Ezzat, Zaynab M. Abdel Megeid
National Research Center,
Textile Research Division, Dokki,
Cairo, Egypt

Ahmed Saeed
Electronics, 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) of conductive yarn to the non-conductive one and number of needles (NN)). A cyclic tester was built to simulate the breathing mechanism of a human being and to explore the influence of these parameters on the gauge factor. The results show that the production parameters have a significant effect on the results of the gauge factor. The best sample suited for breathing sensor is the one with normal knit stitch, less CR and increase in width (NN).

Keywords: 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), (Merrrit, 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) (Liu Su et al., 2016) (Wang, et al., 2014) (Zhang, et al., 2005).

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 develop 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). And 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). And 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 function of 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. Experimental work
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 calculates 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 rows / 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 knit	Float
No. of needles	180	360
Yarn combination ratio; C* : N-C** yarn	1:3	2:2

* C: conductive yarn   ** N-C yarn: non-conductive yarn

- 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 speed modes: A and B were applied on the sensor knitted samples shown in Table 2, the modes are varied in speed and time delay between cycles with 5% stretching of the original length, 20 cycles were recorded and normally two runs were performed to rule any unwanted deviations as the knitted structure would perform different each time stretched as well as to identify sensitivity and repeatability.
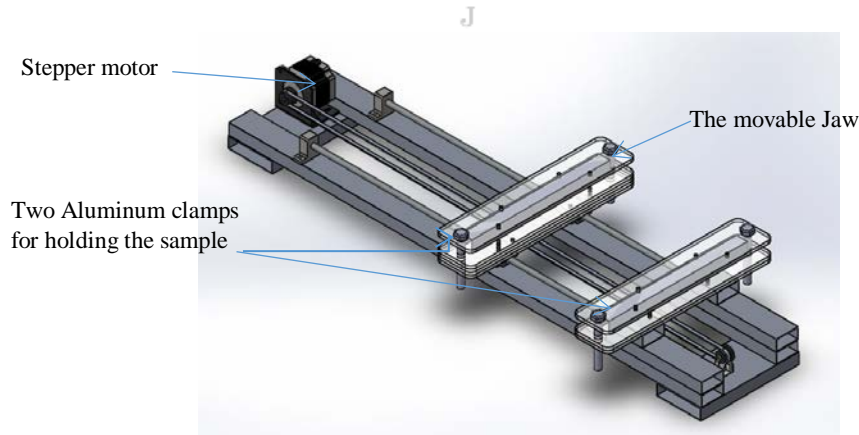

Figure 1. schematic design of cyclic tester

Table 2. Different types of modes to simulate different breathing conditions

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

Analysis of variance was carried out to define the main effect of the studied parameters on the gauge factor which is very important for the sensitivity of the selected sensor (Atalay, et al., 2013), (Atalay, et al., 2015).

3. Results and discussion

Samples specification and the results of the mean values of gauge factor and resistance different (Δ R) in different speed mode A and B are presented in table (3). The speed was varied to evaluate the performance of the knitting sensor. From the table it's clear that, the speed values are very close to each other as a result one speed (A) was chosen to represent the charts for the study.

Table 3. Samples specifications, Δ R/R min (gauge factor)

sample no.	ST	NN	CR	Δ R/R min		Δ R Ω	
				A	B	A	B
1	N	180	1: 3	0.108	0.112	0.60	0.72
2	F	180	1: 3	0.065	0.074	0.16	0.17
3	N	360	1:3	0.127	0.140	1.02	1.10
4	F	360	1:3	0.077	0.083	0.27	0.29
5	N	180	2:2	0.150	0.158	0.37	0.34
6	F	180	2:2	0.036	0.040	0.07	0.07
7	N	360	2:2	0.198	0.198	0.67	0.68
8	F	360	2:2	0.057	0.062	0.11	0.10
S T:	stitch type	NN :	No. of nee dles	CR:	combina tion ratio	A:	Speed mode	Δ R:	Difference in resistance
N:	Normal knit	F:	Floa t	Δ R/R min:	Gauge factor	B:	Speed mode	

3.1. Influence of studied parameters on the gauge factor (Δ R/R min)

A plotted graph between the mean of the gauge factor of speed mode A was carried out from the ANOVA analysis with the different production parameters shown in figure 2.

From figure 2, it can be seen that,

- The first plot at the left side shows the relationship between gauge factor and stitch type (ST). It is clear that, there is a significant effect of the normal knit stitch on the gauge factor P= 0.015.

- The second plot at the right side shows the relationship between gauge factor and number of needled (NN). There is an effect in the increase of the width of the sensor (NN) on the gauge factor but not significant as the ST. P= 0.307.

- The third plot shows the relationship between gauge factor and combination ratio (CR). The difference in the combination ratio doesn't show significant effect P= 0.496.
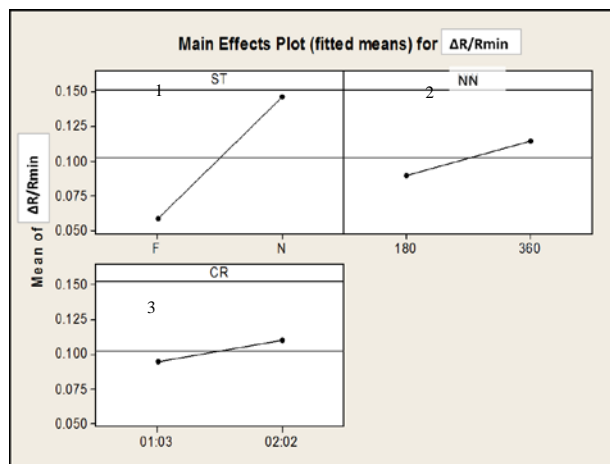

Figure 2. Relationship between the gauge factor and the different production parameter ST., NN and CR.

3.2. The influence of the electrical resistance and the stretching/ contraction movement of the knitted sensor

Figure 3. shows plotted graph between resistance and time (in second) taken during movement (extraction and contraction) for the 8 samples carried out on the cyclic tester. 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 1.1 Ω) for speed A and B, respectively. While sample no. 4 and 7 recorded 0.3 and 0.7 Ω, 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. 3.

From the above, it can be concluded that, the suitable knitted sensor for breathing was sample no. 3 designed from single jersey normal knit, 1:3 conductive yarn to non-conductive one and no. of needles 360 which recorded high gauge factor (0.127) and the highest ΔR of 1.02 as shown in table 3 besides it show a reliable and uniform pattern during the stretching and contraction as shown in fig.3.
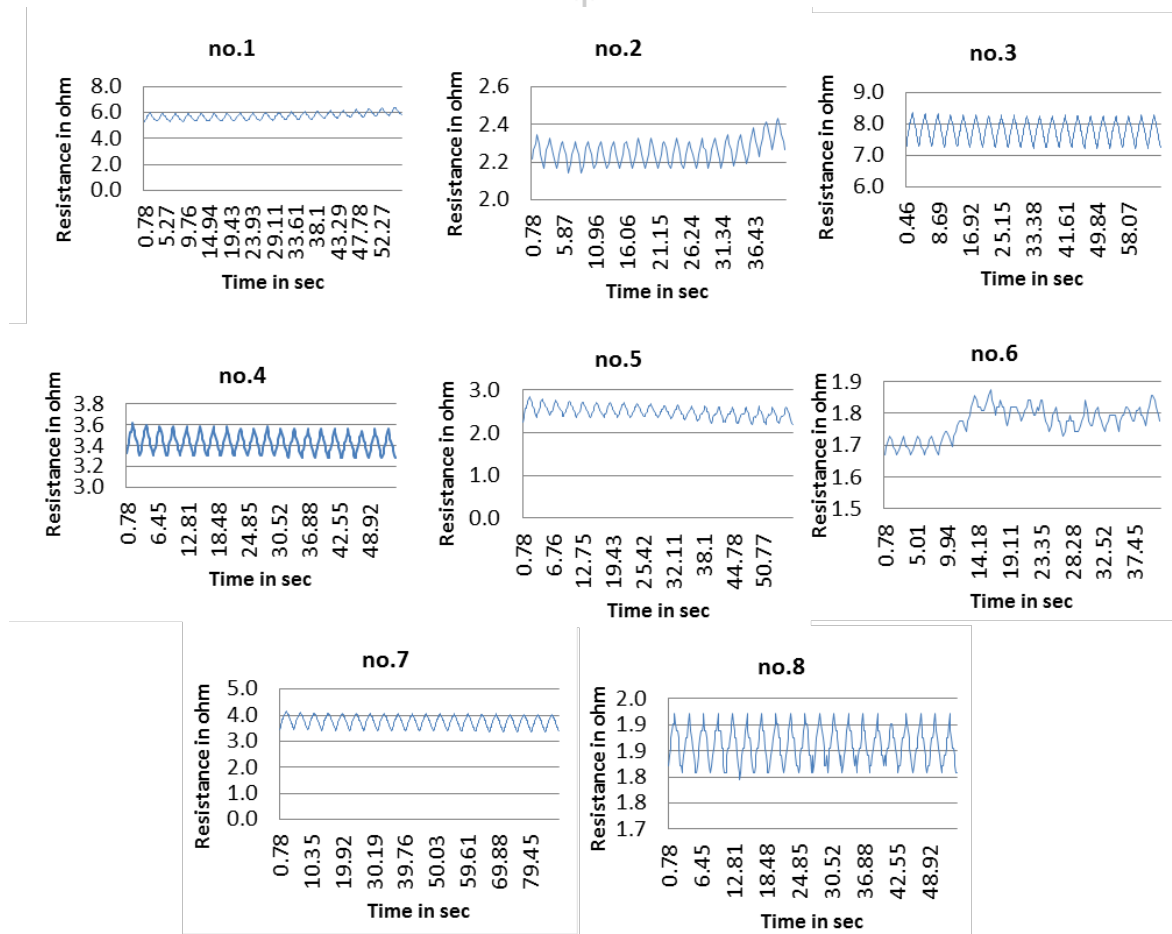

Figure 3. Relationship between resistance and time (in seconds) for the whole samples in the speed mode (A).

4. Conclusion

- Normal knit stitch shows high significant effect on gauge factor than the float one.
- The accuracy of the discrimination of breathing cycle improved by the increase in the ΔR.
- The speed variation shows no effect on the sensitivity of the sensor.
- The results showed that SJ knit fabric with less number of conductive yarns and high NN can be applied as a breathing sensor.
- The authors suggested that further investigation can be applied on other knit structures such as Rib and interlock in order to examine its reliability as a breathing sensor.

5. References

Atalay , O., Kennon, W. R., & Husain, M. D. (2013, Aug). Textile based weft knitted strain sensors: Effect of fabric parameters on sensor properties. *Sensors*, pp. 11114-11127.

Atalay, O., Tuncay, A., Husain, M. D., & Kennon, W. R. (2015). *journal of industrial textiles*, 1-29.

Ceken, F., Pamuk, G., Kayacan, O., Ozkurt, A., & Ugurlu, S. S. (2012). Electromagnetic shielding properties of plian knitted fabric containing conductive yarns. *Journal of engineered fibers and fabrics*, 81-87.

Cheng, K. B., Ueng, T. H., & Dixon, G. (2001, August). electrostatic discharge properties of stainless steel/polyester woven fabrics. *Textile research journal* , pp. 732-738.

Coyle, S., Mitchell, E., Ward, T. E., May, G., O'Connor, N. E., & Diamond, D. (2010). Textile sensors for personalized feedback. *IAPMA congress.* Milton Keynes, UK: ECIR2010 workshop on information access for personal media archives.

Ehrmann, A., Heimlich, F., Brucken, A., Weber, M. O., & Haug, R. (2010). knitted breathing sensor. *knitting*, 222-223.

Guo, L., & Berglin, L. (2009, January). Test and evaluation of textile based stretch sensor. *World textile conference.* Turkey: AUTEX.

Guo, L., Berglin, L., Wiklund, U., & Mattila, H. (2013, March). Design of a garment-based sensing system for breathing monitoring. *Textile research journal*, pp. 499-509.

Li, L., Au, W. M., Li, Y., Wan, K. M., chung, W. Y., & Wong, K. S. (2009). A Novel Design Method for an Intelligent Clothing Based on Garment Design and Knitting. *Textile Research Journal, 79*(18), 1670–1679.

Li, L., Au, W. M., Wan, K. M., Wan, S. H., Chung, W. Y., & Wong, K. S. (2010, June). A resistive network model for conductive knitting stitches. *Textile research journal*, pp. 935-947.

Li, L., Liu, S., Ding, F., Hua, T., Au, W. M., & Wong, K. S. (2012, August 14). Electromechanical analysis of length-related resistance and contact resistance of conductive knitted fabrics. *Textile research journal*, pp. 2062–2070.

Li, Liwen, Yang, K., Song, G., Zhang, L., & Guo, J. (2009, November). Research and application of the property of conductive knitted fabrics. *Modern appplied science*, pp. 84-88.

Liu , S., Yang, C., Zhao, Y., Tao, X. M., Tong, J., & Li, L. (2016, May). The impact of float stitches on the resistance of conductive knitted structures. *Textile research journal*, p. 2016.

Liu, Su, Tong, J., Yang, C., & Li, Li (2016, July). Smart E-textile: Resistance properties of conductive knitted fabric – Single pique. *Textile research journal*, pp. 1-16.

Merrrit, C. R. (2008). electronic textile-based sensors and systems for long term health monitoring. *Ph.D. Dissertation, North Carolina State university, Raleigh.*

Meyer, J., Arnrich, B., Schumm, J., & Troster, G. (2010, August). Design and Modeling of a Textile Pressure Sensor for Sitting Posture Classification. *IEEE*, pp. 1391-1398.

Noury, N., Dittmar, A., Corroy, C., Baghai, R., Weber, J. L., Blanc, D., . . . Comet, B. (2004). VTAMN--a smart clothe for ambulatory remote monitoring of physiological parameters and activity. *Enterprise Networking and Computing in Healthcare Industry, 2004.* (pp. 155 - 160). IEEE.

Paradiso, R., Loriga, G., & Taccini, N. (2005, Sept). A wearable health care system based on knitted integrated sensors. *IEEE Transactions on Information Technology in Biomedicine*, pp. 337 - 344.

Perumalraj, R., & Narayanan, K. S. (2014, June). Nano silver conductive composite material for electromagnetic compatibility. *journal of reinforced plastics and composites*, pp. 1000-1016.

Pinar, A., & Michalak, L. (2006, January-December). influence of structural parameters of wale-knitted fabrics on thier electrostatic properties. *Fibers and textile in Eastern Europe*, pp. 69-74.

Qureshi, W., Guo, L., peterson, J., Berglin, L., Mehrjerdi, A. K., & Skrifvars, M. (2011). Knitted wearablestretch sensor for breathing monitoring application. *Proc Ambience*, 72–76.

Rothmaier, M., Luong, M. P., & Clemens, F. (2008, july 25). Textile pressure sensor made of flexible plastic optical fibers. *Sensors*, pp. 4315-4329.

Wang, J., Long, H., Soltanian, S., Servati, P., & Ko, F. (2014). Electromechanical properties of knitted wearable sensors: part 1 – theory. *Textile Research Journal*, 3–15.

Yang, C. M., Huang, W. T., Yang, T. L., Hsieh, M. C., & Liu, C. T. (2008). Textiles digital sensors for detecting breathing frequency. *5th International Workshop on Wearable and Implantable Body Sensor Networks* (pp. 276-279). China: IEEE.

ZHANG, H., TAO, X., WANG, S., & YU, T. (2005). Electro-Mechanical Properties of Knitted Fabric Made From Conductive Multi-Filament Yarn Under Unidirectional Extension. *TEXTILE RESEARCH JOURNAL*, 598-606.

Zięba, J., & Frydrysiak, M. (2006). Textronics – Electrical and Electronic Textiles. Sensors for Breathing Frequency Measurement. *Fibers & textiles in Eastern Europe*, 43-48.