Textile electrode characterization: dependencies in the skin-clothing-electrode interface

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Abstract. Given the advances in the technology known as smart textiles, the use of textile electrodes is more and more common. However this kind of electrodes presents some differences regarding the standard ones as the Ag-AgCl electrodes. Therefore to characterize them as best as possible is required. In order to make the characterization reproducible and repetitive, a skin dummy made of agar-agar and a standardized measurement set-up is used in this article. Thus, some dependencies in the skin-electrode interface are described. These dependencies are related to the surface of the textile electrode, the conductive material and the applied pressure. Furthermore, the dependencies on clothing in the skin-textile electrode interface are also analyzed. Thus, based on some parameters such as textile material, width and number of layers, the behavior of the interface made up by the skin, the textile electrode and clothing is depicted.

1. Introduction
As described in [1], using smart textiles for several medical and healthcare applications is becoming more common. One of these applications are textile electrodes. This kind of electrodes can be used to monitoring any physiological parameter in different places such as a hospital, an airline seat or even inside a car. The main reasons could be that the textile electrodes not only are comfortable for the user but also capable of monitoring during long-term because seem not be irritation problems unlike the standard electrodes with hydrogel [2].

However, textile electrodes also show some drawbacks. As there is no hydrogel, the problems related to the lack of contact increase. Furthermore, several aspects of the theory of electrodes and the skin-electrode interface should be revised deeply. Therefore, based on previous studies accomplished by several authors such as [3], [4] y [5], the aim of this paper is to contribute a little bit in the field of the textile electrode characterization.

2. Methods
Based on the measurement set-up described in [3] and shown in figure 1(a), a set of tests are done to check the dependencies on the skin-textile electrode interface impedance, \( Z_{\text{skin-textile}} \). These dependencies are related to the conductive material of the textile electrode, its contact surface and also the pressure applied on it and, finally, the interaction between the textile electrode and clothing. In order to characterize the textile electrodes, a skin dummy with a conductivity, \( \sigma \), of \( 1 \cdot 10^{-3} \mu S \cdot \text{cm}^{-1} \), is made. This conductivity matches the wet skin conductivity at a frequency of
100 kHz, [6]. The mentioned skin dummy is made of a 5% solution of agar in a saline medium, i.e. distilled water with sodium chloride (NaCl). On this agar phantom, two electrodes are placed in a 10-cm distance. Whereas one of these electrodes is used as reference electrode, the other electrode is the textile electrode under study. It is worth mentioning that the reference electrode is made of platinum and its surface is 3 cm x 5 cm. Later, 2-wire measurements are done using the HP4192A device in ratio mode (A(dB) - B(dB)) and a front-end board. The measured impedance could be evaluated as a function of not only the skin-dummy impedance but also the impedances related to the skin-textile electrode interface and the skin-reference electrode interface, i.e. 

\[ Z_{\text{meas}} = Z_{\text{skin-textile}} + Z_{\text{skin}} + Z_{\text{skin-ref}}. \]

Therefore, assuming that \( Z_{\text{skin}} \) and \( Z_{\text{skin-ref}} \) are non-variant over the tests, the differences between measurements are just related to the skin-textile electrode interface impedance, \( Z_{\text{skin-textile}} \). However, this method works only if the stability of the skin-dummy impedance can be assured. As shown figure 1(b), the in-frequency and in-time stability of the agar phantom can only be assured at the first six hours because of liquid loss. Thus, there are some options. On one hand, it is possible to make other skin dummy of any material which retain better the water, e.g. graphite instead of sodium chloride as suggested in [7]. On the other hand, it is also possible to use a different skin dummy made of agar for each test. In this case, a new agar phantom is used for each test. Finally, there is an additional option when measuring electrodes with an interposed fabric layer, which consist in wrapping the agar with a thin polyethylene layer.

![Figure 1](image1.png)

**Figure 1:** (a) Set-up of measurements. The skin-dummy made of agar has a volume of 280 cm\(^3\) (14 cm x 10 cm x 2 cm) and the distance between electrodes is 10 cm. (b) In-time stability of the agar phantom.

### 3. Results & Discussion

#### 3.1. Dependencies on conductive material

To check the dependencies regarding the conductive material which the textile electrode is made of, the set-up is used to measure a set of textile electrodes. These electrodes have the same area, 3.5 cm x 3.5 cm, but different manufacturing, i.e. they are made of different conductive materials or made using different techniques. The mentioned electrodes are made of materials manufactured by A-Jin Electron Company. In this case, the naming of the selected products is W-290-BG, W-290-Silver, M-200-PCNR y WD-270-PCN(ATU). These products are made using different plating methods: Au, Ag, Cu+Ni+Carbon and Ni+Cu+Polyurethane(PU), respectively. An in-depth description of the materials can be looked up in the company website.

As shown figure 2(a), above a frequency of 10 kHz, all values of the measured impedance seem to match regardless of the textile electrode used. On the other hand, for lower frequencies, this fact does not happen. Thus, it appears that at frequencies above 10 kHz, the skin-electrode
interface is not dependent on conductive material. For this reason, other factors as the electrode surface and the pressure applied are checked.

3.2. Dependencies on pressure

Regarding to above results, the dependencies on pressure are tested. Applying a set of weights over the same textile electrode, the pressure is changed. It is worth mentioning that the electrode is based on the A-Jin Electron product named W-290-GG and its surface is 3.5 cm x 3.5 cm. As expected, the more pressure is applied, the lower the measured impedance, see figure 2(b). The main reason is because of the air gap between the textile electrode and the skin dummy is lower. Thus, whereas the capacitive component of the skin-electrode interface, \( C_E \), increases, the skin-electrode impedance is reduced as can be checked in the equation described in [5],

\[
Z_{\text{electrode}} = R_{sc} + \frac{R_s}{1 + j\omega R_s C_s} + R_{EL} + \frac{R_E}{1 + j\omega R_E C_E}.
\]

Note that for weights above 0.75 kg, the variations between the measured impedances are lower because the air gap has been almost completely minimized.

3.3. Dependencies on electrode surface

To test the dependencies on clothing, four electrodes with the same conductive material but different surfaces are used. The tested surfaces are A, 2A, 3A and 4A, where A is an area of 3.5 cm x 3.5 cm. It is worth mentioning that the textile electrode is made of a material which belongs to Statex Company and is named MedTex P-130.

As shown figure 3(a), as larger the surface of the electrode, lower the measured impedance. This fits theory and the aforementioned equation because as larger the surface, more capacitance, \( C_E \), and as mentioned previously, the skin-electrode impedance, \( Z_{\text{electrode}} \), becomes lower.

3.4. Dependencies on clothing

From the electrode with a surface 2A, 3.5 cm x 7 cm, and made of the product called MedTex P-130, several measurements are done placing, previously, several clothing between the agar phantom and the textile electrode. The reason is to simulate the situation where textile electrodes are placed in a seat, e.g. in automotive applications. The several clothing tested are a thin piece of 100% cotton, a thick piece of 100% cotton and also a very thick piece of 100% acrylic. Furthermore, placing two layers is also tested, i.e. over the thick piece of cotton, the thin piece of cotton as much as the very thick piece of acrylic are tested.

Of course the behavior becomes purely capacitive, with a measured capacitance which depends inversely on the fabric thickness. The values of the measured capacitance are \( 2.29 \cdot 10^{-10} \)
Figure 3: (a) Dependencies on Electrode Surface. (b) Dependence of the measurement error on electrode mismatch.

F, $9.93 \times 10^{-11}$ F and $6.27 \times 10^{-11}$ F for the thin cotton piece, the thick cotton and the double layer of cotton pieces, respectively. The result is not only a huge electrode impedance but a high mismatch between electrodes. The dependence of the measurement error on the ratio between the electrode mismatch and the measurement system input impedance is known. Although in most applications this effect is attenuated by the fact that at medium-high frequencies the mismatch is low, in this case remains high at frequencies where the system input impedance has decreased due to the system input capacitance as shown figure 3(b). The solutions are then on the electronics side (driven guards, distributed front-ends, CMFB). All these issues cause that the capacitive component of the skin-electrode interface, $C_E$, becomes non relevant.

4. Conclusion

By this paper, a further step is expected to have done in the textile electrode characterization. Although a better phantom with low liquid loss is required for a long-term monitoring, characterizing properly textile electrodes with a phantom made of agar seems to be a good choice. The first tests show that at frequencies above 10 kHz, the electrode surface and the applied pressure are parameters more decisive than the conductive material. Furthermore, in case of there is no direct contact between the skin and the textile electrode, injecting at higher frequencies, above 100 kHz, is recommended to minimize the high value of the skin-clothing-electrode interface impedance. Nevertheless, the effects of electrode mismatch can become worse at these frequencies.

References

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