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Reliability of Electrocardiogram Signals during Feature Extraction Stage for Smart Textile Shirts

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Reliability of Electrocardiogram Signals during Feature Extraction Stage for Smart Textile Shirts

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Abstract. Wearable smart textiles have garnered significant interest due to their high flexibility, reusability, convenience and ability to work on home-based, real-life and real-time monitoring. Wearable smart textiles are shirts with inbuilt textile sensors that enable electrocardiogram (ECG) data to be collected more comfortably and smoothly outside the laboratory and clinical environment for a continuous and longer duration for ECG data collection. However, the existing ECG wearable smart textile main challenge is maintaining the quality and reliability of data across multiple wearable smart textile shirts. Therefore, this research analyses the capability of ECG morphology during Feature Extraction stages for different wearable smart textile shirts. This paper reports the experiment conducted on eleven healthy volunteers, either wearing the Hexoskin smart shirt or the HeartIn Fit shirt or both. ECG data were recorded while they are doing normal daily routine activities for at least 45 minutes. The study demonstrates a significant possibility of reliability in Feature Extraction stages at different time instances among subject and wearable smart textiles shirts. With R peaks average between 0.543 to 1.194 mV and R-R interval average between 0.625 to 0.799 seconds, the study concludes that both wearable smart textiles do not significantly differ in Feature Extraction stages. Thus, both wearable smart textiles gave a significant result, although both are affected by their wearer's motion artefacts during the shifting of body postures and the wearer's body physical states. Furthermore, the ECG morphology in this study has yielded a promising result in real life and as on-the-go ECG smart textile biometric readiness for future explorations.

Keywords: Feature Extraction, ECG, wearable, smart textile.

1. Introduction

Human beings are unique, and all humans are like a library on the move of limitless biometric modalities. Furthermore, human bio-signals, such as the Electrocardiogram (ECG), give each individual more accessible and reliable identification forms and may be utilised in everyday life [1]–[3]. In the meantime, developments in the textile sector have spurred a drastic change, leading to a new wave of innovation. Wearable technology, smart materials, and data integration will significantly impact what people wear and accelerate the fundamental shift in textile innovation. At the same time, human biometric revolutions of new wearable smart textile applications have resulted from the combining of biometric, ECG, and textile technologies.

An ECG is a depiction of an electric cardiac activity that quantifies muscle contractions. Several personal characteristics, including age, sex, fitness and genetics, have been deemed to impact the contractions of the cardiac muscles. While general cardiac activities in healthy human beings are the same, certain features may cause considerable variations. As shown in the earliest explorations by Kyoso & Uchiyama [4] and Biel *et al*. [5], this irregularity of ECG morphology between the different individuals can instantly identify a person. Subsequently, ECG has since been extensively explored as identification of human biometrics [2], [6].

Meanwhile, wearable smart textile technology, on the other hand, is becoming an increasingly important tool. Due to its enormous size, weight, and mobility difficulty, the device has limited use until it becomes far smaller and portable. These advanced technologies have allowed it to escape the laboratory settings or clinical environment's that usually puts a limit on recording patients data. A wearable smart textile that measures physiological functions correctly and constantly during the workout, training or actual typical day-to-day activities while less affecting movement mechanics of its use might be a significant asset [7]–[9].

The HeartIn Fit shirt and the Hexoskin smart textile shirt were among the wearables launched to the market, promising to assess various physiological parameters. Each smart textile comes with a textile sensor embedded and closely fit against the wearer's body. Users may watch each smart textile recording through a specific application on a smart device in real-time. Moreover, both wearable smart textiles are intended to collect a wide range of physiological biometric information. Besides, They can track the intensity of physical activity on the move by integrating heart rate and ECG. Furthermore, despite the potential benefits of combining this data, the Hexoskin smart textile has a number of intriguing research that strengthens its data-gathering capabilities. [10]–[12]. Both smart textiles that can be worn have not yet been assessed together on a fair playing field. This research aimed to test and monitor the acquisition capabilities of HeartIn Fit and Hexoskin wearable smart textiles on similar ground, with an emphasis on the QRS Feature Extraction stage.

2. Methods

Study work in [8] stated that a t-shirt style wearable ECG device would be acceptable for daily monitoring and long-term use among persons who engage in a lot of physical activity. Furthermore, The quality of the ECG signal was more inferior in the state of walking than in the form of rest, as shown by Fouassier *et al*. in [7]. Besides that, researchers in [7], [13] also suggested that Smart textiles should be tested for ECG monitoring over a longer time to determine their performance and reliability.[11], [14].

Meanwhile, the Hexoskin Smart shirt in Figure 1(a) is one of the commercially available ECG smart textiles shirts on the market, with many studies on its potential and performance. Although the smart textile can acquire ECG patterns, most published research employs this intriguing smart textile to measure other modalities such as heart rate and breathing rate [10], [15], [16]. On the other hand, In Figure 1(b), HeartIn Fit smart textile shirt was another intriguing wearable device that is able to capture data on the ECG morphology available to users worldwide. Both shirts were used as part of this study.

Furthermore, both Hexoskin and HeartIn smart textile were chosen for this research mainly because of their portable characteristics and capable of collecting ECG signals with a single lead textile ECG electrode. Both solutions can acquire and show ECG waveforms constantly in real-time. Besides that, this smart textile is re-washable for improved hygiene, has always been available to the global consumer market, and data can be analysed and monitored remotely.

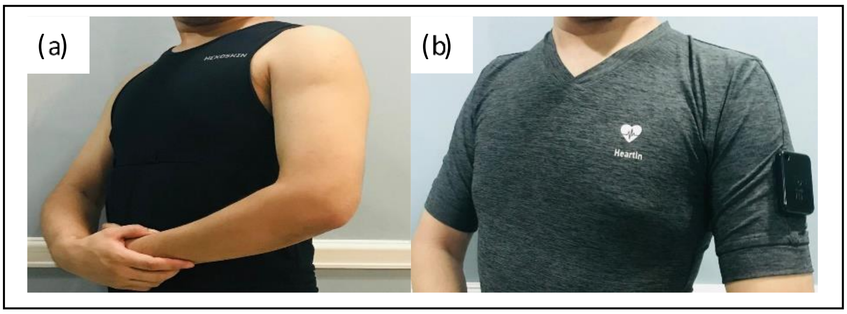

Figure 1. (a). Hexoskin Smart Shirt. (b). HeartIn Fit Shirt.

Therefore, to determine the reliability of wearable Hexoskin smart textile and HeartIn Fit smart textile as data acquisition on ECG biometric on the go. An exciting scale of experiment was set up to test and compare the capability and the reliability of both wearable smart textile in Feature Extraction stages for ECG acquisition in a real-life setting as well as on the go biometric acquisition.

This study shows the peak detection results from the HeartIn wearable shirt and the peak detection in the established textile shirt of Hexoskin, which had extensively supported by plenty of studies [10]–[12]. Furthermore, eleven healthy non-smoking people, eight male and three female, aged between 25 and 61, participated in this investigation. No cardiovascular or orthopaedic problems were reported in all participants that stopped them from doing their usual daily human activity. A full verbal explanation of the experimental methods and potential hazards has been provided to participants. The smart textile is used for at least 45 minutes with every participant throughout their everyday activities. For this study, six people wore the Hexoskin smart textile shirt, three wore the HeartIn Fit, and two others wore both smart shirts at separate times.

3. ECG Feature Extraction in wearable smart textile

Figure 2(a) shows the QRS Subject 1 taken for 45 minutes each in the morning, evening and night within one day of acquisition while doing regular daily life routine in their desired environment. Meanwhile, Figure 2(b) proved that the QRS retain the same pattern after three days, after a week, after two weeks and even retain the same patterns of QRS after three months of Subject 1 taken by wearing the smart textile.

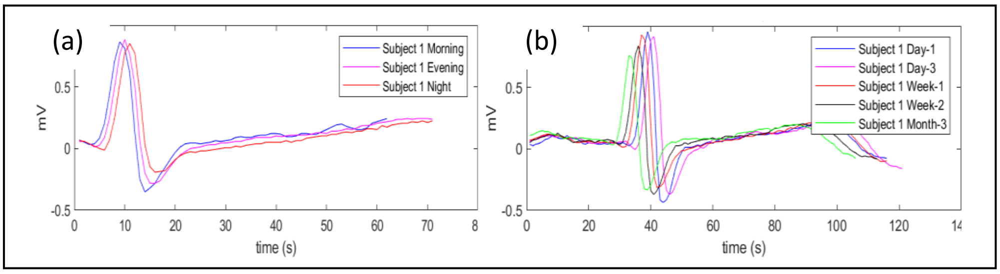

Figure 2. (a). QRS subject in one day. (b). QRS subject in three month

Figure 3(a) and (b) showed the ECG morphology of Subject 4 taken three months apart wearing the smart textile. The morphology of Subject 4 retains almost the same pattern even after a three-month interval.

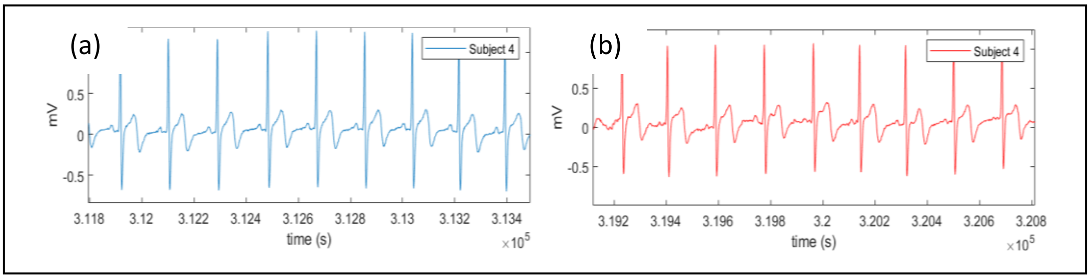

Figure 3. (a). ECG Subject 4 month-1. (b). ECG Subject 4 month-3

Subsequently, Table 1 shows the R peaks and R-R interval values and their standard deviation of subjects data. All the values are based on a four-beat heart rate sampled from the subject wearing Hexoskin smart textile.

Table 1. R-Peak and RR interval of Subject with Hexoskin Smart textile

Subject Number	R-Peaks (mV)	R std (mV)	RR interval (s)	RR std (s)
Subject 1	1.1392	0.0292	0.7988	0.0289
Subject 4	1.1942	0.0294	0.6680	0.0087
Subject 6	0.7526	0.0446	0.7881	0.0255
Subject 7	0.9203	0.0317	0.6660	0.0192
Subject 8	0.5427	0.0301	0.6309	0.0059
Subject 9	1.0048	0.0339	0.7207	0.0090
Subject 10	0.8768	0.0470	0.6289	0.0000
Subject 11	1.2160	0.0326	0.6250	0.0074

Next in Figure 4. illustrates the detection of R-Peaks in ECG morphology for Subject 5 and Subject 3 wore HeartIn Fit smart textile shirt.

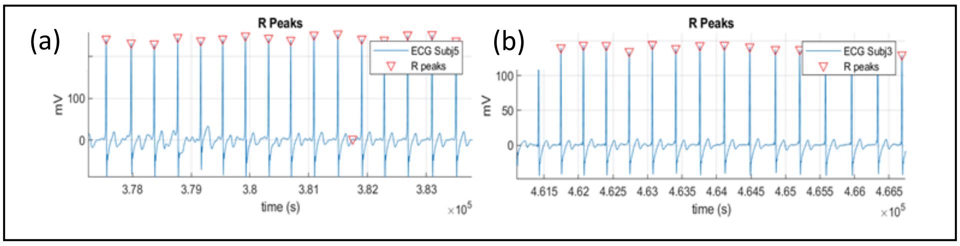

Figure 4. (a). R-Peaks Subject 5 wear HeartIn, (b). R-Peaks Subject 3 wear HeartIn

Among Hexoskin Smart shirt wearers are Subject 9 and Subject 6, following figure 5. below mapping the ECG morphology waveform of both wearers with R-Peak detection and marking in the signal.

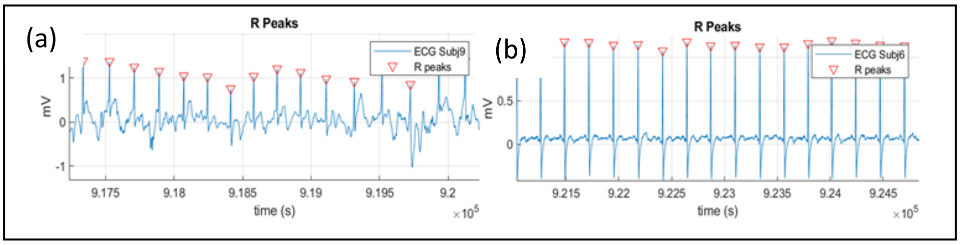

Figure 5. (a). R-Peaks Subject 9 wear Hexoskin, (b). R-Peaks Subject 6 wear Hexoskin

Figure 6 illustrate the R-Peaks of Subject 1 in ECG morphology recorded with smart textiles Hexoskin and HeartIn Fit.

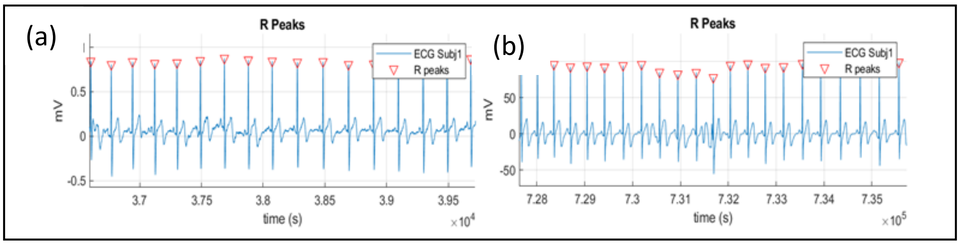

Figure 6. (a). R-Peaks Subject wears Hexoskin, (b). R-Peaks Subject wear HeartIn smart textile

In Figure 7. One of the study subjects demonstrated the Q peaks, R, and S peaks detection in the Feature Extraction stage.

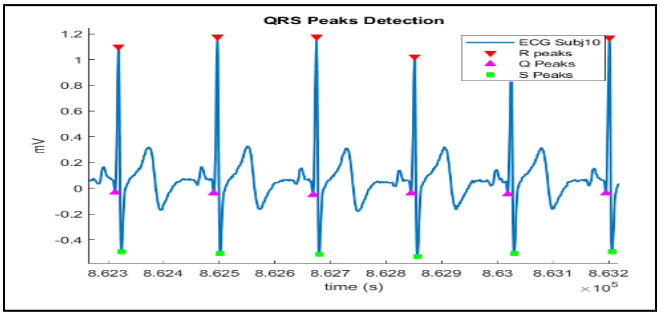

Figure 7. QRS-Peaks of Subject 10

4. Discussion

Both smart textile shirts have proven to record ECG signals for extended periods without limiting the subjects' daily routine or activities. This satisfies society's demands which are more concerned about their health condition, like monitoring their health state while staying comfortable [17], [18]. One of the vital advantages of ECG smart textile over conventional gelled electrode for long-time acquisition and monitoring of ECG was the less possibility of rash or skin reaction [19] and contribution of bacteria growth [20] around the electrode adhesive of the conventional ECG method. Therefore, the primary objective of this study was to provide test results for the HeartIn Fit and Hexoskin wearable smart textiles while simultaneously gathering physiological data throughout everyday routine activities in Feature Extraction phases. Based on our limited knowledge, such experimentation has never been done in the past.

Based on the finding in Figure 2, the subject ECG morphology in the morning, evening and night within the same day still retains the same pattern. These exciting results also show that the same pattern of the ECG signal still maintains even after three days. Moreover, after seven days, 14 days and even three months apart, the ECG morphology pattern of QRS is still alike. Meanwhile, as shown in Table 1, the R peaks and RR interval values of Hexoskin subjects based on regular four-beat heart rates show that the variation range is between 0.543 mV to 1.216 mV with the range of 0.673 mV. Furthermore, the interval between one dominant peak to another dominant peak in the subject's typical ECG morphology sequence varies between 0.625 seconds to 0.799 seconds. Besides that, both R peak and RR interval standard deviation values are minimal, indicating that in normal condition ECG, the pattern is almost similar and consistent within the same subject. However, the pattern and value among subjects are significantly different. One possible explanation of the outcomes is that each subject's ECG morphology differs significantly, as suggested in [6], [21].

Meanwhile, it is essential to consider signal quality when working with wearable devices, which might depend on the connection between signal and noise regarding motion artefacts [22], [23]. As depicted in Figure 5, the primary source of movement artefacts is the change between textile electrodes incorporated in smart textile and skin surfaces that are in contact during participant movements [23]. It is widely agreed that smart textile size, textile type, adhesion level and electrode position can impact how much motion artefacts contribute to signal quality [23], [24]. When comparing both smart textiles, the ECG morphology obtained shows that the HeartIn Fit shirt is the most impacted by movement artefacts. This is due to the textile electrode placement of HeartIn on the left and right sides of the shirt. Besides that, because of its unisex design, the HeartIn Fit is preferable for female subjects.

In contrast to HeartIn Fit, the Hexoskin smart textile sensor is implanted on the front sides of the shirt, which could be one of the reasons for the reduction in artefacts. Furthermore, it is widely agreed that both smart textiles show promising results in acquiring the ECG from the subject body and further ease the peak detection of the dominant pattern on the ECG morphology. Whether by using HeartIn or Hexoskin smart textile, it seems that the same subject retains equivalent dominant morphology in terms of intersubject variability, as illustrated in Figure 6.

The HeartIn and Hexoskin smart textile have been evaluated in the current study in ordinary everyday living life outside the laboratory compound. However, assuming that it would be utilised in high-adrenaline events, such as intense physical activities or other more vibrant sports, the results should be cautiously extrapolated as it could lead to additional artefacts that impair signal-to-noise relationships and quality. Furthermore, in terms of the reliability aspect, Hexoskin's smart textile enables data to be saved locally on its devices with the ability to view real-time data on the mobile smartphone. This is different for the HeartIn Smart textile as the data acquired are remotely analysed on a smartphone. Furthermore, the HeartIn developer also suggested that the communications device for data gathering and synchronisation must constantly be within the coverage area of the wearable smart textile device.

5. Conclusion

The ECG morphology analysis has certainly obtained reasonable identification rates in computer simulation and research laboratories. However, assessments are still inadequate under less controlled settings. Meanwhile, explorations in the Feature Extraction stage using Hexoskin's Smart textile shirt and HeartIn Fit Shirt in uncontrolled environments did not show anything significant difference when assessed in ordinary routines of everyday subject living. Both attractive wearable smart textiles are able to produce almost the same ECG morphology waveform, with the HeartIn producing a more precise and smooth ECG waveform in contrast to Hexoskin smart textile shirt. However, HeartIn is the most affected motion artefact in this study due to its textile electrode position. Meanwhile, in terms of the flexibility of the wearer, Hexoskin Smart Shirt is superior to the wearer as it does not bond between smart textile and phone limited coverage distance.

In terms of Feature Extraction, both wearable smart textiles successfully produce and reproduce ECG morphology data sufficiently for fiducial point detection of QRS peak in the studies. Subsequently, both technology does not significantly differ on the waveform in Feature Extraction stages within the venture subject ECG signal. Furthermore, the results indicate that the R peaks average lies between 0.543 to 1.194 mV and an R-R interval average between 0.625 to 0.799 seconds. It should be emphasised that both smart textiles shirts facilitate the usage of HeartIn Fit's and Hexoskin wearable smart textile as a wearable integrated physiological acquisition to quantify ECG in ordinary everyday life routines. Thus, this study proves that even though in different smart textile brands, textile electrodes and electrode positions were applied, the Feature Extraction stage was successfully implemented and achieved the desired performance of the study without much significant variance. In fact, the outcome is proof of the successful application of HeartIn Fit and Hexoskin wearable smart textiles in different physical activities in future everyday life routines in terms of performance and reliability for future applications such as biometric recognition.

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