Journal of Fiber Bioengineering and Informatics 7:3 (2014) 397–408
doi:10.3993/jfbi09201409

Portable Health Monitoring Device for Electrocardiogram and Impedance Cardiography Based on Bluetooth Low Energy

Xinyu Hu [a,b], Xianxiang Chen [a], Ren Ren [a,b], Bing Zhou [a,b], Yangmin Qian [c], Huaiyong Li [c], Shanhong Xia [a,*]

[a] *State Key Laboratory of Transducer Technology, Institute of Electronics, Chinese Academy of Sciences, Beijing 100190, China*

[b] *University of Chinese Academy of Sciences, Beijing 100190, China*

[c] *Navy General Hospital of PLA, Beijing 100048, China*

Received 26 Feburary 2014; accepted (in revised version) 23 June 2014; available online 23 September 2014

Abstract

Portable health monitoring device could benefit the life quality of patients as well as decreasing health care costs. Monitoring Electrocardiogram (ECG) and Impedance Cardiography (ICG) simultaneously can help evaluate cardiovascular disease comprehensively. However most of the ICG monitoring devices are only used in clinical measurement instead of family monitoring. Based on the above concern, this paper designed a portable health monitoring device based on Bluetooth Low Energy (BLE) which is valued for its ultra-low power consumption for long-term continuous non-invasive cardiac activity monitoring by measuring ECG, ICG, acceleration and angular acceleration of body. There are mainly four advantages of this device: 1) High integration: ECG, ICG, acceleration and angular acceleration can be monitored in a single circuit; 2) Low power consumption: The device can monitor continuously for over 83 hours when powered by a 3.7 V lithium polymer battery with 1000 mAh; 3) Small size: The area of the PCB is only 30 mm×40 mm, so it is very easy to be attached to clothes; 4) Wireless communication: The acquired data can be transmitted to a personal computer or a smart phone wirelessly via Bluetooth. Different body postures (upright or supine) can result in change of ICG signal, which can be used for adjusting patients' hemodynamic parameters.

Keywords: Portable Health Monitoring Device; Impedance Cardiography; Electrocardiogram; Bluetooth Low Energy; Hemodynamic Parameters

1 Introduction

Cardiovascular disease is one of the leading causes of mortality in most countries. Although

*Corresponding author.
Email address: shxia@mail.ie.ac.cn (Shanhong Xia).

invasive techniques, such as thermodilution, give satisfactory results on the estimation of Stroke Volume (SV), they still are not quite suitable for repeated measurements or long-term monitoring due to the pain caused by invasive techniques. During the past three decades, there are several non-invasive techniques that can be used for monitoring cardiac mechanical activity, including Magnetic Resonance Imaging (MRI), ultrasound Doppler and Impedance Cardiography (ICG). Nevertheless, compared to ICG technique the other two non-invasive techniques of cardiac mechanical activity are very inconvenient and expensive, so they are not suitable for long-term portable monitoring [1]. Different from ECG (cardiac electrical activity), ICG is a novel technique capable of quantifying cardiac mechanical activity. ICG technique mainly includes direct measurements of base impedance, varying impedance, velocity index, acceleration index, pre-ejection period, left ventricular ejection time. These direct measurement parameters can be used for estimating hemodynamic parameters, such as Stroke Volume (SV) and Cardiac Output (CO) [2]. Non-invasive hemodynamic parameters monitoring by Impedance Cardiography has been applied to more than four million patients till now. Cardiac output measured by Impedance Cardiography technique has been demonstrated to correlate well with CO obtained by thermodilution with correlation coefficients ranging from 0.76 to 0.89 [3].

Bluetooth Low Energy (BLE) has many advantages over Classic Bluetooth and other wireless communication technologies. Compared to Classic Bluetooth BLE is a significant improvement, as it has low energy consumption which provides a new technical support for portable and wearable applications. The improvement of low energy consumption allows two different types of implementation modes, single mode communication and dual mode communication. Single mode implementation only supports BLE and cannot communicate directly to Classic Bluetooth. While dual mode implementation can support both Classic Bluetooth and BLE. Just like Classic Bluetooth BLE works on the same frequency range (2.402-2.480 GHz), one of the differences between them is the amount of radio channels. Different from 79 radio channels 1 MHz each of them of Classic Bluetooth, BLE only has 40 radio channels, but each of them is 2 MHz [4]. BLE's controller is also more intelligent, which can sleep for longer periods to save power if without any tasks and can be woken up only if it needs to perform an instruction. There is no doubt that BLE will be the perfect choice for portable monitoring device.

Monitoring Electrical Activity (ECG) and mechanical activity (ICG) of the heart simultaneously can help us evaluate cardiovascular disease comprehensively. Acceleration and angular acceleration also can provide movement status which is especially important for elderly people. The major accomplishments of this paper is the design of a small-sized, light-weighted, integrated and low power portable device which can provide a continuous long-term non-invasive portable monitoring for cardiac electrical activity and mechanical activity.

The remainder of this paper are divided as follows: in Section 2 we analyzed the electrical circuit modeling of tissues and then we introduced the overall design of the health monitoring device in Section 3. In Section 4 we applied filtering algorithm to remove baseline drift from ECG and ICG signal. Finally, we analyzed power consumption of the device and impact of postural change to ICG signal in Section 5 and Section 6. Then we obtained our conclusions in Section 7.

2 Electrical Circuit Modeling of Tissues

ICG technology is based on bioimpedance, so we need to know that structure of tissues with different content may have different electrical characteristics. There are several models to describe