Wearable Electronic Devices for Electrocardiograph Measurement

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Abstract. The early diagnosis of developing cardiac disease requires the steady and ongoing monitoring of electrocardiograph (ECG) signals. Wearable technology will need to advance quickly to support the daily collecting of ECG data for continuous monitoring of ECG signals in daily life. This study evaluates wearable technology's most recent advancements and potential uses for textile electrodes in ECG monitoring. In accordance with the various electrode types, several wearable device applications for monitoring ECG signals will also be shown. Wearable electrodes can be categorized as contact or non-contact electrodes. Contact electrodes can be further subdivided into electrodes with metal integration in the textile, electrodes with carbon coating on the textile, and electrodes that are densely woven from conductive polymers. Textile electrodes with integrated conductive elements, capacitive electrodes, and metal-integrated textile electrodes are the three types of non-contact electrodes. For the daily monitoring and early diagnosis of cardiac disease, these portable wearables are crucial.

Keywords: Electrocardiograph, Wearable Electronics, Textile.

1. Introduction

The electrocardiogram is now a very well-established test in medicine. Usually, electrodes in direct contact with the chest and extremities were used to obtain biological point differences. The equipment used to measure ECGs in hospitals is larger. It is too late to monitor the ECG when a patient has a heart attack. According to mortality data from 2015, the cardiovascular disease claimed the lives of 17.7 million individuals worldwide. Since this statistic equates to 31% of all fatalities [1], it is crucial to monitor the patient's ECG over an extended period of time. However, it is impractical to have each patient carry around a hospital ECG monitoring gadget, for instance. Investigating the use of wearable technology to monitor ECG signals is crucial.

A sensor technology that has been advancing quickly in recent years is wearable sensors. They have a variety of uses and are widely applied to various facets of national life and production. Wearable sensors are divided into three categories: skin contact sensors, non-direct contact sensors, and implantable sensors depending on how they make contact with the human body. Wearable sensors have the benefit of being able to continuously monitor vital signs including heart rate, blood pressure, and blood samples. In a study by Remo Lazazzera et al., a new type of watch was proposed capable of monitoring blood pressure and blood oxygen at the same time [2]. The signals are filtered and crossed by acquiring two photograms to obtain the time delay between them. The heart rate and time delay were then fed into a linear model to estimate systolic and diastolic blood pressure. This approach results in a wearable device that is easier to use and carry. By the same token, monitoring of ECG signals has been a new addition to wearable devices in recent years. It facilitates the early diagnosis and treatment of patients with heart conditions. An ECG sensor was embedded in a chest strap to capture the wearer's ECG signal. The ECG signal and heart rate are displayed in real-time via Bluetooth transmission to a mobile device application. Although the wearer's comfort is somewhat limited, the ECG signal is measured consistently and accurately output over a long period.

In this article, contact electrodes and non-contact electrodes will be described. Among this contact, electrodes are metal-integrated textile electrodes, carbon-coated textile electrodes and conductive polymer deep textile electrodes. These types of electrodes should have a good fit and be comfortable and durable. This allows for a long and comfortable fit without causing significant damage to the skin.

Other factors need to be considered in these contact electrodes, such as the dryness of the skin, whether sweat has an effect on the measurement of the ECG signal and whether sweat has an effect on the fit. Non-contact electrodes are textile materials that are placed between the skin and the electrodes, such as vests or underwear. They are divided into metal-integrated textile electrodes, capacitive electrodes, and conductive element-integrated textile electrodes. Since these electrodes do not directly contact the skin, they are gentler on those with sensitive skin, such as young children and the elderly.

Wearable ECG monitoring devices will not only improve the comfort and convenience of heart health monitoring but will also provide daily monitoring of ECG signals and early prevention of heart disease in patients. This may help to reduce the mortality rate from heart disease in the future.

2. Wearable devices for ECG monitoring

Contact and non-contact textile electrodes are the two varieties of textile electrodes used for ECG measurements. Contact-type textile electrodes are those that consistently make direct contact with the skin to detect signals. Non-contact electrodes, which monitor the ECG signal on the textile material that serves as an interface between the skin and the electrode without making direct skin contact, are dry electrodes that are capacitively linked. When skin damage from direct contact with the electrode could occur, especially for young children and the elderly, these non-contact textile electrodes are essential.

2.1. Contact electrodes

2.1.1. Metal-integrated textile electrodes

Textile electrodes are insulating, and therefore, conductive yarns can be woven into the fabric during the production of textile electrodes [3]. Textile-based wearable devices can be made in the form of a vest for detecting ECG signals [4]. Such vests (Fig.1) are mainly used to measure events such as irregular heart rates. The vest does not require any other medium or substance, such as a gel. It consists of two woven electrodes made of conductive fibers that come into direct contact with the human skin, thus allowing accurate measurement of changes in the human heart rate. The vest system ensures good signal quality [5], and the absence of any means of adhesion ensures comfort for the human skin.

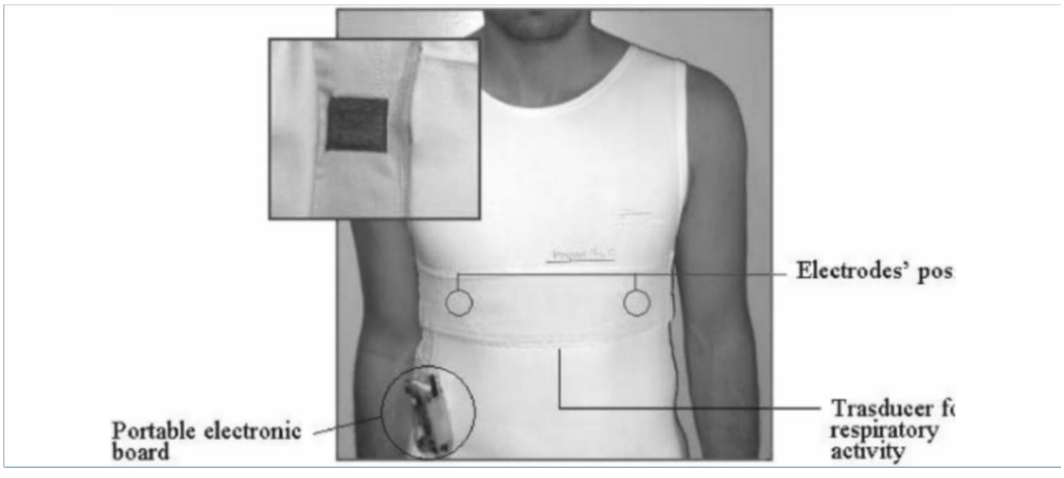

Fig. 1 In the textile electrode's inset detail [4].

In the experiments of Wanqing Wu et al. [6], the conductive fabric provided partial polarisation for ECG measurements and therefore, no conduction gel was required. Compared to copper wire, silver wire is more conductive and has better ductility. Metallic silver is coated on cotton and nylon to form a textile electrode of conductive material. The electrodes are also combined with a vest to measure the body's ECG signal, resulting in a reasonably quality ECG signal and better comfort (Fig. 2).

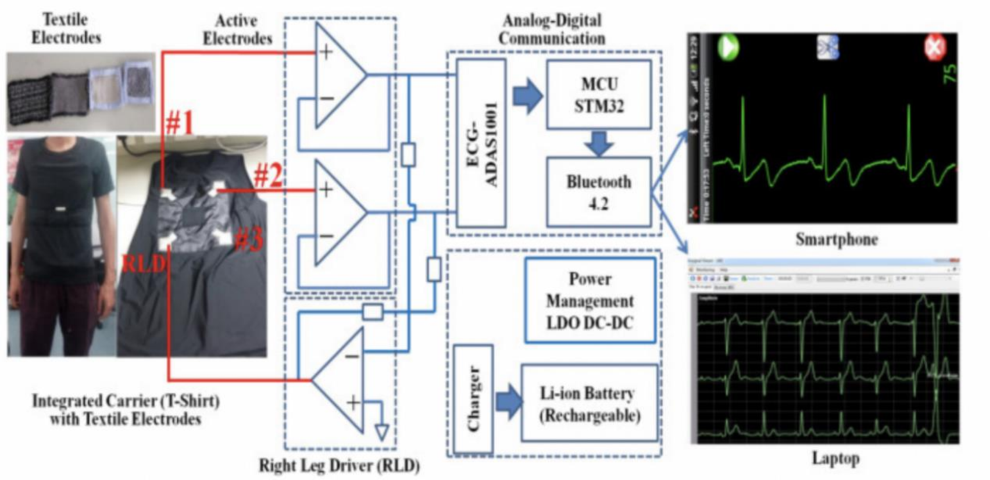

Fig. 2 Integration of a textile electrode-based wearable system for ECG evaluation and measurement [6].

2.1.2. Coated textile electrodes

Carbon materials have shown important benefits in conductive fabrics because of their low cost, corrosion resistance, flexibility, electrical properties, and high aspect ratio [7]. Carbon-based materials such as graphene, carbon nanotubes, chemically altered graphite, and carbon have all been used to create conductive fabrics for bioelectric potential monitoring [8]. Murat KayaYapici et al. used graphene coatings on fabrics to form conductive textile electrodes [9]. It has been used for the acquisition of biological signals, particularly ECG signals. After discrete wavelet transforms processing of disturbances such as noise and EMG signals due to motion correlation and using low-pass, as well as high-pass filtering to deal with distortions, an almost perfect overlap with conventional silver chloride/silver (Ag/AgCl) ECG waveforms, was finally obtained.

Lee, J.W., and Yun, K.S. [10] proposed a wearable ECG monitoring garment made from a conductive carbon-based paste. This paste was applied to the skin and left to dry for five minutes to form patch electrodes. One of the key factors affecting contact impedance is the contact area between the electrode and the skin, which is almost 100% for the carbon-based paste on the skin. This layout effectively cuts down. Even when jogging or engaging in other workouts, a fairly steady ECG signal may be seen. However, the electrodes in this investigation were in close proximity to the skin. Long-term clinical investigations are required even though there was only a little redness and irritation during the experiment and no severe skin damage (Fig. 3).

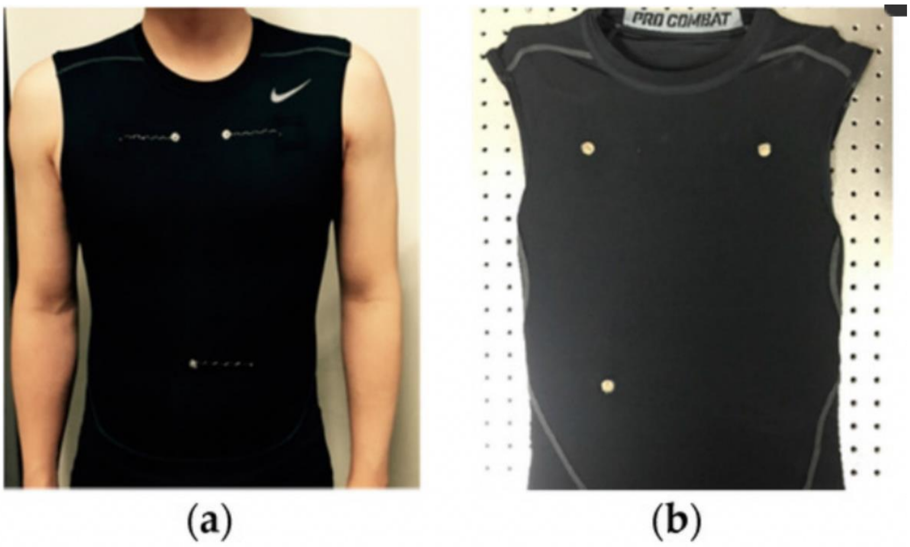

Fig. 3 Electrocardiogram (ECG) measurement garment. (a) Outside of the garment; and (b) inside of the garment [10].

2.1.3. Deeply woven electrodes made of conductive polymers

Due to the adaptability, durability, and ease of production of conductive polymers, it is quite simple to create lightweight conductive materials. It will be more advantageous for medical wearable device applications [11, 12]. Woven textiles composed of poly-3,4-ethylene dioxythiophene-treated doped polystyrene sulfonates (PEDOT: PSS) do not result in electrochemical impedance mismatches in the tissue because of their low cost and biocompatibility [13]. Thus, it may be utilized without gel. The final textile electrodes can be treated with a highly conductive polymer like PEDOT: PSS to provide reliable ECG readings and reusable textile electrodes [14]. Similar to this, in a work by Castrillon, R [15], textile ECG electrodes were created by soaking standard textiles in PEDOT: PSS and sewing them to a layer of foam and polyester that was non-conductive. The findings demonstrated that under both static and dynamic settings, the signals acquired using the textile electrodes were of equivalent quality to those collected using conventional Ag/AgCl electrodes.

In addition to this, in a study by YogitaMaithani [16], silver nanorods embedded in polydimethylsiloxane (PDMS) dry electrodes were proposed. Since this material has some antibacterial properties, the electrodes made remain harmless to the skin after several hours, even if they are in close proximity to the skin. The study's findings demonstrate that the enhanced polymer electrode, which has a lower skin contact impedance than the conventional Ag/AgCl wet electrode, can record high-quality ECG data. Because the conductive gel in typical Ag/AgCl electrodes wears down over time from repeated usage, their impedance rises. However, polymer electrodes allow the detection of long-term ECG signals because their impedance values remain almost constant over a long time.

2.2. Non-contact electrodes

2.2.1. Metal-integrated textile electrodes

Textile ECG non-contact electrodes with an incorporated metal wire that can be made of stainless steel, copper, or silver. Using different metallic wires, conductive fabrics may also be created. For instance, a textile-based non-contact ECG signal collection device was suggested in research by Li et al. [17]. The technology is based on textile electrodes in stainless steel conductive fabrics that are electrically linked. Three-dimensional weaving was used to create the conductive fabric. In order to join the warp and weft layers and create three-dimensional woven composites, bonding threads are interlaced in the thickness direction. These spatially webbed textiles are then cured with a matrix under certain circumstances. The high density of the three-dimensional woven textile also helps to maintain the shape of the conductive textile. This results in a coupling capacitor that is more stable, which improves the electrical conductivity of the textile and facilitates the acquisition of the ECG signal on the subject's surface.

In the investigation of Jeong Su Lee et al., conductive foam was used to cover the electrodes' surface [18]. Ni/Cu was applied to the material's whole surface to make the foam conductive. A chest strap has an electrode attached to it. The electrode is constructed of a flexible material to reduce user discomfort. The capacitive coupling technique may be used to measure the ECG signal on fabric. Without harming the skin or removing the garment, the wearer may effortlessly attach and detach the device from the clothing. In order to reduce the instability of the electrode contact brought on by movement, the electrode surfaces are covered with conductive foam, which also functions as a barrier to limit external movement artefacts introduced via the belt (Fig. 4).

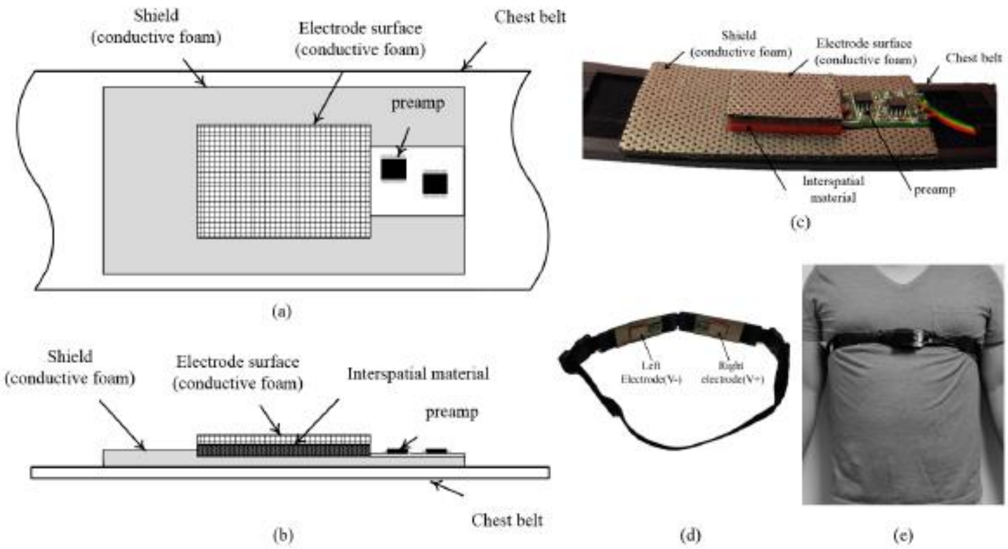

Fig. 4 The flexible electrode's configuration includes (a) top view, (b) side view, (c) photo of the real electrode, (d) overall design, and (e) wearing a system around people's waist [18].

2.2.2. Capacitive electrodes

Capacitive electrodes can be integrated into clothing, such as T-shirts. The ability to sense a person's ECG signal during everyday activities while maintaining the wearer's comfort. In addition, capacitive systems can be integrated into a variety of objects, including chairs, car seats, wheelchairs or beds. Capacitive dry electrodes are suited for continuous, sustained monitoring since they don't need a conductive liquid or direct skin contact. Despite a layer of material separating the skin and the electrode, the electrode nevertheless enables the ECG signal to be sensed on the skin's surface through capacitive coupling, making it suitable for long-term ECG monitoring in a moving environment. Capacitive electrodes can measure ECGs on textile materials. In a study by Sumit Majumder et al., a wireless ECG monitoring system based on stretchable dry capacitive electrodes was developed [19] for the long-term monitoring of cardiovascular health. In the test, the testers wore electrodes that were attached to a fabric that resembled cotton. Due to its thinness and proximity to the skin, cotton is ideal for capturing the ECG signal. Additionally, the wearer finds it easier to carry and use the smaller electrodes (Fig. 5).

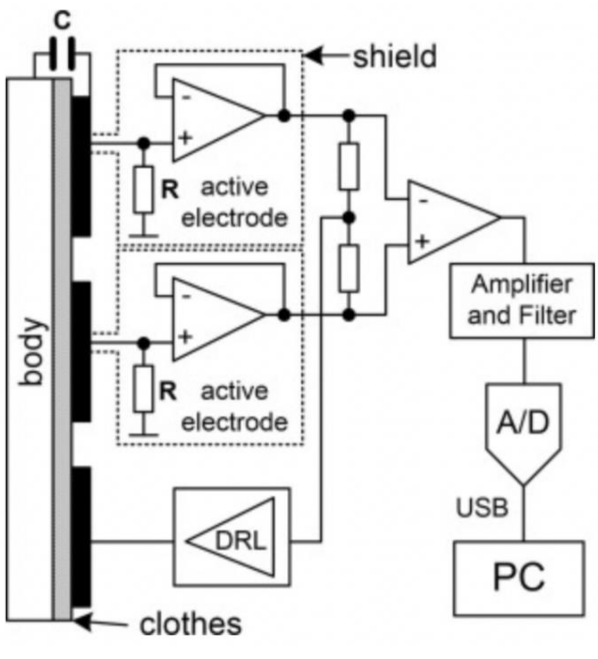

Fig. 5 shows how capacitive ECG sensing works [19].

One plate of the capacitor is represented by the active electrode region, while a second plate—a virtual plate of the capacitor—is represented by the skin surface. The garment serves as the dielectric substance that is sandwiched between these plates. Cotton or a cotton and polyester blend makes up the majority of clothing materials. As dielectric layers, a variety of different materials can be utilized.

In a study by B. Chamadiya et al. [20], capacitively linked electrodes were used to create a wearable device for ECG signal monitoring. Electrodes were attached to a stretcher, a hospital bed, and a wheelchair as part of this experiment. Since these are the hospital systems that patients use the most frequently from the time, they need emergency medical treatment until they are released from the hospital, they cannot survive without them. The test subjects' ECG signals were effectively recorded throughout the trial, and neither the thickness nor the makeup of their garments had any impact. The quality of the ECG test is unaffected when the subject is wearing clothes that is at room temperature.

3. Discussion

With contact electrodes, the ECG signal may be monitored unhindered since the electrode makes direct touch with the skin, regardless of the material. As a result, the ECG signal is measured more accurately and steadily. Disposable silver chloride/silver gel electrodes are the most popular electrodes for measuring ECG signals when a direct metal-to-skin contact is required, and this is true for both clinical and portable systems. These electrodes provide a very steady electrical contact with the skin by reducing the impedance between the electrode and the skin using an electrolyte gel. However, as time increases, the disadvantages become apparent. The gel can become dehydrated over time and therefore needs to be reapplied after a certain period. At the same time, dehydration of the gel can cause some irritation to the skin and thus some damage to the person. In the case of carbon-coated textile electrodes, no similar problems arise. The conductive carbon-based paste takes only five minutes to form an electrode on the skin and its contact area with the skin is almost 100%. This is a great help in improving the accuracy of this ECG signal measurement. Naturally, this substance still has the potential to irritate delicate skin and have other negative effects on people. This is a useful material for direct skin contact in the case of conductive polymers. Conducive polymers' adaptability, robustness, and ease of fabrication make it very simple to create lightweight conductive materials. Additionally, some materials are suitable for developing wearable technology because of their inexpensive cost. The antibacterial qualities of some materials for conductive polymers provide significant benefits for electrodes that come into direct contact with skin. There is no discomfort or skin irritation because of this.

The benefit of non-contact electrodes is that they do not require direct skin contact and do not irritate or harm the skin as a result. Therefore, non-contact electrodes are a huge benefit for anyone with sensitive skin, such as infants, children, and the elderly. There are, however, some issues as well. More study is required to ascertain if the electrodes are influenced by the material to which they are connected because they are not in direct touch with the skin. Since the electrodes don't make direct contact with the skin, they might become unstable during activities like human movement. Researchers developed the idea of detecting ECG signals using conductive foam together with flexible electrodes and capacitive electrodes as a result. The combination of flexible electrodes and conductive foam provides sufficient user comfort and immunity to external motion artefacts. Since the capacitive electrodes are in direct touch with the skin and don't need a dielectric, they are ideal for long-term, continuous recording of ECG data. Due to their small size, the electrodes are transportable.

4. Conclusion

Wearable devices are now developing at a rapid pace and can also be used in a large number of medical devices. Wearable medical devices allow us to measure many physiological activities. The

ECG is among the most significant of these physiological signals and is extremely useful in the early detection and treatment of cardiovascular disease. Additionally, early detection and prevention of cardiovascular disease are crucial because it is a condition with a high fatality rate worldwide. Wearable medical gadgets are crucial in this situation for monitoring ECG signals. This is due to the size of the medical equipment used in hospitals, which prevents the steady long-term monitoring of patients. Therefore, wearable medical devices that monitor ECG signals are crucial for both the early identification of cardiovascular illness and the ongoing surveillance of the condition as it progresses.

Contact electrodes and non-contact electrodes are the two types of electrodes used in wearable medical devices. Contact electrodes can measure ECG signals directly and accurately in direct contact with the skin but may cause some irritation to the skin. This can have a significant impact on people with sensitive skin, such as infants and the elderly. Direct contact with the skin may also be affected by the condition of the skin, such as sweat, making the measurement results inaccurate and unstable. In this case, it is proposed to mix electrodes with other materials such as carbon coatings and conductive polymers before contacting the skin. This method reduces skin irritation to a certain extent and lasts longer. Non-contact electrodes don't make direct skin contact; thus they don't seriously irritate the skin. However, because the electrodes are attached to other materials, they may be affected by the material to which they are attached during movement and may not be able to measure the ECG signal accurately. It is therefore important that the electrode material is selected in such a way as to minimize motion artifacts. This will allow the wearer's ECG signal to be measured consistently and without the effects of movement.

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