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SEAMLESS INTEGRATION OF TEXTILE-ELECTRONICS IN KNITTED FABRICS FOR PERSONALIZED HEALTH

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ABSTRACT

Development in the field of wearable technology is beginning to spread in society. It mainly refers to incorporated electronics devices which can be worn comfortably on the body. This paper presents an evaluation of a developed implementation of a well-known knitting technique to create textile-electronic interconnections that can be used for all kinds of electrical signals. Conductive textile wires have been produced and electrically characterised for power transmission, analogue, digital and biopotential signals. The results obtained for the different signal measurements are satisfactory and structures like the samples can be used for wearable applications. The results are encouraging for future development of a complete wearable garment with integration of only a minimum of necessary electronic components for supporting developers in research on for instance p-health application.

KEYWORDS

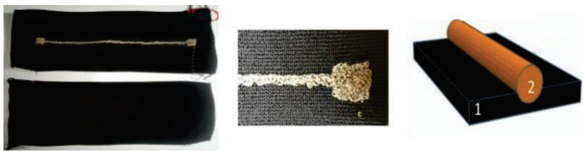
Textile-electronics, Textile knitting, Intarsia, Wearable sensing solutions, Electrical characterisation, Biomedical application.

INTRODUCTION

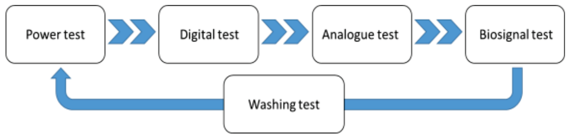
Wearable technology products are advanced elements that a person can wear during daily activity to generate, acquire, store, and transmit data. The usability of wearables has been developed for monitor productivity, identification and intervention for safety hazards or risks, and for health and wellness [1, 2]. Wearables are most commonly found in accessories made of plastics and rubber [3], but it is also possible to find textile electronics integrated in chest straps, wests and event T-shirts. One of the most important feature that wearables offer is comfort while wearing, which consequently broadens the areas of application and uses of a given sensor [4]. Developing new textile methods for embedding conductive structures in fabrics enables manufacturing of seamless interconnection between sensors, often in contact with the body and sensing electronics, would facilitate the production of functionalized garments in a textile friendly manner. Most often conductive interconnections are achieved in wearables by incorporating either wires or conductive ribbons, this approach increase the complexity of the production. Using intarsia knitting technique has allowed us to produce wholly textile conductive tracks for electrical interconnections. This text presents the technical evaluation of knitted samples for interconnections that has the potential to be used for all kind of electronic signals such as: power supply, electro-stimulation, bioelectric signal recording as well as analogue and digital communication.

MATERIALS AND METHODS

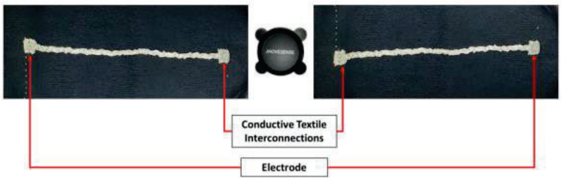
The samples were knitted on a Stoll ADF530-KI 7.2 multi-gauge with 14 gauge needle-bed, using 12 gauge needle. The materials used were: for the conductive parts a silver-coated polyamide multifilament with a yarn number of 117/1 2-ply [5], and the non-conductive parts were done with a multifilament polyester yarn with yarn number 78 dtex 72 filaments plated with a polyamide/lycra 78/78 dtex. A total of 12 pairs of knitted textile conductive wires were manufactured, having four different lengths (15, 25, 35 and 50 cm), for three different widths (2, 4, 6 needles).



a) Samples



b) Measurement protocol



c) Bioelectric signal recoding setup

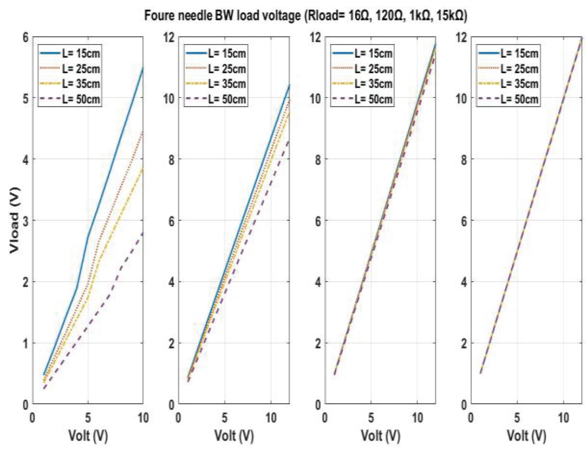
Figure 1. a) pictures of the samples, b) graphical view of the measurement protocol, c) setup for bioelectric signal recording.

Electrical characterization and performance measurement tests have been performed following the protocol indicated in Figure 1 (b). For each different length and width, the characteristics have been studied from different application domains using specific test setups described below.

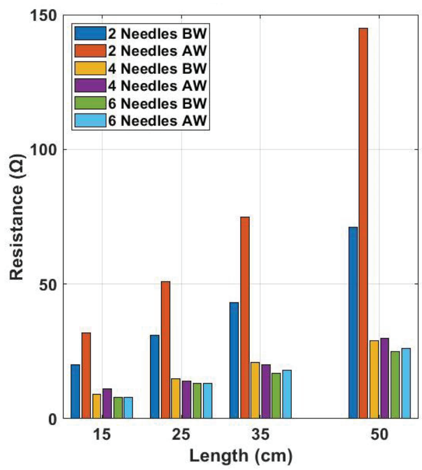
Power measurement: A single output U8002A DC power supply (Agilent, Malaysia) have been used to generate DC voltage ranging from 0 to 12 V. Two multi-meters: 34401A & 34405A (Agilent, Malaysia) have been used as voltmeter and ampere-meter. Resistors from 16 Ω to 15 kΩ have been used as a load. The samples were used in a standard closed-circuit configuration. **Digital communication**: Three different digital communication (UART, SPI, I²C) were tested with each sample, a Raspberry PI3 and Arduino UNO have been used and configured to perform the different communication as a master and slave respectively. The samples were placed interconnecting specific communication lines. A Picoscope 5442D Mixed signal oscilloscope (Pico Technology, USA) was connected in parallel to the different interconnection wire. During the transmission of data between the slave and master. Two main parameters were chosen to be checked for the three digital communications to set up the limit of application, these were: checking the behaviour of the different digital communication pins when connected to different samples during data transmission; define the transmission speed limit for each digital communication to have a correct data transmission when using the samples. **Analogue transmission**: A SDG1025 waveform generator (SIGLENT, USA) was used to generate a 1Vp-p sinusoidal waveform from 10 Hz $\leq f \leq$ 25 MHz, the MSO2012 mixed signal oscilloscope (Tektronix, USA) was used to record the readings, and a resistor of 100 Ohm has been used as a load. The samples were used in a standard closed-circuit configuration. **Bioelectric signal recording**: The Movesense device (Suunto, Finland) was used for performing one lead ECG measurement by first using the strap delivered with the Movesense device for wearable application [6], and second by replacing the strap with the samples. In order to connect the Movesense device to the samples an in-house made adapter between the device and the samples was utilised, see Figure 3. The ECG recording was obtained for a period of one minute, using a 128 Hz sampling frequency, while the volunteer remained in seated position keeping a shallow breathing paced at 10 breaths per minute. **Washing:** To get an indication on whether or not washing might influence the performance of the samples, they were washed once according to ISO standard (6330:2012 Textiles – Domestic washing and drying procedures for textile testing) [7].

RESULTS AND DISCUSSION

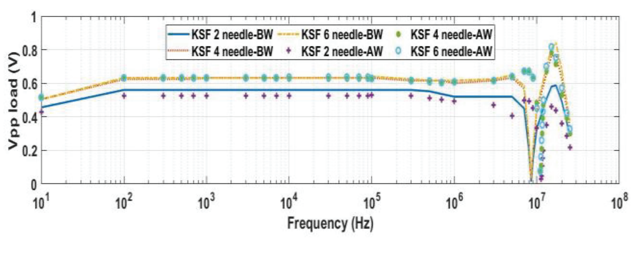
Power supply: Figure 2 (a) shows an example of the load voltage measurement, all samples present the same behaviour. The experiment shows that the resistive load voltage (or load current) tends towards linearity, for load equal or greater than 1 kΩ the length and the width do not have an impact on the measurement and the voltage drop is insignificant, and most of the power is distributed in the load. However, with a load less than 1kΩ, the load voltage drop can reach up to more than 70%. **Resistance variation:** Figure 2 (b) present the resistance measured on the samples with different lengths and widths before and after washing (BW & AW). It is clearly shown that the resistance increases with the length and that for each segment of length the measured resistance decreases with the width, the variation of resistivity varies from 4 to 104% Ω after only one wash depending on number of needles used. **Digital communication:** The result observed shows that transmitted message for all sample in the three-digital communication (SPI, I²C and UART) was correctly sent and received from both master and slave device without errors of transmission below baud limitation, where above this limitation the message start to be lost. All samples were tested and presented the same performance for the transmission information. **Analogue measurement:** Figure 2 (c) presents the voltage measured on the resistive load, before and after washing for different widths at different frequencies, the result obtained shows that neither the length nor the width impacts the frequency behaviour. All samples present the same type of functional behaviour with a slight increase in voltage up to 100 Hz, then a broad flat band up until ca 100 kHz and above that some resonant behaviour. It is apparent that the washing of the samples had an impact on the resonance frequency obtained. **Bioelectric signal recording:** Figure 2 (d) presents recordings taken with one lead ECG signal measured using, top pane: the Movesense strap; middle pane: knitted samples both without any kind of filtering and bottom pane: knitted samples after applying digital low pass filter (LPF) of 15 Hz. The ECG waveform was obtained independently of sample used for interconnection. The obtained recording with the conductive fabrics presents a very small ripple, not noticeable in the recording obtained using the Movesense strap. The signal to noise ratio calculated for the Movesense strap and knitted samples raw are 40 and 23 dB, respectively, which exhibit a good quality ECG signal.



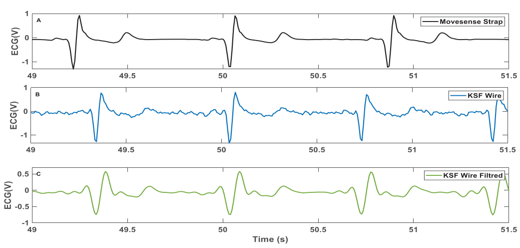
a) Power supply results



b) Resistance variation result



c) Analogue measurement results



d) Bioelectrical measurement results

Figure 2. Experimental results on knitted wire.

CONCLUSION

The purpose of this manuscript was to report on the electrical characterization and functional evaluation of the performance of knitted textile conductive wires for different electronic applications such as: power supply, bioelectric signal recording, analogue and digital communication. The resistivity of the samples is at least 10 times the resistivity of normal copper wire used for low voltage electronic applications. As expected, given the smallest cross-sectional area the two needles wire present the highest resistance compared to any other sample, independently of the length. For the rest of the widths and lengths, the different samples comply with the expected linearity showing decreasing resistance for increasing in width. With increasing length, the resistance increases accordingly. The average of the resistivity from the knitted samples is higher than the same amount of yarn interlaced only with itself due to the fact that the conductive pathways are knitted on the surface of the fabric and bound to it with the non-conductive yarn. The performance observed for power characterization shows that the length and the number of needles does not impact the current through for upper load value exceeding 1 kΩ. The results confirm the linearity expected from Ohmic conductors. All the samples work correctly independently of the communication mode tested (UART, I²C and SPI) for baud rate up to 2 Mbps without any error in the transmission line, which is enough to use the textile wire for a large digital communication application. However, we noticed that the samples are impacted by contact with human skin, so when experimenting on the different wires, the message transmission started to be erroneous, and this is because the lead wires are not protected by insulators. The analogue signal measurement showed that all samples present a filtering behaviour in the high end of a large band of frequencies applied with cut-off frequency of 8.6 MHz or 11.4 MHz depending on if the samples were washed or not. All conductive wire samples clearly present the acquired ECG waveforms including the QRST complex that allows for a straightforward detection of the R-peak. As expected, the signal quality of the recording is inferior for the knitted fabrics. In general, the bioelectric signals recorded is similar to other reported in the literature [8]. This study has been designed from a research perspective, focusing mainly on measurement performance. After the evaluation, the obtained results and the calculated parameters, we find the performance of the conductive textile wire satisfactory for the intended purpose of this development. Integrating these knitted wires is encouraging for the development of a complete wearable garment that adds only necessary electronic components for supporting developers in research on p-health application.

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