Review on Data Acquisition of Electrocardiogram Biometric Recognition in Wearable Smart Textile Shirts

Muhammad Muizz Mohd Nawawi1,*, Khairul Azami Sidek1, Alaa K Y Dafhalla2 and Amelia Wong Azman1.

1Department of Electrical and Computer Engineering, International Islamic University Malaysia, Kuala Lumpur, Malaysia.
2Department of Computer Engineering, College of Computer Science and Engineering, University of Ha’il, Kingdom of Saudi Arabia.

*Corresponding author: muizz.nawawi@live.iium.edu.my

Abstract. Electrocardiogram (ECG) wearable smart textile shirt has widely been investigated due to its high flexibility, reusability, comfort, and the possibility of being used for home-based, real-life activities and real-time measurement. ECG smart textile shirt is an embedded textile sensor inside a cloth that can capture ECG data in more convenient ways and ease user-friendly, especially for continuous and long-term ECG data acquisition outside the laboratory environment. However, the current challenge with ECG smart textile shirt is the reliability and quality of data acquired by the wearable smart textile. This review will mainly focus on the research strategies in the early stages regarding data acquisitions in ECG smart textile shirt. It will introduce researchers’ data acquisition methods in the biometric recognition system using wearable ECG smart textile. The Scopus and Mendeley databases review may help future researchers consider different parameters, which affect the reliability and data quality when selecting data acquisitions strategies in a biometric recognition system using wearable ECG smart textile shirt.

Keywords: ECG, biometric, acquisition, smart textile, wearable.

1. Introduction
As the world keeps advancing to digitalisation, technologies are pushed to a certain stage, where almost anything and everything can be mimicked, duplicated, hacked, replicated, and identity theft skyrocketed in terms of cases [1], [2]. Everything from economic, finance, healthcare, cybersecurity, and human turns into digitally coded for most daily transactions in this digitalisation era. The conversational identification properties such as smart cards and passwords are widely used and open to counterfeit and falsification by irresponsible people [3], [4]. Meanwhile, physiological biometric properties such as the face, iris, gait, and fingerprint face the same war of treat [5]–[8].

Uncompromised to this issue had sparked the new interest in liveness detection in human biometric recognition, and liveness detection itself is to decide if the biometric being captured is a real measure of the authorised, living person present at the time of detection [9]. Besides that, as personal biosignal properties, ECG is the heart’s electrical activity, and it was proof of liveness at the point of detection [4], [10], [11]. Meanwhile, ECG smart textile is a new technology that has embarked on the market trend globally. There is an increasing number of studies that focus on this innovative technology merging between textile and ECG [12], but those studies mainly concentrate on ECG...
monitoring [13]–[18]. Therefore, there is still plenty of space for this new field to be explored in the field of biometric recognition and focusing on its data acquisition.

ECG smart textile is a type of smart shirt in which tracking devices are often inserted into garments to identify, measure, track and report vital human signals such as works in [19], [20]. Textile electrodes used in ECG smart textiles are more comfortable and user-friendly, unlike traditional gelled electrodes, especially for continuous monitoring of cardiac conditions. Furthermore, the conventional gelled electrodes produce rash or skin reaction along with the electrode adhesive. [21]–[23], and it also contributes to bacterial growth [24].

Wearable ECG smart textile in data acquisitions is also a tough challenge because textile ECG electrodes’ consistency depends significantly on various factors. Those factors are skin to textile surface, moisture [25], contact strain [26], positioning of electrodes, user movements, acquisition of real-life data [27], long-term ECG acquisitions [28], [29] and validity [30]. However, the appealing prospect and smart textile’s bright future had gained a pool of interest in this promising field, especially in its reliability and performances as an ECG data acquisitions tool.

2. ECG data acquisition in wearable smart textile
Fukuma et al. in [31] stand with the belief that a t-shirt type wearable ECG system was suitable for continuous, daily long-term use among young people with high physical activity. The research had made ECG data acquisition using an electrode textile material called Hitoe embedded into a commercially available t-shirt as in Figure 1(a). The study consists of the 100-male respondent with a mean age of 52 ± 5.4 years. The study prolongs for over two months, with each participant were required to wear the smart textile for 10 hours long each day for four days a week to monitor their ECG. Even though the research produced a promising prospect in monitoring the ECG, the study only has a male subject.

Similarly, Tsukada et al. in [18] also used the same material as [31], which is the Hitoe textile material patch sewn to a t-shirt for males and brassiere for females respondent in the research. This study supported by 66 adult respondents consisting of 47 male and 19 females within the age range of 35.5 ± 10.3 years. The work performed data acquisition of the smart textile towards the respondent in supine rest, sitting and physical exercises. The results show that the signal to artefact ratio was better in male than in the female. The research was outstanding in proving the reliability of smart textile using Hitore material patch. However, the work’s duration and iteration were unclear.

Meanwhile, Boehm et al. in [32] developed a 12-lead ECG smart textile t-shirt prototype using Shieldex Medtex P180 material as their sensor. The study tested the prototype in Figure 1 (b) with three male subjects under three different physiological conditions: lying down in a bed, sitting, and walking. The work also admitted that more subjects are needed to ensure the smart textile prototype’s long-term functionality and stability. Even the duration of the experiment and the respondent’s age was not clearly mentioned in this study.

Yu et al. in [33], the same researcher team in [32] use 12 lead ECG smart textile t-shirt prototype as in [32], moved to another level by taking the research further with five subject daily life routines at home and workplace for 422 hours of the uncontrolled environment outside the laboratory. However, there is no clear information regarding the gender and age of the subject in this study, but the researcher agrees that one lead ECG is sufficient for a wearable smart textile.

Meanwhile, Chetelat et al. in [34] worked with Long Term Medical Survey System (LTMS-S) as in Figure 1 (c), which consist of a system embedded within a vest of wearable smart textile. Out of 16 subjects in the study, which were divided into two groups with a mean age of 26.3 ± 7.3, only ten subjects were involved in the ECG data acquisition stages using LTMS-S wearable smart textile. Furthermore, the research did not specify the age group of participants engaged with ECG data acquisition. The work consists of different physiological conditions in standing, sitting, supine, running, and walking, but the study did not clearly highlight the data acquisition duration.
Furthermore, the ECG signal’s quality was lower in walking condition than in the other three rest conditions demonstrated by Fouassier et al. in [29]. This study was supported by 12 lead ECG acquisition T-shirt called Cardioskin™ by Bioserinity, as shown in Figure 1 (d). The study acquired ECG from 30 subjects, 21 male and nine females within the age of 29.5 ± 7.8 years, while wearing the smart textile for 3 minutes in each of three resting positions that standing, seated, supine rest and walking. Besides that, researches in [28], [29] suggested that smart textile should be evaluated over a more extended period for ECG monitoring regarding their reliability and performance [30], [36].

Among commercially available ECG smart textile in the market and have numbers of research on its capability and performance are like Hexoskin in Figure 1(e). The manufacture descriptions show that the smart textile has the capabilities in ECG morphologies data acquisition. However, most published papers use this interesting, smart textile focusing on other modalities like heart rate and respiration [27], [28], [35], [37], [38]. On the other hand, HeartIn smart textile in Figure 1(f) was another interesting ECG smart textile capable of capturing ECG data that is commercially available. Meanwhile, in Figure 2, this study showed promising results of ECG waveform captured from both Hexoskin and HeartIn smart textile shirt for the same subject. Similarly to what had already established in the global market, Emglare smart textile is another name that can yet claim its capability in ECG data acquisition.
3. ECG data acquisition in biometric recognition in wearable smart textile

A few studies have been done regarding data acquisition in ECG biometric recognition using smart textile. The best available research using commercial smart textile is successfully performed by Ye et al. in [39] using VitalJacket [40], and this is followed seven years later by Pourbabae et al. in [41] that used smart textile from OMSignal [42], [43]. Furthermore, the work in [39] showed that ECG signal capture from smart textile can be used as robust biometrics and as an automatic login solution for wearable smart textile. Extracted ECG fiducial point data from five fire-fighters over six months period was used in [39] and proved their theory.

In contrast, the study in [41] believes that fiducial point detection is an error-prone strategy affected by changes in the signal slopes, inverted or abnormal waves, noise and artefacts. The researcher works with 33-female subjects record their ECG daily for six weeks, where all the subject were required to provide at least five ECG recordings on different days using the smart textile. However, the actual effect of other physiological condition, gender differences and age of the subject is the element that both researchers can further investigate.

4. Future work in ECG data acquisition for wearable smart textile.

Through an analysis of the research work surveyed, it can be concluded that ECG biometrics based on wearable smart textile shirts have the potential to be one of the leading biometric traits. However, some challenges still need to be addressed, particularly concerning the acquisition strategies. It is remarkable how the ECG, which currently acquired widely through medical-grade equipment, is measurable through wearable smart textiles in seamlessly integrated systems, significantly increasing the acquisition process’s comfort. Research should continue to explore seamless acquisition settings and address the possibility of non-contact ECG measurement to further enable real ECG biometric applications in smart textiles as the gap is still wide open in this field.

Table. 1. Summary of ECG data acquisition with smart textile (NS- Number of Subjects; M-Male; F-Female)

| Researcher | Type of smart textile | NS  | Gender | Age (years) | Duration | Activity            |
|------------|-----------------------|-----|--------|-------------|----------|---------------------|
| Fukuma et al. (2019) | Hitoe Prototype [31] | 100 | M:100 F:0 | 52±5.4 | 2 months (320 hours) | Daily life routine |
| Tsukada et al. (2019) | Hitoe Prototype | 66 | M:47 F:19 | 35.5±10. | - | Supine, seating and |
Undoubtedly, there are a number of wearable researches in biometric [44], but in the smart textile fields, the numbers are still far left behind. Many studies in wearable smart textile still focusing on the reliability of monitoring the ECG with the smart textile [45], [46]. Little has been known to the world regarding ECG studies in the smart textile shirt as summarised in Table 1. To the best of our knowledge, only two available studies in smart textile shirt venture to biometric recognition. There are no substantial baseline numbers available on the optimum subject, duration and activity, to achieve reliability performance on ECG smart textile. For instance, many researchers favour acquiring the ECG data during supine rest, seating, and walking to simulate smart textile reliability in daily human routine performance. Some researchers prove smart textile performance outside the controlled environment focusing on human daily life routine activities in the workplaces and home. However, the actual effect of different physiological conditions, gender differences, and age is still lacking and can be further investigated in ECG smart textile.

5. Conclusion
In this review work, we pointed out the potential limitation present in the past published articles on wearable ECG monitoring smart textile shirt focusing on data acquisition, challenges, and issues in the field of biometric regarding the wearable ECG smart textile shirt. There is still plenty of space that can be filled regarding the stability, reliability, and performance of ECG wearable biometric smart textile shirt as a data acquisition over a more extended period and in real-life scenarios. Furthermore, there are also a lot of opportunities for ECG smart textile biometric to grow in multi-demographics studies.

Acknowledgement
The author wants to thank the International Islamic University Malaysia (IIUM) for all the facilities and the Ministry of Higher Education Malaysia for this study’s scholarship.

6. References
1. Nadzri N I M Sidek K A and Wicaksono D H B, 2016 Development of an electrocardiogram based biometric identification system: A case study in the university J. Telecommun. Electron. Comput. Eng. 8, 4 p. 115–120.

2. Srivastava R and Singh Y N, 2019 ECG analysis for human recognition using non-fiducial methods IET Biometrics 8, 5 p. 295–305.

3. Dong X Si W and Huang W, 2018 ECG-based identity recognition via deterministic learning Biotechnol. Biotechnol. Equip. 32, 3 p. 769–777.

4. Anita Pal Y N S, 2018 ECG Biometric Recognition 834, April Springer Singapore.

5. Tseng K K Lo J Chen C C Tu S Y and Yang C F, 2018 Electrocardiograph identification using hybrid quantization sparse matrix and multi-dimensional approaches Sensors (Switzerland) 18, 12.

6. Komeili M Louis W Armanfard N and Hatzinakos D, 2016 On evaluating human recognition using electrocardiogram signals: From rest to exercise in Canadian Conference on Electrical and Computer Engineering p. 16–19.

7. Komeili M Louis W Armanfard N and Hatzinakos D, 2018 Feature Selection for Nonstationary Data: Application to Human Recognition Using Medical Biometrics IEEE Trans. Cybern. 48, 5 p. 1446–1459.

8. Sellami A Zouaghi A and Daamouche A, 2017 ECG as a Biometric for Individual’s Identification in The 5th International Conference on Electrical Engineering – Boumerdes (ICEE-B) p. 1–6.

9. Schuckers S A C, 2009, Liveness Detection: Fingerprint, in Encyclopedia of Biometrics, S. Z. Li and A. Jain, Eds. (Boston, MA: Springer US), p. 924–931.

10. Xiao J Hu F Shao Q and Li S, 2019 Low-complexity compressed sensing reconstruction method for heart signal biometric recognition Sensors (Switzerland) 19, 23.

11. Patro K K and Kumar P R, 2017 Machine learning classification approaches for biometric recognition system using ECG signals J. Eng. Sci. Technol. Rev. 10, 6 p. 1–8.

12. Yang K Isaia B and Brown L J E, 2019 E-Textiles for Healthy Ageing sensors 19, 4463.

13. Acar G Ozturk O and Yapici M K, 2018 Wearable Graphene Nanotextile Embedded Smart Armband for Cardiac Monitoring in Proceedings of IEEE Sensors p. 1–4.

14. An X and Stylios G K, 2018 A Hybrid Textile Electrode for Electrocardiogram (ECG) Measurement and Motion Tracking Materials (Basel). 11, 1887.

15. Ankhili A Tao X Cochrane C Koncar V Coulon D and Tarlet J M, 2019 Ambulatory evaluation of ECG signals obtained using washable textile-based electrodes made with chemically modified PEDOT:PSS Sensors (Switzerland) 19, 2.

16. Achilli A Bonfiglio A and Pani D, 2018 Design and characterization of screen-printed textile electrodes for ECG monitoring IEEE Sens. J. 18, 10 p. 4097–4107.

17. Tong W Kan C and Yang H, 2018 Sensitivity analysis of wearable textiles for ECG sensing in International Conference on Biomedical and Health Informatics, BHI 2018 March p. 157–160.

18. Tsukada Y T et al., 2019 Validation of wearable textile electrodes for ECG monitoring Heart Vessels 34, 7 p. 1203–1211.

19. Stoppa M, 2014 Wearable Electronics and Smart Textiles: A Critical Review Sensors (Switzerland) 14 p. 11957–11992.

20. Koncar V, 2019 Smart textiles for monitoring and measurement applications .

21. Murat Kaya Yapici, 2017 Intelligent Medical Garments with Graphene- Functionalized Smart-Cloth ECG Sensors Sensors p. 1–12.

22. Seshadri D R et al., 2019 Wearable sensors for monitoring the physiological and biochemical profile of the athlete npj Digit. Med. 2, 1.

23. Hosaka R and Noji R, 2017 A wearable 12-lead ECG T-shirt with textile electrodes for unobtrusive long-term monitoring – Evaluation of an ongoing clinical trial IFMBE Proc. 65 17, 1 p. 1061–1064.

24. Crawford J and Doherty L, 2012 Practical Aspects of ECG Recording M & K Update Limited.

25. Weder M et al., 2015 Embroidered Electrode with Silver/Titanium Coating for Long-Term ECG Monitoring sensors 15 p. 1750–1759.
[26] Das P S Hossain F and Park J Y, 2017 Chemically reduced graphene oxide-based dry electrodes as touch sensor for electrocardiograph measurement Microelectron. Eng. 180 p. 45–51.

[27] Montoya A H K Mitryzk J R and Molesky M J, 2017 Comparative Accuracy of a Wrist-Worn Activity Tracker and a Smart Shirt for Physical Activity Assessment Meas. Phys. Educ. Exerc. Sci. 21, 4 p. 201–211.

[28] Banerjee T Peterson M Oliver Q Froehle A and Lawhorne L, 2018 Validating a commercial device for continuous activity measurement in the older adult population for dementia management Smart Heal. 5–6, November p. 51–62.

[29] Fouassier D Roy X Blanchard A and Hulot J S, 2020 Assessment of signal quality measured with a smart 12-lead ECG acquisition T-shirt Ann. Noninvasive Electrocardiol. 25, 1 p. 1–7.

[30] Tanner E A et al., 2015 Validation of Hexoskin biometric shirt to COSMED K4 b2 metabolic unit in adults during trail running Sport. Technol. 8, 3–4 p. 118–123.

[31] Fukuma N et al., 2019 Feasibility of a T-Shirt-Type Wearable Electrocardiography Monitor for Detection of Covert Atrial Fibrillation in Young Healthy Adults Sci. Rep. 9, 1 p. 1–6.

[32] Boehm A Yu X Neu W Leonhardt S and Teichmann D, 2016 A Novel 12-Lead ECG T-Shirt with Active Electrodes Electronics 5, 75 p. 1–15.

[33] Yu X et al., 2017 A wearable 12-lead ECG T-shirt with textile electrodes for unobtrusive long-term monitoring – Evaluation of an ongoing clinical trial in IFMBE Proceedings 65 p. 703–706.

[34] Chételat O et al., 2015 Clinical validation of LTMS - S: a wearable system for vital signs monitoring * in Conference proceedings - IEEE engineering in medicine and biology society p. 3125–3128.

[35] Smith C M Chillrud S N Jack D W Kinney P Yang Q and Layton A M, 2019 Laboratory Validation of Hexoskin Biometric Shirt at Rest, Submaximal Exercise, and Maximal Exercise while Riding a Stationary Bicycle J. Occup. Environ. Med. 61, 4 p. E104–E111.

[36] Haddad M et al., 2020 Ecological Validation and Reliability of Hexoskin Wearable Body Metrics Tool in Measuring Pre-exercise and Peak Heart Rate During Shuttle Run Test in Professional Handball Players Front. Physiol. 11, July p. 1–8.

[37] Montes J Young J C Tandy R and Navalta J W, 2018 Reliability and Validation of the Hexoskin Wearable Bio-Collection Device During Walking Conditions. Int. J. Exerc. Sci. 11, 7 p. 806–816.

[38] Tan D Y W and Yong T H, 2018 Suitability of smartshirt by Hexoskin to monitor heart rate for racket sports in International Conference on Robotics, Automation and Sciences, ICORAS 2017 p. 1–4.

[39] Ye C Kumar B V K V and Coimbra M T, 2011 Human identification based on ECG signals from wearable health monitoring devices ACM Int. Conf. Proceeding Ser. p. 1–5.

[40] Silva Cunha J P Cunha B Pereira A S Xavier W Ferreira N and Meireles L, 2010 Vital-Jacket®: A wearable wireless vital signs monitor for patients’ mobility in cardiology and sports 2010 4th Int. Conf. Pervasive Comput. Technol. Heal. Pervasive Heal. 2010 April.

[41] Pourbabaei B Patterson M Reiher E and Benard F, 2018 Deep Convolutional Neural Network for ECG-Based Human Identification in CMBES Proceedings p. 1–4.

[42] OMsignal, 2017, Deep Convolutional Neural Network for ECG-Based Human Identification, Whitepaper by OMsignal.

[43] Steinberg C et al., 2019 A novel wearable device for continuous ambulatory ECG recording: Proof of concept and assessment of signal quality Biosensors 9, 1 p. 1–13.

[44] Lehmann F and Buschek D, 2020 Heartbeats in the Wild: A Field Study Exploring ECG Biometrics in Everyday Life p. 1–14.

[45] Arquilla K K Webb A and Anderson A P, 2020 Textile Electrocardiogram (ECG) Electrodes for Wearable Health Monitoring Sensors (Switzerland) 20, 1013 p. 1–14.

[46] Hsu C C Lin B S He K Y and Lin B S, 2019 Design of a wearable 12-lead noncontact electrocardiogram monitoring system Sensors (Switzerland) 19 7.