Smart Wireless Wearable ECG to Measure Heart Function

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Abstract. Healthiness is one of the over-all contests for people. Modernized healthcare system
is to furnish better healthcare services to human beings at any time, from somewhere and at any
locations in a financial and pleasant manner: very beneficial and easy. By using mobile phone,
healthcare device can be made on hand for all people, even for those dwelling in far-flung areas
the usage of smartphone except a whole lot access to other kinds of communications. This
proposed system graph is to measure and display essential ECG records for a correct description
of fitness repute and fitness. Developments in exclusive wearable factors and assemblies, as
nicely as in communication technological statistics have spread out for a new technological
know-how of health care systems.

Keywords: Smart wireless; Low power; Wearable ECG sensor; Measure heart function.

1. Introduction

Health monitoring is an instance of a region, an area integrative to look for, where a development in
wearable technological knowledge is performed. Recent years have seen the focus and the improvement
of many shirt-type wearable ECG gadgets with implanted electrodes and lead wires, which can be easily
manipulated even for people without clinical knowledge [1-4]. The motherboard creates a device for the
soldier that was successful in alerting and sending critical sign information to medical triage. Huanqian
Zhang et al [5] developed a new approach by using feed forward combined adaptive filter which could
suppress Motion Artefacts (MA) and maintained low distortion for detecting the QRS waves in ECG.
The sensors within the motherboard are related to a personal recognition monitor. Such systems, supply
phone and bendy surveillance of one-of-a-kind Personality Company’s internal fitness care, excessive
working conditions, sports, at many others. On the opposite hand, in early 2000’s several research
projects have attempted to expand WBANs for fitness monitoring; typically that specialize in the
development of an infrastructure optimized for reducing electricity consumption even as increasing the
reliability of the communication between sensors and far off devices, and additionally on records
security [6][9], and more recently in 2014 and 2015 [10][11]. The approach used to be at the lead-off
advanced for the extraction of motor unit movement potentials in-ground electromyograms (EMGs) [12]
and later tailored for ECG applications. There are lots of wearable systems to measure coronary heart
function.

This paper proposes a wearable wireless real-time recognition device. First, the anti-electromagnetic
interference conductive silicone is utilized as the electrode of the ECG signal. Next, tremendously
integrated committed analogy chips are used to capture ECG sign and a 32-bit low-power microcontroller is adopted to enforce algorithms of filtering and detecting ECG sign R-wave. Finally, a variable step-size least imply rectangular (LMS) algorithm is validated in the device, and the low-power Bluetooth 5.0 is used to gain wireless transmission of detection structures and smart terminals. All of this will be described successively and respectively in our method and system architecture and explained in further in the section analysis of experimental results.

2. Method & System Architecture
The system block diagram is shown in Figure 1, which includes sensor signal acquisition, signal preprocessing, data transmission and display. ADS1292 is used for collecting signal in ECG analog front end, and the sensor ADXL345 collects acceleration. Then ECG signal de-noising and the calculation of heart rate is implemented by using MCU (STM32L151). The real-time transmission of the low-power Bluetooth chip nRF52832 is used to achieve real-time communication between the acquisition system and the personal domain terminal, in which the APP can display the ECG, heart rate and acceleration signals to achieve the convenience and human-computer interaction of the system for sensing ECG signals.

![Block diagram of the ECG recognition system.](image)

3. Signal Processing Algorithm
Microcontrollers which are the core-processing unit of the entire gadget is used for processing ECG signal in the acquisition device. Through STM32L151, The sign de-noising and the R-wave positioning of the ECG signal are applied and the heart charge cost is calculated.

3.1. Analysis of ECG
The amplitude of the ECG signal collected by the conductive silicone electrode is weak and contains interference, including power frequency interference, myoelectric interference, motion artifacts (MA) interference, etc. Because the collected ECG signal module is sampled by using a single lead, the useful frequency is concentrated at 0.05-40Hz [13]. The power line interference is filtered by the negative feedback applied by the right leg drive circuit. The electromyography interference is a high frequency component of the ECG signal. A digital FIR low-pass filter can be used to filter out the high-frequency interference.

When detecting ECG signal in motion, the body activity during the acquisition of the ECG signal should be considered[14]. The relative displacement occurs between the collecting electrode and the skin on the chest strap, thus larger low-frequency MA interference is introduced into the acquired ECG signal.

3.2. Adaptive Filtering Algorithm
The ECG signal as a random signal can be filtered by the principle of coherent noise reduction with adaptive filter. The adaptive algorithm discussed in this paper uses the acceleration signal as a reference signal, which is produced by the ADXL345 accelerometer sensor, and then the filter coefficient is adjusted to automatically adapt to the current motion conditions of the body, which removes the MA interference from the ECG signal.
Block diagram of adaptive filtering is shown in Figure 2. Noisy signals are including the clean ECG signal and MA interference, which are recorded simultaneously with the reference signal \[^{[17]}\]. Using the optimal Wiener filtering criterion, the mean square error cost function is selected. Through the adaptive algorithm, the filter coefficient is continuously updated to achieve the minimum error cost function.

![Figure 2. Adaptive filtering block diagram.](image)

A Least Mean Square (LMS) algorithm with a variable step size is used in the ECG detection device, and an adaptive filter is calculated by the steepest descent path convergence. For M-order LMS Algorithm, the updating formula is as follows:

\[
\begin{align*}
\mathbf{w}(k + 1) &= \mathbf{w}(k) + 2\mu e(k)x(k) \\
e(k) &= d(k) - rf(k)
\end{align*}
\]

(1)

(2)

Where the input reference sequence is the step size of the adaptive filter, which is related with the convergence rate.

![Figure 3. Workflow of the variable-step LMS algorithm.](image)

In order to reduce the calculation and improve the filtering efficiency, the variable-step LMS algorithm is used to achieve the purpose of filtering out the MA interference in the single-chip microcontroller.
Algorithm flow chart is shown in Figure 3. First, the three-axis acceleration signal of the motion sensor is filtered by smoothing process. Next, the maximum and minimum values found in the data intercepting a piece of acceleration signal are subtracted to obtain the variation component, thereby sensing the human motion. Then according to the size of the change component, this article divides the human body motion into three states: intense, strong and weak, which is corresponding to three different step sizes. The convergence step is appropriately changed according to the intensity of the human body, thereby realizing faster filtering of MA interference in the system.

3.3. Measure Heart Function
Differential threshold algorithm [15] is used to achieve real-time positioning of R wave after filtered ECG signal in the microcontroller system. The heart rate is calculated using the number of sample points between the two adjacent R waves located as a measure parameter, and the formula is given:

\[
HR = \frac{60F_s}{RR}
\]

Where Fs is the sample rate for ECG signals, and RR is the number of sample points between the two R waves.

4. Analysis of Experimental Result
The appearance of the wearable ECG detection device and electrodes are shown in Figure 4(a). After the detection device is wearied on the chest of the human body as shown in Figure 4(b), the ECG data and triaxle acceleration can be received on the mobile phone APP through Bluetooth. The display of signal waveform and heart rate on the Mobile APP are shown in Figure 4(c). The detection device is 4.5cm in length and 2cm in width, with small size, high real-time performance and high accuracy.

4.1. Power Consumption of the Device
The Kiteley 2230 DC Power is utilized to provide DC power for measuring voltage and current values. When the ECG detection device is unconnected and connected to the mobile phone APP, the test results of the power consumption is shown in table 1. It can be seen that the device can work normally for more than 10 hours under the power supply of an 110mAh lithium cell, thus the power consumption of the device is relatively low.
Table 1. System power consumption.

| STATUS OF BLUETOOTH CONNECTION | Unconnected status | Connected status |
|-------------------------------|-------------------|------------------|
| VOLTAGE (V)                  | 3.7               | 4.2              |
| CURRENT (mA)                 | 1.4               | 1.3              |
| POWER (mW)                   | 5.18              | 5.46             |

4.2. The Error of Heart Rate

The heart rate measured by the detection device is compared with the standard medical monitor of the Mind ray MEC-1000 to indicate the relative error of the system heart rate. The results are shown in table 2, in which the data is measured by 1 to 5 testers at rest and the other is measured by 6 to 10 testers in the case of body movement. It can be concluded that the heart rate value measured by the ECG detection device is within 1% in Resting ECG, and within 4% when the body is moving.

$$\text{Error} = 1 - \frac{|ECG \text{ measurement device (bpm)}|}{|A \text{ medical monitor (bpm)}|} \times 100\%$$

Table 2. Heart rate comparison between test device and medical monitor.

| Group number | A medical monitor (bpm) | ECG measurement device (bpm) | Error (%) |
|--------------|-------------------------|-----------------------------|-----------|
| 1            | 63                      | 63                          | 0         |
| 2            | 73                      | 74                          | 1.36      |
| 3            | 72                      | 71                          | 1.39      |
| 4            | 69                      | 68                          | 1.44      |
| 5            | 68                      | 67                          | 1.47      |
| 6            | 93                      | 90                          | 3.23      |
| 7            | 84                      | 82                          | 2.38      |
| 8            | 88                      | 91                          | 2.27      |
| 9            | 84                      | 86                          | 2.38      |
| 10           | 83                      | 80                          | 3.61      |

5. Conclusion

In this paper, a wearable real-time ECG measurement device was designed to examine the ECG signals of everyone. Combining triaxle acceleration sensors, the variation of triaxle acceleration is used to perceive the situation of human motion, and a variable-step LMS adaptive algorithm implemented to filter motion artifacts (MA) of ECG signal is proposed, then the R-wave algorithm is used to calculate the heart rate. The results show that the ECG detection device has low power consumption, small size, and can display ECG signals in real time. The heart rate error during body movement is within 4%.

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