A review of heart rate measurements for smartwatches

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Abstract. Heart rate is one of the most important physiological data of basic signs in human activities. By daily monitoring of heart rate data, it is helpful to know the running condition and state of the body in time. For some people with heart disease, timely heart rate monitoring can help to launch a daily warning. With the development of information technology, smart health wearable products represented by smart watches are widely popular, and heart rate detection function has been added to the products. This paper introduces the principle of heart rate detection, studies and discusses two detection schemes for the heart rate detection function on smartwatches, and compares the two schemes to obtain the advantages and disadvantages of the existing heart rate detection schemes, so as to provide people with a better choice of smartwatches.

Keywords: heart rate, SmartWatch, Heart Rate, heart disease

1. Introduction

In recent years, with the development of electronic technology and information technology, intelligent devices are gradually popularized in daily life applications. Wearable intelligent products are emerging in an endless stream. Among them, smart wearable products that combine medical treatment and health gradually rise to meet the health detection requirements in people's daily lives and have been more widely used. Recently, sports wearables company Garmin Ltd. Garmin published record revenue for the full year and Q4 of 2021, with revenue for the quarter rising 3% to $1.39 billion, compared to $1.35 billion in the year-ago period. Net sales in the fitness segment, led by mobile wearables, grew 16% from $1.3 billion to $1.5 billion. In 2021, total revenue grew 19% from 4.1 billion dollars to 4.9 billion dollars [1]. It can be seen from this data that people's demand for wearable smart devices for health is also increasing year by year.

2. The development of heart rate watches

Heart rate is one of the most important physiological data related to human life. The development of intelligent wearable devices that can measure heart rate in the form of medical health can be generally divided into four stages.

2.1. Phase 1

Heart rate watches were introduced around 1990. At this time, smart wearable products that can measure heart rate have been rapidly developed in the form of healthcare electronics. However, in this stage, restricted by computer, semiconductor, network, communication and other related technologies, the function and form of heart rate measurement products are relatively monotonous, and they are just applied as an information measurement device [2].

2.2. Phase 2

By 2020, due to the rapid development of computer, semiconductor, network, or communication technology and other related technologies, human heart rate measurement wearable products have been developed to a quite perfect degree. In this period, storage technology, data interaction technology, or some display technologies have been used by skilled enterprises on such products. Taking human heart rate meter as an example, based on the above technological development, wearable products for human heart rate measurement have been able to achieve better communication with users. In addition to realizing the storage, display and operation of the technical parameters of the body's heart rate directly, it can also realize the later calculation, sharing and data transmission of the data [3].

2.3. Phase 3

In 2010, with the development of intelligent technology, wearable products for heart rate detection also ushered in a year of leaps and bounds. A variety of related products emerge in endlessly, and the use of methods are also relatively diverse. Take the wristwatch for heart rate detection as an example. At this stage, conduction electronic technology, image technology, wireless communication technology and control technology have greatly promoted the booming development of wearable device industry for heart rate detection. At this stage, companies that manufacture heart-rate detection devices rapidly occupy the market with their own representative industries [4].

2.4. Phase 4

Since 2016, on the basis of product diversification and technical diversity, heart rate detection devices are gradually developing towards the trend of functional diversification. They are also becoming more personalized. Taking the heart rate monitoring watch as a representative, it can complete the user's positioning, detection, monitoring, prompting, communication, data transmission, communication and other functions under various conditions, and gradually tends to the private customization mode [5].

3. The principle of heart rate detection of smart watch

Due to the small size and low power consumption of smartwatches, there are two kinds of human heart rate measurement methods that can be used in smartwatches at present: One method of measurement is the use of light reflection, another methodof measurement is the use of electric potential.

3.1. Light reflection method

The main measurement method is to use a single band light source, directly provide the original light information, and then receive the reflected light information of the tissue. The changes in reflected light intensity caused by slight changes in the tissue volume of the heart beat time were measured, and pulse wave information was obtained, and the heart rate was obtained by measuring the peak value.

Another method is to obtain the value of blood oxygen saturation by photoelectric volumetric analysis using dual-wavelength optical information. Optical information needs to be adjusted. The intensity of light reflected by the cell to two different light sources at each time was obtained by irradiating the tissue alternately with two light sources of different bands. After demodulation, the bleeding oxygen saturation was calculated according to Beer-Lambert Law's law. However, at present, few products using this technology can achieve blood oxygen test, because this technology is not accurate enough in the application of watches [6].

3.2. Electrode measurement method

This method requires two electrodes, one is the place where the watch is worn and the other is the palm of the other hand that touches the sensing electrode. Cardiac electrical signals can be obtained by double-electrode ECG detection, and the average heart rate value can be obtained by peak detection [7].

This kind of measurement method is able to achieve direct detection output ECG in theory, but due to restricted by watch size and chip technology, the results of ECG waveform is still not perfect, so at present, many smartwatches using this measurement method only show the heart rate index but not the complete ECG.

4. Hardware circuit analysis of reflective heart rate detection smartwatch

The reflective heart rate detection smartwatch studied in this paper takes Apple Watch as an example, and the specific hardware circuit is analyzed as follows.

The hardware circuit of Apple Watch is mainly composed of three parts, including reflective photoelectric sensor, Analog Front End (AFE) and Microcontroller Unit (MCU). AFE uses a front-end analog chip from Texas Instruments, which is an integrated analog-to-digital converter with the function of signal transmission and fault detection for photoelectric sensors. The operating current is less than 1mA, and the operating power consumption is much lower than other solutions, which can better prolong the battery life and reduce the power consumption. Under different ambient light conditions, it can also have excellent measurement performance. MCU is the core logic software algorithm in smartwatch, and the product still uses the MCU of Texas Instruments. This is a very mature chip, which uses the ARM core MCU. It is a mixed signal processor with 16-bit resources and ultra-low power consumption that Texas Instruments has been pushing in the market since 1996. It is widely used in medical and industrial fields [8]. The AFE4400 circuit diagram in the chip is shown in Figure 1.

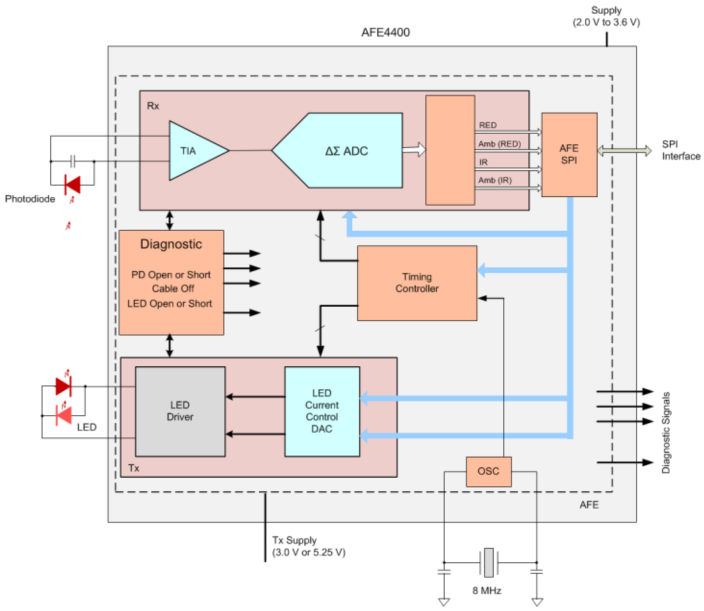

Figure 1. AFE4400 circuit diagram [9].

5. Hardware circuit analysis of electrode heart rate detection smartwatch

The hardware circuit of electrode smartwatch is relatively simple, which mainly consists of contact electrode, signal processing chip and MCU device. This paper takes Huawei smartwatch as an example to analyse its hardware circuit. The detailed analysis is as follows：

The electrode is a bioelectric sensor, which is used to capture the electrical signals sent by the human body and heart and input them to the signal processing chip at the back end. After filtering, amplification and digital signal processing, it outputs accurate and detailed information related to the human body. Therefore, in terms of electrode bio-induction sensors can be set at the induction site of the watch and human wrist. It is usually recommended to choose stainless steel, silver chloride, silver plated copper powder and other inductive materials to strengthen the induction. At present, most of China's domestic chips can achieve this function, which is a relatively mature chip technology. This product adopts the chip of NeuroSky, which has analog front-end circuit and powerful digital signal processing function. It has very low power consumption, can collect biological signals, has 16-bit core processing and can convert the collected signals into digital signals through analog digital converter [10]. MCU is a micro microcontroller, is a high performance, high integration of software processing chip. Its application market is mainly the consumer market. It has a wide range of applications in smartwatches, biometrics and medical fields, and supports a variety of operating systems. It is the main chip often used in smartwatches. Figure 2 is the hardware circuit diagram of electrode sensing and measurement.

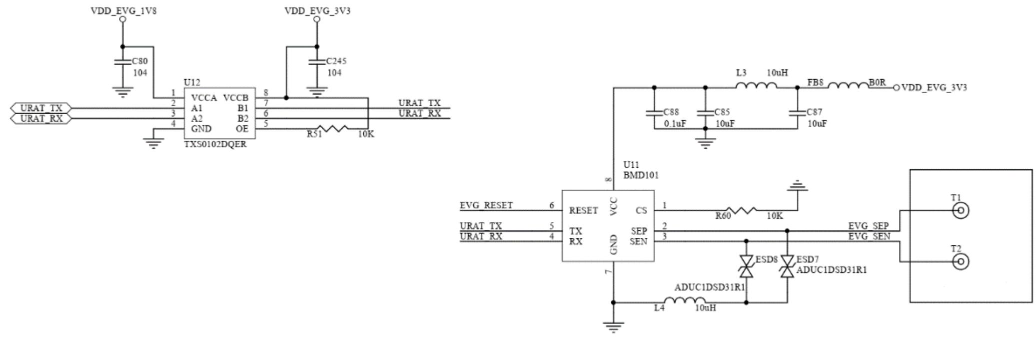

Figure 2. Electrode sensing measurement hardware circuit diagram

6. Pros and cons of reflective and electrode heart rate detection smartwatches

By comparing the functions of reflective and electrode heart rate detection smartwatches, the specific advantages and disadvantages are shown in Table 1.

Table 1. Comparison of reflective and electrode heart rate detection smartwatches

Detection method	Reflection type	Electrode type
Heart rate detection	Yes	Yes
Blood oxygen detection	Yes	No
Electrocardiogram detection	No	Yes
Motion state detection	Yes	No
Power dissipation	Emitting light, high-energy consumption	Low-energy consumption
Anti-interference performance	Susceptible to external interference, such as different body hair	Little interference
Convenience of operation	One hand operation, easy to detect data, more suitable for remote monitoring	Two-handed detection data

From the comparison in the above table, it can be seen that the function of reflective heart rate detection is more than that of electrode type, but the overall power consumption and anti-interference performance are poor and easy to be affected by surrounding environmental factors. However, the operation is convenient.

Although the function of the electrode type is less than that of the reflection type, the overall power consumption is low, the external interference is small, and the data will be more accurate. It is more suitable for static use.

7. Future trends of heart rate detection with smart watches

Based on the current research on the detection methods of center rate detection of smart wearable devices in the market, there are many detection schemes using reflective and electrode heart rate detection. At present, these two schemes have been the most common two detection schemes in medical heart rate home detection, and are relatively mature detection methods. With the update and iteration of smart wearable products in the market, more emerging concepts have been applied to smart wear. For example, heart rate detection schemes for complex impedance and mechanical vibration detection are still in the conceptual stage. They appear in many of the concept products of the new generation of smart wear. Its actual application scheme has not appeared yet, and is not mature enough, but it has great market potential and development prospects. In particular, the complex impedance detection method, which is more scientific, forms a test category together with the skin electrical activity detection. In this category, it can also react with the multiplexed electrodes of ECG detection, so as to grasp the heart rate state more accurately, which has a broad market application field and development potential.

For the electrode heart rate detection scheme, although its components drive less energy, resulting in low drive power consumption in the operation of the scheme, it needs to use two electrodes in the process of use, so it has specific requirements for the application of the product and high requirements for the design of the product. When the user performs electrode detection, the electrodes need to be separated by a certain distance. Therefore, the wearable products of electrode heart rate detection, such as exercise bracelets, do not adopt this scheme basically. At present, the most successful product designed is the heart rate band, because its product is designed to be used close to the heart, making the collection of heart rate relatively convenient.

In addition, compared with the electrode biological testing scheme technology, the biggest difference of the reflex heart rate testing scheme is the phenomenon of delay. Therefore, the average heart rate obtained is not the current heart rate, but the average heart rate in a past period, which is not representative in real time [11].

In combination with several mainstream heart rate detection schemes and technologies currently applied in the market and future conceptual schemes, as well as the advantages and disadvantages of these products, there will be more combinations and applications of schemes in smart wearable products in the future to improve the needs and functions of heart rate detection. For example, ECG can be combined with photoplethysmogram to enable continuous noninvasive blood pressure detection. Electrode measurement and complex impedance measurement can be performed with shared electrodes, which can maximize the use of limited wearable device volume to measure more parameters. The above multi-sensor fusion method will also provide new research directions for our subsequent intelligent wearable products, better provide heart rate detection services for consumers, and meet various detection needs.

8. Conclusion

Economic development and social progress bring more convenience and material improvement to the people. However, the change of living environment, sometimes not necessarily good for people. Long periods of immobility, for example, are associated with a greater risk of chronic cardiovascular disease related to the heart, whether young or elderly. On the other hand, smart wearable detection devices can quickly help people carry out real-time detection, and more conducive to people's observation and detection of their own health status. Through the research on the existing heart rate detection wearable devices, it is concluded that reflective heart rate detection is more commonly used in the current market applications. However, due to the influence of light sensitivity, there will be certain errors in light and movement. Electrode heart rate monitoring, another well-established method, is not easy to use. Each has its own advantages and disadvantages. In the future, in order to better avoid defects and better meet the detection needs of consumers, integrated intelligent wearable products will be the development trend.

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