Utilizing Wearable Devices to Assess the Level of Fatigue System

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Abstract. In recent years, with the rapid advancement of technology, smartwatches have emerged as an eye-catching accessory offering new and convenient features. In today's fast-paced world where individuals lead hectic lives and work under immense pressure, fatigue often takes its toll on their bodies. In this study, we have developed an APP software that integrates the built-in heart rate detection function of the watch with our proprietary heart rate variability analysis program. The aim is to determine whether the user is experiencing fatigue. Once the APP software detects a high fatigue state, it immediately alerts the user. This innovative solution is expected to enhance the quality of life for individuals who may be unaware of their fatigue levels while working.

Keywords: Wearable Device · Internet of Things · Heart Rate Variability

1 Introduction

Since 2011, smartwatches have been on the market and have made significant progress in terms of functions, especially in the field of smart sports watches. Currently, smartwatches primarily focus on collecting health information by tracking metrics such as calories burned, distance covered, and sleep monitoring. Many users rely on the data collected by their smartwatches to observe and manage their own health. With the inclusion of heart rate sensors, most smartwatches also offer real-time heart rate monitoring, allowing users to optimize their workouts and exercise routines. Moreover, this heart rate data can also be utilized for breathing exercises and relaxation techniques. Most of these features focus on fitness, but there is still room for improvement in detecting fatigue and addressing other health concerns.

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Newspapers and magazines have recently been drawing attention to the growing issue of overwork in the workplace. A recent research [1] report that working more than 49 h a week, experiencing a high psychological workload, and having young children or elderly people with disabilities at home are factors that increase the risk of fatigue. Over time, this can have a significant impact on work efficiency and overall health, potentially leading to chronic fatigue. Common symptoms of chronic fatigue include weakness, poor memory, and digestive problems such as peptic ulcers, stomach pain, and diarrhea. Fatigue slows down the brain's ability to respond to stimuli, reduces alertness, and manifests in other behavioral symptoms. Therefore, monitoring heart rate is crucial to assess fatigue levels, as several factors can significantly endanger the human body.

By combining the watch's built-in heart rate detection function with our innovative heart rate variability analysis program, this study determines the user's level of fatigue. It then issues a warning alert to the user through the developed APP software. This is expected to improve the quality of life of users who may be working without realizing that they are fatigued.

2 Related Work

Fatigue [2] is a normal physical and psychological phenomenon. Temporary fatigue is a common occurrence when individuals experience excessive workload, stressful environments, intense physical exertion, or even anxiety. However, with adequate rest, this fatigue typically dissipates within a short period of time. The most common causes of fatigue are irregular lifestyles or lack of sleep. Studying the issue of fatigue is crucial for several reasons. First, it significantly affects physical well-being. Prolonged periods of fatigue and stress can significantly increase the likelihood of developing heart disease and high blood pressure, since fatigue weakens the body's defenses and makes people more susceptible to disease. Second, it has profound effects on mental and emotional health. Fatigue can easily induce feelings of depression, anxiety, and irritability. Furthermore, it hampers concentration, memory, and decision-making abilities. When people are tired of doing important or dangerous tasks for a long time, it can affect their daily lives or lead to serious mistakes with potentially very bad results. When tired, people may experience symptoms such as depression, low self-confidence, anxiety, difficulty focusing, thoughts of suicide, restlessness, allergies, paranoia, fear, and difficulty sleeping. Numerous methods can be utilized to evaluate one's level of fatigue, with some being more subjective, such as the implementation of questionnaires.

There is also a physiological method to measure fatigue by analyzing data, particularly heart rate [3,4]. The heart rate serves as the primary measure of an individual's physical condition. As the term implies, it refers to the frequency of heartbeats. A typical resting heart rate for a healthy person ranges from 60 to 100 beats per minute, with an increase occurring during exercise. The heart rate is a physiological marker that fluctuates in response to bodily changes and varies based on one's physiological conditions. In the event of poor health, it is possible for the heart rate to rise.

Heart rate (HR) and heart rate variability (HRV) are important indicators of recovery and balance of the autonomic nervous system [5]. HR is an indication of the number of heartbeats per minute. HRV is the change in the time interval between successive heartbeats. HRV is a reflection of the activity of the autonomic nervous system and the balance between its sympathetic and parasympathetic divisions. A high HRV is considered a sign of good health, adaptability, and strength. On the other hand, a low HRV may be related to stress, illness, or overtraining. HRV is influenced by the activity of components of the autonomic nervous system that change during sleep or wakefulness. Technological advancements have revolutionized the creation of affordable wearable devices that can precisely measure and gather various biological data, such as HRV. These wearable devices include HR monitoring bands, smartwatches, and fitness trackers, specialized HRV monitoring devices, finger sensors, and optical HR monitoring technologies. We can use these wearable devices to collect HR data and analyze HR variability, allowing us to evaluate the user's autonomic nervous system activity at any time.

Smartwatches are increasing in popularity. However, HR monitoring bands and HRV monitoring devices can be influenced by exercise and surrounding noise. As a result, some researchers have begun exploring the use of smartwatches to track and analyze HRV. The research [6] examined the accuracy of PPG signals collected by Samsung Gear Sport smartwatches against medical grade chest ECG monitors. It focused on HRV parameters in the HR and time domains, as well as in the frequency domain. The study showed that satisfactory HR, time-domain HRV, low-frequency, and high-frequency parameters were obtained during participants' sleep, whereas being awake resulted in satisfactory AVNN and HR accuracy, with bigger errors in the remaining HRV parameters. The use of a smartwatch for measuring HRV was found to be a suitable alternative to ECG-based HRV, according to a study [7]. Smartwatches provide accurate measurements and allow the full range of HRV to be measured, including the low-frequency component. Although using HRV labeling that primarily evaluates short-term variability can be helpful, it is still necessary to exercise caution. Therefore, in the course of this study, we successfully determined the user's level of fatigue through a combination of the built-in HR detection function of the watch and our innovative HRV analysis program. The user is then alerted of a warning through the developed app software. The aim is to enhance the users' quality of life by assisting them in acknowledging and resolving fatigue, even if they are oblivious to it.

3 Methodology

A wearable smart watch is provided to the user for measurement in this study. The user can set the device up and start measuring HR to assess fatigue simply by connecting the watch to a mobile phone app. The user will then be able to be more aware of whether or not he or she is in a state of fatigue. The architecture of the system is shown in Fig. 1.

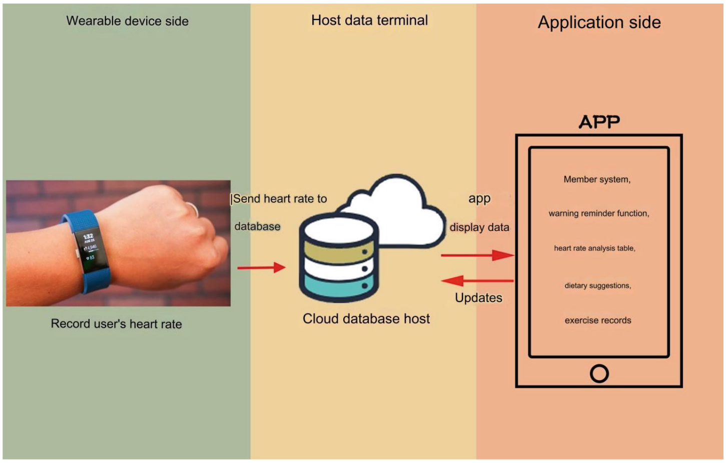


Fig. 1. The architecture of the system

The primary investigation of the study will be presented in three sections: first, developing the APP application program; second, creating a program to analyze HRV to assess fatigue status; and third, creating a program to offer nutritional guidance and record exercise.

3.1 APP Developing

To design the APP, this project is set to utilize the Java development environment of Android Studio. This includes the Java Development Kit (JDK) and the standalone Android Software Development Kit (SDK) tools. Additionally, MySQL will be employed to create a database for securely storing all relevant data. The system flow chart is shown in Fig. 2. The APP provides the following features.

A. **Member system**
To access the app page and its functions, registration as a member is necessary. Therefore, it is important to register as a member for the first time while using the app. This provides a reference for future comparisons when recording various heart rates and basic information. During registration, personal details such as name, age, height, weight, and other essential information should be entered for future reference in exercise and dietary calculations.

B. **Heart rate chart**
We have created a comprehensible chart for heart rate analysis, with monthly, weekly, and daily intervals for users to select from. Additionally,

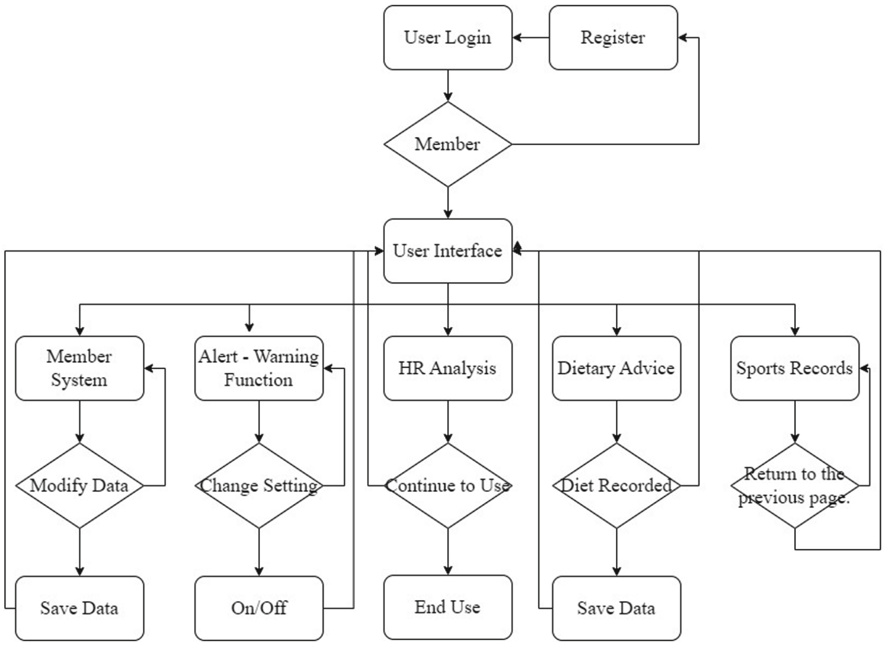


Fig. 2. System Flow Chart

users can choose a comfortable interface for analysis to conveniently check heart rate fluctuations.

C. **Warning alerts**

By analyzing the heart rate, it becomes evident whether the user is experiencing fatigue or not. Hence, this design sends vibration warnings to both the watch and the mobile phone when the user is fatigued, reminding them to take a break. The user can choose to enable or disable this function to prevent alert sounds from affecting his work during vital moments.

3.2 Developing a Program to Determine Fatigue

The study implemented a smartwatch to record the user's HR. After computing the RR interval, HRV analysis was performed utilizing the fast Fourier transformation technique to indicate the presence of fatigue in the user.

Table 1. Criteria for each band of heart rate variability

	Frequeny	Meaning
High Frequency (HF)	0.15 ∼ 0.4 Hz	parasympathetic nervous activity
Low Frequency (LF)	0.04 ∼ 0.15 Hz	sympathetic nervous activity
Very Low Frequency (VLF)	0.003 ∼ 0.04 Hz	temperature homeostasis, partial parasympathetic control

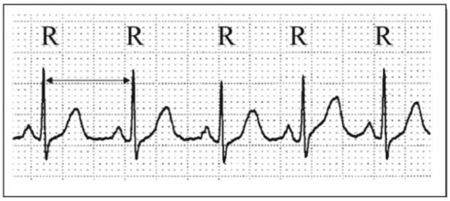


Fig. 3. The time between two neighboring R-waves

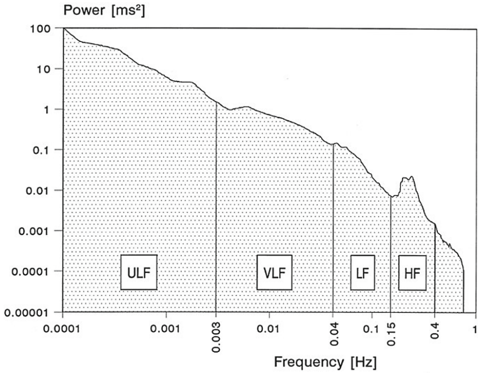


Fig. 4. Bandwidth of frequency domain analysis

A. **Derive the RR interval**
We use the HR tracking function of the smartwatch to automatically monitor HR. We then calculate the RR interval by using successive cycles of received heartbeats, subtracting the seconds corresponding to each R-value from the seconds of the previous point. The RR interval is shown in Fig. 3.

B. **Heart Rate Variability Analysis**
HRV analysis has two categories: time domain analysis and frequency domain analysis [5,8]. Time domain analysis is further divided into geometric and statistical methods. However, it is mainly used for long-term analyses. For immediate analysis, frequency domain analysis is preferred. The Fast Fourier Transformation (FFT) method is commonly used in frequency domain analysis. We utilized the Welch periodogram technique based on FFT [9] in this study to convert the time-series data into frequency data.
The continuous RR intervals are converted into the frequency domain using the Fast Fourier Transform during frequency-domain analysis, and the resulting spectral signals are carefully analyzed by the receiver. Based on Fig. 4 and table 1, we can deduce that frequency domain analysis encompasses the following metrics.

- Total power (TP): The intercepted frequency is less than 0.4 Hz, which refers to the variation of normal heartbeat intervals.

- High frequency power (HF): the intercepted frequency is from 0.15 to 0.4 Hz, which refers to the variation of normal heartbeat intervals in the high frequency range and represents the index of parasympathetic nerve activity.
- Low frequency power (LF): The intercepted frequency is from 0.04 to 0.15 Hz, which refers to the variation of normal heartbeat intervals in the low frequency range and represents the index of sympathetic nerve activity or the simultaneous regulation of sympathetic and parasympathetic nerves.
- Very low frequency power (VLF): The intercept frequency is from 0.003 to 0.04 Hz, which refers to the variation of normal heartbeat intervals in the very low frequency range.
- Ultra low frequency power (ULF): The intercept frequency is less than 0.003 Hz, which refers to the variation of normal heartbeat intervals in the ultra low frequency range.
- Normalized low frequency (normalized LF, nLF): refers to LF/(TP - VLF) $\times$ 100, representing the index of sympathetic nerve activity.
- Normalized high frequency (normalized HF, nHF): refers to HF/(TP - VLF) $\times$ 100, which represents the index of parasympathetic nerve activity.
- LF/HF stands for low and high frequency power ratio: an indicator of sympathetic/parasympathetic balance or an indicator of sympathetic regulation.

The standard established by the aforementioned method is utilized as a fatigue index, based on the balance between sympathetic and parasympathetic indexes.

3.3 Developing Dietary Advice and Exercise Logging Programs

A. **Dietary Advice**

A study [10] showed that a moderate amount of vitamin C supplementation can stabilize emotions, including fatigue, depression, insomnia, stress, overeating, anger, and other negative emotions were reduced by 35%. The nutritionist at the medical center has also provided a diet to help alleviate fatigue. They suggested specific foods from the following food categories, which are listed in the Table 2 below.

Table 2. Dietary Tips for Combating Fatigue

Category	Category Description
Complex Carbohydrates	Brown Rice, Whole Grain Bread, Mixed Grain Bread
Vitamin B12	Clams, Dried Small Fish, Oysters, Pork Liver, Salmon, Snapper, Swordfish
Folate	Wheat germ, Dark green vegetables (e.g. spinach, asparagus, cauliflower, mustard greens), Soybeans, Chicken liver
Iron	Brown sugar, Black sesame, Dried oysters, Wolfberries, Red cabbage, Red beans, Black beans
Vitamin C	Bell Pepper, Mung Bean Sprouts, Kiwi Fruit, Pomegranate, Papaya, Cauliflower, Tomato
Zinc	Oysters, Pumpkin seeds, Sunflower seeds, Pine nuts, Cashews
Magnesium	Pumpkin seeds, Sunflower seeds, Dark green vegetables

Rather than relying on coffee and soft drinks to support a tired body, we will provide advice on how to improve the diet by matching it with the appropriate dietary menu. Users can also upload their dietary records to calculate their daily calorie intake, so they can see which part of their intake is too much or too little and alert themselves.

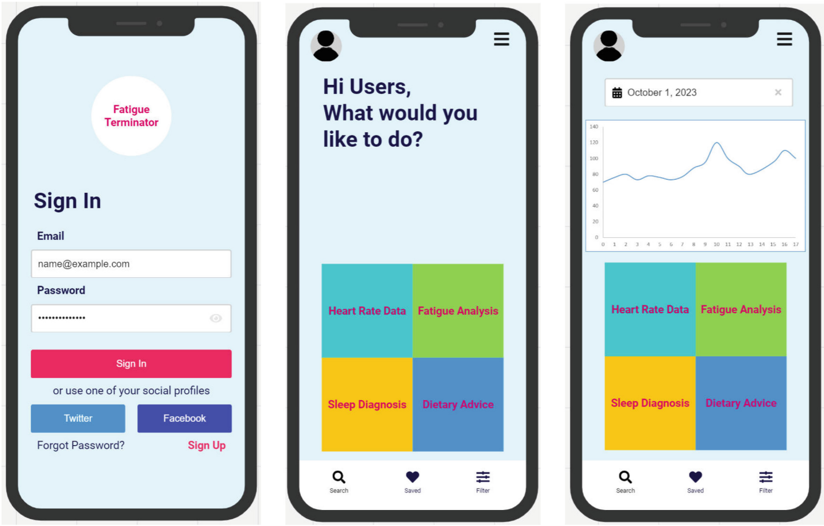
B. **Sports Records**

According to research conducted by [11], it has been demonstrated that exercise may be an effective solution for improving chronic fatigue syndrome. Therefore, an interface will be set up to allow users to use the exercise animation provided by the app directly in the system to briefly stretch their muscles and bones, achieve the effect of exercise and record it in the app. In addition, this interface will provide feedback activities to allow users to complete tasks and provide rewards for success to motivate users to exercise. This project is expected to provide several exercise instructions, such as: stress relief yoga, walking, eye care exercise, etc., without having to go to the sports centre can also be implemented.

4 Results

We use the smartwatch to monitor HR and transmit data to a remote database. Subsequently, we employed a developed app to retrieve the HR data from the database and provide real-time analysis of the user's fatigue level. The app features a user-friendly interface and intuitive operation, allowing users to accurately determine their fatigue state.

The HR data, which are obtained from a smartwatch, represents the number of heartbeats per minute. This particular parameter plays a crucial role in assisting medical professionals in evaluating an individual's overall cardiovascular health. Using these HR data, we employ Eq. 1 to calculate the time elapsed between consecutive R peaks, which serves as a significant measure of HR variability. The RR period signifies the time interval between two consecutive heartbeats and is closely correlated with HRV. HRV, in turn, refers to the temporal



(a) Login screen (b) Main screen (c) Heart rate screen

(d) Fatigure analysis (e) Sleep diagonsis analysis

Fig. 5. The screen of APP

fluctuation that occurs between successive heartbeats and provides insight into the adaptability and responsiveness of the cardiovascular system. It is a widely-used method for assessing the health and functionality of the cardiovascular system.

$$\text{RR interval (ms)} = 60000/\text{HR} \tag{1}$$

If the heart rate is 60 beats per minute (BPM), then the RR interval would be 1000 milliseconds (ms). This indicates that there is a 1,000-ms (or 1 s) gap between consecutive heartbeats when the heart rate is 60 BPM.

We utilized the Welch periodogram technique, which is based on the Fast Fourier Transform (FFT), to convert the time series data into frequency data. The continuous RR intervals were transformed into the frequency domain using the FFT method during the frequency domain analysis, and the resulting spectral signals were analyzed meticulously. Welch's method is a valuable approach for estimating spectral density. It entails segmenting the data, applying a windowing technique, performing FFT computations, calculating the power, and then averaging the results. Next, we calculate the spectral parameters. These parameters often consist of the low-frequency and high-frequency components, which are associated with sympathetic and parasympathetic nervous system activity, respectively. Once we have the spectral parameters, we analyze the HRV results. We compare the LF, HF, and LF/HF values with established reference ranges to assess the individual's autonomic balance and overall HRV status.

The login screen for the APP program is displayed in Fig. 5(a). The main screen of the APP program can be seen in Fig. 5(b). In Fig. 5(c), we have the Heart Rate screen. The fatiguing analysis screen is shown in Fig. 5(d). Lastly, the sleep diagnosis analysis is presented in Fig. 5(e).

5 Conclusion

We are exploring the revolutionary use of wearable smartwatches to detect and notify users of their fatigue levels. Our research focuses on developing an app software that seamlessly integrates with the heart rate detection feature of smartwatches. By analyzing heart rate variability, we can identify signs of fatigue. Smartwatches have been monitoring health metrics since 2011. We can use them to address the problem of fatigue. Our aim is to improve people's well-being by warning them in advance about possible fatigue, particularly when they may not realize that their energy is decreasing while they are working or going about their daily activities.

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