Development of E-textile electrodes: washability and mechanical stresses

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Abstract. E-textile, as a growing field in the current era, gained a lot of attention and currently, some tremendous outcomes of these fields can be seen. They are being used in specific functional requirements depending on application types in various fields including medicals, military, safety and leisure, etc. E-textile structures can contain various elements including wearable motherboards, sensors, electrodes, antennas, actuators, and power sources. These components are integrated with available textile materials according to their usage requirements. For the use of e-textiles in daily life and to make them popular with consumers, these products must be reliable and reusable for a prolonged time. The e-textile market has developed rapidly in the past few years especially in the applications of wireless communication, monitoring, gaming, and data collection. Among these applications, products related to health monitoring gained attraction due to their importance in diagnosing the real-time health problems of the customers. The current study is focused on wearable ECG electrodes to make them reliable and washable. Embroidered electrodes are prepared and washed multiple times to check the washing impact on ECG signals performance. Available mechanical tests are performed to predict equivalent damage as during washing. Hence these predictions, in the coming future, can be used to check, analyse and predict the washability of e-textile prototypes at different stages of manufacturing without actually washing of samples for a multiple numbers of wash cycles.

1. Introduction

In the current era of the world, we are using a large number of smart devices in our daily life. These devices can be of different types ranging from mobile phones to smart wearing garments. The conventional textile can be converted into smart textile by integrating some state-of-the-art user-defined product on it. These smart textile systems can be used for performing various tasks including detection and monitoring from outside environment and giving responses or information to a centralized database. These e-textile systems can also be used for personal human data monitoring based on medical, sports or any other sort of purposes. These products are penetrating in our daily life now days depending on their usage and output we received [1].
For the use of e-textiles in daily life and to make them popular with consumers, these products have to be reliable and reusable for a longer period time. The E-textile market has developed rapidly in past few years especially in the applications of wireless communication, monitoring, gaming, and data collection. Among these applications, products related to health monitoring gained attraction due to their importance in diagnosing the real-time health problems of the customers. One common example is real-time ECG monitoring for the intensive care customers and recording their data in the central data system [2][4]. A wide range of products covering these applications is available in developed markets. But these products lacks in terms of reliability and washability for their multiple usages during a given specific lifetime. To make these applications useful and adoptable by the general public, they should be reliable and reusable with acceptable results in general household conditions [3].

Different studies have been published based on the washability of electronic textile components. Dabby et al [5] examined the washability of their developed wearable electronic sensors system for ECG and heart rate measurements. They claimed that all samples’ results were still acceptable after 10 washing cycles and they were damaged after completing 25 washing cycles. They concluded in their research that severe stretching and twisting forces spoiled the samples during the wash process. Chow et al [6] embedded textile pressure sensors into smart fitness socks with the help of conductive threads. Then these socks were washed for 15 wash cycles. Wash results revealed that conductive threads increased their resistance significantly which reduced the performance of sensors in socks. Molla et al [7] washed these samples containing solder joints, LEDs and traces in a household washing machine. Change of their resistance and delamination at different points after 10 washing cycles were discussed. They concluded that the failure prospect was higher on solder joints near LED samples.

The current study is focused on wearable ECG electrodes to make them reliable and washable. Different types of embroidered electrodes are prepared and washed multiple times to check the washing impact on ECG signals. In our previous studies, the wash cycle in a normal household washing machine was analysed. These analyses were used to find possible available mechanical actions undergone during the washing process. Afterwards, these mechanical actions were performed separately on these embroidered ECG electrodes. The results of these mechanical tests were then used to predict the wash damage without washing of these samples. Hence these predictions, in the coming future, can be used to check, analyse and predict the washability of e-textile prototypes at different stages of manufacturing without actually washing the samples for a multiple number of wash cycles. These steps can be helpful for manufacturing organizations especially electronic companies that are working on parts manufacturing of e-textile products but don’t have strong experience in textile fields.

2. Material and Methods
Embroidered electrodes, made by embroidery machines using conductive silver-coated polyamide yarn, were used in this experiment (Figure 1) [8]. Connection yarns are used to connect these electrodes with pressor snap buttons. These buttons were made of pure conductive metals and do not impact the output results. Connection yarns have been tested separately with different types of protection on them. This practice was performed to check connection yarn’s damage and to reduce their destruction as much as possible during the wash process. For embroidered electrodes, Shieldtex 117/17-2 ply HCB yarn was used. The same yarn was used as connection threads.

![Figure 1. ECG electrodes.](image)

Produced skin electrodes output was recorded in terms of ECG signals. ECG signals were recorded
with the help of SHIELD-EKG-EMG (OLIMEX) processing board and ARDUINO software [4]. These signals were then processed on MATLAB. These signals were filtered on the Butterworth passband and notch filter. A notch filter was used to remove 50 Hz power line noises. Linear resistance of connection threads was recorded in terms of an ohm per unit length and change in resistance was calculated. Agilent 34401A digital multi meter (Figure 2) was used to measure the linear resistance of these samples. The surface resistance of conductive electrodes was measured with the help of four probe surface resistance measurement devices. Ossila four probe surface resistance device was used for this experiment.

![Figure 2. Testing equipment.](image)

Front loading washing machine MIELE W3240 (Figure 2) was used for the washing of these samples. This is one of the most commonly used household washing machines. The commercial washing machine was preferred over laboratory washing machines because ultimately these e-textile products will be used in normal household machines by customers. Similarly, commercial detergent was preferred on standard detergent for better simulation with normal usage of these products. All washing conditions were maintained as described in ISO 6330 washing procedure standards, to obtain standard repetition of these results in the future. Mild washing process (silk) with 400 rpm tumbling speed was used in all experiments.

Martindale abrasion test was performed on a separate set of each sample. Change in resistance was recorded after abrasion cycles. A total of 10000 abrasion cycles were performed for each set of samples. Martindale abrasion tester, by “James H. Heals & Co Ltd” with 9 K Па load on samples, was used in these experiments (Figure 2).

### 3. Results and discussion

#### 3.1. Washing

All the electrodes and connection yarns were washed up to 50 washing cycles. Changes in linear resistance from original resistance for connection threads were calculated (Figure 3). Connection yarn was washed in three different ways including connection yarns without any protection on it, connection yarns with TPU protection placed on it and connection yarn with simple yarn stitched above connection yarn forming a bridge to protect the inner material from a different type of damages during washing.

Figure 3 shows the results of each type of connection yarns after washing. Connection yarns protected with simple yarn showed the least damage as compared to the other two types. The ratio of change in resistance with original resistance remains near 1 after 40 number of wash cycles in case of simple yarn protection. Whereas, it goes higher in the other two types of connection yarns experimented here. Hence embroidered ECG electrodes were prepared to protect connection yarns with simple yarns on it. These electrodes were then washed up to 50 washing cycles and change in linear resistance was measured.

Figure 4 shows the results of ECG electrodes after 50 washing cycles. The ratio of change in resistance to original resistance was under two for 15 numbers of washing cycles and goes above 3 after 50 numbers of washing cycles.
3.2. ECG Measurement

ECG signals were recorded before and after fifty washing cycles with the help of SHIELD- EKG-EMG (OLIMEX) device. Figure 5 shows the ECG plots before and after washing cycles. These curves are plotted with the help of MATLAB. The sampling frequency was 250 Hz. These signals were filtered on the Butterworth passband and notch filter. A notch filter was used to remove 50 Hz power line noises.

Figure 5. ECG of embroidered electrodes.

ECG plots are still under acceptable conditions after fifty wash cycles. Signal to noise ratio before washing was 39.41 dB and after 50 washes it was 21.27 dB. As a silver coating on conductive yarn...
surface was damaged during wash cycles, this removal increases the electrical resistance of conductive yarn. This phenomenon is also clear from linear electrical resistance measurement where the ratio of change in resistance to the original resistance is increased almost three times after fifty number of wash cycles.

3.3. Martindale Abrasion Test
A separate set of samples for ECG electrodes was used to perform Martindale abrasion tests. 10000 abrasion cycles were performed on four sets of samples and change in resistance was noted. Surface resistance was increased about two times after exercising 10000 abrasion cycles (Figure 6). Change of resistance is observed to be linear for these abrasion cycles experiment. Figure 7 explains the relationship between damages done by washing and abrasion cycles. We can co-relate these damages with each other and in future, this can be used to predict the damages that washing can create in e-textile prototypes without actually washing samples. In the current experiment, we can predict that damage occurred by 10 wash cycles is equivalent to damage that was observed by 10000 abrasion cycles. This is an initial prediction and it can be validated by further experiments and also by increasing the number of samples.

Figure 6. Martindale Abrasion test.

Figure 7. Comparison of washing and abrasion cycles.

4. Conclusion
This research was performed to enhance the use of flexible, easy to use and user-friendly skin electrodes for real time ECG measurement. But these products should be reliable and washable. These electrodes
were washed up to 50 washing cycles to check the impact of washing on these samples. Equivalent mechanical stresses were performed on these samples to predict the resistance to wash damage without washing the samples in actual wash conditions. After these experiments, we can predict the relationship between damages by washing and abrasion tests. These mechanical tests can be used to prepare the e-textile prototypes by electronics experts without the actual washing samples to predict the lifespan and quality of outcomes from these samples.

In current consideration, we can predict that damage by 10 wash cycles is equivalent to damage occurred by approximately 10000 abrasion cycles. Although mechanical damage is not the only one that occurs during the wash process. There can be other damages such as chemical, temperature, and water itself that can affect the e-textile performance during the wash process, however the mechanical damage remains one of the most impacting forces in the wash process. All other forces are being investigated on electrodes and other e-textile prototypes and will be published separately.

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