Wearable Physiological Multiparameter Capturing Device for Mobile Medical Monitoring

Yue Zhang, Lieshuai Zhang
Laboratory of Embedded Systems and Technology of Graduate School at Shenzhen, Tsinghua University, Guangdong Province, China
zhangyue@mail.tsinghua.edu.cn, zhangls15@mails.tsinghua.edu.cn

Abstract. This paper describes a wearable physiological multiparameter capturing device for mobile medical monitoring. With the novel structure of the device, it can be used in unobtrusive, long-term real-time monitoring of multiple parameters such as PPG, ECG, body temperature, etc. without inferring with the wearers’ daily activities and without restricting their mobility. Several days’ continuous long-term monitoring would provide a valuable reference in disease prevention and treatment. Also, the device can be used in health examination, for, the traditional health examination in the hospitals is often time-limited, so some potential diseases especially cardiac diseases may not be detected in time. The author also introduces the whole monitoring system briefly.

1. Introduction
With the development of society and the continuous improvement of living standards, people are paying more and more attention to health. People had to go to the hospital to get health examination before. But nowadays, it has become more and more convenient as wearable mobile medical monitoring systems (WMMMS) have drawn a lot of attention from the research community and the industry during the last decades [1]. One can easily get his health status through the WMMMS when he is out of the hospital in his personal environment.

Moreover, WMMMS can provide support for the treatment of post-stroke patients and individuals undergoing cardio-pulmonary rehabilitation, as well as other areas of rehabilitation [2] for it can handle long-term unobtrusive monitoring of one’s physiological multiparameter and then give real-time feedback information. According to the research [3], in 2013 there were more than 2200 Americans die of cardiovascular disease (CVD) each day, an average of 1 death every 40 seconds. So it is extremely important for the patients with CVD to keep aware of their health condition any-time and any-where to make sure they can get timely access to treatment in case of unexpected accidents. Obvious, WMMMS is their best choice.

With the great motivation of physical demand and commercial value, people have developed a great number of wearable health-monitoring systems in the world. An advanced care and alert portable telemedical monitor (AMON) [4], was designed for high-risk cardiac/respiratory patients. The system could continuously collect and evaluate multiple vital signs and then provide intelligent multiparameter medical emergency detection. BIOTEX [5] was an EU-funded project that aimed to develop textile sensors to measure physiological parameters and the chemical composition of body fluids, with a particular interest in sweat. It integrated a textile-based fluid handling system for sample collection and transport with a number of sensors including sodium, conductivity, and pH sensors. Sensors for sweat rate, ECG, respiration, and blood oxygenation were also included. A photodiode [6]
was designed for use in autonomous and low-power homecare applications. The ring-shaped photodiode gives optimal gathering of light and thereby enable very low light-emitting diode (LED) driving currents for the pulse oximeter.

General speaking, an overall WMMMS architecture is depicted in Figure 1.

Often, wearable devices comprising various types of miniature sensors were designed to capture physiological parameters, such as ECG signal, blood pressure(BP), oxygen saturation and so on. And then these parameters would be processed by Microcontroller Unit (MCU) or transferred to a phone or a Personal Digital Assistant(PDA) for further processing through wireless media, for example, Bluetooth, ZigBee, etc. When necessary, all of the parameters may gather into a medical center for more comprehensive analysis.

In this paper, a novel wearable physiological multiparameter monitoring device is proposed. It meets the certain requirements of wearable devices including low-power consumption, small size and weight, unobtrusiveness, etc. And also, it has several unique features which would be specifically introduced in the following paragraphs. Additionally, combined with the device, a whole WMMMS is introduced, which the author believes has great utility value in the area of health monitoring.

The remainder of this paper is organized as follows. The second part gives an overview of the device. Then, the third section discusses each part of the device in detail. Part IV describes the overall system in brief. Finally, Part V summarizes the full article.

2. Device Overview

The patch-type device as shown in Figure 2 comprises two parts: a shell made of flexible material adapting to be attached to the skin of the human body and the circuit section in the shell. It is designed to capture Electrocardiograph(ECG) signals, photoplethysmography(PPG) signals, body temperature, posture and motion information and then transfer the data to a mobile terminal for further analysis through Bluetooth. It also has an alarm module. When receiving an alarm signal from the terminal, the module would be activated.

In the front face of the case (Figure 2(a)), there are two electrodes on the sides which are used to
capture ECG signals. Unlike traditional ECG acquisition equipment, dry metal electrodes are chosen here. People can easily use specially designed medical double-sided adhesive which is attached with conductive gel agglomeration to stick the device on the chest for long-term monitoring without uncomfortable sensing. This design assures high-quality ECG signals as well as avoids the drawbacks of the traditional wet electrodes. Beside every electrode, a vibrating motor is put as the alarm module which can be set to vibrate in certain conditions, such as low battery, lead-off, or arrhythmia occurring.

The small metal electrode near the center is a temperature sensor used for detecting body temperature. Meanwhile, this electrode plays another role as detecting the lead-off.

On the back (Figure 2(b)), a pulse wave sensor is set to capture PPG signals which can be reanalyzed to get several vital parameters. The electrodes, the pulse wave sensor and the shell body are formed integrally through liquid state silicone injection and solid state silicone molding, for a good waterproof performance. In the shell is a flexible circuit board whose functional block diagram is shown in Figure 3.

Another novel design of the device is its removable back cover. As shown in Figure 2(c), when the cover is removed, we can see an external memory card which enables extremely long-term data storage and also very convenient data extraction. At real-time monitoring, Bluetooth can satisfy the need of data transferring. Additionally, after a period of monitoring, we can easily extract data from the external card for further comprehensive analysis. Besides, a chargeable cell is packaged in the cover which connects with the circuit board through specific metal contacts. There are several advantages of this design. At first, it lengthens the time of continuous monitoring. When the battery dies, it is very convenient to replace a spare cover full of charge instead of replacing the whole device. Because if it is needed to replace the whole device, it may take time to re-paste the device and adjust it to acquire good quality signals. Also, there is no need to place an extra charge port at the device. After removing the cover, we use a specialized charger to charge the cell. When screwing in the cover, the flexible material of the cover and the body would squeeze each other, ulteriorly enhancing the waterproof performance of the device. These features work together, making a wonderful waterproof performance and making it possible for wearers to use the device even when having a bath.

3. Unit in Detail
This section describes the sensors and the process of the signal acquiring and transferring. The main challenge at this stage was to derive all of the above signals clearly and precisely and also to keep the size and the power consumption to a minimum.

3.1. ECG Signal Acquisition
For cardiac and respiratory patients, ECG signal is a very important parameter to determine their health risk. As mentioned above, combined with dry metal electrodes, an ADS1292R chip of TI is used as the kernel to capture ECG signals. This chip is a low-power, 2-channel, 24-bit analog front-end
specifically designed for biopotential measurements. With high levels of integration and exceptional performance, it enables the creation of scalable medical instrumentation systems at significantly reduced size, power, and overall cost. It has a flexible input multiplexer per channel that can be independently connected to the internally-generated signals. It also has a lead-off detection functional block whose basic principle is to inject an excitation signal and measure the response to find out if the electrode is off. This block makes it possible for us to use a third electrode to detect lead-off. In the device, temperature sensor plays this role.

Before the ECG signals enter the ADS1292R chip, a low pass (cutoff 80Hz) filter is integrated in the amplifier stage. The signals are digitized at 125Hz sampling frequency. Figure 4 shows the ECG signal which was captured by the device. Every beat is relatively clear but baseline drift and some other noise still exist. To distinguish P wave, QRS waves and T wave, certain post-processing is needed.

Analysis of ECG signals is mainly as follows:
1) Preprocessing: Use digital filter to process the signals to reduce the impact of noise, baseline drift and artifacts.
2) Feature extraction: Detect the R waves, which determines the heart rate, to segment each beat and then determine positions of P waves, T waves, etc.
3) Detect existence of different arrhythmia using certain features.
Additionally, the respiratory rate can be analyzed from ECG signals. Also, ECG signals play a great role in the sleep test combined with acceleration and gyroscope sensor.

3.2. PPG Signal Acquisition
Pulse waves are important signals for human health, for we can extract blood pressure [7], oxygen saturation [8], etc. from the signal. This makes it possible for people to measure blood pressure and several parameters related with blood with the convenient and fast non-cuff type measurer. Here, we use photoplethysmography (PPG). PPG is an optic signal related to the volumetric pulsations of blood in the tissue. In turn, it is related to arterial pressure pulsations. Features of the PPG signal have been correlated with important hemodynamic phenomena, including arterial blood pressure [9], etc.

Figure 5 shows the PPG signal which was captured by the device. We can see that every beat is very clear but the dicrotic wave is not so distinct. The baseline drift of the signal is obvious too. Post-processing is needed to obtain high-quality PPG signals. Meanwhile, in the following research, how to obtain better PPG signals is a main task.

By analyzing the PPG, blood pressure can be derived. The oxygenation saturation level can be determined by measuring the absorption at two different wavelengths. The respiratory rate can also be extracted from PPG. Combined with ECG signals, more accurate respiratory rate would be obtained.
3.3. Body Temperature Acquisition
Body temperature is a basic physiological parameter of humans. The LMT70 temperature sensor of TI is used to measure human skin temperature. The LMT70 is an analog output temperature sensor that has 0.05°C typical accuracy within the human body temperature range (20°C-42°C) and 0.36°C max accuracy over the full temperature range of -55°C-150°C. The LMT70 is TI’s smallest, most accurate temperature sensor and is perfect for applications where high thermal accuracy is required and PCB board space is limited. At present, one disadvantage of this module is that after turning on the device, it needs about ten minutes to stabilize the temperature. But in long-term monitoring, the impact of this disadvantage can be overlooked. The electrode of the temperature is reused as a third electrode as mentioned before.

3.4. Posture and Motion Information Acquisition
Acceleration sensors and gyroscope sensors provide information on the posture and activities of the wearer. STMicroelectronics’s LSM6DS3 chip is used here. The LSM6DS3 is a system-in-package featuring a 3D digital accelerometer and a 3D digital gyroscope performing at 1.25 mA (up to 1.6 kHz ODR) in high-performance mode and enabling always-on low-power features for an optimal motion experience for the consumer. High robustness to mechanical shock makes the LSM6DS3 the preferred choice for the creation and manufacturing of reliable products. This unit is set for the following usages: First, the data is used for classifying different postures, for example, sitting, standing, etc. and different motion gestures—e.g., walking, running or riding. This detection would be combined with the ECG in the arrhythmias detecting and PPG in the blood pressure calculating, for, in different postures and activity levels, different thresholds may be set. Second, the data is used for automatic step detection and sedentary reminding as well as falling detection.

At present, an algorithm to detect steps has been implanted in the device. The process is as follows:
1) Determine if the wearer is standing.
2) Calculate Equation 1, where x, y and z represent the module value of 3D gyroscope sensors and a, b and c represent the weights.
   \[ A = \sqrt{ax^2 + by^2 + cz^2} \]  
   (1)
3) Peak detection: find the peak of A in Equation 1. Of course, for better precision, an appropriate threshold and stride frequency would be set to reduce interference.

3.5. Bluetooth Low Energy System-on-Chip
Together with all the acquisition units introduced before, a powerful but low-power Microcontroller Unit is needed to consummate the device. Here a Bluetooth low energy (BLE) System-on-Chip (SoC) nRF52832 is selected. The nRF52832 SoC is a powerful, highly flexible ultra-low power multiprotocol SoC ideally suited for Bluetooth low energy (previously called Bluetooth Smart) low-power wireless applications. The embedded 2.4GHz transceiver supports Bluetooth low energy, ANT and proprietary 2.4 GHz protocol stack. It is designed perfectly suitable for the wearable world,
for its low-power, small size, outstanding transmission distance and strong processing capacity.

4. Overall System

With the demand of small size, low-power, unobtrusiveness of the acquisition device, the processing capacity of the device is powerful but limited. Meanwhile, for the requirement of mobile telemonitoring, a whole system is designed for data acquisition, transmission, storage and analysis.

At first, in the whole system, a mobile terminal is needed. It can be a mobile phone or PDA with the application (APP) we developed for the system. The mobile terminal is mainly responsible for collecting, analyzing and transmitting human physiological multiparameter data. Through Bluetooth, the mobile terminal could gather physiological data dynamically and continuously from the wearable device. We can have a visualized view of the ECG signals and the analysis result on the screen of the mobile terminals (Figure 6). Also, we can put our finger on the LEDs (PPG sensor) of the device and then activate it from the mobile terminal, PPG signals would be acquired. Meanwhile, the communication module of the mobile terminal would transmit the data to the medical center for further analyzing via 3G/4G network.

At the medical center, the real-time monitoring software will play its role effectively. The real-time monitoring software is designed to receive physiological data from mobile terminals and then analyze and display the user's health condition in real time (Figure 7). The results of the analysis will be sent back to mobile terminals and the data will be sent to database for storage. At this stage, the main challenges are how to ensure the integrity of data and how to improve the precision of analysis on the premise of real-time guaranteeing.

There is another analysis system which is called comprehensive analysis software. The comprehensive analysis software is mainly in charge of long-term data analysis. It processes users' history physiological data from the database and then generates a useful diagnostic report. In the comprehensive analysis software, different kinds of arrhythmia are labeled in different forms. Manual modifications are also enabled for the doctors who use the system. It has broad application prospects in the field of health care.

Alexandros et.al.[10] listed 16 features, including appropriate placement on the body, real-time application, ease of use, reliability, etc. to evaluate the valuation of wearable systems. Through comparisons, we found that our system had involved all the features. In addition, several features coincide exactly with the requirement.

This system fits several areas:

1) Hospital monitoring: Patients' sphere of activities is greatly bound to bedside by virtue of traditional monitor which increases medical workers' workload. Our system enables patients to move freely without the need of medical workers accompanying their side.
2) Health examination: In traditional health examination, ECG examination only lasts several minutes or even less. Therefore the data is limited and potential disease may not be detected on this occasion. In contrast, people can wear this physiological multiparameter capturing device during the whole health examination, greatly lengthening the time of ECG/BP detection.

3) Personal family care: Using the system, people can also acquire physiological parameters, having an access to knowing their health conditions any-time out of the hospital.

5. Summary
In this paper, we have conducted a deep introduction on a wearable physiological multiparameter capturing device. It meets several advanced features of wearable devices.

1) Multiparameter Monitoring: The device is capable of capturing ECG, PPG, body temperature, posture and motion information all in a single device.

2) Unobtrusive and Long-term Monitoring: The device provides several days’ continuous monitoring without discomforting the wearer.

3) Overall Waterproofness: The material, structure and manufacturing technique of the device enable the user wearing the device even when having a bath.

The whole system including a mobile terminal(with developed APP) and medical center(with real-time monitoring software and comprehensive analysis software) is introduced concisely. The system ensures complete cycle process of physiological data, which the author believes has great utility value and commercial value.

Suitable algorithm of data compression and encryption is being studied to improve the efficiency and security of data transmission. Also, in the future, we plan to improve the system from three aspects: promoting quality of the signals captured, increasing types of the parameters monitored, improving accuracy and efficiency of the analysis algorithms. As the promotion of the use of the system, we believe that more valuable information would be extracted through data mining of physiological multiparameter.

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