Wearable respiratory belt for human breathing control

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1 Abstract

We designed and manufactured a working prototype of a wearable respiratory belt. The belt can work as a stand along system or can be embedded into clothes. The system is intended for remote health monitoring (particularly to monitor human respiration) such as home healthcare, remote medicine and remote socio-medical assistance as well as to monitor patients. The fully functional prototype proofs the concept that the elongation in the respiratory belt causes by human respiration is accurate enough to measure and to monitor human respiration.

2 Introduction

Microsystems, ICs and other electronics are increasingly frequent as parts of medical and healthcare wearable devices including a smart textile and wearable belts. Right now, there is no common opinion what type of interconnection technique to use to connect the electronic part that is typically rigid, to soft, stretchable and thermo-sensitive textile. Different research organizations pursue different approaches [1-4]. In this paper we detail the work conducted on development and integration electronics based on out off-the-shelf components into/on the textile.

3 Respiratory belt design and manufacturing

The wearable respiratory belt is a system to measure and to monitor human respiration. While the belt is strapped around the chest, expansion and contraction of the chest during breathing, causes the belt elongation. The elongation in its turn results in inductance and/or resistance change in the conductive yarn and/or wire, knitted in the non-conductive fabrics of the belt. Such changes are detected and processes by the electronic embedded into/on the respiratory belt and transmitted to the base station. The system provides a complete patient coverage while providing true breathing movement tracings.

During our study we explored 2 different types of conductive yarn: a copper wire yarn (3 copper wires of 112 µm), further called in the article a copper yarn belt and a silver plated polymer core yarn, as a silver yarn belt respectively. The electronic circuit is simple and consists of two inverters and two capacitors combined to form an oscillating circuit. The resonance frequency of the oscillating circuit is proportional to the inductance of the belt. The electronic components are assembled on 0.3mm PCB of 8mm x 8mm using a conventional assembly technique that includes a solder paste dispensing, SMD placement, followed by solder reflowing process. The electronic is designed in such way that it requires only 3 connections to the breathing belt.

To interconnect the copper yarn belt we used standard soldering technique realized by a soldering iron. A localized contact with the soldering iron for very short period of time causes no damage to thermo-sensitive fabrics of the breathing belt. For the

silver coated polymer core yarn, the standard soldering technique does not suit, that's why we used a conductive silver filled epoxy based paste to create the electrical interconnection between the electronic and the breathing belt. The conductive paste was applied by dispensing, followed by paste curing. To prevent any damage in the belt fabrice we applied a curing temperature of 60°C. The last step of the assembly was an encapsulation of the electronics. As an encapsulant material we used a biocompatible PDMS from Dow Corning: SILASTIC® MDX4-4210 [5], suitable for a skin contact regime as a part of a surface device, and for a prolonged contact timescale of 24h to 30 days.
To conclude, we embedded electronics into textile by using the standard interconnection techniques and encapsulation without compromising the initial properties of textile (comfort, breathability, durability, resistance to washing and etc.). On the figure 1 there is an example depicted of the assembled electronic board and integrated into the respiratory belt, including the encapsulation. We assembled and electrically characterized more than 10 respiratory belts.

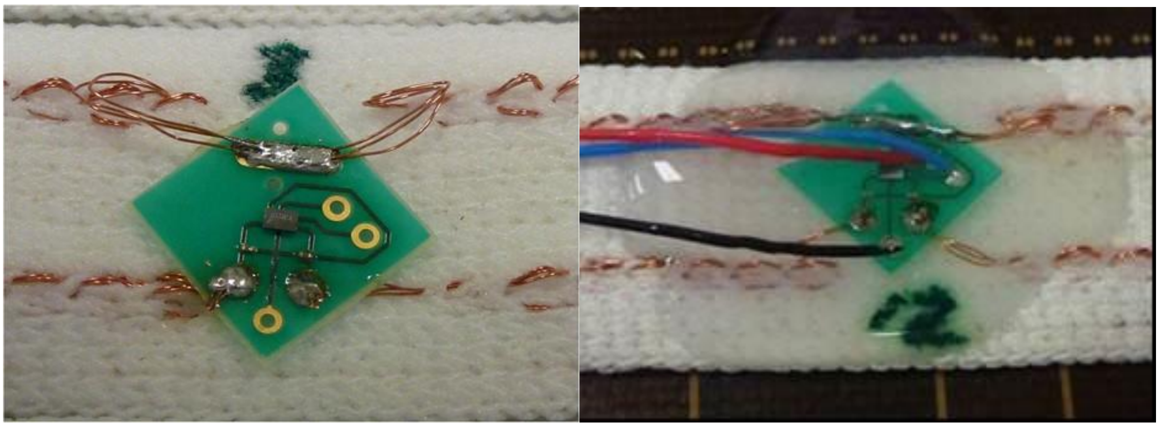

Figure 1: The breathing belt capture: electronic is electrically interconnect to the breathing belt (left) and the electronic is encapsulated and embedded on breathing belt (right).

4 Electrical characterization

First, we have characterized the conductive part of the belts (copper wire yarn and silver coated polymer core yarn) by using the LCR meter Agilent E4980A. We measured the resistance and the inductance at 2 MHz. The 2 MHz is the maximum frequency of the LCR meter, although the working frequency is slightly above 4 MHz (4.5-4.6 MHz as it will be explained later on). The conductive part of the belts are made of two conductive tracks knitted in the non-conductive fabrics of the belt with separation of 0.8 cm. For characterization we connected electrically the two conductive tracks by soldering for copper yarn and we clamped the silver yarn tracks at the first extremity. Finally, we conducted the 4-wire measurement method at the other extremity. Once the conductive part of the belt is characterized, we connected the electronics and measured the variation of the frequency versus the belt elongation from 0 to 20 cm, one measure per cm. The frequency measurement is made by an oscilloscope Tektronix TPS2024. The results of the characterization is depicted on the figure 2 and 3.

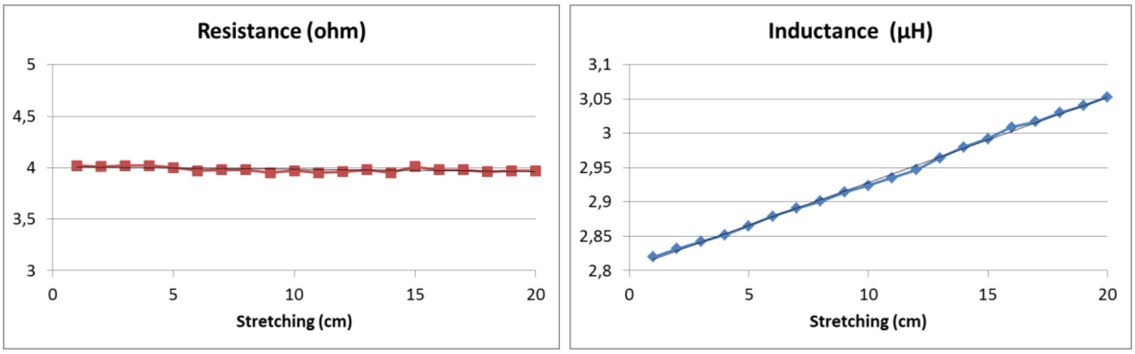

Fig. 2: Typical resistance (left) and inductance (right) of copper yarn belt versus the belt elongation.

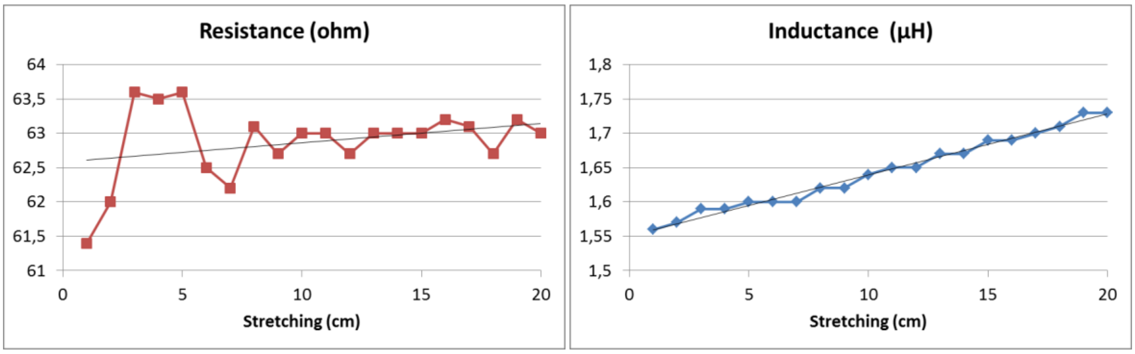

Fig. 3: Typical resistance (left) and inductance (right) of silver yarn belt versus the belt elongation.

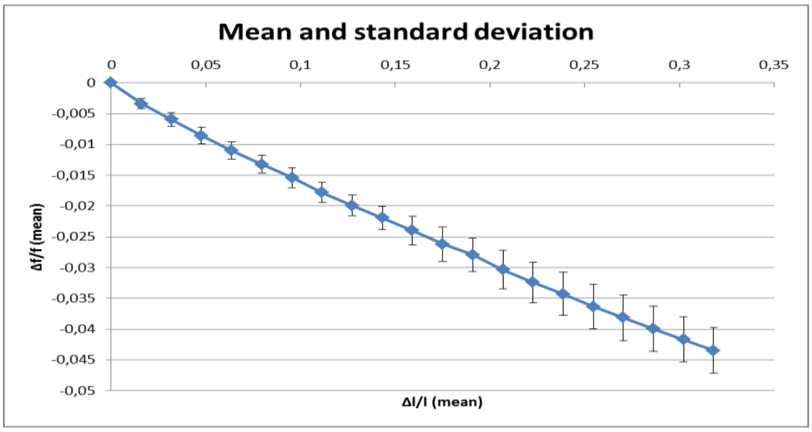

Fig. 4: Mean value and standard deviation of relative frequency change for 13 copper yarn belts versus the breathing belt relative elongation.

For the copper yarn belts, we can see that the inductance varies linearly when the belt is stretched (correlation factor is 0.998). This variation is not significant and is in the range of 0.3% to 0.4% of the total value for each centimetre of elongation, but this is sufficient to measure a variation in the frequency of the oscillator. The

resistance does not change because of the copper wires are insulated. The resonance frequency for each copper yarn belt with no elongation is in the range of 4.5 MHz and 4.6MHz. We measured frequency changed versus the belt elongation, the result of relative frequency change (mean value and 1 sigma standard deviation) versus relative belt elongation is plotted on the chart (figure 4). The respiratory belts has relatively low power consumption that is in the range of 7-8 mA.
For silver belts, the inductance is also linear but the value is weaker and the variation is less pronounced and noisier than for the copper yarn wire (typical correlation is 0.95). The resistance varies irregularly and unrepeatable, takes time to stabilize after the elongation, and differ from one belt to another. We think that there are small loops of silver along the belt which are or are not in short circuit when the belt is stretched. The loop organization is not always the same and moreover changes with the belt elongation. In fact, a bulk silver has a lower resistivity than a bulk copper (Ag=1.59×10^{-8} Ohm•m and Cu= 1.68×10^{-8} Ohm•m) but in our case what we called in the article the silver wire is actually a silver coated polymer core yarn that has resistance as we obtained from the measurements, in 20 time higher that for the copper yarn belt. Because of the higher resistance of the silver wire, the quality factor of the copper coil is much better (is 20-25 for copper versus 1-2 for silver). It has also an effect on the power consumption, the current at 3,3v is 10-11 mA for silver yarn belt versus 7-8 mA for the copper yarn belt.
Both the inductance and the resistance have an effect on the oscillator's frequency, and in case of the silver wire belt because of irregular and unrepeatable resistance variation versus the belt elongation, there is irregularly variable resonance frequency. Comparing with the copper yarn belts, the frequency is noisy and unrepeatable even on the same belt and there is no correlation between different belts. For silver belts another inductance measuring method must be used and eventually the electronic circuit must be adopted to the high and noisy resistance of the silver wire.

5 Conclusion

We built a working prototype of a wearable respiratory belt using out off-the-shelf electronic components. The prototype proofs the concept that the elongation in the respiratory belt causes by human respiration is accurate enough to monitor a human respiration. The system is intended for remote health monitoring (human respiration).

6 References

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