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The Evolution of Electrocardiogram (ECG) Monitoring Systems in Home Based Cardiac Care: A Literature Survey

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Abstract

The field of cardiac care is evolving, with innovations in wearable electronics and Health - Internet of Things, (Health - IoT), undoubtedly contributing to effective personalised care of patients with cardiac disease in the home environment. Over recent years, attention to soft electronics has sparked an interest in their application in wearable sensor technology, with the latest contributions in research focusing on multimodal sensing of physiological parameters such as blood pressure, surface body temperature, and bioelectric signals like the ECG. This has led to the increased adoption of flexible and wearable biophysical sensor technology in IoT enabled remote monitoring of cardiac disease, due to its advantages over rigid sensors in achieving intimate skin coupling for bio signal sensing, and improved patient comfort. Moreover, clinical feasibility studies that employ the use of such technology have shown results that compare favourably well with the use of multi-lead Holter monitoring devices. However, widespread implementation of this technology is still lacking in low to middle income countries (LMICs), which have the highest burden of mortality and morbidity attributed to cardiac disease to date. This is largely due to the cost of most commercially available products which limit widespread public use. This article will review cost-effective Internet of Things (IoT) enabled ECG monitoring systems, with a focus on flexible biophysical sensor technology that has wireless connectivity - (Bluetooth enabled or Near Field Communication), energy optimization - (Wireless energy harvesting and low power usage), multimodal sensing, and can be mass produced through roll-to-roll manufacturing processes.

Keywords
Soft electronics, Flexible biophysical sensors, ECG monitoring, Health - IoT and Low-cost design.

1. Introduction

1.1 The Inception and Progression of Electrocardiography in Clinical Practice

At the close of the 19th century, a new era arose in the medical field in which conventional clinical assessment methods were combined with the technology present at the time to diagnose cardiac disease. Through the use of X-rays and the electrocardiogram, introduced in 1895 and 1902 respectively, the structure and function of the heart could be assessed objectively (AlGhatrif and Lindsay, 2012). This way, physicians could finally link symptoms and signs of heart diseases such as Heart Failure, Cardiac Arrhythmias and Ischemic Heart Disease, with corresponding electrophysiological and/or X-ray image phenomena. Prior to this, research had already been conducted in electrophysiology to pave way for the clinical use of the electrocardiogram.

In 1786, animal experiments conducted by Dr. Luigi Galvani demonstrated that skeletal muscle could produce electrical current. Nearly half a century later in 1842, Dr. Carlo Matteucci demonstrated the close association of electrical current with every frog heart-beat (Figure 1). Towards the end of the 19th century, Augustus Waller published the first human electrocardiogram and also revealed that ventricular contraction was preceded by electrical activity (AlGhatrif and Lindsay, 2012; Matteucci, 1842; Waller, 1887).

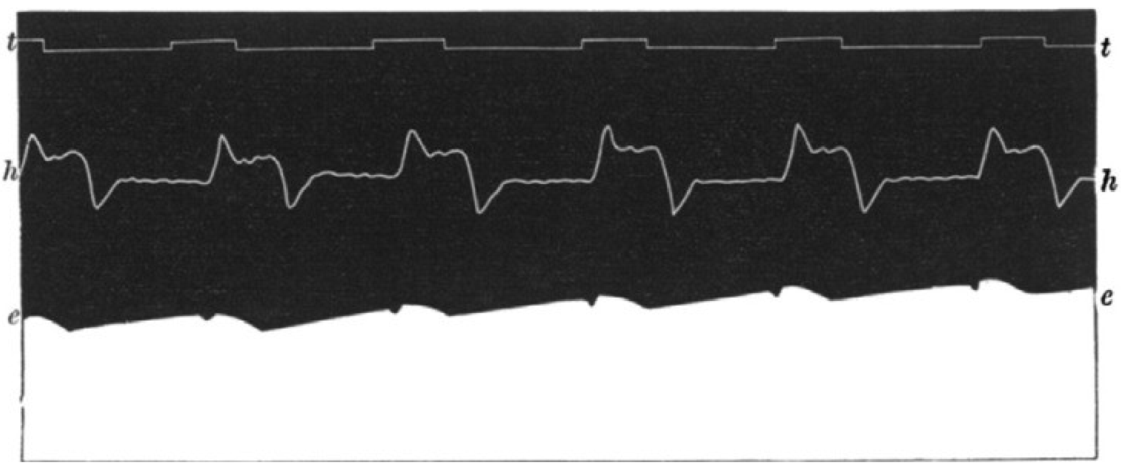

Figure 1. First human electrocardiogram published by Augustus Waller.

The method of recording electric potentials from the skin surface as is practised in modern day electrocardiography, was developed by both Dr. Willem Einthoven, a Dutch physiologist, and Augustus Waller, in the early 20th century, with the former being the first to coin the term "electrocardiogram" at the Dutch Medical Meeting of 1893 (AlGhatrif and Lindsay, 2012). The first iteration of an ECG monitoring device for clinical use consisted of a string galvanometer, in which a patient immersed his/her limbs, (the right and left upper limbs, and the left lower limb), in cylindrical electrodes filled with electrolyte solution. These three limb leads were used to form the basis of Einthoven's triangle. However, over the next few decades, more leads were added: the 6 precordial leads, and the augmented unipolar leads, to expose bioelectric signals from segments that were not covered by the three limb leads, and thus aid in the diagnosis of cardiac pathology that was not visible using Einthoven's triangle. The creation of these additional leads thus ended the advancement of the standard 12-lead ECG as it is known today (AlGhatrif and Lindsay, 2012) (Figure 2).

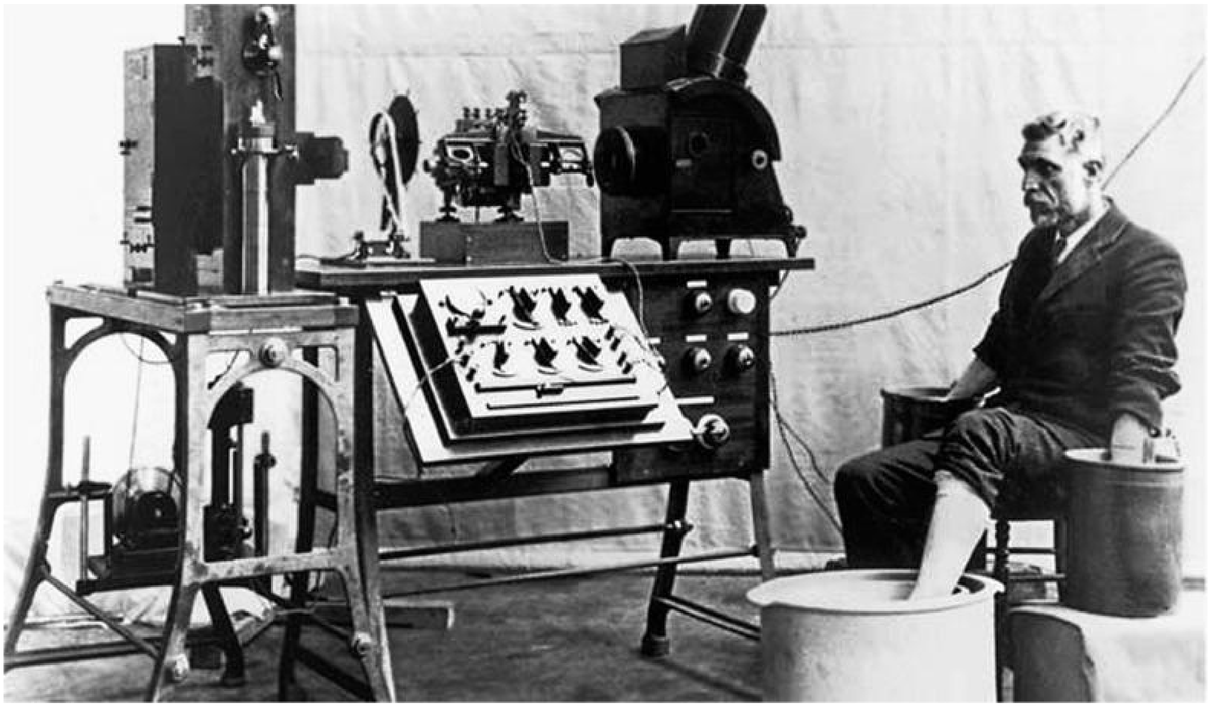

Figure 2. A string galvanometer electrocardiograph showing a patient immersing his extremities (right and left arms, and left leg) in cylindrical electrodes filled with electrolyte solution.

1.2 Electrocardiography in modern day clinical practice

Electrocardiograms (ECG/EKG) are recordings of electric potential changes at the skin surface that result from depolarization and repolarization of heart muscle (Levick, 2009). This electrical excitation of cardiac muscle is initialised in a specialised region called the sino-atrial node (SA node) located in the posterior wall of the right atrium. The spread of cardiac excitation throughout the myocardium (heart muscle) creates ionic currents in the extracellular fluid which surrounds cardiac muscle cells, resulting in potential differences across the body surface of around 1mV. These are then recorded using sensitive voltmeters connected to electrodes placed on the body surface, which give the overall magnitude and direction of these electrical impulses taken from different angles or "leads". Changes in the normal timing, duration and magnitude of these bioelectric signals are usually indicative of structural or functional abnormalities of the heart seen in cardiac disease.

The potential differences are recorded on a strip of moving paper or computer screen to produce an ECG trace, with the paper speed standardised at 25mm/s or 0.2s per large square division (Figure 3).

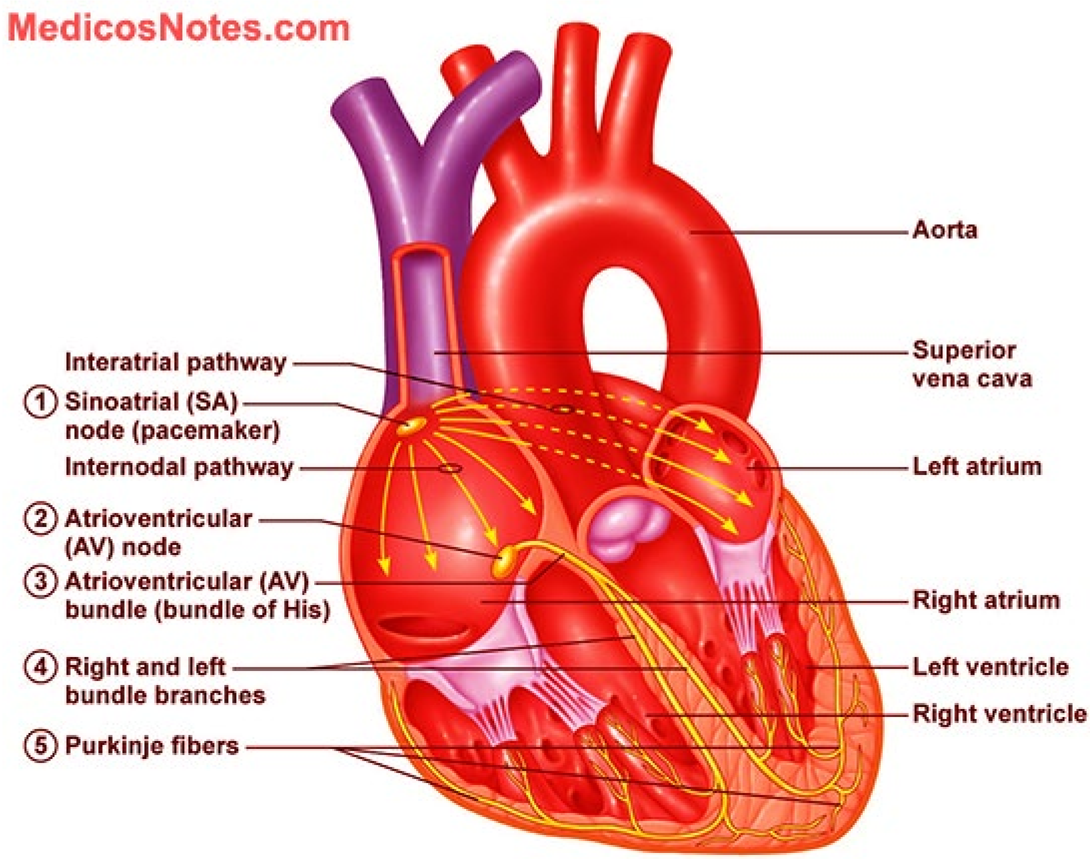

Figure 3. Illustration of the specialised conduction system of the heart [shown in yellow], cardiac excitation spreads from the SA node through to the rest of the myocardium via this path.

An ECG tracing shows three main deflections per cardiac cycle. These include:

1) The P-wave, which represents atrial depolarisation, and has a normal duration of about 0.08s.
2) The QRS complex, which represents ventricular depolarization, and has a duration usually less than 0.1s.
3) The T-wave, which represents ventricular repolarization.

Following a deflection, the ECG trace returns to the baseline or isoelectric state, and two important segments shown on the trace at this state include:

1) The PR interval, which represents the delay of the electrical impulse (cardiac excitation) experienced at the atrio-ventricular node (AV node). This delay results from a fibro-tendinous structure called the annulus fibrosus that is responsible for separating the atria from the ventricles electrically, thus ensuring that they are not electrically excited simultaneously. The delay experienced at the AV node is normally 0.12 - 0.20s.
2) The ST segment, which corresponds with the ventricular action potential plateau phase and represents uniform ventricular depolarization.

Important additional features extracted from the ECG trace include the heart rate, the heart rhythm, the axis, and the magnitude of deflections (Figure 4).

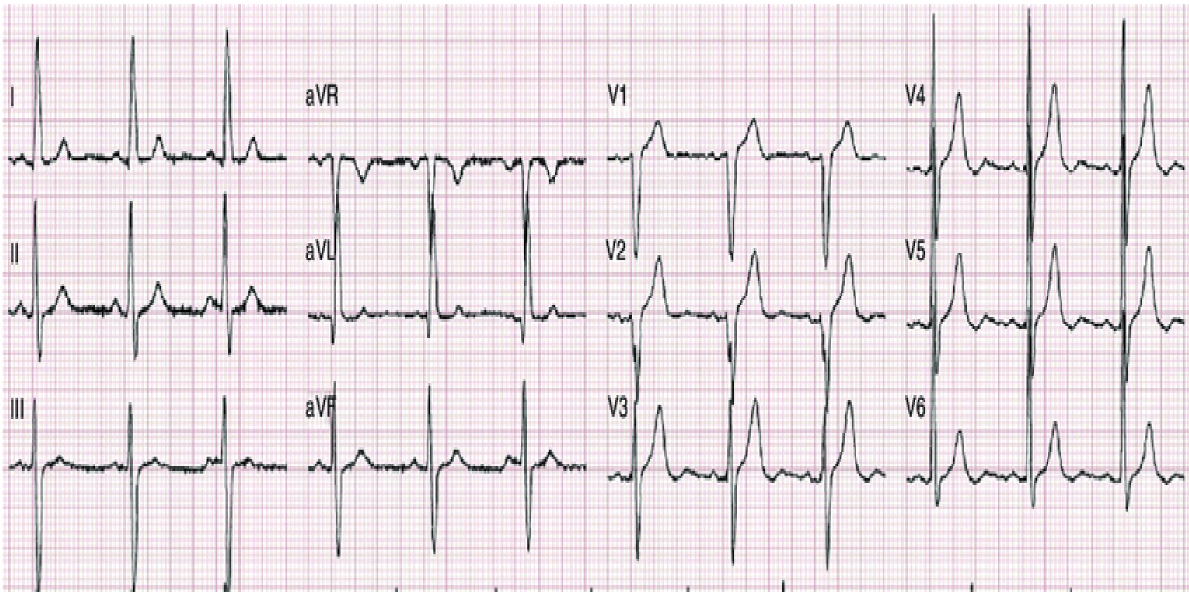

Figure 4. An ECG tracing of the heart, showing sinus rhythm with a heart rate of 75 bpm.

Leads are potential differences between two electrodes on the body surface, and these show the heart's electrical activity from different angles. This gives a more comprehensive view of the wave of cardiac excitation as it spreads throughout the heart muscle. In clinical practice, the 12 standard ECG leads used include the unipolar precordial leads V1 to V6, as well as the unipolar augmented limb leads (aVL, aVR, and aVF), and the bipolar limb leads (I, II, and III). The limb leads give a view of the heart's electrical activity in a frontal plane, whereas the precordial leads provide a view in the transverse plane (Figure 5).

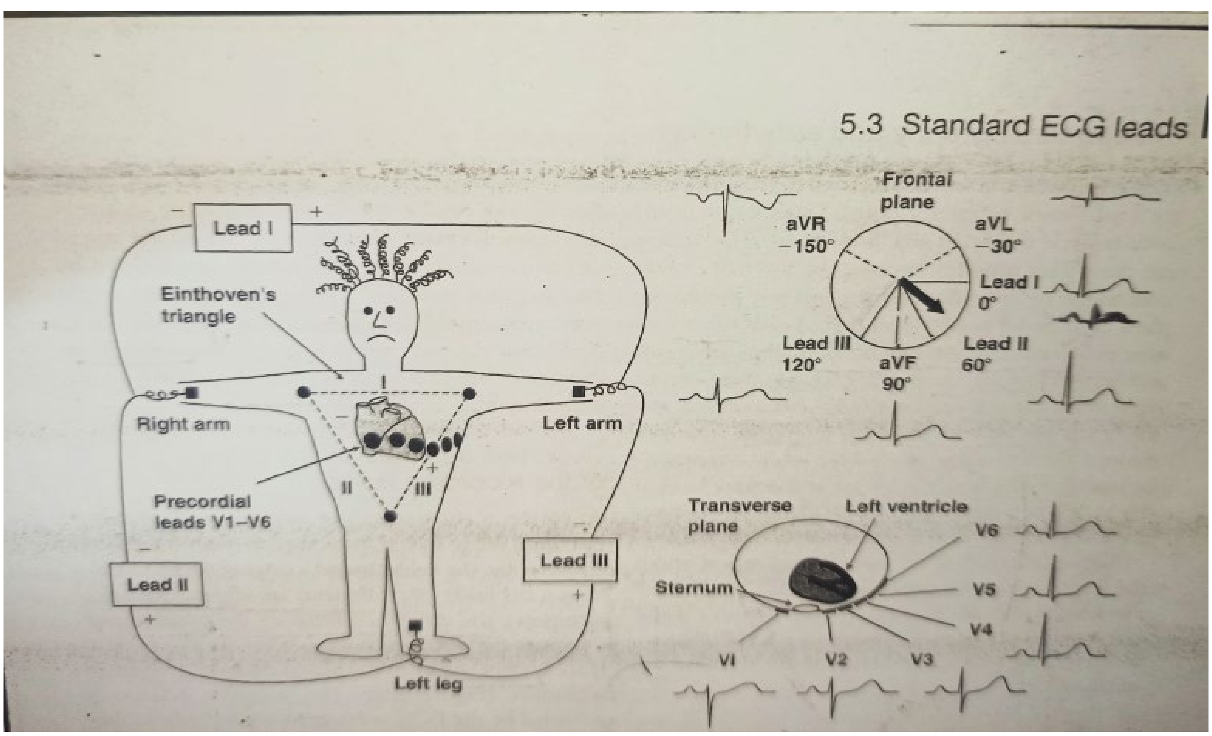

Figure 5. Diagram illustrating placement of leads, and the ECG tracings obtained from the different views.

Electrocardiograms have significant clinical impact, as they are a first line screening and diagnostic tool in the evaluation of patients presenting with cardiac complaints. In addition, they are often used to monitor patients on therapy for conditions such as cardiac arrhythmias, and are used to evaluate the cardiac health status of a patient prior to, during, and after a major surgical procedure depending on the patient's risk factors for cardiac disease.

Multi-lead Holter monitoring devices and similar ECG monitoring systems, are the clinical standard for detection and diagnosis of cardiac diseases characterised by abnormalities in cardiac rate and rhythm, based on continuous ECG waveforms (Lee et al, 2018). Although these devices are often used in a clinical set-up, they are often bulky and too technical for unskilled users, and therefore susceptible to poor patient compliance when used in the home environment. Fortunately, through advances in electronics miniaturisation and improvements in semiconductor performance, significant strides have been made in reducing the overall size and complexity of ECG monitoring devices. This has led to commercially available portable single-lead to multi-lead products that are smaller and much easier to use than Holter monitors. However, though patch-based, these devices are made up of mechanically rigid components which limit intimate skin coupling, and reduce patient comfort. Thus limiting their effectiveness during repetitive, and prolonged daily use (Lee et al, 2018) (Figure 6).

Figure 6. Side by side comparison of Holter ECG monitor (Left) and an IoT enabled wireless ECG sensing device (Right).

1.3 Soft electronics in cardiac care

The need for highly precise and personalised ongoing healthcare, that offers great comfort to the patient, has led to the integration of wearable technology with soft electronics. Soft electronics loosely refers to a class of electronics where electronic components are either embedded in or consist of soft, conformable or flexible conductive material. In cardiac care, many of the technologies involving soft electronics have begun to address the limitations of wearable devices that use rigid components. Thus newer products with soft or body surface conformable epidermal components are now emerging on the market, and this has resulted in a significant improvement in biosensing technology available to ECG monitoring systems (Figure 7).

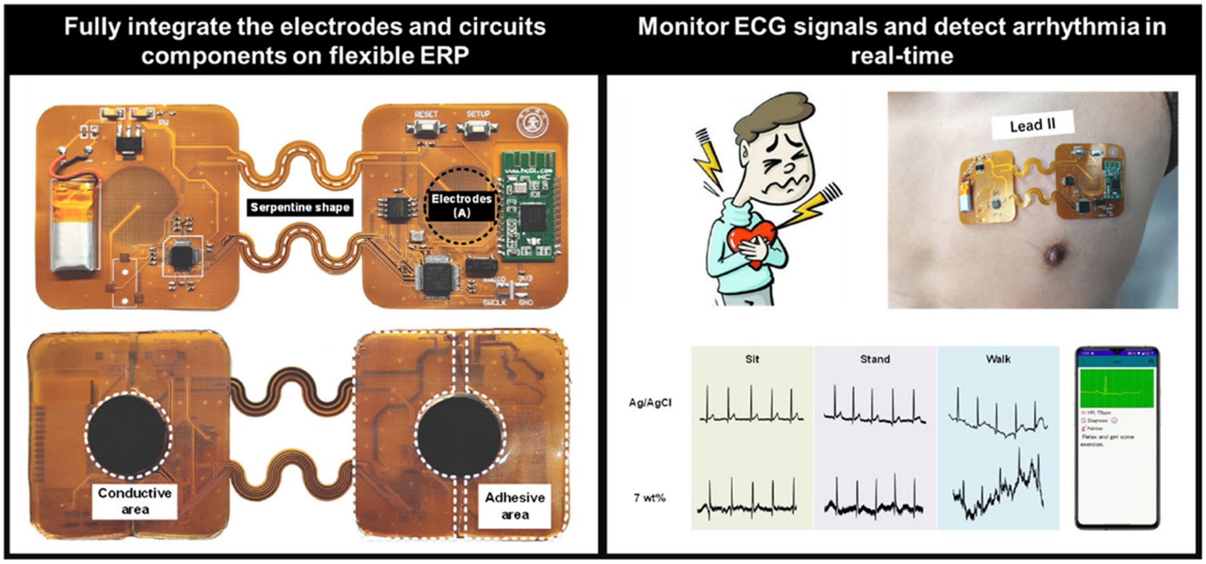

Figure 7. Flexible and wearable biosensing technology used in cardiac care.

Flexible, wearable, and wireless biophysical sensors are the latest instalment when it comes to remote and ambulatory monitoring of patients with cardiac disease. Recent research has led to the design of biophysical sensors that are not only flexible, i.e., able to stretch and conform to the skin surface, but also harness technologies such as wireless data transmission, energy optimisation through low power usage and wireless energy harvesting, as well as achieve economies of scale when mass produced through roll-to-roll manufacturing processes. These novel epidermal sensors are soft and conformal, and together with their associated circuitry, are encased within ultrathin layers of soft and flexible material to allow them to achieve very close contact with the skin surface (Lee et al, 2018). This way, sensors can be lightweight, occupy a small body surface area, and be comfortable to use, while ensuring that a precise recording of bioelectric signals like ECG signals is made during their extended use. Other advantages offered by such biophysical sensors include multimodal sensing - (for example, blood pressure estimation and temperature sensing), reduced cost, and low power consumption. These benefits, together with the application of health-IoT (The Internet of Things in Healthcare), in wearable electronics, have thus enabled cardiac care to become more decentralised - as patients can be managed remotely, and within the reach of those requiring continuous monitoring.

To progress beyond the limitations that arise from the use of metal-based thin film electrodes used in wearable sensors, various studies have reported improvement in sensor performance with new electrode material alternatives like nanocomposite, as well as carbon and polymeric materials (Bandokar et al, 2015; Kabiri et al, 2017; Rim et al, 2015). The present review will look at sensors with metal-based thin film electrodes that are embedded in soft and flexible 'substrate', since these have undergone clinical feasibility studies. A brief overview of IoT in cardiac care will be made, followed by a discussion on promising flexible, wireless and wearable biophysical sensors that can be used in IoT based ECG monitoring systems. Finally, to conclude the review, future perspectives and challenges involving the use of such technology will also be discussed.

1.4 Objective

The objective of this study is to review cost-effective IoT enabled ECG monitoring systems that make use of flexible biophysical sensor technology.

1.5 Background

Cardiac disease encompasses clinical conditions that result from abnormalities in heart structure and function. In clinical practice, these diseases are classified within the umbrella term Cardiovascular diseases (CVDs) since pathological processes that affect the heart are intimately associated with disease processes affecting the blood vessels. This should come as no surprise, as the heart and blood vessels are what constitute the cardiovascular system. This intimate connection can be illustrated through an example as follows: poorly controlled hypertension and/or poorly controlled diabetes mellitus (diseases that affect blood vessels) can result in ischaemic heart disease (IHD), which can manifest clinically as angina or a myocardial infarction (cardiac disease).

Globally the more common manifestations of CVDs encountered in clinical practice are cerebrovascular disease, coronary artery disease (CAD), arterial atherosclerosis, hypertension, peripheral arterial disease (PAD), congenital heart disease, valvular heart disease (VHD) and venous thromboembolism. About one- third to one-half of all cases of CVDs result from CAD, and complications such as myocardial ischemia/infarction and heart failure (HF) resulting from this condition contribute to significant morbidity and mortality related to CVDs. According to the 2019 WHO statistics, 85% of CVD related deaths were due to heart attacks and stroke, with over 75% of these deaths occurring in low to middle income countries (LMICs) (WHO, 2019). This underscores the need to come up with effective strategies in LMICs to help detect and/or monitor cardiac abnormalities leading to these complications early, in order to provide timely clinical intervention.

2. Literature Review

2.1The IoT and remote monitoring of cardiac disease

In 1999, Kevin Ashton introduced the term Internet of Things (IoT) (Merchant N, n.d), and it refers to the collective network of interrelated devices together with their technology (sensors, processing ability, software etc), that connect to each other, and to the cloud, exchanging data via the internet or other communication protocols. Health IoT had already launched its presence in the 1990’s through the introduction of basic telehealth and remote healthcare monitoring services, and as a result of advances in data analytics and miniaturisation of electronic components in the early 2000’s, wearable health devices and intelligent medical equipment entered the picture.

The efficacy of remote management of patients with cardiac disease has been demonstrated in various clinical studies. In a meta-analysis review of a remote monitoring based approach in caring for patients with chronic heart failure, Mohammed Mhanna et al (2016), concluded that hemodynamic and arrhythmia telemonitoring guided management could reduce the risk of heart failure related hospitalisations (Mhanna et al, 2021). Another systematic review by Keshia R De Guzman et al (2022), came to the conclusion that remote patient monitoring of chronic diseases such as hypertension (a risk factor for cardiac disease) was highly cost-effective, though the cost-effectiveness for remote monitoring of heart failure differed according to the disease severity (De Guzman et al, 2022). Although the role of remote monitoring of cardiac diseases such as heart failure is still subject to debate, many clinical trials seem to propose that remote monitoring of the condition improves clinical and survival outcomes.

Physiological parameters monitored when managing cardiac patients remotely often include blood pressure (BP), heart rate (HR), ECG wave patterns, as well as other patient factors such as weight and activity profile. This information is crucial as it is used to design personalised treatment regimens for patients being monitored, evaluate their response to treatment, and look out for patterns that may point to potential clinical complications. As such, this information needs to be stored in an environment where it is secure, can be accessed in real time, and can be utilised remotely. This is best achieved by integrating patient monitoring systems with the Internet of Things.

ECG monitoring systems that are able to link to cloud platforms where the data they collect is stored and analysed, increase the amount of patient information available to healthcare givers. This together with the speed at which the information is collected, transmitted, and analysed, enhances the decision making capabilities of both the patients and caregivers, thereby improving the health outcomes for those being managed for cardiac disease. IoT enabled ECG devices generally consist of the following:

An ECG sensor network

This is the starting point of the entire system architecture, and it is involved in the collection of biophysical data in the form of electrical impulses sensed by the ECG surface electrodes and then transmitted to the IoT cloud wirelessly. Wearable ECG electrodes are used to ensure continuous ECG data collection and transmission over a long period of time (hours or days), and amplification and filtering of the collected signals is done to improve their quality. Specific transmission protocols such as Near Field Communication and Bluetooth can be used, as these can provide sufficient data transmission rates for ECG signals without requiring a lot of energy consumption.

The IoT cloud

The collected ECG data is stored and analysed in the IoT cloud. This ensures that sensitive patient data is stored in a secure location, and also provides the added benefit of allowing data processing that requires a lot of computational power to be performed by the much more capable servers of the IoT cloud. Thus significantly reducing the computational burden on smart devices. IoT clouds for ECG monitoring systems typically have the following features;

Data cleaning - Noise that may have been introduced into the ECG signal during data collection and transmission needs to be cleaned. This is achieved through the use of a filter which removes noise introduced in the ECG signal to ensure that it is clean. Furthermore, data auditing can be done to detect contradictions and anomalies in data.

Data storage - The data collected from the ECG monitoring system is crucial for diagnosis of cardiac disease, as well as monitoring of established cardiac disease in order to mitigate potential complications. This underscores the importance of having a repository for such data so that it can be used for future analysis. The data usually includes historical patient information, the time, and parameters such as ECG signal amplitude, direction, timing and duration. Furthermore copies of the data need to be stored for data recovery in the event of unforeseen disasters.

Data analysis - Data analysis platforms are often provided by the IoT cloud, and these can be used to extract useful information from the data sent to the cloud. This can be done through specific machine learning algorithms or data mining techniques. An example of this is the use of a deep learning resnet model in order to detect cardiac arrhythmias in real time.

Disease warning - Heart attacks can occur unexpectedly, potentially endangering the life of patients with heart disease. It is therefore important to put disease warning features on an IoT cloud as this reduces the case fatality rates of cardiac complications. By using data analysis results, the IoT cloud can help interpret in real time the health status of patients, and issue warnings to healthcare providers or family members in case suspicious findings indicative of life threatening complications are noted.

User interface

The user interface plays a role in the visualisation and management of data. Commonly in the form of a graphic user interface (GUI), the ECG data stored in the IoT cloud is accessed in a more user friendly manner. Generally for the end user, the GUI may exist in the form of a mobile app - offering immediate response to user input, or a web-page (Figure 8).

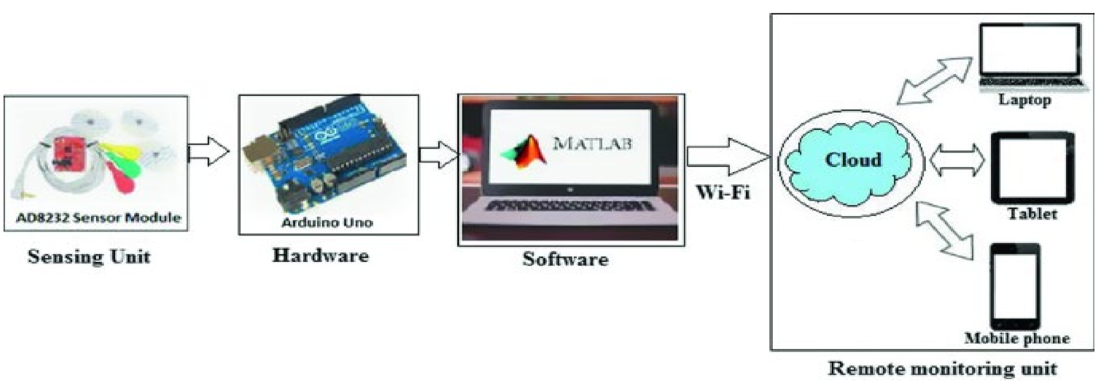

Figure 8. Typical architecture of IoT based ECG monitoring system.

2.2 Flexible, wireless, and wearable biosensing technology and its implementation in IoT enabled ECG monitoring systems

2.2.1An overview of flexible sensor technology

The increasing burden of cardiovascular disease in a growing and ageing population globally, along with a continuous increase in healthcare costs, worsened by a shortage of healthcare personnel and healthcare equipment in low resource settings, have led to the adoption of a more decentralised and telemonitoring based management in cardiac care. This evolution in the healthcare system has been greatly assisted by advances in wearable electronics used in remote physiological monitoring of those being managed for heart disease. At the forefront of this, has been the introduction of soft and wearable sensing technology in recent years.

Soft and wearable sensors, are a subclass of soft electronic devices, and have a diverse range of applications in the healthcare sector which include but are not limited to; detection of bioelectric signals (ECG, EEG), indirect BP estimation, analysis of sweat and saliva, and detection of bacterial antigens on mucosal or skin surfaces, etc. Unlike traditional rigid sensors used in the detection of ECG signals, these flexible sensors have high biocompatibility, offer intimate skin coupling, are more comfortable to use during extended periods, and are conformable with the body surface. These advantages allow an overall improvement in ECG signal quality, and enable monitoring of patients to be done for extended periods, for example, during sleeping. Thus high quality physiological data can be obtained which will be crucial for the management of cardiac patients, and in addition, the quantity and quality of data available to machine learning algorithms in the IoT cloud will be greatly improved.

The 'substrate' for flexible sensors often consists of materials that contain polyurethane, polyimide or polyethylene naphthalene, including polymers with hydrogel as well as elastomeric properties (Lieu et al, 2017; Scholten and Meng, 2015). In addition to their biocompatibility with the skin surface, and body conformal properties, these materials are also capable of responding to electrical, chemical, magnetic, mechanical or thermal external stimuli that may be present in the environment where they are applied (Ghosh et al, 2023). Most flexible sensors make use of thin film metal based electrodes, and the latest wearables that employ flexible sensor technology, make use of energy harvesting, and low battery power utilisation, allowing the battery to be self-sustainable (Ghosh et al, 2023).

2.2 Typical design and usage of flexible ECG sensors

In designing flexible ECG sensors, most manufacturers tend to use an encapsulating layer of polyurethane surrounding a flexible printed circuit board made up of two or more thin layers of silicon, with mounted electronic components. This ensures stretchability of the sensor along the curvilinear body surface, along with reducing the air gap between the sensing surface of the device and the skin, (thus allowing intimate skin coupling), which increases the signal-to-noise ratio. A suitable medical grade and biocompatible skin adhesive is then applied on the sensing surface, to ensure that the sensor remains fixed in place for a prolonged period. Additionally, conductive hydrogel may also be applied to the sensing surface to improve signal integrity. A considerable portion of the surface area that faces the skin is devoted to the ECG electrodes, usually two, that are spaced sufficiently apart, and made up of thin film metal embedded within the polymeric substrate. Multimodal sensing can also be applied, e.g, temperature sensing and indirect BP estimation using a PPG sensor, depending on the surface area of the device. For mass production of the biosensors, roll-to-roll manufacturing processes are applied, which is suitable for the flexible material, thus allowing economies of scale to be achieved (Figure 9).

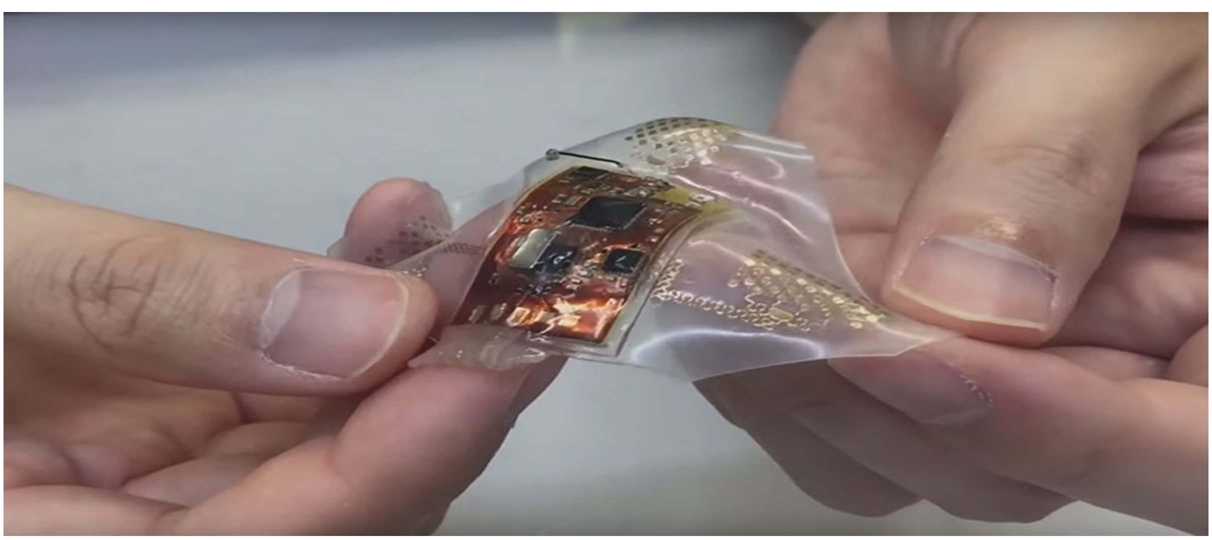

Figure 9. A Flexible sensor consisting of a flexible printed circuit board encapsulated in polyurethane.

The commercially available WiSP cardiac biosensor consists of a substrate layer that is flexible and contains electroless nickel immersion gold electrodes. It employs ultra-thin multi-layered conformal mechanics in its design to achieve intimate skin coupling and improve the integrity of ECG signals (Lee et al, 2018). Additionally, it is low-cost - being mass produced through roll-to-roll manufacturing processes, disposable, lightweight (about 1.2 grams), and capable of energy harvesting by using near-field-communication (NFC) technology. This makes it ideal for use in home-based, and ambulatory cardiac monitoring.

Near-field-communication is a short-range form of wireless communication that uses magnetic induction. Through NFC, devices brought into contact, or within a short distance of each other, (usually a few centimetres), are able to communicate wirelessly. The WiSP microcontroller contained in the WiSP cardiac biosensor, leverages this technology during power-up or power-down, as well as during the retrieval of logged ECG data, thus optimising power consumption, and prolonging battery use. Additional measures that can be used to optimise power consumption in flexible biosensors similar to the WisP device, as proposed by Nguyen C.H et al (2022) in their prototype, include utilising low power Bluetooth communication, and reducing the input voltage levels of the microcontroller unit to a minimum operating range (about 2.2 Volts) (Nguyen et al, 2022).

When used in IoT enabled ECG systems, the bio sensor transmits the data it records to a mobile device, which could be a smartphone or smartwatch, via Bluetooth or NFC. From there, the information is relayed to the IoT cloud server. Health data is usually transmitted to the cloud server from the mobile gateway via MQTTP (message queueing telemetry transport protocol), and can be retrieved onto the mobile device, using a suitable graphical user interface. Remote monitoring of the patient by healthcare workers is made possible by using a web application. Deep learning models such as 1D convolutional neural networks implemented in the IoT cloud, can then aid medical personnel in analysing ECG patterns in order to assess the patient's cardiac health status (Figure 10).

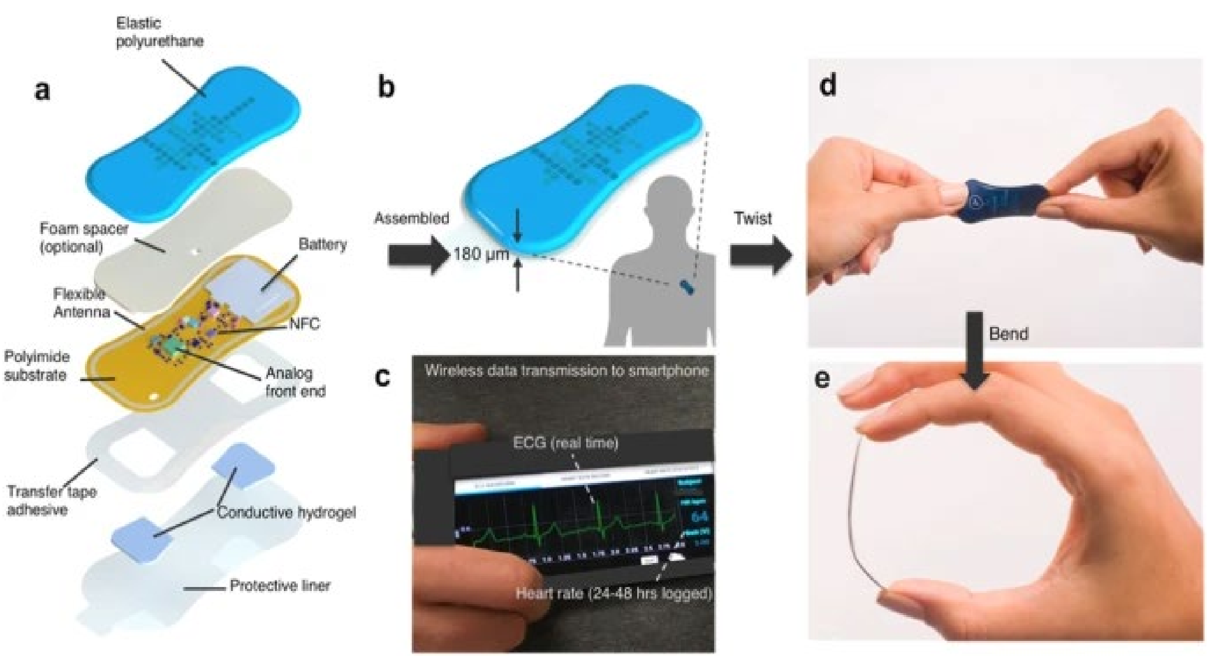

Figure 10. Schematic illustrations of the WisP cardiac biosensor.

The clinical utility of the WiSP biosensor and similar flexible sensor technology has been shown in clinical feasibility studies. The WiSP device has demonstrated its ability to capture full, differential ECG signals in healthy subjects across leads I, II and III. In addition, a study to remotely monitor a group of patients with atrial fibrillation using the WiSP biosensor showed heart rate results that had a strong correlation with heart rate figures that were tabulated from a Holter monitor (Lee et al, 2018). In separate studies on BP estimation using a flexible, wireless biosensor, Nguyen C.H et al (2022) in a clinical study produced experimental results that met the standards for BP monitoring devices set by the British Hypertension Society, and those contained in the Association for the Advancement of Medical Instrumentation (Nguyen et al, 2022).

3. Discussion

The unique design of flexible ECG biosensors that employs stretchability, conformal mechanics, lightweight, low cost, and energy optimisation, offers a way to facilitate remote telemonitoring based management of cardiac patients at a large scale in low resource settings. This technology combined with associative technologies such as health - IoT, and artificial intelligence, has the potential to decentralise cardiac care, and streamline workflow in hospital/clinic settings, while at the same time reducing cardiac care costs, and improving the quality of life for those undergoing treatment for heart disease.

Compared to their rigid counterparts, flexible sensors are more comfortable to use, thus improving patient compliance to treatment plans involving prolonged or ambulatory monitoring, and offer increased skin coupling, which improves ECG signal quality. Additionally, due to their ability to stretch, multimodal sensing is easier to implement in flexible sensors, therefore increasing the variety of sensory data available for use during physiological monitoring of patients. This increases the availability of quality data available to learning models utilised by the IoT cloud, and in turn, this allows more reliable disease predictions to be made. Furthermore energy optimisation through the use of NFC technology, or low power wireless transmission of data, as well as using minimal operating voltage ranges for biosensors extends battery usage and prolongs the functionality of the device.

The unique design of flexible ECG biosensors also allows more economic mass production methods such as roll-to-roll processes to be applied during manufacture, significantly reducing their cost on the market, and thus allowing them to be more accessible to those in need of constant monitoring.

Despite the progress brought about by flexible sensor technology, limitations still exist. Thin film metal electrodes used in flexible biosensors for instance, are prone to strain induced cracking with prolonged use. This limits their sensitivity, and thus improvements are being explored which make use of semi-fluid or tattoo like conductor materials, that achieve greater skin coupling intimacy, with a greater signal-to-noise ratio, and are biodegradable. Furthermore cheaper, and more environmentally friendly production methods are yet to be introduced, that minimise the pollution brought about by the production of semiconductor materials.

In clinical studies, ECG data from devices such as the WiSP biosensor compares favourably to that which is obtained from Holter monitors, thus demonstrating that IoT based ECG systems that make use of these wearable flexible sensors can be used reliably in home-based cardiac care. Further studies also demonstrate that patients find them easier and more comfortable to use, thereby improving patient compliance. However, more studies involving different demographic characteristics of patients need to be conducted at a larger scale, in order to reliably assess the efficacy of flexible and wearable biosensor technology in cardiac care.

4. Conclusions

As the field of soft electronics evolves, more strides will be made in improving the biosensor technology available for remote physiological monitoring of cardiac disease. Continuous and careful research into unique materials that can be used to improve sensor technology will have to be made in order to improve the functionality of wearable sensor devices. Furthermore, more clinical trials will need to be conducted in order to assess the current impact of remote telemonitoring based cardiac care.

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