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Technical note

A flexible touch sensor based on conductive elastomer for biopotential monitoring applications

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ABSTRACT

This paper proposes a novel flexible touch sensor based on conductive elastomer (CE) for biomedical applications. The CE electrodes are simple and easy to use, and made of a silver-coated glass (Ag/G) composite material. The purpose of this work is to produce a novel dry electrode, where skin preparation is not needed anymore in order to avoid the skin from becoming irritated. The CE electrode has a length of 55 mm and width of 35 mm. The surface resistivity of the CE electrode is 0.2 ohm/sq. The proposed system does not require additional active electrodes, and a single-layer standard printed circuit board (PCB) was developed to allow for portable electrocardiography (ECG) and electromyography (EMG) signal acquisition. The proposed electrodes, used in contact with the fingertips, are demonstrated and evaluated for the biopotential monitoring applications of long-term ambulatory ECG from fingertips and EMG signal from human index finger to control man-machine interface device. We used two CE electrodes for obtaining ECG signal from fingertips and another electrode is used on the left leg. In case of EMG signal acquisition, we used two CE electrodes on the index, ring finger and another electrode is used for reference. We measured the impedance as per the frequency change and compared the outcomes with those of Ag/AgCl electrodes. Afterward, we measured the ECG signal and investigated possible artifacts caused by motion. Skin-electrode impedance of the CE was measured and compared to the Ag/AgCl electrodes, where we found lower impedance for CE electrodes. In addition, the power spectrum of the biopotential signals obtained from the CE electrodes are evaluated and compared to those obtained with Ag/AgCl electrodes for estimating signal quality. The results indicate that the proposed touch sensor is capable of bringing a good quality biopotential signals.

1. Introduction

Cardiovascular maladies are some of the most serious hazards to human health, and heart disorders that suddenly and incidentally occur not only bring a great deal of stress and mental pain to patients, but are also endanger their lives. Long-term continuous ECG monitoring has been recognized to be a significant component to care for aged individuals, especially those who suffer from cardiovascular disease, as well as to monitor the health of athletes or fitness enthusiasts, and several groups have developed device prototypes for these purposes. The early interpretation and monitoring of cardiovascular disease is particularly important, and electrocardiography (ECG) is one of the most important health monitoring methods. An electrocardiography provides a significant amount of information of the condition of the human heart. Continuous monitoring of an ECG signal is essential for those who are in a critical condition, and for that reason, portable biopotential monitoring devices are popular nowadays and are now commercially available in the market. However, researchers continue to develop devices that convenient to use and are error free in order to add comfort to the patient's life. The biopotential is recorded as the potential that is generated by nerves and muscles, and the potential and frequencies typically range from μV to mV and from 0.1 Hz to 1 kHz [1,2]. The potential of the human cells needs to be amplified to carry out analog to digital conversion (ADC) due to the high impedance of the human skin, the interference from the surrounding environment, and power line noise. An ECG monitor can be divided into a conventional ECG device and a holter ECG device. However, traditional ECG devices have several problems: first, the long-term measurement of an ECG is not possible [3]. Moreover, they are inconvenient for mobile use because the entire device is composed of an amplifier, filter, and ADC. Although a traditional ECG device is smaller

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than the size of a holter ECG, it still requires the use of a large backpack. Therefore, the convenience is still limited. In addition, a perfect ECG signal cannot be measured until the subject is kept in a quiet state, otherwise noise is introduced. On the other hand, electromyography (EMG) [4] measures muscle response or electrical activity in response to a muscle stimulation which is used in medical, fitness, rehabilitation, prostheitc control and bio-mimetic technology. EMG signal can be used to operate human actuated devices for daily life activities which means functional substitution of human organs. EMG signal can be acquired from human finger to control the bionic devices which reflect the muscles motion [4]. For all these applications, a portable device is required to be easily wearable and capable of recording vital biopotential signals. Two types of electrodes can be used, including a dry electrode [5] and a wet electrode. A silver/silver-chloride (Ag/AgCl) electrode is extensively used as a wet electrode for regular biopotential measurement due to the low skin-electrode contact impedance, and this enables a high fidelity signal to be recorded [6–9]. This electrode has three main parts: the sensing area, conductive gel, and an adhesive backing pad. Nevertheless, these are generally not suitable for long-term monitoring because they have been reported [10] to cause skin allergies, including skin irritation and dermal inflammation. Also, the skin of the subject needs to be shaved and cleansed with alcohol sometimes. Therefore, researchers are currently developing alternative electrodes that can be used anywhere. Dry electrodes [3,10,11] seem to be a very promising alternative for use in long-term ECG monitoring. Dry electrodes are made of metal, CE or conductive fabric and are body compatible and comfortable for daily wear. They can maintain good contact with the skin, even during motion, and are thus suitable for use in ambulant situations, such as home-care and to monitor exercise. Dry electrodes can be configured as part of contact or non-contact devices. Conductive textiles [7,12–14] are used in dry contact electrodes, and these materials are soft and flexible. Researchers have developed composite electrodes that use conductive textile and some other material. For example, dry conductive textile electrodes made of nanosensors or nanomaterial systems [6,8,15] have been used for ECG monitoring. A comparison [16] was made between disposable silver/silver-chloride and reusable conductive textile based electrodes to monitor ECG signals during exercise. Attempts have also been made to develop screen-printed conductive networks on textiles to monitor the biopotential signal. However, screen printing [9,17] requires dedicated equipment and conductivity is limited as a result of the surface coating. Conductive textiles [1] have been used to measure the impact of the skin-electrode impedance on the ECG measurements. Novel ECG electrode films [18] have been proposed by using low-impedance carbon adhesive electrodes that were developed by mixing carbon black powder and a quaternary salt with a visco-elastic polymeric adhesive. Dry electrodes have also been made based on carbon nanotubes (CNT) and polydimethylsiloxane (PDMS) [19–21] material, and these have shown a capability of long-term wear and a robustness against motion and sweat during electrocardiogram and electroencephalogram monitoring. It is necessary to implement a simple fabrication process that optimizes the conductivity, flexibility, and comfort, and some fabrication processes are too costly and complicated. Therefore, electrode fabrication depends entirely on using highly effective machinery to reduce the cost of the electrodes. Flexible, polymeric [22,23] dry electrodes have been proposed for use in long-term biopotential signal monitoring. Of the different types of electrode, most of the dry electrodes have received a considerable amount of interest because of their electrical and mechanical properties. In general, different types of electrodes are made from various materials that are readily available in the market. Even though portable biopotential monitoring systems are available, long-distance personal healthcare applications have received an increasing amount of attention from researchers in recent years. Telemedicine and web-based [24–26] health monitoring have attracted much attention for researchers due to their universality. Furthermore, cardiac patients can check their signals from a smart phone by using bluetooth communication. Biopotential signals can also be monitored without attaching sensors to the surface of the body, and this is referred to as non-contact ECG. A non-contact ECG measurement was proposed with a subject wearing normal clothes and sitting on a chair [27]. However, the impedance between the skin and the non-contact electrodes is very high as a result of the insulation. For that reason, a high input impedance amplifier is required in order to amplify the ECG signals. Therefore, an additional active electrode is required to obtain the original ECG signal. In order to improve the signal quality of the ECG, the signal needs to be purified using an additional hardware-based filter. Therefore, it is very necessary to provide a high amount of power to operate the device. Capacitive measurements of an ECG signal have been reviewed for use in mobile healthcare [28]. Our proposed system uses a CE to build electrodes for biopotential recording. The CE is more flexible when compared to other materials, and it can be stretched without having negative effects on the skin. It conforms well to the contour of the skin and thus improves the contact of the skin electrode. Moreover, it can be integrated into clothes to provide wearable, unobtrusive monitoring that is suitable for long-term operation. However, since the CE electrodes do not use adhesive or gel membranes, they are more susceptible to noise interference, such as that due to power line noise and motion artifacts. The electrode should be tightly hold to overcome this noise interference, since fingertips is used for biopotential monitoring. Many studies have been carried out for long-term biopotential monitoring, and on the other hand, user-friendly and portable biopotential monitoring devices have been recently studied in the literature. Some researchers have published technical papers that address the portability of such systems. However, little effort has been undertaken to analyze the issues related to the electrode placement. In this work, a conductive elastomer (CE) based electrode is proposed to record ECG from fingertips and EMG from index finger in detail. The weak biopotentials are extracted from the dry electrodes and are amplified, band-pass filtered and ADC converted for real-time viewing on a display.

1.1. Skin-electrode interface models

The electrical activities, including the constant DC electric field, constant charge-carrying current flux, the time-varying electric field, or current are linked with the biological scheme. These activities are related to time-dependent biochemical characteristics, and the allotment of ions or charged molecules in a biological structure are associated with the biopotential phenomena, and deviations in this allocation are associated with specific processes that occur as a result of the biochemical counteractions. The biopotential electrodes [29,30] are nonlinear, and can be represented with an equivalent circuit, as shown in Fig. 1(a), where R_d stands for the resistance that occurs between the skin and the electrolytes, C_d represents the electrical charge between the skin and the electrode during charge transfer, R_s is the series resistance, such as with the electrolyte gel, and the battery E_{hc} represents the half-cell potential between the skin and the electrolytes.

The biopotentials are the electrical potentials that are created as a result of distributed ions, such as Na+, Ca+, and Cl− ions inside of a living body. These distributed ions are responsible for the charge transport in an organic system, and on the other hand, electrons are responsible in the leads of the biopotential device. A biopotential is a result of impulsive cells of the heart muscle. Biopotentials are carried to the surface of the body due to the conductivity of the human body, and ion currents have to be converted to electron currents by