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Wearable heart rate monitoring intelligent sports bracelet based on Internet of things

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ABSTRACT

Aiming at the shortcomings of traditional health monitoring equipment, such as large size, not easy to carry, this paper proposes a wearable heart rate monitoring intelligent sports bracelet monitoring system based on the Internet of things, which is used to monitor the user's changes in the human heart rate during sports. Through the Internet of things technology, ZigBee wireless sensor, Bluetooth and other communication technologies, data will be transmitted to personal terminal PC or only mobile phone for real-time monitoring, storage and analysis. The Internet of things communication network technology is used to transmit the data to the monitoring terminal platform. After the processing and analysis of the data, the abnormal data will be given an alarm in time to realize the monitoring of the heart rate health status of mobile personnel in the process of movement.

1. Introduction

With the continuous development of society and the progress of science and technology, in recent years, the quality of life of residents has been improved, the awareness of personal health care has been enhanced, and the goal of pursuing healthy physique has been growing [1–3]. In recent years, with the continuous progress of global mobile communication network technology, the popularity and coverage of mobile intelligent terminals have been greatly developed. A large number of mobile applications and services emerge as the carrier. These accessible application services are gradually changing people's daily life [4–6]. With the concept of intelligent health, users can view their health status anytime and anywhere by using mobile communication technology and mobile intelligent terminal. With the continuous development of information technology and sensor technology, the use of digital means for the collection, storage and analysis of human movement related data is the inevitable trend of human pursuit of the development of sports information, accelerating the scientific and modern pace of human movement health monitoring [7–10].

With the rapid development of sensor technology, information and communication technology, especially the development of Internet of things technology and wireless sensor network technology, the research and development of wearable intelligent sports bracelet medical care device has provided tremendous opportunities and challenges. In recent years, many research units and enterprises at home and abroad have carried out more research on wearable intelligent mobile mobile mobile mobile device, and obtained rich research results and experience [11,12]. This kind of device mainly monitors the movement information (acceleration, speed, position, etc.), vital signs information (blood glucose, blood pressure, heart rate, body temperature, blood oxygen content, etc.) and environmental information (temperature, humidity, etc.) of human body, and analyzes the data in combination with relevant theories, and gives specific feedback suggestions [13–15].

Based on the Internet of things technology, this paper designs a wearable sports health monitoring system based on the Internet of things, which is used to realize the physiological health monitoring of individual exercise or group exercise [16–18]. The schematic diagram of the system is shown in Fig. 1. The system is mainly composed of wearable health data acquisition terminal, mobile intelligent terminal and cloud platform. It collects the physiological health parameters of human body through sensors and preprocesses the data, and then transmits the data to the mobile intelligent terminal through ZigBee wireless transmission network or Bluetooth. The mobile intelligent terminal uses WiFi network to transmit physiological parameters to the cloud platform for data storage and analysis in the cloud platform, so as to conduct real-time and remote monitoring of various physiological indicators

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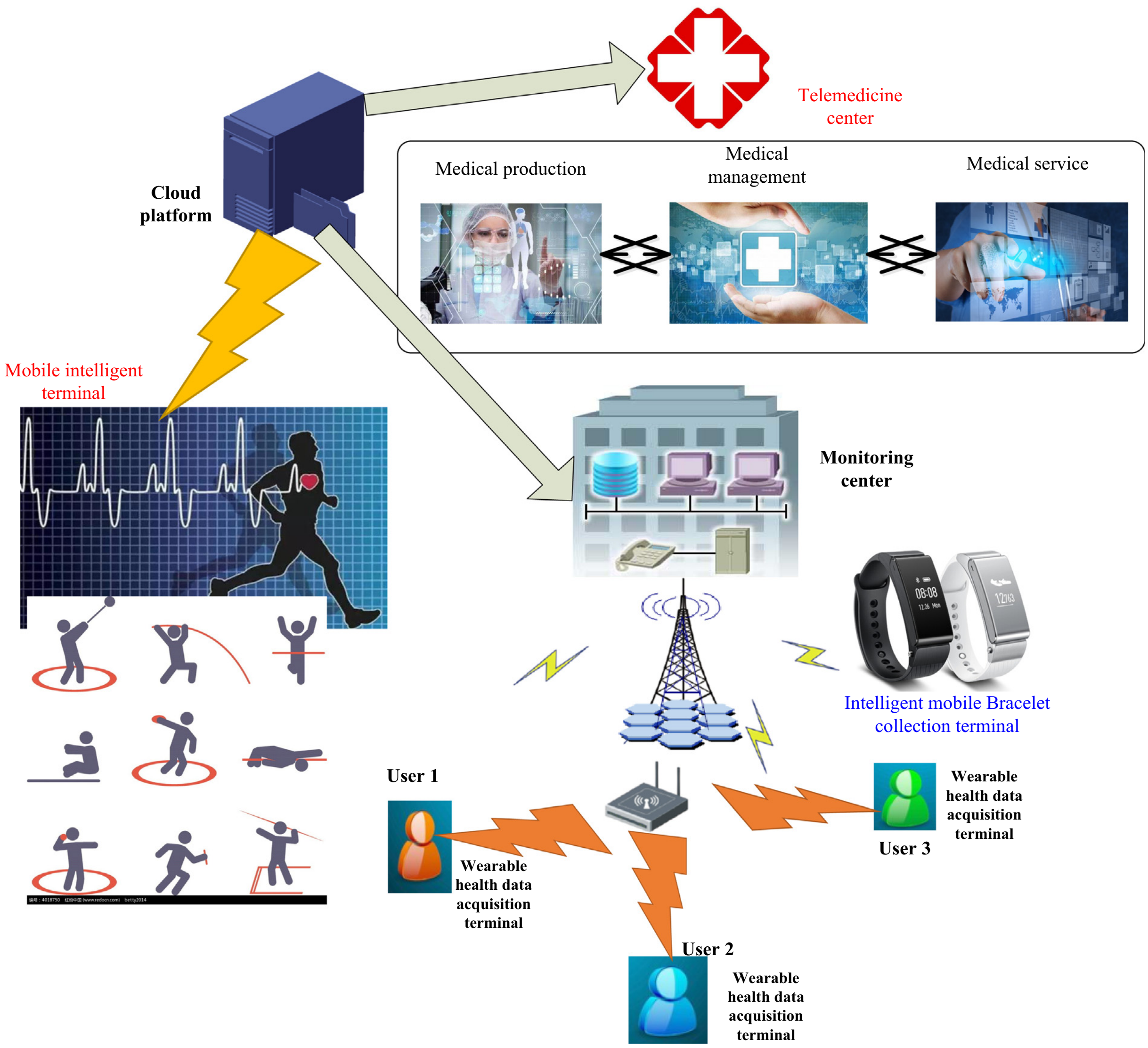

Fig. 1. System principle block diagram.

of the human body, and realize data detection, wireless data transmission, historical data storage, data trend presentation, intelligent risk warning and other functions [19,20].

Heart rate can be analyzed and extracted by ECG, arterial blood pressure, pulse wave and other signals, while ECG and pulse wave signals are closely related to bioelectrophysiology and bio mechanical force respectively, which are easily affected by the interference of electrical signal, mechanical force or vibration, and generally external electrical signal or mechanical force interference can occur less at the same time [21,22]. At present, there is no equipment that can collect ECG and pulse wave signals of human body in a long time, real-time and simple way. Therefore, this paper combines smart phone with wearable heart rate monitoring smart mobile bracelet, and proposes a scheme that can collect heart rate signals for a relatively long time. On this basis, the quality of ECG and pulse wave signals is evaluated by analyzing their time-domain characteristics. According to the evaluation index, a dynamic adjustment filter is used to estimate the optimal two-way heart rate. Finally, the weight coefficients of the two sensors are adaptively adjusted by the filter residual to fuse the heart rate, so as to accurately and reliably estimate the heart rate of the tested person. The results show that the wearable heart rate monitoring intelligent exercise bracelet can effectively reduce the impact of interference on heart rate estimation, and can be used for relatively long-term, low load continuous monitoring under daily behavior.

This paper proposes a kind of wearable intelligent hand ring sports health monitoring system based on the Internet of things, which uses the technology of Internet of things, embedded, sensor, etc. to monitor the human heart rate sports health state in the process of athlete training, student sports, marathon competition, etc. The main contents of this paper are as follows: the first chapter analyzes the research background, research status and research significance of the wearable heart rate monitoring intelligent mobile Bracelet based on the Internet of things; the second chapter describes the overall framework of the heart rate monitoring system; the third chapter introduces the heart rate monitoring algorithm in detail; the fourth chapter is the experiment and analysis part; the fifth chapter is the summary of this paper.

2. The whole framework of heart rate monitoring system

There are three traditional methods of pulse measurement: one is to extract the ECG signal; the other is to calculate the pulse rate from the fluctuation measured by the pressure sensor when measuring the blood pressure; the third is the photoelectric volume method. The first two methods will limit the patient's activity, if used for a long time, it will increase the patient's physical and psychological discomfort. The wearable heart rate monitoring intelligent mobile Bracelet pulse sensor used in this paper is photoelectric volume method. As one of the most common methods in monitoring measurement, photoelectric volume method pulse measurement has the characteristics of convenient wearing and high reliability, which is especially suitable for monitoring exercise heart rate. In order to monitor the heart rate of athletes conveniently, quickly, effectively and in real time, considering the portability and low power consumption of the system, this paper designs a wearable intelligent mobile Bracelet real-time heart rate monitoring device. On the basis of experimental test and analysis, an adaptive hybrid filtering algorithm is proposed to improve the reliability of real-time monitoring system and realize long-term real-time monitoring of exercise heart rate.

2.1. Internet of things architecture

The IoT architecture referenced in this paper can be divided into three layers: perception layer, network layer and application layer, as shown in Fig. 2. The sensing layer is composed of various sensors and sensor gateway technology architecture, including carbon dioxide concentration sensor, temperature sensor, humidity sensor, QR code tag, RFID tag and reader, camera, GPS and other sensing terminals; it also includes heart rate meter, sphygmomanometer, blood glucose meter and other vital signs acquisition terminals. The function of perceptual layer is equivalent to the nerve endings of human's eyes, ears, nose, throat and skin. It is the source of Internet of things to identify objects and collect information. Its main function is to identify objects and collect information. Cloud storage refers to a system in which a large number of different types of storage devices in the network work together through application software through cluster application, grid technology or distributed file system functions to jointly provide data storage and business access functions to ensure data security and save storage space.

The network layer is composed of various private networks, Internet, wired and wireless communication networks, network management systems and cloud computing platforms, which is equivalent to the human nerve center and brain, and is responsible for transmitting and processing the information acquired by the perception layer. The application layer is the interface between the Internet of things and users (including people, organizations and other systems). It combines with the needs of the industry to realize the intelligent application of the Internet of things. Internet of things is widely used, including warehousing and logistics, intelligent transportation, intelligent building, environmental monitoring, industrial safety, medical care, intelligent home, etc. The application of exercise heart rate monitoring system belongs to the vital signs monitoring part of intelligent health, which can be divided into medical care.

There are many architecture of the Internet of things. The smart city proposed by IBM and the industry 4.0 proposed by Germany are both broad prospects for the application of the Internet of things. The basic function of the Internet of things is to connect objects. Whether it is from things to things, machines to machines, or people to things, things to people, it is a description of the Internet of things from a certain angle. We can flexibly choose the appropriate system architecture according to the needs of the system, so we will not compare the advantages and disadvantages of various IoT architectures here.

2.2. Overall framework of bracelet monitoring system

In the sensing layer of the heart rate monitoring system of this paper, the intelligent heart rate acquisition device of the mobile bracelet made by "pulse sensor + ticc2540" is used as the sensor node. Android mobile phone is used as sensor gateway, Bluetooth and heart rate collection device are used for communication at Android mobile terminal, HTTP protocol is used for communication with web server, and Android application software for sports heart rate monitoring and sports heart rate monitoring website are used as application layer.

The heart rate monitoring system of Intelligent Exercise Bracelet involves embedded, Android, web application and other related technologies, and each part should be organically combined into a coordinated system to complete the exercise heart rate monitoring service together. As a whole, the system is divided into three parts: heart rate collection module, Android application and web service. Next, the overall operation process of the system is described from

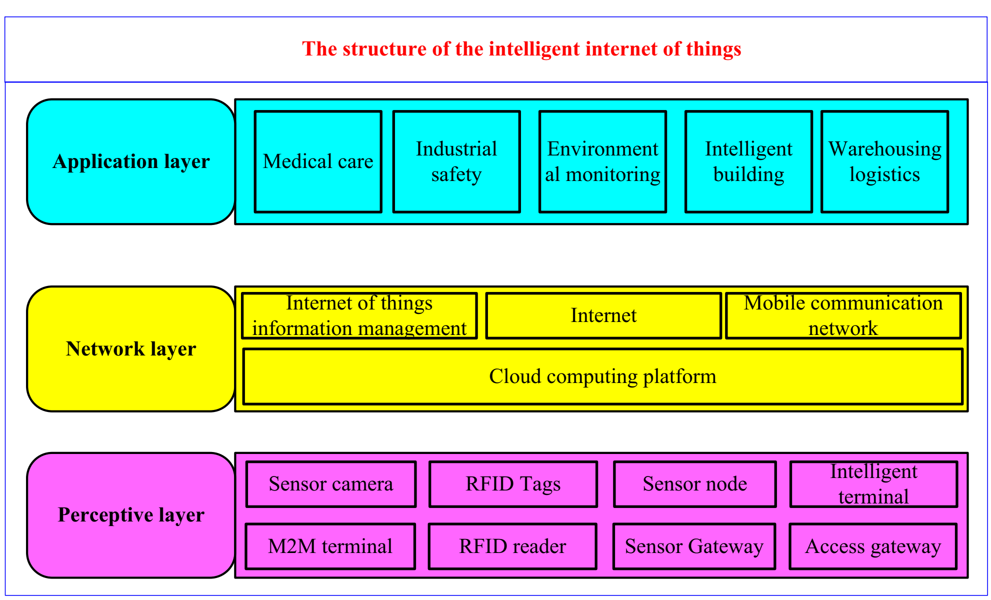

Fig. 2. IoT architecture reference.

the perspective of the overall data flow. Some data flows are shown in Fig. 3.

2.3. Design of heart rate acquisition module

The heart rate collection equipment of intelligent mobile Bracelet needs to complete the real-time heart rate collection, first collect the pulse information, and then obtain the time t of each pulse from the pulse information, heart rate HR = 60/T. Using heart rate filtering algorithm to filter the collected heart rate information. Finally, through Bluetooth and smartphone communication, the filtered data is sent to the mobile phone. The hardware framework design of heart rate acquisition module is shown in Fig. 4. The design of the heart rate acquisition equipment of the intelligent movement Bracelet includes two parts: hardware and software. The pulse sensor used in this system is a foreign open-source hardware sensor, which has been introduced into China in recent years. It can sample the light environment of human finger blood flow. The pulse data is obtained by using 80C51 control AD converter to sample the pulse analog signal, and the heart rate is calculated according to the pulse period T.

The wearable health data acquisition terminal collects the user's personal physiological health indicators, mainly collecting the user's heart rate indicators and exercise volume. ARM processor is used as terminal controller, heart rate sensor son7015 and step acceleration sensor mma9555lr1 are configured to collect physiological health parameters, and the collected data is transmitted to mobile intelligent terminal through Bluetooth or ZigBee wireless communication module for data collection and processing. The mobile intelligent terminal is mainly used to summarize and process the user health parameters collected by the collection terminal, and then upload the data to the cloud server through mobile network, Wi Fi and other communication methods for data analysis and processing. According to the different system mode, the mobile intelligent terminal adopts different hardware schemes to meet the needs of individual users and group users respectively.

The mobile hand ring is mainly composed of pulse and heart rate sensor module, inertial sensor module, Bluetooth communication MCU and power supply. The power supply is directly powered by lithium battery, and outputs stable voltage to the inertial sensor module through LDO module. The pulse and heart rate measurement module is used to obtain the real-time information such as the pulse and heart rate of the sportsman. The pulse and heart rate measurement module designed in this paper uses the photo capacitance method (PPG) which is simple and reliable in implementation. At present, PPG pulse and heart rate measurement mainly has two modes of reflection and projection. The transmission contact pressure is large and the signal-to-noise ratio is high, which is not suitable for wearable practical application scenarios. In this paper, PPG reflection mode is used, and filter circuit is used to improve signal-to-noise ratio and ensure signal quality. In order to penetrate the skin, fat, muscle, blood vessel wall and other tissues without damage to human cells, the pulse and heart rate module uses a green LED with a wavelength of 650 nm as the light source. But usually the output current of photosensitive element is very low, and the electrical signal containing pulse information obtained by photoelectric conversion is relatively weak, which is easy to be interfered by the external electromagnetic signal.

3. Heart rate estimation of ECG and pulse wave fusion

At present, most of the exercise bracelets monitor the heartbeat by measuring the reflected light. The specific process is as follows: the bracelet hits a beam of light on the skin. When the heart pumps blood, the blood vessels are full of blood. The blood tends to absorb green light and reflect red light, so the heart will produce reflected light of different colors when it contracts and relaxes. The bracelet records the heart rate by detecting these reflected light. Three evaluation factors, namely, feature point detection matching degree, signal short-term energy and signal fluctuation degree, are selected to comprehensively evaluate the quality of ECG and pulse wave signals respectively. According to the quality index SQI, the opti-

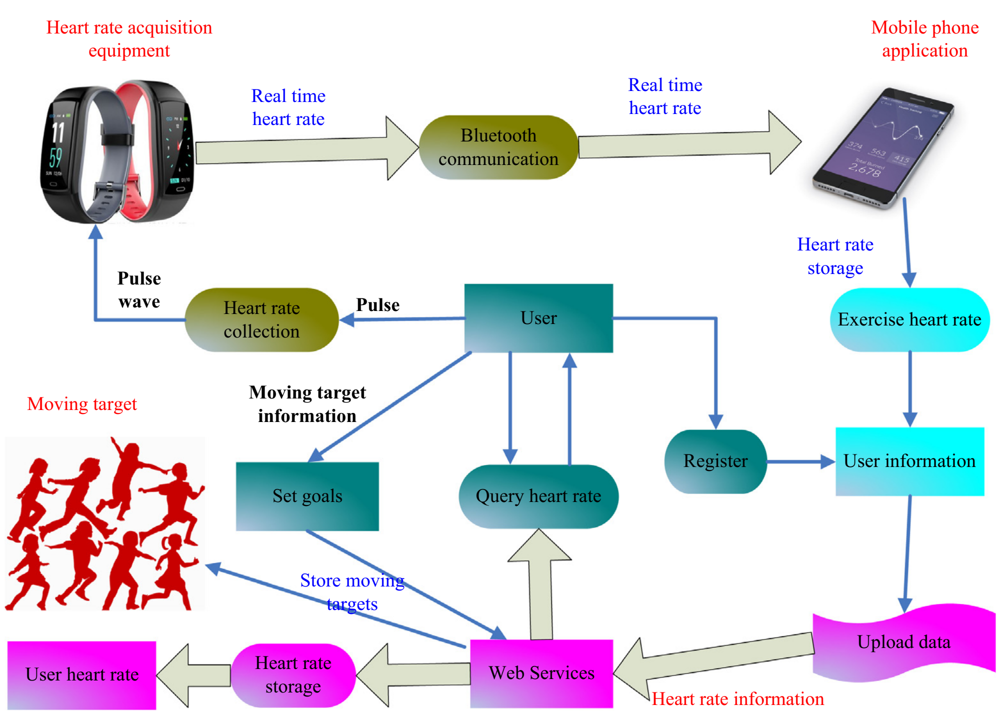

Fig. 3. Data flow chart of exercise heart rate monitoring system.

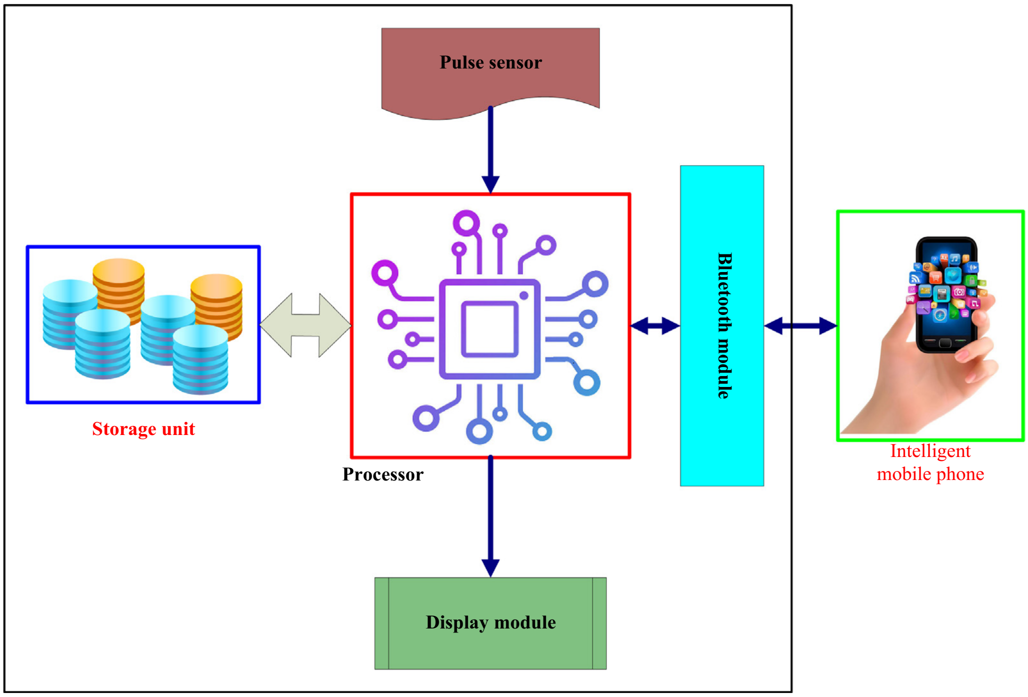

Fig. 4. Heart rate acquisition equipment.

mal estimation of HR_{Ecg} and HR_{Pulse} are made by dynamically adjusting Kalman filter. Finally, the data fusion of HR_{Ecg} and HR_{Pulse} are made by adjusting the weight coefficient of the sensor through the residual of Kalman filter, and the fusion heart rate HR_{Fusion} is obtained. Signal quality evaluation refers to the analysis of signal noise and interference to evaluate the level of signal quality. Kalman filter algorithm is simple and often used for optimal estimation of heart rate, respiratory rate and other signals.

3.1. Feature matching detection

Feature point matching detection is based on the different sensitivity of different feature point detection algorithms to different types of interference. When the interference is small, the markers are basically the same, and when the interference is large, different markers will be obtained. The heart rate signal waveforms collected by the system in the daytime and at night are shown in Fig. 5. The change of heart rate is mainly related to external interference factors, but not to time. The signal quality is evaluated by comparing the different R/P wave detection results of different algorithms.

Considering the processing power of mobile phone and the real-time demand of the system, the algorithm needs to consider both accuracy and complexity. In this paper, the original signal is firstly subtracted from its mean value and then divided by the maximum value of the signal to be normalized. Then, DT algorithm based on filter and threshold and MT algorithm based on adaptive threshold detection of moving window are used to detect the feature points.

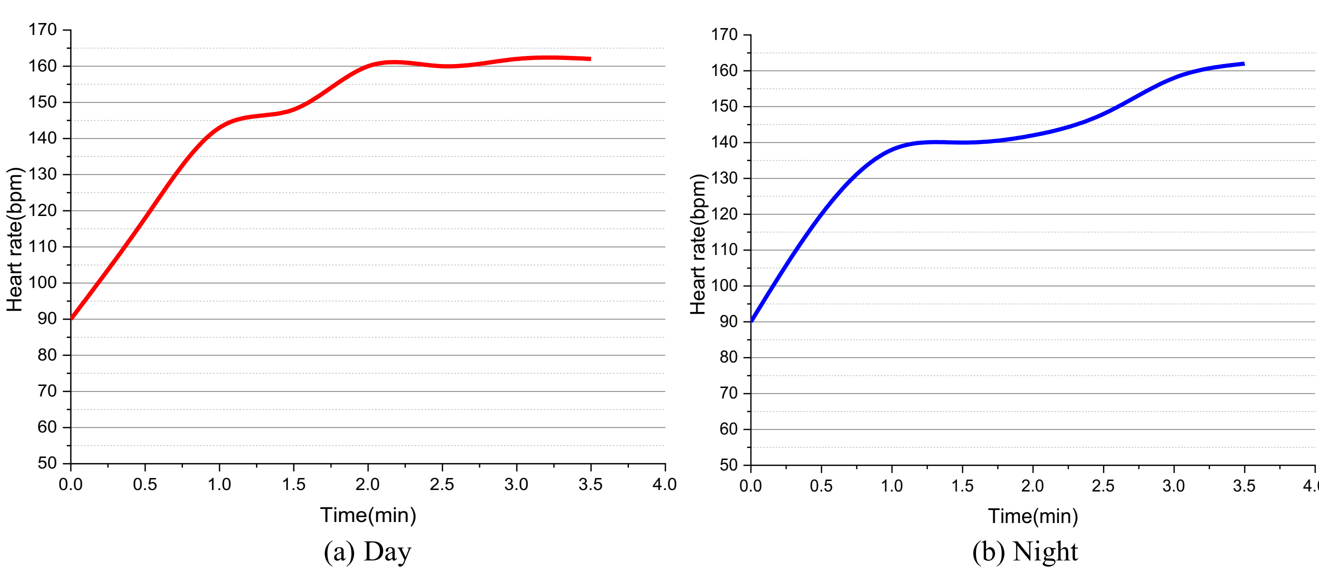

Fig. 5. Waveform characteristics of heart rate signal.

Moreover, the parameter settings can meet the needs of more accurate recognition when the heart rate is in the range of 45–130 bpm. DT algorithm includes digital filtering, which has better anti-interference ability and higher accuracy than MT algorithm. MT algorithm is simple, fast and has high accuracy when the interference is small, but it is sensitive to noise.

(1) DT algorithm

Firstly, the signal is preprocessed, including: 8–16 Hz band-pass filter to suppress noise and baseline drift; after differentiation, the square is calculated to obtain slope information and enhance QRS wave; then the slope value of R wave is obtained by integrating ECG data in 100 ms mobile window. Then the detected peak position and maximum slope value information are extracted. According to QRS detection rules, T-wave interference is removed, and the peak is identified as R-wave peak or noise peak, and the detection threshold is updated. According to the observation of pulse wave signal, the P wave has similar characteristics with the R wave of ECG signal, and it is the place with the most intense slope change in the signal. After testing, when the integration window is set to 150 ms, this algorithm is also suitable for the recognition of P wave.

(2) MT algorithm

MT algorithm adapts to adjust the threshold according to the change of signal amplitude in the moving window. It sets the width of the moving window as 360 ms and the moving step distance as 180 ms to find the maximum and minimum value of the signal in the window. In this paper, we choose 0.64 times of the difference between the two as the threshold. If the difference between the maximum value in the window and a point is less than this threshold value and the point is the point with the maximum amplitude in the window, it is positioned as the wave peak point.

It is found that T wave of ECG signal acquired at sternum position is large, which is easy to interfere with R wave location. Therefore, for ECG signal, this paper first inverts the normalized signal, then uses DT and MT algorithm to locate the S-wave, and then uses each S-wave as the reference to find the maximum value in the first 0.1 s window of the normalized signal, which is located as R-wave, and achieves good results.

(3) Heart rate calculation

In this paper, heart rate calculation in a period of time is defined as:

$$HR = \frac{60}{\Delta T/(n-1)} \tag{1}$$

where ΔT is the interval between the first and last R/P waves in a 6 s wide time window ω; n is the number of R/P waves in the window

(4) Signal quality index based on R/P wave matching degree detection

The signal quality index ($mSQI$) based on R/P wave matching degree detection is defined as $mSQI(k) = M_{match}(k,w)/(M_{both}(k,w) - M_{match}(k,w))$. Where, $k$is the current R/P wave and $w$is the 6 s wide sliding analysis window. In this paper, it is defined that when two algorithms mark the same R/P wave position within $1/f_s$, they are considered as the same R/P wave. The number of R/P wave matching detected by the two algorithms in W is M_{match}, and the number of R/P wave detected by each algorithm is $M_{DT}$and M_{MT}, $M_{both} = M_{DT} + M_{MT}$. It is easy to know that if $0 \leqslant mSQI \leqslant 1$, the closer $mSQI$is to 1, the higher the signal quality is.

3.2. Algorithm database validation

MGH/MF (Massachusetts General Hospital/Marquette Foundation) waveform database comprehensively collects a variety of physiological signals including ECG (three lead ECG), art (artery pressure) and pulmonary artery pressure. In this paper, we extract a segment of ECG lead II and art signals that are interfered at different stages, but the quality of ECG lead V signal is still relatively high, as shown in Fig. 6. It can be seen that although the heart rate still fluctuates slightly after fusion, the large abnormal fluctuation caused by interference is avoided, which is consistent with the change trend of reference heart rate, preliminarily indicating the effectiveness of this method.

The subjects used this system and ST-1212 workstation to carry out the synchronous acquisition experiment under the daily travel behavior, the latter can provide the standard 12 lead data. Taking the lead data with the highest signal-to-noise ratio as the standard ECG signal and the $HR_{Reference}$ of estimated heart rate obtained by DT

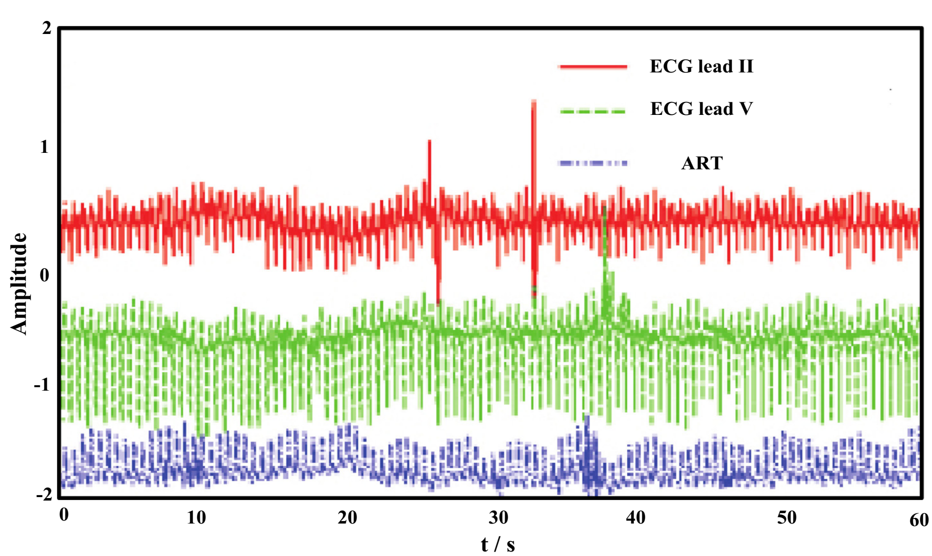

Fig. 6. Physiological signals of MGH/MF waveform database.

Table 1
Heart rate estimation error before and after data fusion of daily behavior test.

Experiment number	Action category	Exercise intensity	ΔEHR/bpm	ΔPHR/bpm	ΔFHR/bpm
1	Sit quietly	*	0.0323	0.0009	−0.1231
2	Quiet lying	*	0.0321	0.0076	0.0157
3	Walk	56	0.1459	−0.0217	−0.0894
4	Walk	59.6	0.2456	0.2125	−0.3179
5	Walk	69	0.5798	0.5678	0.2889
6	Walk	76	−1.2842	−0.2843	−0.4765
7	Walk	86	1.3292	0.2683	−0.3162
8	Run	113	−13.5384	−25.1634	−16.6537
9	Downstairs	58	0.1243	0.0992	0.1367
10	Downstairs	60	−0.3196	0.1934	−0.0978
11	Downstairs	66	0.8126	−0.4438	−0.5946
12	Downstairs	81	1.172	−1.7814	−0.8967
13	Downstairs	81	−9.1244	−29.265	−14.9255
14	Upstairs	57	0.7685	0.7431	0.3563
15	Upstairs	67	1.9638	−1.1872	−0.2592
16	Upstairs	81	1.9652	−4.4523	0.6492
17	Upstairs	81	3.6126	−5.9266	−2.9489
18	Upstairs	81	−10.5875	−39.934	−21.8352

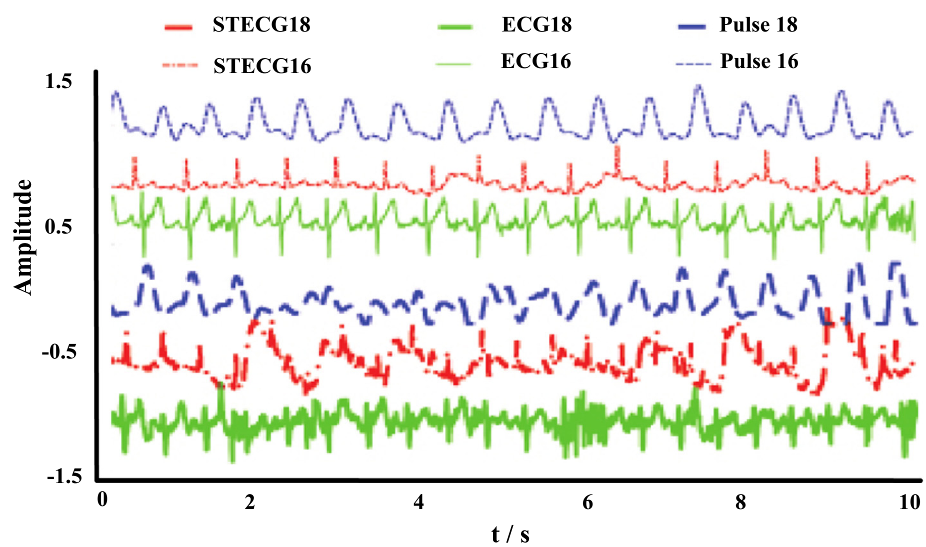

Fig. 7. Comparison of signal quality under different exercise intensity.

algorithm as the reference, the error of heart rate estimation of the system is calculated respectively, which is recorded as ΔEHR,ΔPHR and ΔFHR in turn. This paper defines heart rate estimation error as the mean value$\bar{u}$and root mean square error s of the difference between heart rate estimation value and $HR_{Reference}$, expressed in $u \pm s$. Table 1 summarizes the results of synchronous test and analysis of 18 cases with different actions and different intensities under daily behaviors. Because of the too large range of motion, the system and ST-1212 workstation can not continuously provide signals for analysis, so this paper is not used for accuracy and anti-interference analysis, but as the limit of system use conditions. Taking No. 18 as an example, the comparison of signal quality with No. 16 is shown in Fig. 7, where STCG18 refers to the ECG signal of No. 18 workstation.

It can be seen from Table 1 that reliable heart rate estimation can be obtained from ECG and pulse wave signals in static state, and the fusion heart rate error is also very low. In the walking state, with the acceleration of the stride, the pulse wave signal is more reliable than the ECG signal, which is caused by the impedance change of the electrode contact part during walking, but it has little effect on the pulse sensor at the earlobe. In the downstairs state, the height of each step is 25 cm. When the downstairs speed is within 1 step/s, the reliability of pulse wave is higher than that of ECG signal. When the downstairs speed is higher than that of ECG signal, the reliability of pulse wave is faster than that of ECG signal. This is because when the downstairs speed is faster, the vibration amplitude of body at the moment of contact between foot and stair increases rapidly. When the system is used in the static state and the normal range of motion, the heart rate error of fusion heart rate is lower and the root mean square error is smaller than that obtained from ECG or pulse wave signal alone, which indicates that the heart rate estimation algorithm of the intelligent hand ring motion of heart rate monitoring has strong anti-interference, so that the system can still estimate the heart rate accurately when disturbed.

4. Experiment and analysis

Under the win8 operating system, the 64 bit operating system is adopted, and the processor Intel (R) core (TM) i7-9700 k CPU based

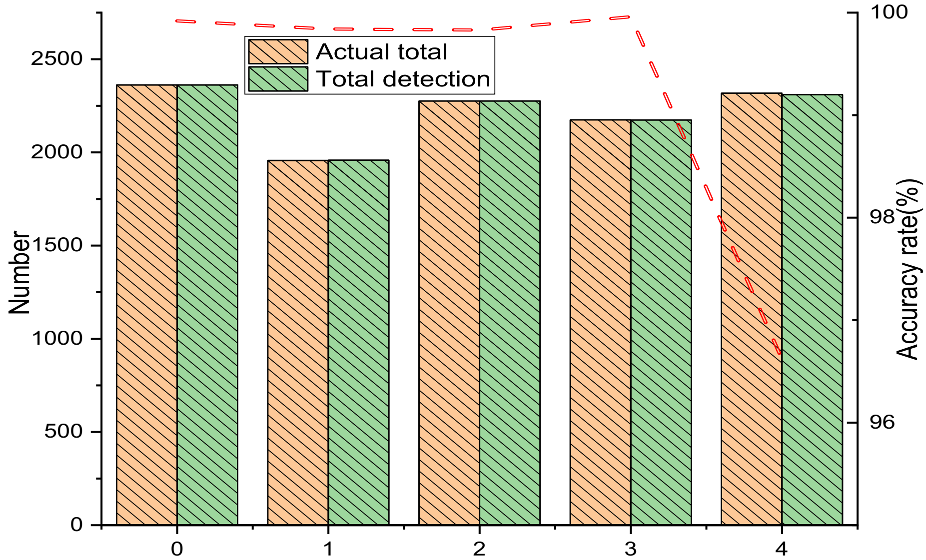

Fig. 8. Comparison of actual and detected quantity.

on x64 is adopted@ 3.60GH. In the simulation experiment, a computer is used to simulate the ECG data acquisition terminal, through the mixed programming of MATLAB and VC, read the ECG data file, and then use the CSocket connection to send the ECG data to the iPhone terminal in real time. The data is from MIT-BIH arrhythmia database. There are 48 pieces of data in MIT-BIH database. Each data has two groups of ECG data of different leads (usually MlII lead and V1 lead). The sampling frequency is 360hz, the time length is about 30 min, the resolution of 11 bits, and the amplitude is within 10 mV. Here, 5 pieces of data from No. 100 to No. 104 are used. Among them, No. 102 and No. 104 adopt the modified lead V5, and the other three data adopt the MlII lead, taking the data volume 30 min before each data. In order to adapt to the real-time processing and display of mobile client, the ECG data read here is sampled to 180hz.

Android platform has good human-computer interaction. Users can choose to start or end the test, or save the current displayed dynamic ECG and view the history. After the start of the test, the mobile phone client uses the adaptive differential threshold method to detect the ECG data after the digital filtering pretreatment. After the experiment, the R-wave detection results are counted, excluding the R-wave number within the initialization time. The experimental results are shown in Table 2 and Fig. 8.

Accurate recognition of R wave is the basis of real-time monitoring of wearable heart rate in intelligent mobile bracelet. It can be seen from Table 2 that the R-wave recognition accuracy of No. 00-No. 03 data is over 99.70%, and the accuracy of No. 104 data is low, because there are serious high-frequency noise interference and a large number of ECG artifacts in some time periods, and the QRS wave of ECG signal is seriously distorted, which leads to many errors. It can be seen that the mobile client software needs to further strengthen the anti-interference ability. In general, the method used in this paper is simple, easy to implement, and has high accuracy, which is suitable for the application of wearable heart rate monitoring intelligent mobile Bracelet Heart rate monitoring equipment.

5. Conclusion

This paper proposes a kind of wearable intelligent hand ring health monitoring system based on the Internet of things, which uses the technology of Internet of things, embedded, sensor and so on to monitor the human heart rate in the process of athlete training, student sports, marathon competition and so on. Through the wearable health data acquisition terminal, real-time collection of vital sign parameter information such as heart rate, body temperature, blood oxygen, etc. during the exercise process, the data is transmitted to the monitoring terminal platform by the Internet of things communication network technology. After the data processing and analysis, the abnormal data is timely alarmed to realize the monitoring of heart rate health status of mobile personnel during the exercise process. The design and development of the wearable sports health monitoring system based on the Internet of things is very important for healthy life. It is not only an intelligent monitoring device, but also a necessity to promote sports and enjoy healthy life. It is hoped that in the future work, with the accumulation of knowledge and experience, more resources can be obtained to further optimize and improve the sports heart rate monitoring system, so that the sports heart rate monitoring system can better provide sports load monitoring services for the sportsmen, and make the data collected by the long-term monitoring system become the basic data of sports heart rate research. In this

Table 2
. Simulation experiment results.

Num	Actual total	Total detection	Wrong inspection	Missed detection	Total error	Accuracy rate (%)
00	2362	2362	2	2	3	99.92
01	1957	1958	4	3	6	99.84
02	2276	2276	4	4	7	99.83
03	2175	2174	0	2	2	99.96
04	2318	2310	51	49	100	95.62
Total	11,088	11,080	61	60	118	98.94

paper, the focus of physiological parameters is on heart rate. Other parameters have not been discussed too much, but in the future, we can add other physiological parameters such as blood pressure to the interference and influence of heart rate.

CRediT authorship contribution statement

Ningning Xiao: Methodology. **Wei Yu:** Validation. **Xu Han:** Formal analysis.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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