A Breathable 1.1 oz Ripstop Nylon (BRN) Based Wearable Dry ECG Sensors A Pilot Study

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Abstract. Selection of conductive polymer towards the design of dry bio potential sensor for physiological signal recordings is quite challenging. Such dry sensors are much essential for long term continuous monitoring applications. This specific study suggests a development of breathable 1.1 oz Ripstop nylon (BRN) based dry electrocardiogram (ECG) sensors for continuous recording cardiac rhythms. Bipolar limb lead configurations, Lead 1, Lead 2 and Lead 3 configurations were considered towards recording of ECG signals and its performance was assessed in terms of signal quality, ECG fidelity point tests, fidelity characteristics Ripstop based dry sensors found to yield comparable results with that of standard Ag/AgCl wet sensors for shorter duration recordings assessment and better per-formance while using it for longer duration (72 hrs) recordings setup. This pilot study has been carried out with 82 healthy volunteers and the proposed system has to be validated with larger group before the procedure can be introduced to the clinical routine.

Keywords: wearable · ECG · dry Sensors · Conductive Polymer

1 Introduction

Wearable monitoring based medical devices has created a huge impact [4,5,11,13,14] especially in the field of Cardiology Medicine. Typical symptoms, such as syncope, palpitations along with sudden cardiac death were found to occur frequently where the traditional Holter based offline cardiac monitoring fails to alert the patients [2,6,10,11] .Several at-tempts have been made in the recent past towards the development of dry ECG sensors to overcome the issues pertaining to the standard Ag-Agcl wet ECG sensors [1,3–5,7,9,11–14].Specifically conductive polymer based ECG sensor design has gained much importance and found

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to be an alternate solution towards developing dry sensors to record bio potential variation from limbs and chest regions. Furrukd Sana et al., 2020 have made a brief study on the availability of cardiac monitoring devices with wearable facilities [7]. The brief report provides an insight on the potential ambulatory devices that works based on wearable devices including the smart phone. Hafiz Imtiaz Ahmed et al.,2022 have suggested a homecare cardiac care monitoring identity that comprises of 3 lead EKG patches with a Bluetooth module to wirelessly transmit the ECG signals to the android driven mobile app [1]. A system on chip based first level prototype setup was proposed to monitor the cardiac activities was proposed by Arya Jain et al., 2022 [3]. The preliminary study revealed that the setup could be used as a potential wearable device for cardiac monitoring application. An attempt has been made by Shao et al., (2020) towards development of wearable ECG tele monitoring system. The system comprises of wearable ECG patch-es, with android mobile app where every 30 s ECG data in real time can be collected and displayed for real-time assessment [8]. A specific study was reported by Sun et al., 2020 [12] towards the development of wearable ECG monitoring system where nRF51822 microcontroller with low power ECG chip ADS1292R were used to collect ECG recording. Avvaru et al., (2021) have proposed Ag-Nyw textile-based ECG sensor design which had the constituent of Nylon ($70 \pm 3\%$), copper ($16 \pm 5\%$) and nickel ($14 \pm 2\%$) [2] and a full fledge wearable ECG system was reported [9].

Selection of conductive (polymer to be used as a dry sensor for long term wearable monitoring applications is quite challenging for the bio-medical engineering community. The polymer fabrics should be breathable, allow for easy air circulation wick away perspiration and should keep always the body cool. This study suggests the usage of breathable 1.1 oz Ripstop Nylon (BRN) light weight conductive polymer for ECG sensor development. The density of the weave is generally correlated with the factor, breathability. It is a well-known fact that more densely woven the fabric, the less breathability it possesses. BRN is a breathable fabric with 60% Nylon and 40% silver composition. Due to biocompatibility property, BRN can be used for medical applications.

2 Dry ECG Sensor Design Setup

Breathable 1.1 0z Ripstop Nylon (BRN) based ECG sensor design involves selection of BRN material, size and shape of the sensor, inclusion of medical grade button to ensure the required bio potential from the limb and chest regions. Figure 1 shown the BRN ECG sensor setup. Various sizes, 2 × 2 cm, 4 × 4 cm, 8 × 8 cm square shaped sensor design were selected for the proposed study. It was observed during the experimental study that the other geometric patterns, rectangular and circular shapes doesn't yield the required bio potentials required for cardiac activities assessment. Further during the experimental study, it was also observed that the square shape 2 × 2 cm sensor design showed good impedance characteristics as compared to that of the standard Ag-AgCl Wet sensors. Figure 2 shows the wearable recording setup using the BRN sensors.

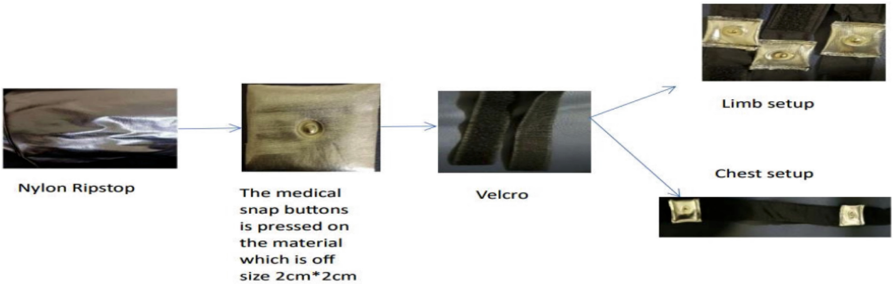

Fig. 1. BRN Dry ECG Sensor Setup

Fig. 2. Wearable Recording Setup

Fig 3 shows the experimental study set up towards assessing the impedance characteristics of proposed BRN ECG dry sensor. As the frequency increases, the impedance decreases and the experimental study revealed the suitability of the designed BRN sensor for cardiac signal recordings.

In order to collect the ECG recordings, Velcro based chest and limb belts as shown in Fig. 1 were developed and BRN dry ECG sensors were placed according to Einthoven ECG placement setup. The electronic assembly as reported in [2,9] were developed for the proposed study and comparisons were performed in term of fidelity metrics as well as visual quality inspection by the Cardiologists.

3 Evaluation

The study was carried out after obtaining due ethical clearance from M S Ramaiah medical college hospital ethics committee. According to 1964 Helsinki declaration, study protocol was design with inclusive and exclusive criteria's and 82 healthy volunteers and 26 cardiology patients were involved in this pilot study.

The performance of the proposed BRN dry ECG sensor is assessed in terms of ECG signal quality assessment metrics such as, SNR and PSNR as well as

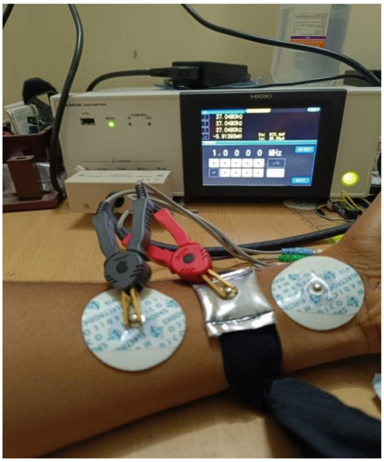

Fig. 3. Impedance Measurement

ECG fidelity points in terms of heart rate variability. Fig. 4 shows the recordings obtained from the designed ECG sensor and Fig. 5 illustrates the selected portion of the raw recording and the cleaned signal suitable for analysis. Table 1 shows the signal quality results in comparison with standard Ag-AgCl wet ECG sensor. The proposed sensor found to yield better signal quality which is very much essential for home centric remote applications. Table 2 shows the heart rate variability for dry and wet ECG sensors for selected sample subject and the result reveals the quality of heart rate metrics for cardiological rhythms assessment. Table 3 shows the impedance measure obtained from the proposed dry ECG sensor i.e. BRN as well as from the traditional wet ECG sensor. The impedance value should decrease as the frequency increases for an ideal sensor. It can be observed from the Table 3 that the performance of the BRN dry sensors found to be better than the wet sensors.

Table 1. Signal Quality results

Material	SNR	PSNR
Wet sensor (Ag-Agcl)	59.061	48.85
Dry sensor (Ag-Agcl)	68.209	54.715

4 Discussion

This specific study attempts to propose a new conductive polymer, breathable 1.1 oz ripstop nylon material towards designing the wearable ECG sensor for

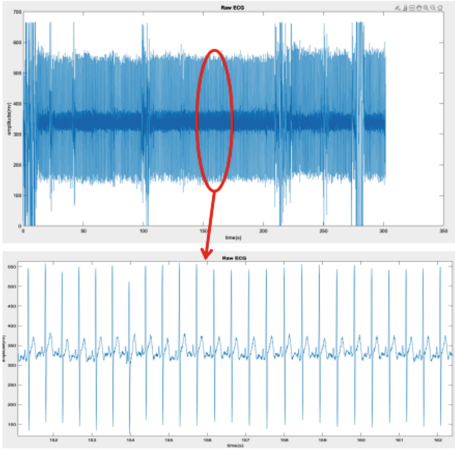

Fig. 4. Raw ECG signal recordings from proposed BRN ECG sensor

Table 2. HRV with Ag-AgCl and Nylon Ripstop

Subject	Wet Sensor (BPM)	Dry Sensor (BPM)
1	79.74	74.82
2	120	78.08
3	135	110.54
4	85.8	80.67
5	58	88.46

continuous monitoring applications. Selection of materials for dry sensor plays a major role as the efficiency of required biopotential for cardiac assessment rely on skin conductive properties of the polymers along with the biocompatibility. Several works that have been reported in the literature [1,3,7–9,12] makes use of nanomaterials and conductive polymer materials, it is very important to consider the availability of the materials, design cost and its efficacy towards yielding the required diagnostic quality. The availability of the BRN in the local market at a very low cost along with the involvement of low-cost electronic assemblies makes the proposed dry sensor more suitable for resource constrained settings. The pilot study reveals that the proposed BRN dry ECG sensors yield better signal quality as well as impedance compared to that of the traditional wet ECG sensors.

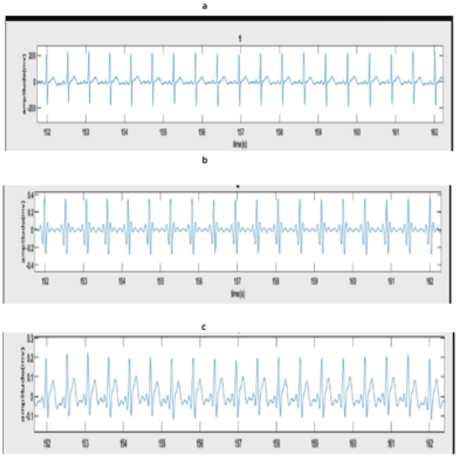

Fig. 5. Selected Time Series: a - Raw signal, b - filtered signal, c - ecg signal after the removal of baseline wander

Table 3. Impedance Characteristics

Frequency	Impedance (Z) in Ω BRN	Impedance (Z) in Ω Ag/AgCl
350K	28289	47275
500K	20796	29779
750K	13800.5	22520
850K	10804	21770.5
1M	4802.5	9773
5M	2707.5	4017.5
7M	1774	2449.5

5 Conclusions

An attempt has been made by making use of breathable 1.1 oz ripstop nylon as conductive dry sensor for acquisition of electrocardiogram (ECG) signals for long term monitoring as well as ICU monitoring applications. The pilot study shows the efficacy of the designed dry ECG sensor for diagnostic applications. Special attention has to be given further in terms of battery consistency, wireless communication modalities and mobile app based solutions for the clinical assessment to make sure that the proposed dry sensing mechanism can be considered as a screening tool for identifying cardiology ailments in the low resource constrained settings.

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References

1. Ahmed, H.I., Saleem, D.M., Omair, S.M., Shams, S., Sheikh, N., Tariq, A.: Conceptual hybrid model for wearable cardiac monitoring system. Wireless Pers. Commun. **125**(4), 3715–3726 (2022)
2. Avvaru, S., Sriraam, N., Prakash, V., Sahoo, S.: Wearable Ag-NyW textile electrode for continuous ECG monitoring. Res. Biomed. Eng. **37**(2), 231–247 (2021). https://doi.org/10.1007/s42600-021-00147-2
3. Jain, A., Singh, M., Singh, B.: Real time system on chip based wearable cardiac activity monitoring sensor. Meas. Sens. **24**, 100523 (2022)
4. Kim, H., Kim, E., Choi, C., Yeo, W.H.: Advances in soft and dry electrodes for wearable health monitoring devices. Micromachines **13**(4), 629 (2022)
5. Majumder, S., Chen, L., Marinov, O., Chen, C.H., Mondal, T., Deen, M.J.: Non-contact wearable wireless ECG systems for long-term monitoring. IEEE Rev. Biomed. Eng. **11**, 306–321 (2018)
6. Rajanna, R.R., Sriraam, N., Prakash, V., Vittala, P.R., Arun, U., Sahoo, S.: External cardiac loop recorders: functionalities, diagnostic efficacy, challenges and opportunities. IEEE Rev. Biomed. Eng. **15**, 273–292 (2021)
7. Sana, F., Isselbacher, E.M., Singh, J.P., Heist, E.K., Pathik, B., Armoundas, A.A.: Wearable devices for ambulatory cardiac monitoring: JACC state-of-the-art review. J. Am. Coll. Cardiol. **75**(13), 1582–1592 (2020)
8. Shao, M., Zhou, Z., Bin, G., Bai, Y., Wu, S.: A wearable electrocardiogram telemonitoring system for atrial fibrillation detection. Sensors **20**(3), 606 (2020)
9. Sriraam, N., Srinivasulu, A., Prakash, V.: Wireless Cardios framework for continuous ECG acquisition. J. Med. Eng. Technol. **47**(4), 201–216 (2023)
10. Sriraam, N., Chakravarty, P.: Review of the requirements for a wearable, low-cost external cardiac loop recorder with WBAN in resource-constrained settings. Crit. Rev. Biomed. Eng. **51**(5), 27–41 (2023)
11. Sriraam, N., Vittal, P.R., Arun, U., Angadi, K., Halli, A., Chakravarthy, P.: Wearable wireless multiparameter monitoring systems (WEMUMS) for resource constrained settings. In: 2021 3rd International Conference on Electrical, Control and Instrumentation Engineering (ICECIE), pp. 1–4. IEEE (2021)
12. Sun, Z., Ye, J., Zhang, X., Yuan, M., Zhong, Z., Tan, X.: Development of a wearable wireless ECG monitoring system with ultra-low power consumption. Zhongguo yi Liao qi xie za zhi = Chin. J. Med. Instrum. **44**(1), 28–32 (2020)
13. Tao, Q., et al.: Clinical applications of smart wearable sensors. iScience **26**(9), 107485 (2023)
14. Zulqarnain, M., et al.: A flexible ECG patch compatible with NFC RF communication. NPJ Flexible Electron. **4**(1), 13 (2020)