All Electrical and Real-time ECG, Respiration, Airflow, and Skin Conductance Monitoring System

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Abstract—**In this paper, we propose a low-cost and real-time multiple physiological parameter monitoring system that measures ECG, respiration, airflow and skin conductance by using an all-electrical method. Skin conductance is chosen to evaluate the activity within the sympathetic axis of the autonomic nervous system. Bio-impedance (BI) and resistance measurement technique using DC servo loop are employed to achieve all-electrical measurement. The system was implemented on printed-circuit-board (PCB) with off-the-shelf components and the total cost of the components is less than a dollar. Measurement results show that ECG, respiration, airflow and skin conductance can be clearly measured simultaneously without interference.**

***Keywords*-Electrocardiogram, respiration, skin conductance, airflow, healthcare.**

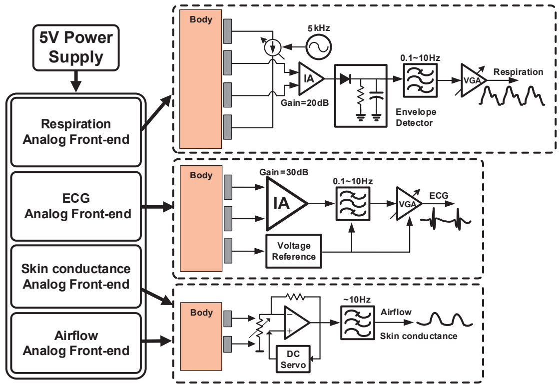

Figure. 1. The description of the proposed system.

I. INTRODUCTION

According to the studies presented in [1], approximately 4% of males and 2% of females in North America, which amounts to a total of 18 million people, suffer from sleep apnea. In order to diagnose sleep apnea, previous methods have mostly focused on measuring multiple physiological parameters such as blood oxygen levels, electrocardiogram (ECG), heart rate, respiratory activity, and peripheral arterial tone (PAT). Despite the simplicity of skin conductance measurement, monitoring skin conductance for the diagnosis of sleep apnea has often been neglected in the past. However, recent research [2] shows that skin conductance can be used as an important indicator of sleep apnea since it provides a sensitive measure of assessing alterations in autonomic nervous activity [3]. Unfortunately, measuring skin conductance together with other bio-signals can be problematic since analog-front-end for other bio-signals may cause unexpected current flow through the body. In this paper, we propose a cost-effective and interference-free multiple physiological parameter monitoring system that enables simultaneous measurement of ECG, respiration, skin conductance, and airflow in order to open up the possibility for the use of in-home portable sleep apnea monitoring device.

II. SYSTEM ARCHITECTURE

A. System Description

The proposed multi-physiological parameter measurement system is shown in Fig. 1. The system includes four analog-front-ends that measure respiration, electrocardiogram (ECG), skin conductance and airflow. These analog-front-ends are implemented on a printed-circuit-board (PCB) with off-the-shelf components such as operational amplifier and thermistor so that it can provide a cost-effective solution. With proper connection, the proposed system can be used with a smart device.

B. Analog-front-end

Bio-impedance [4] is used for respiration measurement. The AFE for respiration includes instrumentation amplifier (IA), envelope detector, band-pass filter, and variable-gain amplifier (VGA). The volume change of the abdomen due to inhalation and exhalation causes impedance change of the body. The impedance change can be monitored as voltage by injecting constant AC current into the body.

The AFE for ECG includes IA, band-pass filter, VGA, and voltage reference. Voltage reference sets the bias voltage of circuit to be half the supply voltage so that ECG signal is not saturated. IA is implemented using conventional IA architecture with three operational amplifiers. The cut-off frequency of band-pass filter is set from 1Hz to 10Hz in order to minimize 60Hz power supply noise.

The AFEs for airflow and skin conductance have same architecture since resistance change should be measured for both signals. An amplifier, low-pass filter, and DC servo loop are included in the AFE. Thermistor (NTC-100KGJG) is used for airflow measurement.

The direct combination of each analog-front-end may cause unwanted interference. For example, skin conductance cannot

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be simultaneously measured with ECG, since the internal voltage reference in the ECG analog-front-end sets the bias voltage of the body and this causes unexpected current flow toward skin conductance measurement circuit. This problem is solved by applying proper filtering that prevents unnecessary current flow through body and employing DC servo loop that removes DC voltage fluctuation. These techniques enable simultaneous measurement of skin conductance with other bio-signals.

III. EXPERIMENTAL RESULTS

A. Measurement Setup

The measurement setup for the evaluation of the proposed system is shown in Fig. 2. A total of nine electrodes and thermistor were placed on the user's body to measure ECG, respiration, airflow and skin conductance. The system was powered up with 5 V DC voltage. 5 kHz AC signal was injected for bio-impedance measurement. The measured data were further processed with LabVIEW.

B. Measurement Results

To verify the functionality of the proposed system, measurements were performed on a 22-year-old male subject sitting on a chair. Fig. 3(a) shows the skin conductance measurement result with interference from other analog-front-ends. The measured skin conductance is out of normal physiological range. Fig. 3(b) shows the measurement result after eliminating the interference. It can be seen that the measured skin conductance with dry finger and wet finger is 9.2 µS and 13.8 µS, respectively.

Fig. 4 shows the measured data of ECG, respiration, airflow and skin conductance, respectively, where the four bio-signals were clearly measured without any interference. ECG was measured with clear PQRST waveform as shown in Fig. 4(a). The measured respiration was shown in Fig. 4(b), where it can be seen that inhalation and exhalation causes an observable peak corresponding to respiration. The measured waveform of airflow is shown in Fig. 4(c). It can be seen that respiration and hold are identified clearly. The waveforms of respiration and airflow synchronized with the respiratory period. The measured waveform of skin conductance is shown in Fig. 4(d), where it is clearly measured with other bio-signals simultaneously without any interference.

Table I summarizes the performance of the proposed system and compares it with recently published multi-physiological parameters monitoring systems implemented on PCB. This work achieves the monitoring of the largest number of the bio-signals including skin conductance by using an all-electrical method.

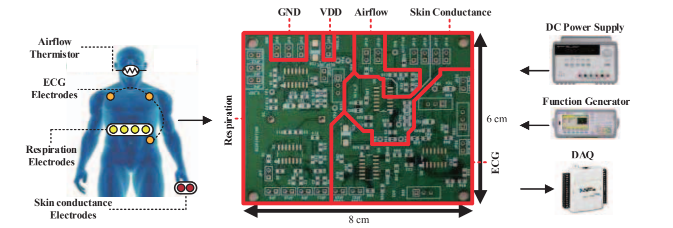

Figure. 2. Measurement setup for the proposed system.

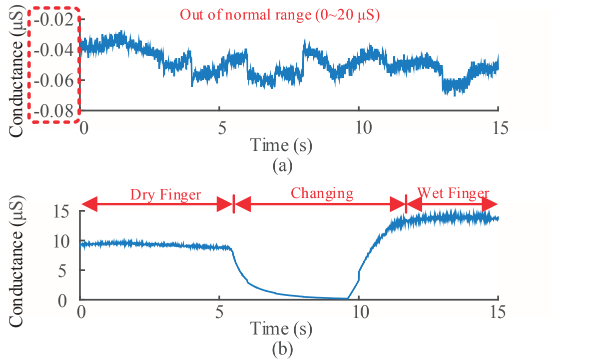

Figure. 3. Skin conductance measurement results. (a) With interference from other analog-front-ends. (b) After eliminating the interference.

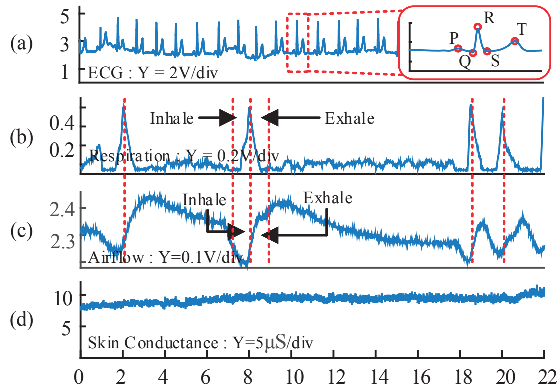

Figure. 4. Simultaneous measurement result of the proposed system. (a) ECG, (b) Respiration, (c) Airflow, (d) Skin conductance.

TABLE I. PERFORMANCE COMPARISON

	[5]	[6]	This Work
Functionality	ECG, BI, PWV	Respiration, ECG, EMG	ECG, BI, Airflow, Skin Conductance
Additional Sensor	No	Yes (Accelerometer)	No
Supply Voltage	10V	3.7V	5V
Power	1,077mW	9mW	50mW

REFERENCES

[1] A. Malgotra and D. P. White, "Obtrusive sleep apnea," *Lancet,* vol. 360, no. 9328, pp. 237-245, Jul. 2002.

[2] B. Zakrzewska-Pniewska, et al., "Sympathetic skin response in obstructive sleep apnea syndrome," *Acta Neurobiol Exp*. 1998, vol. 58, pp. 113-121

[3] H. D. Critchkey, "Electrodermal response: what happens in the brain," *Neuroscientist*, vol. 8, pp. 132-142, Apr. 2002.

[4] W. Lee, and S.H. Cho, "Integrated All Electrical Pulse Wave Velocity and Respiration Sensors Using Bio-Impedance," *IEEE J. Solid-State Circuits*, vol. 50, No. 3, pp. 776-785, Mar. 2015.

[5] S. Bang, C. Lee, J. Park, M.-C. Cho, Y.-G. Yoon, and S.H. Cho, "A Pulse Transit Time Mesurement Method Based on Electrocardiography and Bioimpedance," in *Proc, IEEE Biomedical Circuits and Systems Conf.*, 2009, pp. 153-156.

[6] M. Altini, S.D. Din, S. Patel, S. Schachter, J. Penders, and P. Bonato, "A Low-Power Multi-Modal Sensor Network with application to Epileptic Seizure Monitoring," in *Proc. IEEE Annu, Int. Conf. Engineering in Medicine and Biology Society*, 2011, pp. 1806-1809.