Wearable Health Monitoring System using Flexible Materials Electrodes

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***Abstract*—Bio-signals including electrocardiogram (ECG), respiration rate, motion-related signals, plantar pressure distribution are important for monitoring and assessing a person's health status. Via some of the bio-signals, some diseases or abnormalities such as cardiovascular diseases or a human fall can be detected. However, the traditional health monitoring systems have limitations as they are expensive, not-easy-to-use, stationary, inconvenient and uncomfortable to use. It is required an advanced solution for dealing with the limitations while maintaining a high quality of services such as high-quality signals and accuracy. Therefore, we present a novel wireless wearable health monitoring system in this paper. The system consists of an upper limb device and a lower limb device using flexible materials such as polydimethylsiloxane-graphene compound and textile materials for collecting different ECG, EMG, respiration rate, motion-related signals, plantar pressure distribution. The complete system is implemented, tested and verified in a clinical environment in a hospital. The results show that the system can obtain high-quality bio-signals and can be a potential application for both home-care and hospital-care.**

***Keywords*— Bio-signal, Bio-potential, Acquisition, Wireless, Portable, Wearable, IoT**

I. Introduction

Bio-signals play an important role in monitoring and assessing a person's health status. For instance, electrocardiogram (ECG), blood pressure, body temperature, and respiration rate are the vital parameters [1]. By analyzing and extracting important features from these bio-signals or parameters, some diseases such as some of the cardiovascular diseases can be detected [1]. At the hospital, these bio-signals are often acquired by several devices which are often stationary and use many wires (e.g., 3-channel or 12-channel ECG monitoring devices). In some cases where a patient needs to be monitored in 24-72 hours, this can cause some skin damages, inconveniences, and uncomfortability. For example, adhesive Ag/AgCl electrodes used for collecting ECG may cause skin damage, especially for a new-born child when it has been used for a long period of time [2]. In addition, these devices cannot be properly utilized for home-users due to their limitations such as expensiveness, requirements of expert users and inconveniences. Wearable devices that are small, light-weight and can be used for a long period of time are a suitable solution for the limitations.

Many wearable devices for health monitoring have been proposed but they still have limitations [1]. For instance, state-of-the-art wearable ECG monitoring systems still rely on adhesive Ag/AgCl electrodes [3]. In these systems, 50/60Hz noises can be eliminated by filtering hardware or software but other noises such as motion artifacts are not properly considered at the device. Some of the wearable ECG monitoring systems use textile electrodes but they cannot properly remove all noises (e.g., due to movement artifacts and the heterogeneity of the skin-electrode impedance) [4, 5]. Some other systems use three-dimensional accelerometers or piezo-sensors but their collected signals contain noises due to move artifacts and other surrounding sources [6]. Many wearable devices cannot both collect different bio-signals including ECG, respiration rate, motion-related signals, electromyogram (EMG), plantar pressure distribution simultaneously and overcome the limitations. Therefore, this paper presents an advanced wireless wearable e-health monitoring system including an upper limb device and a lower limb device using flexible sensing materials such as Polydimethylsiloxane-graphene (PDMS-graphene) and stretching textile electrodes. The system is non-invasive and comfortable to use for the users. The system is able to eliminate noises from different sources such as surrounding sources and movement artifacts, and then sends the high-quality filtered signals via Bluetooth Low Energy (BLE). The completed wearable system is designed and implemented. Then, it is tested and validated in the clinical environment in the hospital. It is noted that this paper is a summary of a master thesis in which some results have already been published in conferences and registered for a Chinese patent by S. Bao - the main author of the master thesis [7, 8].

II. System design

The proposed devices are designed according to the analysis and clinical findings after the interview with medical experts. The upper limb device can collect ECG, respiration rate and motion signals. The lower limb device can acquire EMG, plantar pressure distribution and motion signals. The structure of these devices is shown in Fig. 1a and Fig. 1b. The flexible materials are compared and properly selected for ECG, EMG, plantar pressure and respiration signal acquisition. Then, the hardware and software parts are designed and the quality of the collected signals is assessed and compared with the clinical gold standards applied in the hospital.

The hardware system mainly contains three parts including data acquisition, signal transformation, and signal processing. The upper limb and lower limb devices use a similar platform and peripheral components. These devices collect the signals

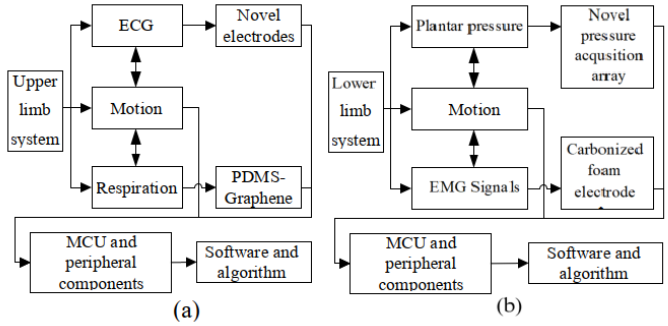

Fig. 1. Structure of upper limb and lower limb devices

from the upper limb and lower limb via different sensors. Then, the micro-controller unit (MCU) processes and analyzed the collected data with our software and algorithms.

In the upper limb device, textile electrodes and a PDMS-graphene stretching sensor are used for ECG and respiration signal acquisition correspondingly. The inertial measurement unit (IMU) is used for collecting motion signals. The research value of the upper limb is to discover and propose a systematic way to evaluate the ECG signal collected by different kinds of textile electrodes and the respiration signal collected by the novel resistance-based stretching sensor. For the lower limb device, carbonized foam electrodes are applied for the EMG signal acquisition, which can reduce the power line interference [9]. A novel high-accuracy array is used for the plantar pressure distribution [7].

III. Implementation and Results

The hardware systems were implemented based on the design concept. In the upper limb device, STM32F405, ADS1292, and MPU9250 were used as MCU, ECG sensor, and IMU, correspondingly. The sampling frequency was 250Hz. A finite state machine (FSM) was designed to control multi-tasks inside MCU and direct memory access (DMA) was utilized to improve energy and latency efficiency. LabVIEW was also designed with the function of real-time raw data demonstration, heart rate and respiration rate calculation and abnormal alert. The implementation of the lower limb device was published in a conference [7]. The hardware cost of the system is 50 US dollars in which the upper limb system costs around 29 US dollars and the lower limb costs 21 US dollars.

PSG (Polysomnography) was used as the gold standard to compare with the proposed upper limb device for the respiration rate. The clinical experiments were conducted on six infants. The mean age of the subjects was 29 days (median 31.5 days, standard deviation 14.1 days, range from 18 to 58 days). Three male and three female subjects were recruited. The waveforms with the same respiration frequency structure and pattern were obtained by the proposed system and PSG. A total of 240 recorded one-minute data sets, 218 sets of data were available for analysis. The remaining 22 sets were lost due to the nurses' medical procedures. The correlation analysis results of 218 sets of data used by PSG and the proposed system were shown in Fig. 2. The correlation coefficient was

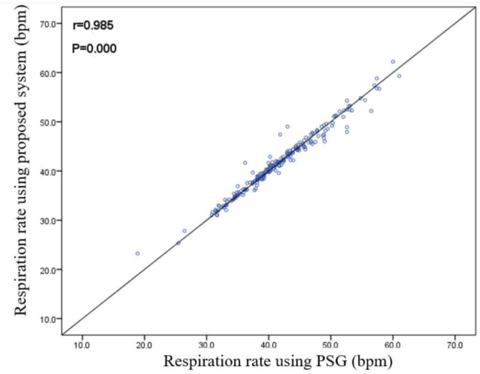

Fig. 2. Results of correlation analysis using PSG and the proposed system

0.98, indicated that the proposed system and PSG had a strong correlation in respiration rate monitoring.

IV. Conclusion and Future Work

This paper presented a wireless wearable system for health monitoring. The system consisting of an upper limb device and a lower limb device could collect the high quality of bio-signals including ECG, EMG, respiration rate, motion-related signals and plantar pressure distribution. In addition, by using flexible materials such as PDMS-graphene and textile materials for collecting the bio-signals, the system does not damage a user's skin while remaining comfortability and convenience. The results show that the system can be potentially applied for IoT-based home-care and hospital-care systems. In future work, more sensors for collecting other bio-signals such as galvanic skin response (GSR) signal, peripheral capillary oxygen saturation (SpO2), and continuous blood pressure will be added into the systems. In addition, advanced algorithms for the evaluation of users' health status will be integrated into the system.

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