Embroidery on Textiles as a Smart Solution for Wearable Applications.

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Abstract:
The research was conducted to evaluate the impact of the fabrication parameters such as using different types and length stitches of conductive yarns on the performance of embroidered fibers which could be applied as smart wearable clothes. Nickel Conductive yarn was used, which embroidered in straight and zigzag stitch types with different length of stitch and 1,2 and 3 lines of threads. the obtained resulted, showed that the lowest value of R(Ω) was 1.24 Ω. with straight stitch types with 3 lines of threads with 5mm of stitch length, the number of stitches lines of thread influences on resistance mean values as 2.721Ω, 2.54Ω and 2.31 Ωfor the 1, 2 and 3 lines of threads respectively. Means of R (Ω) were 1.83 , 2.03 and 2.80 Ω of the length of stitches 3 mm, 5mm and 7 mm significant respectively The nickel conductive yarn could be embroidered on a prototype T-shirt to be a connector between the temperature sensor and screen. This embedded system based on conductive thread could find possible application in medical applications.

Keywords:
Smart Clothes
Conductive Yarn
Embroidery
Wearable technology
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1. Introduction
In recent years, intensive research has been carried out in the area of electronic textiles, particularly in respect of the incorporation of sensing and actuating functions into textile products. Being close to the body, textiles can offer a comfortable، flexible platform for the embedding of sensing functions. The direct consequence of applying this technology is the development of wearable monitoring systems intended for continuous usage in monitoring the human body, for vital signs over extended periods of time. Human body temperature is one of the four vital signs used in conjunction with heart rate, blood pressure and respiratory rate for medical assessment of the state of health. It is an important indicator of the physical condition of the human body and relates to comfort, performance and heat or cold stresses (Husain, et.al., 2014).

Embedding of metallic wires into textile structures for sensing purposes has been documented by several researchers. Various fabric forming techniques such as knitting, weaving and embroidery have been exploited for these purposes (Husain, et.al., 2014).

Clothing and apparel, having a large portable surface and the possibility of integrating built-in sensors, pockets, and embedded electronics, have great potential for application in wearable medical systems (Trindade et al., 2016).

Conductive fibers are the key element to build smart fabrics with known electrical properties (resistance, capacitance etc.). The current conduction in fabrics depends on: conductive material used, percentage of conductive fibers, fabric structure and conductive fiber contact surface. (Capineri, 2014), described the fabrication technologies which use metal fibers only and a mixture with textile fibers. These yarns are produced using textile production technologies. Advanced processes of metallization of polyamide fibers with silver coating are also developed because polyamide gives the yarn strength and elasticity beside having biocompatibility with human body, while thin compliant silver coating guarantees electrical conductivity. The options of metal plated conductive threads are wide. The coating material can be chosen from different metals to balance the performance and the cost. Normally, silver, copper and nickel are the options for commercialized products that can provide a balance between electrical conductivity, mechanical strength and flexibility. Generally, polymer based conductive threads are easy to embroider due to the physical similarity as well as traditional embroidery threads (Zhang, 2014).

There are two fundamental ways to produce a conductive fabric component. In the first, a non-conductive fabric may be plated with a conductor. The other approach is using a conductive yarn on a non-conductive substrate (Chauraya *et. al.,* 2012). This approach uses knitting, embroidery or weaving as the most common fabrication techniques (Seager et al., 2013). Electrically conductive fibers are key component of the smart and interactive textiles that will be used in the future. Thus, they have a wide feature as power and signal transmitters in many prospective applications such as strain sensors and electro-thermal sensors.

The embroidery allows a control and an integration of yarn with different electrical properties, such as different resistances as well as offering many advantages over knitting or weaving. Therefore, Conductive thread and yarn embroidery can be accomplished on single or multiple layers of fabric. Moreover, it can be applied on various types of textile and apparel products in one step such as Antenna and sensors (Mac, *et. al.,* 2004) (Stoppa & Chiolerio, 2014).

The aim of this research was evaluating the impact of the fabrication parameters such as using different stitches of different types of conductive yarns on the performance of embroidered E-clothes, which could be applied in wearable technology in the medical fields.

2. Materials and Methods

2.1 Conductive Threads characterization

Multifilament conductive thread based on the composition of the filaments has been used (Lebrator 40 KururayVectran® Outer Metallization Layer nickel as material)

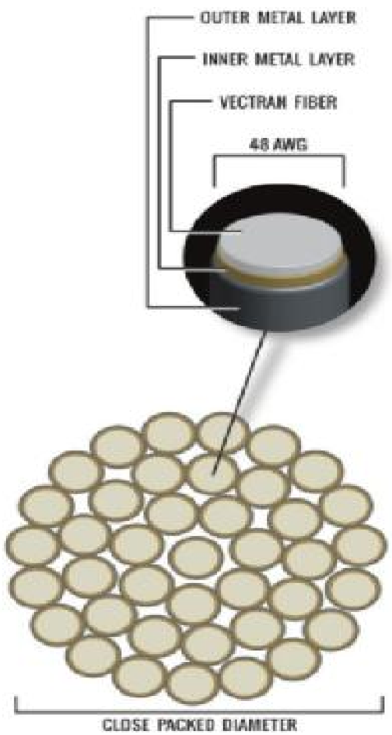


Fig. 1 Across-section of nickel Conductive yarns Lebrator 40 KururayVectran®

2.2 Scanning electron microscopy SEM and energy dispersive X-ray EDX characterization

The instrument Quanta standard Environmental Scanning electron microscope SEM with Energy Dispersive X-ray detector (EDX) at 20 kV was employed to observe the morphology of the samples and perform EDX analyses. Scanning electron microscopy (SEM) analyses were performed using an acceleration voltage of 20 kV. EDX measurements were done in companion of imaging by SEM between 5kV and 20 kV. The preparation of Samples for SEM measurements were coated with golden layer Au using a Sputter Coater Bal-Tec SCD 005. The EDX measurements were carried out. The average fibre diameter was obtained from the SEM images.

2.3 Embroidering Conductive Threads

2.3.1 Computerized Embroidery Machine and Stitch Patterns

The design was relied on:

- Nickel Conductive yarns which embroidered in straight and zigzag stitch types.

- The parameters were used length of stitch with (3,5 &7 mm) and 1,2 and 3 lines of threads .

The reasons for using automatic production of embroidering via computerized embroidery machine is boosting the development of textile-based wearable electronics and reduce the cost significantly. The computerized embroidery machine (MEYAG model 912) as shown in (Fig. 2 A). The embroidered samples were fabricated by this machine. The specifications of embroidering geometries can be designed using computer-aided design / computer aided manufacturing Wilcom Embroidery Studio, ES 65 Designer software on a computer. The defining characteristics including dimensions, arrangement, stitch type and stitch direction of each embroidered objects can be controlled with software for the embroidery machine as shown in (Fig. 2C). The system provides fast and accurate productivity for complex Embroidering shapes, the stitch patterns and the structure of the fabrics, which reduces the error in manufacturing and improves product quality. The intention in the selection of the correct yarn tensions and machine speed is essentially required to have a proper embroidery without breaking the conducive layers of the yarn. In addition, oil could be used as a lubricant to aid the process. Different patterns of embroidered stitches. Considering the current flowing path, Satin stitch and Running stitch are used in this study. Satin stitch is the zigzag pattern that perpendicular to the designed direction. Usually it creates a bold line. Running stitch is a single line of stitch that follows the designed direction. Clearly the running stitch creates the thinnest line compared with other stitches and uses the least length of thread for the same distance. Comparison between these two stitches will be presented.

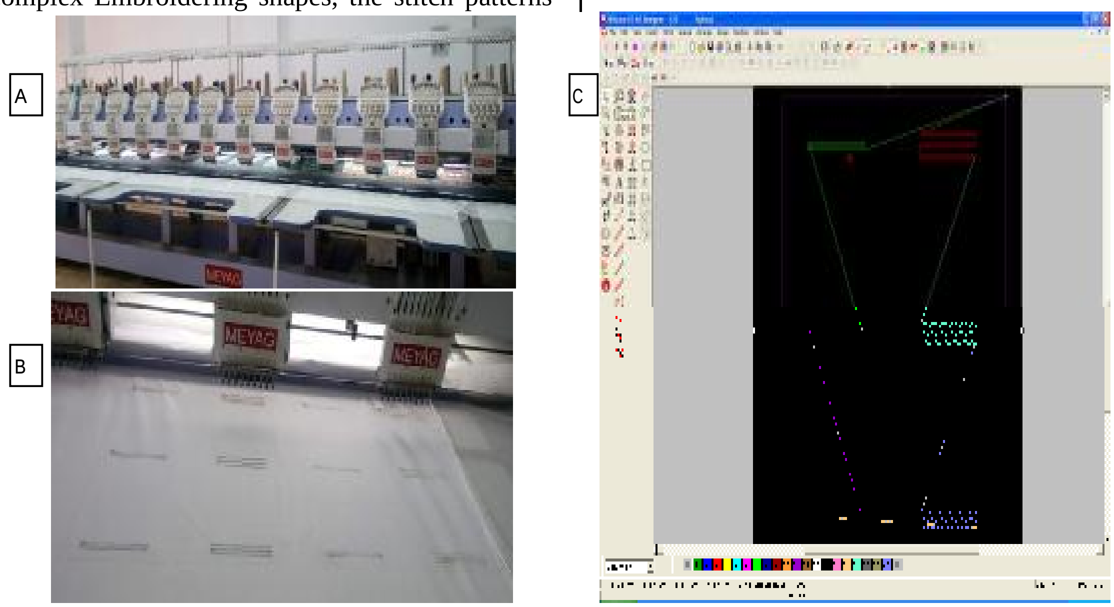


Fig. 2 A; The computerized embroidery machine (MEYAG model 912) and B; the embroidered samples. C; the window of the Wilcom Embroidery Studio, ES 65 Designer software and film of embroidery design containing the straight stitch type with different spacing and length of stitch (on the right) and the zigzag stitch type with different spacing and length of stitch (on the left).

2.3.2 Model of Embroidered Stitches

The stitch formation predominantly utilized in this study is the 'lock stitch' which is the most commonly used in embroidery. The lock stitch as a standard stitch, both for its simplicity and the fact that it tends to produce fabric conductors with lower resistance than other stitch types considered. While there are many different stitch types available, it has been found that conductive yarn does not normally have the same tensile strength as non-conductive yarn. The lock stitch is created with a top thread and a looper thread. The top thread runs through a tension system, take-up lever and the eye of the needle. The looper thread is wound onto a bobbin which is inserted into a casing and used in the lower half on the machine. The conductive layer is embroidered by the conductive thread on the top of a base fabric. A nonconductive thread (usually cotton or polyester yarn) is used to lock the conductive thread via the holes in the fabric. The depths of the holes are equal to the thickness of the fabric. A model was built to estimate the total length of the used thread, see (Fig 3). Taking running stitch as an example, the diagram illustrates the conductive embroidery thread only.

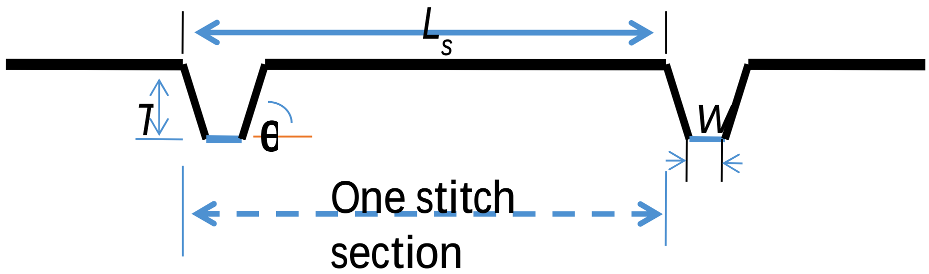


Fig. 3 Model of embroidered conductive thread length using lock stitches

2.4. Electrical properties of embroidered conductive threads

Digital multimeter (Metex - M3800) was used. Samples were air-conditioned and measurement was carried out at 40% RH, 22°C. The resistance of the total length of the used thread based on type, length and depth of stitch was calculated according to (Zhang, 2014).

The volume resistivity and Surface resistivity of materials were measured according to the standard method (ASTM D 4496-04).

2.5. Experimental Design

Three replicates of each treatment were examined and the statistical design was completely randomized

2.6. Data Analysis

The data were subjected to ANOVA and were evaluated by MSTATC program. The differences between means were compared using LSD test at 5% level of significance.

3. Results and Discussion

Scanning electron microscopy and EDX characterization

The SEM micrograph in Fig 4 show diameter of Lebrator 40, with outer metallization layers Nickel ranged from 23.15- 31.35 µm. The presence of Ag and/or Ni in the different types of yarns was investigated by Energy Dispersive X-ray scattering EDX analysis. The Ni content as weight percentage was 62.95 % in Lebrator 40 yarn with outer nickel metallization layers.

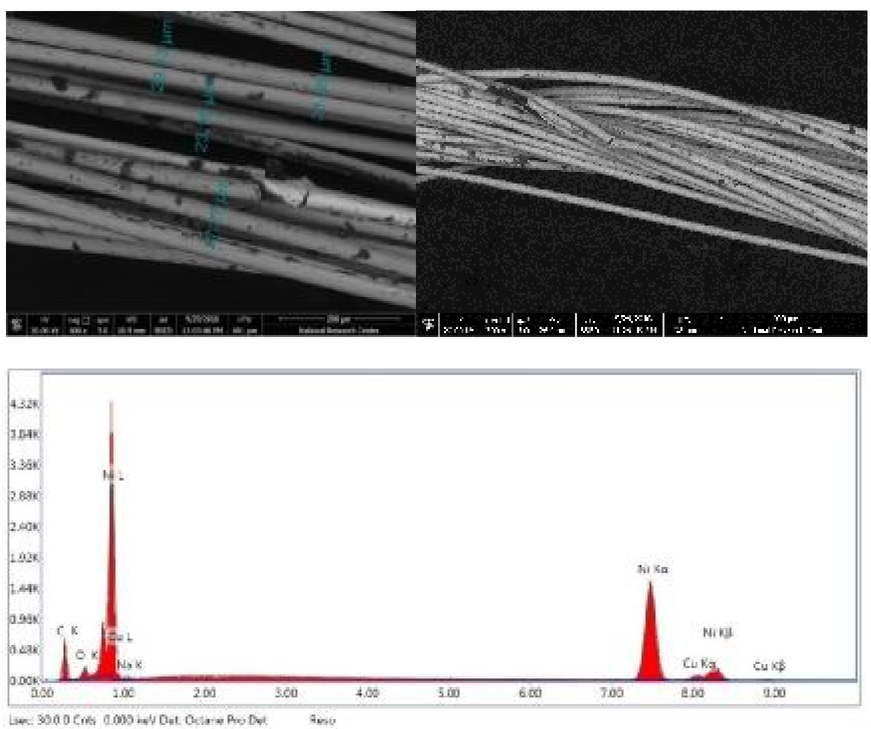


Fig.4 SEM Micrographs and EDX spectrum of Nickel conductive yarn.

Electrical properties of conductive Yarns

The average volume resistivity for embroidered fibers varied significant from 5.584e+009 to 4.356e+009 ohm for straight and zigzag stitch type, respectively, the same findings were detected with surface resistivity of straight and zigzag stitch embroidered which was 2.724e+009 and 2.218e+009 ohm, respectively as shown in (table 1).

Table 1. Volume resistivity and surface resistivity of embroidered fibers with different stitch types.

Stitch Type	Volume resistivity [ohmRV]	Surface resistivity [ohmRS]
Straight	5.584e+009 A	2.724e+009 A
Zigzag	4.356e+009 C	2.218e+009 B
LSD%5	0.0008029	0.0006555

Table 1. Volume resistivity and surface resistivity of embroidered fibers with different stitch length.

Stitch Length	Volume resistivity [ohmRV]	Surface resistivity [ohmRS]
3 mm	5.584e+009 A	2.862e+009 A
5 mm	4.356e+009 C	2.218e+009 C
7 mm	4.398e+009 B	2.333e+009 B
LSD%5	0.0002073	0.0002539

The lowest value of R(Ω) for Lebrator 40 coated with Nickel layers was 1.24 Ω. with straight stitch types with 3 lines of threads with 5mm of stitch length, while the highest value was obtained by embroidering one line of conductive thread in straight stitch type with 7 mm of stitch length as shown as shown in Fig. 5.

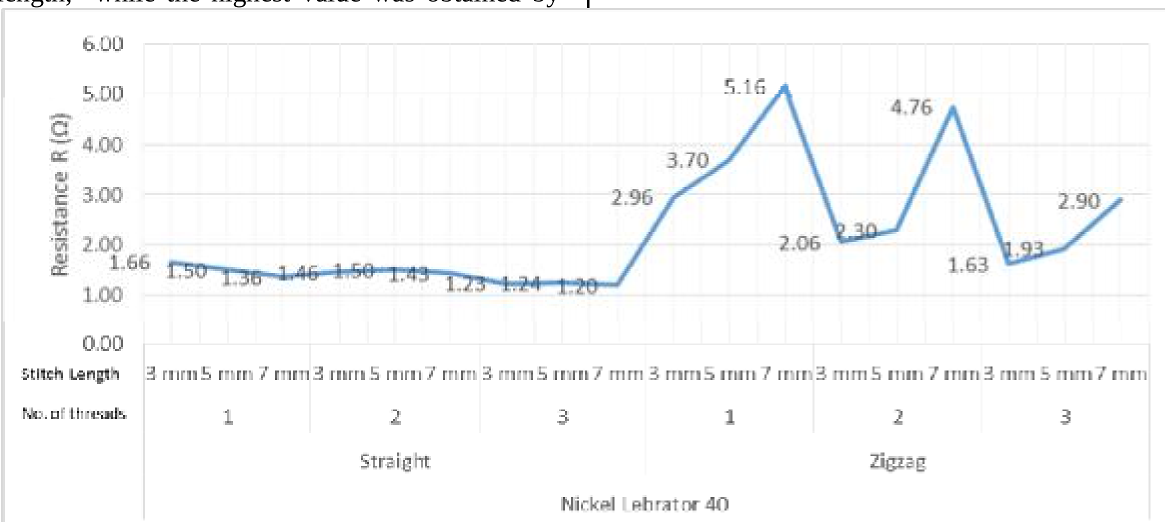


Fig. 5 Effect of yarn type, stitch type, No. thread and length (mm) of stitch on R(Ω)

The type of stitches affected on mean value of resistance R (Ω) as 1.4 Ω for straight stitches while was 3.04 Ω for Zigzag stitches as shown in Fig 6. Straight stitch had a total thread usage shorter than zigzag stitch which can also reduce the thread resistance. The optimum base material and stitch length can provide the balance between the quality of embroidered pattern and the total required length of the conductive thread. A low resistivity indicates a wire that readily allows the movement of electrical charge. (Ová & Grégr, 2010; Morton, 2008).

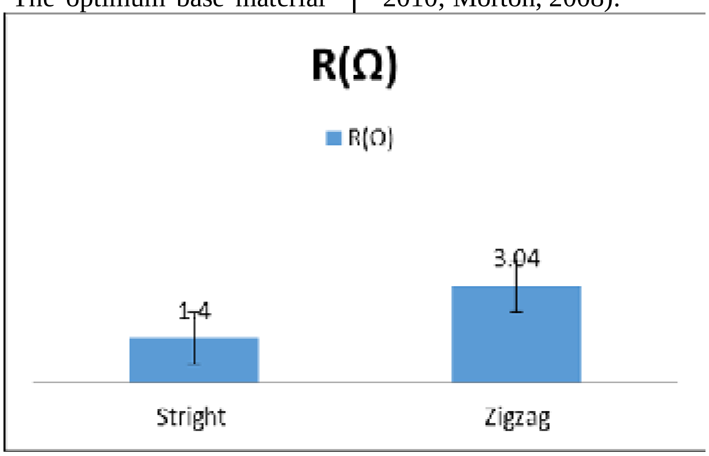


Fig. 6 Means of R (Ω) of the different types of stitches

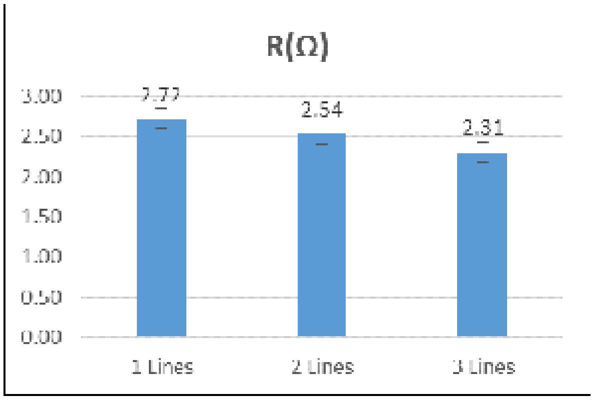


Fig. 7 Means of R (Ω) of the Number of lines

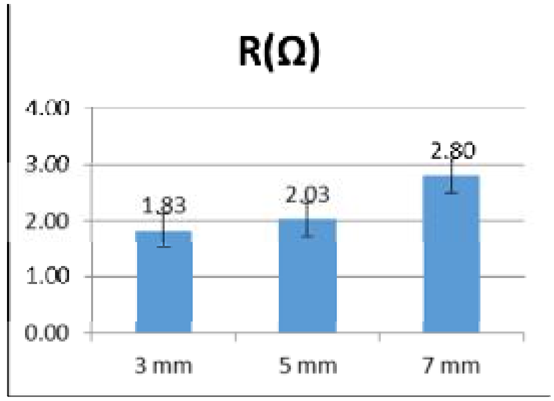
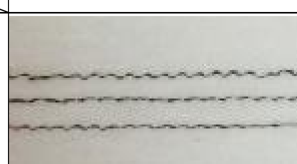
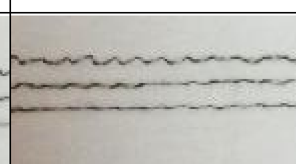
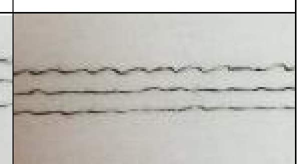
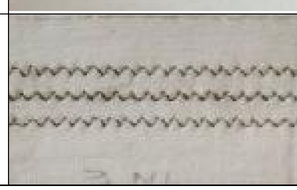
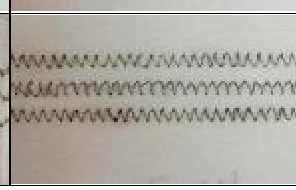
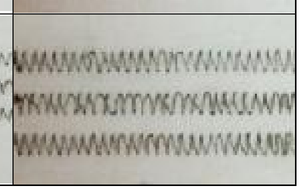


Fig. 8 Means of R(Ω) of the length of stitches

The number of stitches lines of thread influences on resistance mean values as 2.721Ω, 2.54Ω and 2.31 Ωfor the 1, 2 and 3 lines of threads respectively. Means of R (Ω) were 1.83 , 2.03 and 2.80 Ω of the length of stitches 3 mm, 5mm and 7 mm significant respectively as shown in Figs (7&8). the mean of resistance is increased with the increasing of stitch length and decreased with the increasing the line of thread. (Zhang et al., 2012) found that resistivity for the silver Coated material (Ω•m) of Liberator Silver 40, 1.59×10^{-8} (Ω•m) and DC resistance of 100 mm single thread (Ω) 4.3 (Ω) and resistivity for the Nickel Coated material (Ω•m) of Amberstrand Nickel 166, 6.99×10^{-8} (Ω•m) and DC resistance of 100 mm single thread (Ω) 0.3 (Ω).

Model of Embroidering and Stitch Patterns

Table 5. Model of Embroidering and Stitch Patterns

Stitch length / Stitch type	3 mm	5mm	7 mm
Straight			
Zigzag			

4. Conclusion

Nickel Conductive yarn was used, which embroidered in straight and zigzag stitch types with different length of stitch and 1,2 and 3 lines of threads. the obtained resulted, showed that the lowest value of R(Ω) was 1.24 Ω. with straight stitch types with 3 lines of threads with 5 mm of stitch length, The number of stitches lines of thread influences on resistance mean values as 2.721Ω, 2.54Ω and 2.31 Ωfor the 1, 2 and 3 lines of threads respectively. Means of R (Ω) were 1.83 , 2.03 and 2.80 Ω of the length of stitches 3 mm, 5mm and 7 mm significant respectively The nickel conductive yarn could be embroidered on a prototype T-shirt to be a connector between the temperature sensor and screen. This embedded system based on conductive thread could find possible application in medical applications.

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