Limitations and Future of Electrocardiography Devices: A Review and the Perspective from the Internet of Things

A. M. Khairuddin[1], Ku Azir K. N. F[2], P. Eh Kan[3]

Embedded, Networks and Advanced Computing Research Cluster (ENAC)
School of Computer and Communication Engineering, Universiti Malaysia Perlis,
Kampus Pauh, 02600 Ulu Pauh, Perlis, Malaysia

khaiadam93@gmail.com[1], fazira@gmail.com[2], phaklen@unimap.edu.my[3]

***Abstract*— Electrocardiography (ECG) devices are considered essential medical tools for detecting and preventing cardiovascular diseases. These devices are used to obtain information about the structure and function of the human heart. Given the various medical uses of the information from ECG devices, it is essential that these devices provide accurate information about the heart in a precise manner. Although many advances in ECG devices have been made over the years, the literature reveals not only limitations in conventional devices but also highlights how the Internet of Things (IoT) has the potential to improve medical applications in ECG devices. This paper reviews previous works on ECG devices to identify their limitations as well as provides some insights into the development of IoT-based ECG devices.**

Keywords—Electrocardiography; Internet of Things; Digital Health Informatics; ECG devices

I. Introduction

Cardiovascular disease is considered as one of the major causes of premature deaths among adults in Malaysia and many countries around the world. With regard to the detection and prevention of the heart disease, increasing body of scientific evidence suggests performing electrocardiography (ECG) by using electrocardiograph. Electrocardiograph has been found to be a highly effective device for obtaining information about the structure and function of the heart. The ability of ECG devices to convey information about the heart has helped to reduce the number of cardiovascular disease victims and also healthcare costs [1].

Electrocardiography device has evolved since it was first introduced in 1872. The earlier ECG devices were not only developed with analog electronics but also electrically primitive as compared to contemporary devices. Over the years, the introduction of new technologies has contributed to the advances and capabilities of the more recent ECG devices. For instance, the contemporary ECG devices adopt analog-to-digital converter to convert the signal convey by the devices to digital signal that can be manipulated with digital electronics. More recently, interconnected digital technology such as the Internet of Things (IoT) is challenging conventional and widely used ECG devices from the past decades. The IoT is expected to hasten not only the development of new ECG devices but also make them much easier and less expensive to use. The IoT which evolves from the convergence of multiple digital technologies such as wireless communication, real time analytics, sensors and embedded systems allows ECG devices to be sensed and controlled remotely across existing networking infrastructure. With such capabilities, the IoT will not only be able to offer opportunities for more direct integration of the physical world into computer-based systems but also improve efficiency, accuracy and reduced human intervention.

Furthermore, the IoT is anticipated to provide advanced connectivity of devices, systems and services that can go farther than machine to machine (M2M) communications as well as embraces various types of protocols, domains and applications. More specifically, with all these capabilities, the IoT will enable a new way of organizing healthcare services as well as in developing medical devices. Figure 1 illustrates the general IoT structure in healthcare.

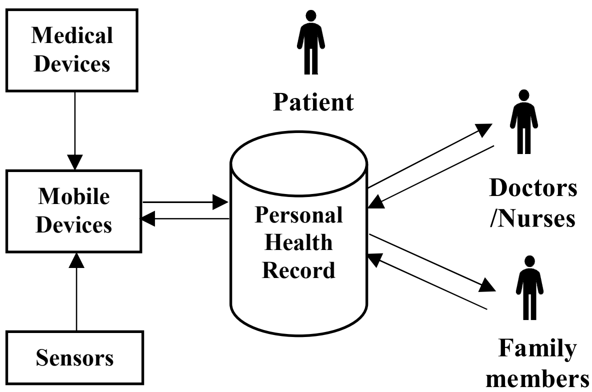

Fig. 1. IoT structure in healthcare

978-1-5090-6255-3/17/$31.00 ©2017 IEEE

Since the ECG device was first introduced, it has been used to examine the human heart to determine its proper functioning. The 12-lead ECG monitoring device consists of electrodes, cables, graph paper and the recording machine. By placing electrodes at the limbs and chest area, the ECG measures the electric activity of the heart by screening the heart at different angles. Changes in the reading of the electric activity of the heart indicate the condition and the location of the damage in the heart. The literature however reveals that conventional and widely used ECG devices have limitations. This paper reviews not only their shortcomings but also attempts to highlight how the IoT is expected to improve future ECG devices.

II. ELECTROCARDIOGRAPHY MONITORING SYSTEM

The main goal of performing ECG is to obtain information about the structure and function of the heart. Electrocardiography can be defined as the process of recording the electrical activity of the heart by placing electrodes on body surface [2]. Electrocardiogram can be specified as the wave forms that represents the electrical activity for every heart beat generated by electrocardiograph monitoring device [3]. The ECG monitoring system can detect symptoms such as palpitations, lightheadedness and syncope [4]. The adoption of wireless technologies and miniaturization have further helped to improve the quality of health monitoring provided by ECG devices [1], [4], [5]. Figure 2 illustrates the electrocardiogram of a normal ECG waveform.

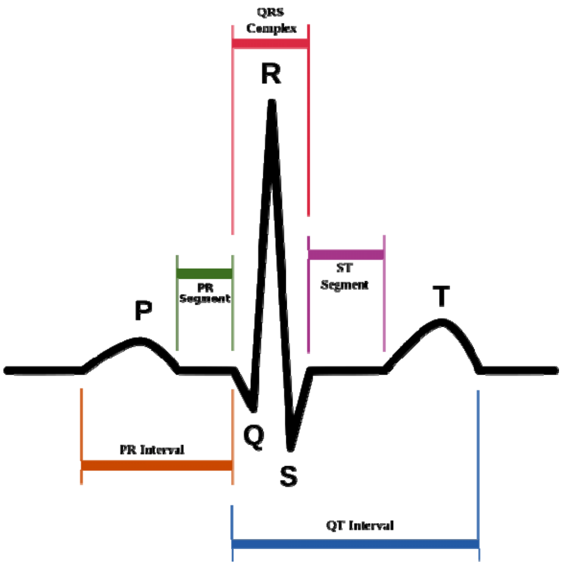

Fig. 2. One complete cycle of ECG waveform [6]

In terms of the electrocardiograph monitoring devices, the literature indicates many advances have been made over years. ECG devices can range from short to long term monitoring with different costs as well as depending on respective medical institutions and countries [4]. In addition, the literature suggests variations and limitations among existing electrocardiograph monitoring devices. For instance, the traditional ECG monitoring system such as the Holter monitor is inconvenient because it is bulky and consists of multiple cables [7]. Figure 3 and Figure 4 present more contemporary wireless ECG devices.

Moreover, the study by [8] found that conductive gel applied in the ECG can cause skin irritation when it is used with electrode as well as leading to degrading ECG signal quality. Other studies on ECG monitoring system have also identified other problems related to the types of electrodes, presence of artifacts and inappropriate signal analysis algorithm for monitoring cardiac anomalies.

Fig. 3. ZIO® XT Patch by IRhythm Technologies [9]

Fig. 4. SEEQ™ MCT Patch by Medtronic [10]

As far as ECG is concerned, it is important for the patient to be able to self-monitor and manage their own health conditions. With regard to this, [11] emphasized on the necessity of efficient energy wearable ECG with high precision result. The ECG device should also be cost effective and minimally intrusive to the user. It is equally important to ensure that the raw ECG signal collected from body surface is free from the presence of artifacts to preserve the accuracy of the ECG signal for medical analysis [12]. QRS (Q-wave, R-wave, S-wave) complex algorithm is essential for processing the raw ECG signal to secure high detection rate of cardiac anomalies.

Previous works have attempted to improve ECG devices in terms of their detection rate, size, power consumption, signal quality and algorithm. For example, [1] proposed a new cardiovascular disease detection system by using Wireless Body Area Network (WBAN) technology together with Undecimated Wavelet Transform (UWT) techniques and Bayesian Network Classifier. The experimental result shows that the average detection rate is 96.1%. The study by [5] designed and developed a miniaturized ECG system that utilizes a programmable single-chip microcontroller and incorporated with alarm systems with wireless transmission. The research by [8] developed a wearable sensing ECG T-shirt that consists of signal processing board and capacitive sensing electrodes to improve comfort of the human chest. This wearable T-shirt also uses low power integrated circuits (ICs) and passive electrodes to reduce power consumption.

Researchers such as [13] used blind source separation (BSS) technique called the Independent Component Analysis (ICA) to remove motion artifact from ECG monitoring system. The other research by [14] embraced motion artifact removal method with a two-stage cascade Least Mean Square (LMS) adaptive filter. In the study by [15], the researchers adopted a belt-type ECG measurement system with three-axis acceleration sensor. The more recent study by [16] developed a lead selection method to detect the optimal bipolar electrode placement for recording of the P-wave. The earlier study by [12] utilized a new algorithm based on three features which included heart rate score, spectral distribution ratio and variance between 12-lead ECG data. The experimental result shows that the proposed algorithm was able to generate high sensitivity of 95%, specificity of 86.7%, and accuracy of 93.1%. In addition, [17] employed a simple method based on four major steps. These steps involved moving average filter, blocking, feature extraction and multistage decision tree algorithm for automatic detection as well as classification of ECG noises. The results of the study indicate that the method can achieve an average sensitivity (Se) of 97.88%, positive productivity (+P) of 91.18% and accuracy of 89.06%.

III. LIMITATIONS OF ECG DEVICES

Given that ECG is an important medical tool used in detecting as well as preventing heart diseases, the literature indicates that over the years various studies have attempted to further improve and design better devices. The review of the literature and past studies however reveals several limitations among ECG devices. The following section explains briefly some of the limitations as identified in previous research.

A. Presence of Artifacts

Findings of previous studies show the presence of artifacts in ECG signal in certain ECG devices. For instance, the studies by [13], [14] show that raw ECG signal can be misrepresented by different types of artifacts such as motion, power-line interference and baseline wandering. Artifacts can create errors which degrade the quality of the ECG signal, as well as reducing the accuracy in predicting cardiac anomalies. Motion artifacts can be reduced by using adaptive filter, but it consumes high computing power. Moreover, the computational output is also inaccurate when the existing adaptive filter is used to choose the reference signal for a moving person [15].

B. Performance Measures

Previous works have also attempted to investigate the accuracy of the ECG devices [18]–[22]. According to these studies, some devices are not able to provide accurate information about the structure of the heart and the function of its electrical conduction system. These studies indicated that certain devices adopted different performance measures or assessment criteria. As a result, they have problems with reporting their results and making comparison based on the different algorithms performance. Accurate performance measures are needed for the assessment of the algorithm's efficiency in QRS (Q-wave, R-wave, S-wave) complex detection, data compression, and data de-noising. The assessment criteria used to evaluate the QRS complex detection algorithm involve cross validation, threshold and robustness [21]. Data compression of ECG algorithm can be assessed by Compression Ratio (CR), Percent Root Mean Square Difference (PRD), Percent Root Mean Square Difference Normalized (PRDN) and Quality Score (QS) [22]. According to [19], the efficiency of the data de-noising of ECG algorithm is determined by Signal to Noise Rate (SNR), Mean Square Error (MSE) and Percentage Root Mean Square Difference (PRD). Nevertheless, there are studies that indicate these common measures may not be adequate to assess the algorithms' performance. This is because the algorithms are needed to be tested thoroughly based on the whole database and some parts of the ECG signal cannot be excluded when comparing with the different algorithms performance [18]. As such, it is important for researchers to be cautious in selecting the performance measures in order to ensure that the results will not be influenced by self-evident propositions.

C. Complexity of Signal Analysis Algorithm

Past studies have also indicated that ECG signal can be affected by various environment parameters such as mental issues and different types of physical activities in detecting cardiac anomalies [23]. Given this, ECG signal need to be analyzed using suitable signal analysis algorithm. However, prior studies have adopted algorithm that has high computational complexity as well as do not fit different environment. This complexity can also reduce battery life of the electrocardiography monitoring system. Moreover, some of the algorithms have weak detection rate due to noise from the recorded ECG signal [17].

D. Types of Electrodes Used

The review of past studies has also indicated that different types of electrodes are used in electrocardiography monitoring system. For example, the study by [24] stated that traditional wet silver chloride electrode is used for accumulating ECG signal from the human body. Figure 5 reveals the wet electrode. Attaching the electrode to wet gel requires lots of preparation and can cause irritation, allergic reactions, inflammation, and bacteria growth [8]. The wet gel also undergoes dehydration which reduce the recorded ECG signal quality. As a result, the wet electrodes cannot be used for a long period of time and must be replaced.

In addition, prior studies have also used dry electrode to collect ECG signal. Figure 6 indicates the dry electrode. However, dry electrode is stiff and can trigger skin irritation. Although textile electrode has been introduced to overcome the limitations of the dry and wet electrodes, it requires high pressure for good skin and electrode contact. Since the textile electrode is embedded inside chest strap or wristband, it can cause discomfort and constraint among the wearers [23].

Fig. 5. BlueFlex ECG Electrode by VERMED [25]

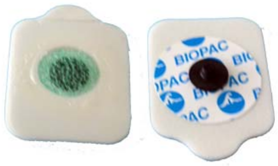

Fig. 6. EL509 Disposable Electrode by BIOPAC [26]

E. ECG Wave Morphology

With regard to ECG wave morphology analysis, previous studies appear to focus mainly on heart rate [27], [28]. [29] stated that one cardiac cycle consists of three major electrical entities. The three entities involved; the P-wave, the QRS complex and the T-wave. These electrical entities are generated by the depolarization and re-polarization of the heart muscle. It is essential to identify the normal heart rhythm of a person before suggesting any specific type of algorithm for ECG analysis and diagnosis. According to [18], the four criteria needed to determine normal beat rhythm included; heart rate, origin of the certain beat, pathway of the impulse and speed of the impulse. Although the detection of heart anomalies from heart rate variability analysis is important, the other three criteria have more significant impact on the ECG wave morphology. As a whole, it is essential to emphasize on these four criteria during the early diagnosis of heart anomalies because each one can cause cascading problems that can magnify abnormal behavior with consecutive beats Figure 7 and Figure 8 reveal the abnormal behavior during ECG diagnosis.

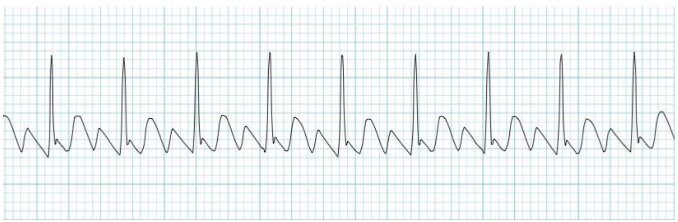

Fig. 7. Atrial flutter [30]

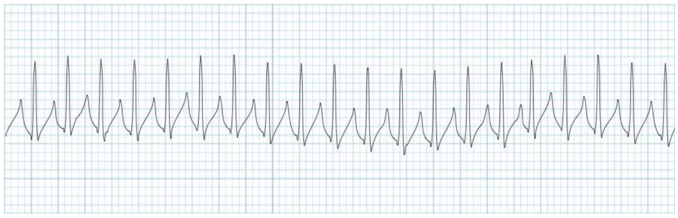

Fig. 8. Junctional tachycardia [31]

F. P-wave and T-wave Analysis

The literature also indicates P-wave and T-wave analysis as another limitation in the area of ECG [16], [18]. Past studies seemed to suggest that some ECG devices have difficulties in detecting as well as analyzing both P-wave and T-wave. P-wave and T-wave are the electrical entities that are collected from ECG recorder during ECG diagnosis. Time intervals between various peaks can help to reveal and classify the possible heart disease [20]. According to [18], it is not easy to detect and classify the P-wave. This is because P-wave possesses small amplitude and attenuation from signal filtering. P-wave is important to ECG diagnosis due to its ability to signify various atrial problems and pathological states by referring to its direction, frequency of occurrence and shape. Apart from the P-wave, it is equally important to detect and analyze the T-wave. Distinctive shapes of visible T-wave and inverted T-wave can point out various heart problems such as beat origin, re-polarization and heart block.

IV. IOT AND ECG DEVICES

The emergence of the Internet of Things (IoT) as one of the most important interconnected technologies is transforming the health care industry. According to the literature, the IoT is able to provide different applications for medical and health care. For instance, the IoT has the potential to offer essential medical applications in areas such as remote health monitoring and delivery, fitness programs, chronic diseases, elderly care, compliance with treatment as well as medication at home. Moreover, the IoT has the ability to connect medical devices such as ECG, sensors and other diagnostic and imaging devices. The networks of IoT-based devices are expected to not only improve the detection and prevention of diseases but also reduce medical costs, increase the quality of life as well as enhance the patients' experience of using these devices. More specifically, the following section explains briefly how IoT can improve ECG devices.

A. Design and Development of Contemporary ECG Devices

With digitization and connectivity, the IoT is poised to transform the way ECG devices are designed and developed. For instance, by adopting IoT, manufacturers of ECG devices can design and develop their devices in simulated laboratory and utilize digital fabrication models. This will enable the manufacturers to detect design and engineering problems before producing the tangible devices. In addition, the IoT allows the ECG devices to be embedded with custom-designed software so that they become not only more responsive and interactive but are also able to track their own activity and results along with the activity of other devices that are connected to them. When the data generated by these contemporary ECG devices are captured and analyzed, they are able to indicate not only how well they are functioning but also how they are used [32].

B. Technology Transition

By incorporating IoT into existing network configuration, healthcare organizations can modernize their existing devices and sensors across the whole healthcare industry through the use of smart resources. However, the integration of existing devices into IoT-based configuration will require backward compatibility and flexibility [33].

C. Network Type

As interconnected digital technology, the IoT is also able to provide three types of network. The three different fundamental network types include; data centric, service centric and patient centric [33]. The three types of networks will be able to create hyper-aware system that is able to respond rapidly not only to human commands and self-direction but also enable closer interaction between patients, family members and healthcare organizations.

D. Electrocardiogram Monitoring

Monitoring of electrocardiogram by using conventional ECG devices is still limited. However, the adoption of IoT to ECG monitoring has the potential to provide maximum information about the electrical activity of the heart as well as allows the information to be fully used. Previous studies have not only discussed the relevance and applicability of IoT to ECG monitoring but have also developed IoT based ECG monitoring system that consisted of a portable wireless acquisition transmitter and a wireless receiving processor [4], [34]–[37]. This system can detect data in real time unlike the conventional system.

E. Mobility

The IoT enables sensors in health monitoring system to be used for monitoring hospitalized patients by collecting and storing ample physiological information. The stored physiological information is wirelessly transmitted to the health professional for detailed medical analysis [38]. The health monitoring system is usually incorporated with enhanced graphics capabilities by using smart phones that display comprehensive information of the patients for medical assessment that can be done anytime and anywhere [39]. This allows a continuous automated flow of physiological information by remote monitoring [40] and lowers the cost of care by removing the need for health professional to take part in data collection and analysis frequently [41], [42]. In addition, physiological information can be shared through wireless connectivity with other medical professionals for health recommendations [43]. The mobile ECG device is demonstrated in Figure 9.

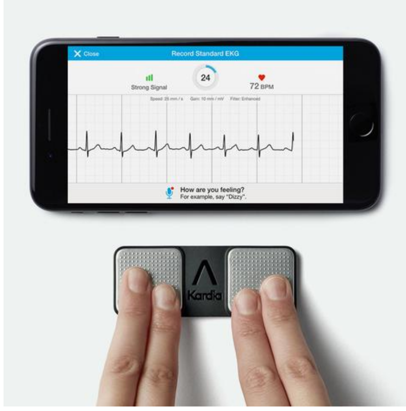

Fig. 9. Kardia Mobile by AliveCor [44]

F. Digital Health Advisor

Traditionally, doctors diagnose and provide treatments to their patients during in house consultation. However, with artificial intelligence (AI) and big data analytics as part of IoT, doctors can monitor and treat both far and near patients with chronic diseases. The IoT enables doctors to track vital signs, family history, medications, major illness, and lab results [45]. By being able to do so, they can conduct early preventive diagnosis to avoid complications [46]. Ambient intelligence provided by the IoT further allows the continuous monitoring of patients [47]. For instance, if the monitoring device used by a patient shows worrying change in heartbeat, the doctor could alert the patient with a call to take medication to resolve the problem at home. This will not only reduce the dependence on doctors, but also offer personalized medical attention and guidance to patients as well as the prevention of medical complications.

V. CONCLUSION

This paper reviews the limitations of ECG devices as well as highlights how IoT is expected to transform the design and development of these medical devices. Based on the review, the paper identified six limitations of past works on ECG devices. The review suggests that these limitations can affect the information about the heart and the function of the electrical conduction system convey by conventional ECG devices. In addition, the paper surveys various aspects of IoT and explains how this interconnected digital technology can help improve ECG devices as well as meet contemporary needs. In conclusion, IoT has the ability to pave the way towards a more systematic and pragmatic approach to designing and developing ECG devices that are able to not only meet contemporary needs but also transforms future healthcare monitoring and delivery.

REFERENCES

[1] M. Hadjem, O. Salem, and F. Naït-abdesselam, “An ECG Monitoring System For Prediction Of Cardiac Anomalies Using WBAN,” pp. 441–446, 2014.
[2] S. M., F. R., P. A., and S. C., “Electrocardiogram pattern recognition and analysis based on artificial neural networks and support vector machines: A review,” *J. Healthc. Eng.*, vol. 4, no. 4, pp. 465–504, 2013.
[3] J. AlGhatrif, Majd, Lindsay, “A brief review: history to understand fundamentals of electrocardiography,” *J. Community Hosp. Intern. Med. Perspect.*, vol. 2, no. 1, pp. 1–5, 2012.
[4] E. Fung, M. Järvelin, R. N. Doshi, and J. S. Shinbane, “Electrocardiographic patch devices and contemporary wireless cardiac monitoring,” vol. 6, no. May, pp. 1–10, 2015.
[5] D. J. Harmah and D. Kathirvelu, “An ubiquitous miniaturized android based ECG monitoring system,” *2013 IEEE Int. Conf. Emerg. Trends Comput. Commun. Nanotechnology, ICE-CCN 2013*, no. Iceccn, pp. 117–120, 2013.
[6] Wikipedia.com, “QRS complex,” *Wikipedia*, 2013. [Online]. Available: https://en.wikipedia.org/wiki/QRS_complex. [Accessed: 27-May-2017].
[7] F. Miao, Y. Cheng, Y. He, Q. He, and Y. Li, “A Wearable Context-Aware ECG Monitoring System Integrated with Built-in Kinematic Sensors of the Smartphone,” *Sensors (Basel).*, vol. 15, no. 5, pp. 11465–11484, 2015.
[8] D. N. Mathias, S. Il Kim, J. S. Park, and Y. H. Joung, “Real time ECG monitoring through a wearable smart T-shirt,” *Trans. Electr. Electron. Mater.*, vol. 16, no. 1, pp. 16–19, 2015.
[9] Medicalexpo.com, “Ambulatory patient monitor ZIO® XT Patch,” 2017. [Online]. Available: http://www.medicalexpo.com/prod/irhythm-technologies/product-94531-588639.html. [Accessed: 27-May-2017].
[10] Medtronic.com, “SEEQ™ Mobile Cardiac Telemetry (MCT) System For Irregular Heartbeats,” 2017. [Online]. Available: http://www.medtronic.com/us-en/about/news/media-resources/media-kits/seeq-mobile-cardiac-telemetry-system.html. [Accessed: 27-May-2017].
[11] C. Wang, H. Jin, Y. Qin, and L. R. Zheng, “A wearable ECG monitoring device with flexible embedded denoising and compression,” *Eur. Solid-State Device Res. Conf.*, vol. 2016–Octob, pp. 79–82, 2016.
[12] Y. Zhang and Z. Hou, “An algorithm for evaluating the ECG signal quality in 12 lead ECG monitoring system,” *Proc. IEEE Int. Conf. Softw. Eng. Serv. Sci. ICSESS*, vol. 2015–Novem, pp. 453–456, 2015.
[13] S. Tian, J. Han, J. Yang, L. Zhou, and X. Zeng, “Motion Artifact Removal Based on ICA for Ambulatory ECG Monitoring,” no. 2, pp. 2–5, 2015.
[14] H. Kim *et al.*, “Motion artifact removal using cascade adaptive filtering for ambulatory ECG monitoring system,” *2012 IEEE Biomed. Circuits Syst. Conf.*, pp. 160–163, 2012.
[15] B.-H. Kim, Y.-H. Noh, and D.-U. Jeong, “A Wearable ECG Monitoring System Using Adaptive EMD Filter Based on Activity Status,” *2015 IEEE 29th Int. Conf. Adv. Inf. Netw. Appl. Work.*, pp. 11–16, 2015.
[16] A. Kennedy, D. D. Finlay, D. Guldenring, R. R. Bond, and J. McLaughlin, “Detecting the elusive P-wave: A new ECG lead to improve the recording of atrial activity,” *IEEE Trans. Biomed. Eng.*, vol. 63, no. 2, pp. 243–249, 2016.
[17] U. Satija, B. Ramkumar, and M. S. Manikandan, “A Simple Method for Detection and Classification of ECG Noises for Wearable ECG Monitoring Devices,” 2015.
[18] M. Velic, I. Padavic, and S. Car, “Computer aided ECG analysis - State of the art and upcoming challenges,” *IEEE EuroCon 2013*, no. July, pp. 1778–1784, 2013.
[19] S. V and J. Y, “A Review on Feature Extraction and Denoising of ECG Signal Using Wavelet,” *2014 2nd Int. Conf. Device, Circuit Syst.*, no. 1, pp. 1–6, 2014.
[20] B. Singh, “A Review of ECG Data Compression Techniques,” vol. 116, no. 11, pp. 39–44, 2015.
[21] S. Saraswat, G. Srivastava, and S. Shukla, “Review: Comparison of QRS Detection Algorithms,” *2015 Int. Conf. Comput. Commun. Autom. (ICCCA 2015) Gt. Noida, [UP], India, 15 - 16 May 2015*, no. 3, pp. 354–359, 2015.
[22] D. C. Pandhe and H. T. Patil, “Review and enhancement of ECG data compression and reconstruction method for portable devices,” *Int. Conf. Energy Syst. Appl. ICESA 2015*, no. Icesa, pp. 490–495, 2016.
[23] K. Takahashi and K. Suzuki, “An ECG monitoring system through flexible clothes with elastic material,” *2015 17th Int. Conf. E-Health Networking, Appl. Serv. Heal. 2015*, pp. 305–310, 2016.
[24] B. Taji, S. Shirmohammadi, V. Groza, and M. Bolic, “An ECG monitoring system using conductive fabric,” *Med. Meas. Appl. Proc. (MeMeA), 2013 IEEE Int. Symp.*, pp. 309–314, 2013.
[25] Vermed.com, “BluFlex ECG Electrodes,” 2017. [Online]. Available: http://www.vermed.com/Electrodes/BluFlex.aspx. [Accessed: 27-May-2017].
[26] Biopac.com, “Disp. RT Dry Electrode, 100/pk,” 2017. [Online]. Available: https://www.biopac.com/product/disp-rt-dry-electrode-100pk/. [Accessed: 27-May-2017].
[27] N. H. Kamaruddin and M. Murugappan, “Early prediction of Cardiovascular Diseases using ECG signal: Review,” *2012 IEEE Student Conf. Res. Dev.*, pp. 48–53, 2012.
[28] J. S. u Lee, J. Heo, W. K. yu Lee, Y. G. yu Lim, Y. H. o Kim, and K. S. uk Park, “Flexible capacitive electrodes for minimizing motion artifacts in ambulatory electrocardiograms,” *Sensors (Basel).*, vol. 14, no. 8, pp. 14732–14743, 2014.
[29] S. Yao and Y. Zhu, “Nanomaterial-Enabled Dry Electrodes for Electrophysiological Sensing: A Review,” *Jom*, vol. 68, no. 4, pp. 1145–1155, 2016.
[30] Lifeinthefastlane.com, “Atrial Flutter,” 2017. [Online]. Available: https://lifeinthefastlane.com/ecg-library/atrial-flutter/. [Accessed: 27-May-2017].
[31] Lifeinthefastlane.com, “Accelerated Junctional Rhythm (AJR),” 2017. [Online]. Available: https://lifeinthefastlane.com/ecg-library/accelerated-junctional-rhythm/. [Accessed: 27-May-2017].
[32] D. Azariadi, V. Tsoutsouras, S. Xydis, and D. Soudris, “ECG Signal Analysis and Arrhythmia Detection on IoT wearable medical devices,” *2016 5th Int. Conf. Mod. Circuits Syst. Technol.*, pp. 1–4, 2016.
[33] S. M. R. Islam, D. Kwak, H. Kabir, M. Hossain, and K.-S. Kwak, “The Internet of Things for Health Care : A Comprehensive Survey,” *Access, IEEE*, vol. 3, pp. 678–708, 2015.
[34] G. Yang *et al.*, “A Health-IoT platform based on the integration of intelligent packaging, unobtrusive bio-sensor, and intelligent medicine box,” *IEEE Trans. Ind. Informatics*, vol. 10, no. 4, pp. 2180–2191, 2014.
[35] X. Zhang, Z. Zhang, Y. Li, C. Liu, Y. Xin, and Y. Lian, “A 2.89-μW Clockless Wireless Dry-Electrode ECG SoC for Wearable Sensors,” *IEEE Asian Solid-State Circuits Conf.*, pp. 11–14, 2015.
[36] J. P. Dieffenderfer, H. Goodell, E. Beppler, R. Jayakumar, J. S. Jur, and A. Bozkurt, “Wearable Wireless Sensors for Chronic Respiratory Disease Monitoring,” *IEEE Body Sens. Networks*, pp. 1–6, 2015.
[37] V. Wahane and P. V. Ingole, “An Android based wireless ECG monitoring system for cardiac arrhythmia,” *2016 IEEE Healthc. Innov. Point-Of-Care Technol. Conf.*, pp. 183–187, 2016.
[38] M. Hassanalieragh *et al.*, “Health Monitoring and Management Using Internet-of-Things (IoT) Sensing with Cloud-Based Processing: Opportunities and Challenges,” *Proc. - 2015 IEEE Int. Conf. Serv. Comput. SCC 2015*, pp. 285–292, 2015.
[39] Z. Yang, Q. Zhou, L. Lei, and K. Zheng, “An IoT-cloud Based Wearable ECG Monitoring System for Smart Healthcare,” *J. Med. Syst.*, 2016.
[40] K. Ullah, M. A. Shah, and S. Zhang, “Effective ways to use Internet of Things in the field of medical and smart health care,” *2016 Int. Conf. Intell. Syst. Eng. ICISE 2016*, pp. 372–379, 2016.
[41] E. Spanò, S. Di Pascoli, and G. Iannaccone, “Low-Power Wearable ECG Monitoring System for Multiple-Patient Remote Monitoring,” *IEEE Sens. J.*, vol. 16, no. 13, pp. 5452–5462, 2016.
[42] D. Niewolny, “How the Internet of Things Is Revolutionizing Healthcare,” *White Pap.*, no. October, pp. 1–8, 2013.
[43] U. Satija, S. Member, B. Ramkumar, and M. S. Manikandan, “Real-

Time Signal Quality-Aware ECG Telemetry System for IoT-Based Health Care Monitoring," *IEEE Internet Things J. 1*, vol. 4662, pp. 1–9, 2017.

[44] Alivecor.com, "Kardia Mobile," 2017. [Online]. Available: https://store.alivecor.com/. [Accessed: 27-May-2017].

[45] D. V Dimitrov, "Medical Internet of Things and Big Data in Healthcare," *Korean Soc. Med. Informatics*, vol. 22, no. 3, pp. 156–163, 2016.

[46] P. A. Laplante, M. Kassab, N. L. Laplante, and J. M. Voas, "Building Caring Healthcare Systems in the Internet of Things," *IEEE Syst. J.*, pp. 1–8, 2017.

[47] K. R. Darshan and K. R. Anandakumar, "A comprehensive review on usage of Internet of Things (IoT) in healthcare system," *2015 Int. Conf. Emerg. Res. Electron. Comput. Sci. Technol. ICERECT 2015*, pp. 132–136, 2016.