Evaluating textile-based ECG collection for Continuous Remote Atrial Fibrillation Monitoring

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Significance of the Problem

This study addresses the problem of continuous heart rate monitoring to detect Atrial Fibrillation (AF) by developing and scientifically testing textile-based ECG technology that can be embedded in clothing. Our innovative and interdisciplinary approach combines textile, engineering, and medical expertise. Atrial fibrillation is the most common arrhythmia in adults and is associated with high morbidity and mortality, including stroke, dementia, heart failure, and death, affecting one in four adults over the age of 40 (Lloyd-Jones, et al 2004). Most adults, particularly those with hypertension, are at increased risk of AF (Lloyd-Jones, et al. 2004, January et al. 2014). AF is often asymptomatic and in its intermittent form is even more difficult to diagnose. In particular, a higher burden of AF is associated with higher risk of stroke (Go, et al. 2018). As such, the use of continuous heart rate monitoring will allow diagnosing AF, assessing AF burden before treatment, and assessing AF control after treatment.

The development of highly-reliable wearable technologies for continuous heartrate monitoring is likely to have a significant impact in the diagnosis and management of AF (Pagola, et al 2018). A number of monitoring techniques have recently been introduced for detection of AF, including: insertable cardiac monitors (ICMs), smartphone applications (Agu, et al. 2013), wearables such as smartwatches (Phan et al. 2015) and textiles with ECG monitoring capabilities (Ankhili, et al. 2018). Textile-based sensing devices are particularly appropriate because the ubiquitous nature of textiles and clothing gives a high potential for comfort and thus wearing compliance. However, there are limitations in the current textile-based sensing environment and a viable medical-grade version has yet to be discovered.

The specific limitation we have addressed through this research is the ability to achieve medical-grade ECG through textile-based sensing systems (Teferra, et al. 2019). The objective of this experiment was to determine the relationship between a) conductive thread b) ECG electrode resistance and c) clarity of EKG readings (Figure 1).

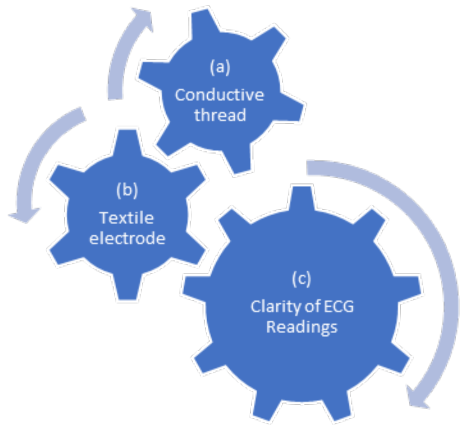


Figure 1: Diagram of study objectives

Defining and understanding the elements of and interaction between the components of textile-based ECG readings will contribute to discovering the ideal thread-to-patch configuration for highly-reliable textile-based wearable technology for continuous heartrate monitoring (Shaikh, et al. 2015).

We hypothesized that reducing the resistance in conductive threads and EKG patches would improve the clarity of EKG readings (Figure 2) and reduce the amount of observable interference. To evaluate the hypothesis, tests were performed to measure a) the effect of the material that our conductive threading was felt onto and b) the effect of the size of the felted circle.

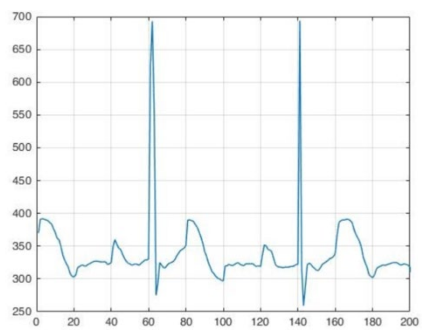


Figure 2: Example of EKG reading

Method

Eight samples were prepared of plain woven fabric: two polyester, two cotton, and four poly/cotton. With a Baby lock embellisher, areas of 1cm X 1cm and 2cm X 2cm were machine felted using nylon and silver roving (Figure 3).

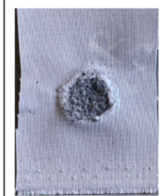
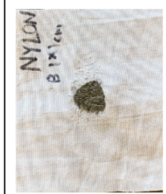
	Type A	Type B	Type C	Type D
Image				
Base Composition	100% polyester, 45° twill, one side brushed	100% cotton, plain weave	80% polyester 20% cotton, plain weave	100% nylon, plain unbalanced weave
Conductive Roving	Sparkfun Conductive Stainless Fiber 316L			
Conductive Yarn Lead	Bekaert Bekinox VN12/8x275/100S 316L			

Figure 3: Composition of all felted electrodes

Bekaert conductive thread measuring 14 inches was felted onto each area (Figure 4) . A Fluke multimeter was used to measure the resistance. A strict testing protocol was observed.

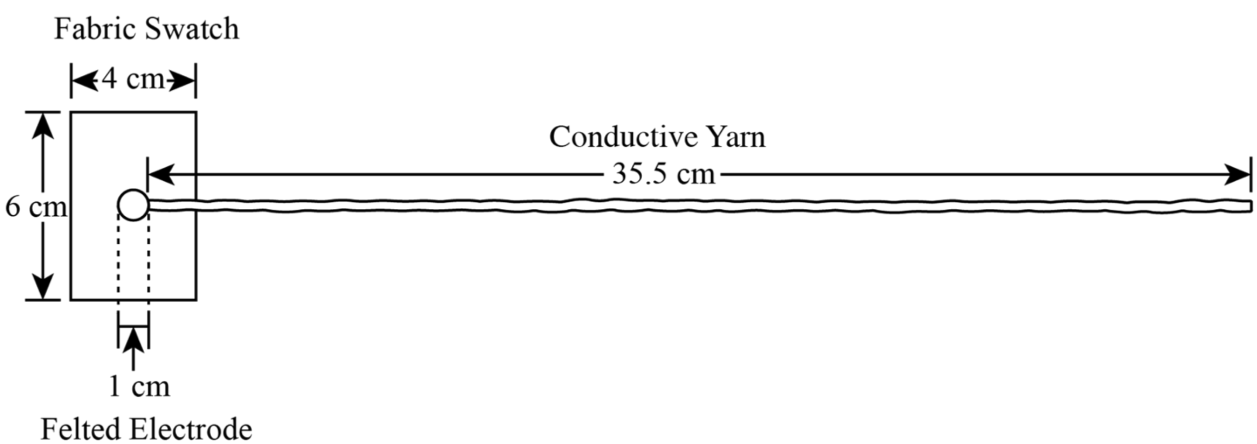


Figure 4: Configuration of each textile electrode

Throughout all testing, the ECG patch and conductive thread laid flat on a non-conductive fabric. One lead of the multimeter was placed on the end of the conductive thread and the other lead was placed on the felted patch. Four different trials were conducted for each patch, to ensure accuracy of data. Between trials, the patch probe was moved around the felted circle to take readings from the front, center, back, and edge of the felted circles (Figure 4).

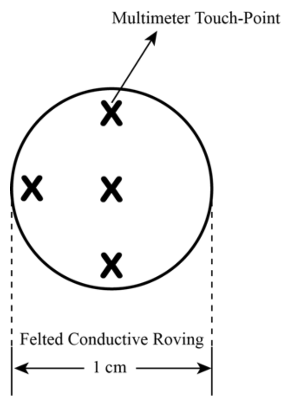


Figure 5: Multimeter touch points

All readings were taken in ohms (Ω). To further increase the reliability of results, three patches of each configuration were made and labeled as the right, left, and bottom, as they would be on a smart shirt. The readings from all patches were then tested and averaged (Table 1).

Fabric	Size	Right Patch Average Resistance (Ω)	Left Patch Average Resistance (Ω)	Bottom Patch Average Resistance (Ω)	Average Resistance of Right, Left, and Bottom Patches (Ω)
Type A	1x1cm	2.55	2.50	2.63	2.56 (0.07)
	2x2cm	3.73	2.83	2.73	3.09 (0.55)
Type B	1x1cm	2.43	2.45	2.35	2.41 (0.05)
	2x2cm	2.85	2.65	2.50	2.67 (0.18)
Type C	1x1cm	2.50	2.40	2.63	2.51 (0.12)
	2x2cm	3.10	3.18	2.50	2.93 (0.37)
Type D	1x1cm	2.48	2.38	2.35	2.40 (0.07)
	2x2cm	2.63	2.48	2.63	2.58 (0.09)

Table 1: Average resistance for each electrode type

Results, Conclusion, Future Study

The four lowest average conductivity readings between the right, left, and bottom patches are 1 cm X 1 cm. The difference between largest (2.56 ohms in the polyester 1x1 patch) and the smallest (2.4 ohms in the nylon 1x1 patch) was 0.16 ohms, which is considered insignificant for our purposes. It should also be noted that none of the 2x2 patches deferred from the results of the 1x1 patches by more than 1 ohm (Figure 6).

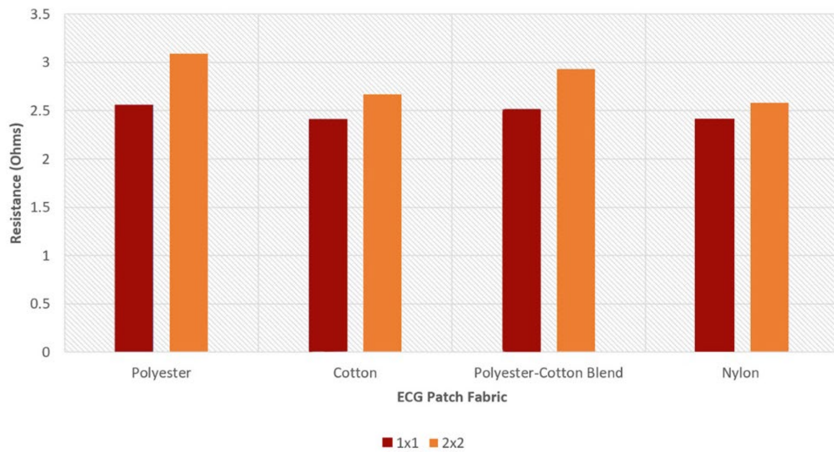


Figure 6: Graph of resistance in Ohms compared to EKG patch size and material

While this is also not a large amount, the consistency of the 1x1 inch patches testing over the 2x2 inch patches is the reason behind our conclusion that the 1x1 inch patches are more suitable for use in the smart shirt. In addition, there was no observable pattern between the patches made of different fabrics.

The potential to shorten reaction time to AF by enabling patients to comfortably and continuously wear a medical-grade textile-based ECG monitoring system can be realized through understanding the behavior of conductive textiles. Our results indicate that a) the type of textile the conductive roving was felt onto did not significantly influence the thread resistance, and b) that there was a direct variation between the diameter of the conductively felted patch and resistance. Future study will build on these results to optimize the conductive paths toward the Printed Circuit Board (PCB), exploring the volume of signal capture and accuracy of transmission.

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