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Contactless Wearable ECG System for Lond Term Monitoring

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Abstract — Electrocardiography(ECG)is the most common and extensively used vital sign monitoring method in the modern health care systems. Different design so fambulatory ECG systems were developed as alternatives to the commonly usedtwelve-lead clinical ECG systems.These designs primarily focus on portability and user convenience, while maintaining signal integrity and lowering power consumption. Here, a wireless ECG monitoring system is developed using flexible and dry capacitive electrodes for long-term monitoring of cardiovascular health. Our capacitive-coupleddryelectrodescanmeasureECG signals over a textile-based interface material between the skin andelectrodes.The electrodes are connected to a data acquisition system tha4 Receives the raw ECGsignals from the electrodes and Transmit the data using Bluetooth to a computer. A software application was developed to process ,store and display the ECG signal in realtime. ECG measurements were obtained over different types of Textile materials and in presence of body movements. Our experiment results showthat theperformance of our ECG system is comparable to other reported ECG monitoring systems. Also, to put this research into perspective, recent ambulatory ECG monitoring systems, ECG systems-on-chip, commercial ECG monitoring systems and different state-of-the-art ECG systems are reviewed, compared and critically discussed.

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Keywords—apacitive coupling; flexible electrodes; ECG sensors; wearable ECG sensing system.

I. INTRODUCTION

Electrocardiogram (ECG) has been proven to be among the most useful diagnostic tests in clinica medicine, which is now routinely used in the evaluation
of and pacemakers, as well as to detect myocardial injury,ischemia,and the presence of prior infarction. In addition to its usefulness in ischemia coronary disease, the electrocardiogram is also useful in diagnosing the disorders in the cardiac rhythm and evaluating syncope. Other common uses of the ECG include evaluation of metabolic disorders, direct and side effects of pharmacotherapy ,and primary and secondary cardiomyopathy

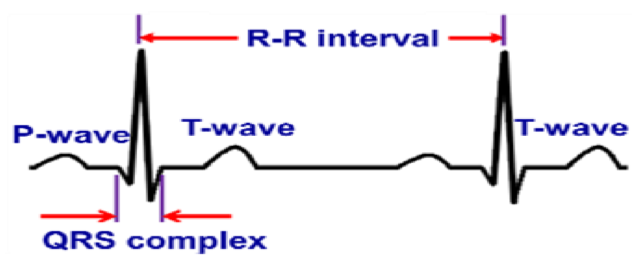

Fig. 1. Basic features in the waveform of an ECG signal

In the early days, realizing a highly sensitive ECG system was a significant challenge. The electrical heart signals attenuate while travelling through the body tissues andbecome weak at the skin's surface. However, Willem Einthoven [1] managed to improve the sensitivity of the ECG sensing systems by using a string galvanometer. Einthoven's improvement was considered to be a giant leap forward for electrocardiography, since the characteristic peaks of the ECGs, now familiar as P, Q, R, S, and T waves, were apparently defined (Fig. 1), while the scientists previously had demonstrated only ventricular depolarization and repolarization[2] Different types of ECG systems [3]–[6] have been Introduced so far to improve the signal quality in the clinical settings. The conventional ECG method uses ahydrogel between the skin and the electrodes to increase the conductivity of the signal path. However, the wet electrode method uses conductive gels that contain toxic materials, which can cause and used to develop a portable wireless ECG monitoring system. The capacitive dry electrodemethod[3], [4] requires neither a conductive interfacial medium, nor any direct contact to the skin, thus making it suitable for long-term irritation to the skin of the patients. Some patients may even be allergic to the nickel particles or the a crylic adhesive present in the popular disposable conductive hydrogel based ECG electrodes [7]–[11]. Therefore, the wet electrode method is not suitable for ambulatory and long-term monitoring oftheECG. In our work,ad ry capacitive-coupled flexible electrodeis designed monitoring. Despite having a layer of interfacial material between the skin and electrodes, the proposed electrode still allows the detection of the ECG signals from the skin's surface Through capacitive coupling, thus making the system suitable for long-term monitoring of ECG in anambulatory environment. The interface material for capacitive electrodes canbeathin layer of textile material such as cotton,which is tightly attached to the skin to ensure an optimal signal quality. Cotton is common fabric for clothes,which,in comparison withother materialssuchas,wool,silk,ornylon,hasahigherdielectric constant, thus, resulting in better capacitive coupling Thesecapacitiveelectrodescanpotentiallybeintegratedwith the smart textiles [13]–[15] to realize a wearable and comfortable long-term ECG monitoring system.Both the capacitive dry electrodes and smart textiles are increasingly being studied and developed for flexible and wearable ECG Monitoring systems In this paper, a detailed and comparative review on the current state of research and developments in ambulatory ECG monitoring systems is presented. A wearable wireless ECG systembasedonaflexibleandcapacitive-coupled active dry electrode is also proposed, which is designed for bothinpatient and outpatient monitoring of the ECG. Thecapacitive-coupled electrode-based system is capable of obtaining ECG signals over a thin layer of cloth,which is transmitted in real-time over the Bluetooth platform for storage and further processing[16].

II. AMBULATORY ECGSYSTEMS

The primary purpose of the ambulatory ECG systems isto facilitate monitoring the heart's activity outside the clinical setting. It also allows for continuous monitoring of cardiovascular health thus enabling detection and diagnosis of any heart related issues at their early onset. Unlike the electro declinical ECG systems, ambulatory ECG systems are small ,portable and generally exploit two to three electrodes to measure and record the electrical signals.Some systems also incorporate wireless communication technologies suchas Bluetooth, Bluetooth low energy (BLE), and ZigBeeto facilitate real-time data transmission. AmbulatoryECG systems with inherent wireless transmission capabilitycan there by play akey role in a smart home-based long-term and remote health monitoring system[17].A general architecture of ambulatory

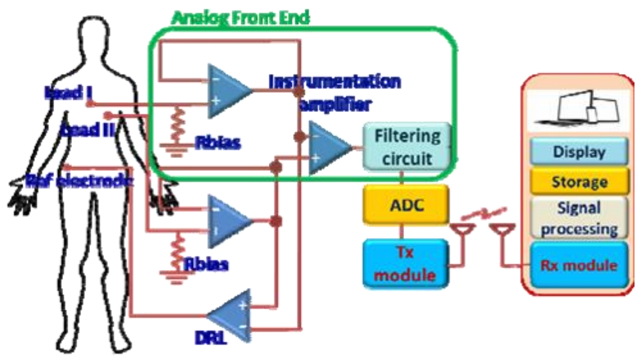

Fig. 2.General architecture of the ambulatory ECG monitoring system

III. PROPOSED ECG SYSTEM

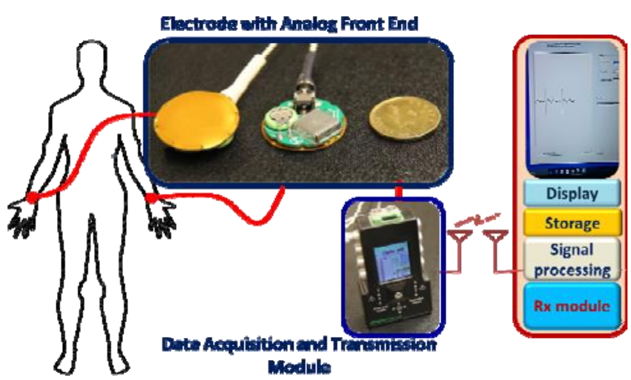

Fig. 3. Block diagram of the ECG sensing system with a photograph of a designed capacitive electrode.

The Biometrics Data Log device acquires the ECG signals using the proposed capacitive-coupled electrodes. Theportable ECG device transmits the measured ECG data over the Bluetoothplatforminrealtimetoawirelessreceiverconnected to the USB port of the computer. The ECG data received from the portable ECG device is processed by an infinite impulse response (IIR) notch (60 Hz) and a band-pass (1 Hz - 30 Hz) filter implemented in the software application to minimize the noise in the ECG traces. After performing the filtering, the ECGreadingsaredisplayedinrealtime.Thesoftwarecanalso store the ECG readings in comma separated value (CSV) format. Each CSV file contains 10-seconds of ECG data. Consecutive acquisitions are automatically stored in files with filenames containing sequentially incremented numbers. Thus, the stored files contain the whole record of the ECG acquisition, until the storing function is stopped by the user.

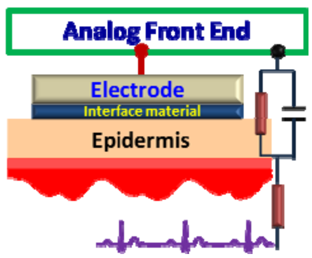

Fig. 4. Electrode-body interface with capacitive coupling of ECG bio-potential.

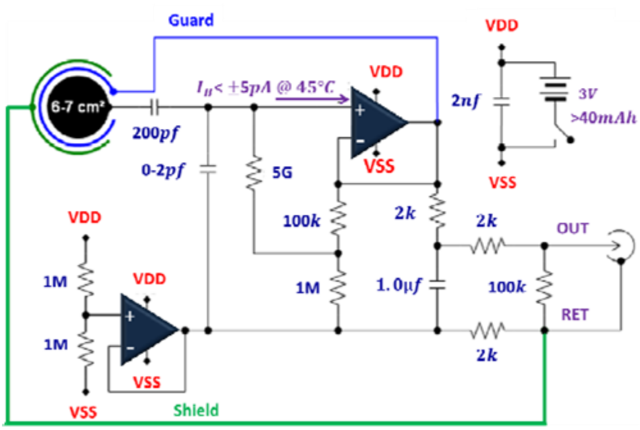

Fig. 5.Schematic diagram of thecapacitiveelectrode.

Fig. 6. Photograph of the ECG measurement set-up.

IV. PERFORMANCE EVALUATION

The proposed ECG monitoring system was used tomeasure the electrocardiogram from three different healthy subjects. The LA and RA electrodes were placed on the forearms of the left and right hand,respectively.The experiment was conducted in a standard room environment.Aformal consent was taken from the McMaster Research Ethics Board (REB)to conduct the experiments. A simple questionnaire wasprepared for the subjects to collect information about any known cardiac
or significant health problems. The impact of different interface materials and body movements on the signal quality arealso evaluated with experiments

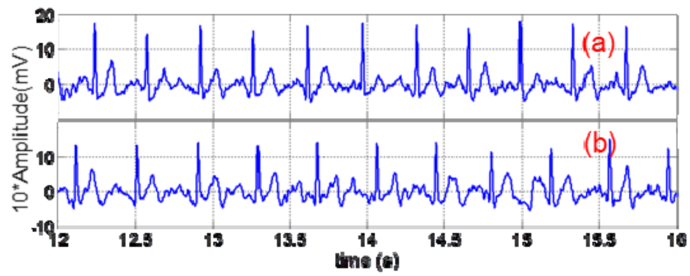

Fig. 7. ECG acquisitions in the time domain without body movement, with electrodes on (a) bare dry skin and (b) cotton fabric covered dry skin.

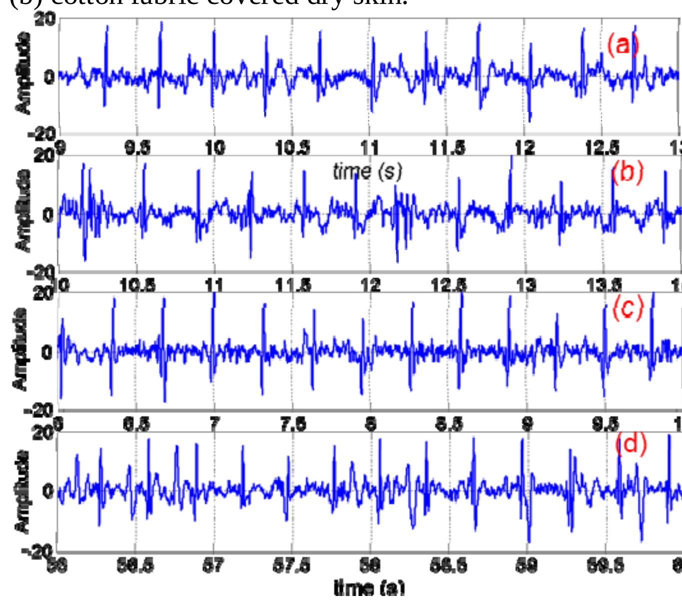

Fig. 8. ECG measured from the textile covered dry skin with body movements: (a) slow abduction–adduction of both hands, (b) fast abduction–adduction of both hands, (c) body rotation, and (a) normal walking.

V. CONCLUSIONS

The proposed ECG electrodes consume small amount power and can run continuously for 2 weeks froma3Vcoincel8l battery that makes the electrode suitable for long-term monitoring. The electrodes are connected to a portable ECG device that is capable of transmitting signals continuously for hours over the Bluetooth platform to apersonal computer in realtime.Therefore, at present, the overall continuous runtime of the system is limited by the battery life of the commercia data acquisitionand transmission module. As observed from the results of the experiments,theproposed ECG monitoring system can properly acquire the ECG signals over the cloth96 with the QRS complexes, P and T waves being clearly distinguishable,whenmeasuredatrest.Theproposedsyste therefore,can potentially be used to detect abnormal ECG.

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