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Wearable Emotion Recognition Technology Based on Heart Rate Variability and EEG Rhythm

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Abstract. This paper explores the utilization of physiological signals, including heart rate variability (HRV) and electroencephalography (EEG), in emotion recognition through wearable devices. Heart Rate Variability (HRV) is closely linked to emotional arousal. HRV can detect subtle changes in heart rate patterns, which are indicative of different emotional states. By analyzing these patterns, researchers can identify and differentiate between various emotions someone may be experiencing. The integration of heart sound signals alongside traditional ECG signals presents an innovative approach, enhancing the accuracy of emotion recognition systems. Similarly, EEG rhythms are investigated for their association with cognitive and emotional states. This involves using brain rhythm sequences in classification tasks. The study underscores the significance of single-channel selection in EEG-based emotion recognition, demonstrating notable improvements in accuracy. Furthermore, wearable emotion recognition devices offer potential benefits for personalized emotion management and mental health intervention, catering to individuals with affective disorders and aiding in medical diagnosis and treatment. The Smartex S.R.L. platform exemplifies the advancement in wearable monitoring technology, facilitating data acquisition and interpretation for emotion recognition, particularly in patients with bipolar disorder. Overall, the paper highlights the evolving landscape of emotion recognition technology, with HRV and EEG emerging as prominent techniques alongside advancements in wearable device design and signal processing methodologies.

Keywords: HRV, EEG, emotion recognition , BCI.

1. Introduction

In recent years, the development of wearable technology has revolutionized various aspects of healthcare, including the assessment and management of emotional well-being. In the field of fitness and Sports Medicine, wearables can track physical activity, monitor exercise intensity, and provide feedback on performance, helping individuals improve fitness levels and prevent injuries. While in neurology, wearables equipped with sensors can track movement patterns, detect tremors in conditions like Parkinson's disease, and monitor sleep patterns, assisting in the diagnosis and management of neurological disorders. Among the myriad applications of wearable devices, one particularly promising area lies in emotion recognition technology, which leverages physiological signals to discern and understand human emotions. This paper delves into the burgeoning field of wearable emotion recognition technology, with a specific focus on the utilization of heart rate variability (HRV) and electroencephalography (EEG) rhythm as key physiological markers.

Emotion recognition plays a pivotal role in understanding human behavior and mental health. Traditionally, emotion assessment has relied on subjective self-reporting methods, which are susceptible to biases and inaccuracies. In contrast, wearable devices offer a non-invasive and objective means of assessing emotional states in real-time, providing valuable insights into individuals' emotional experiences.

The significance of this research lies in its exploration of two prominent physiological signals, HRV and EEG rhythm, for emotion recognition purposes. HRV, reflecting the variability in time intervals between consecutive heartbeats, serves as a sensitive indicator of emotional arousal. Through HRV analysis, various features can be extracted from heart rate signals, encompassing time-domain indices, frequency-domain indices, and non-linear dynamic methods. These features capture different aspects of heart rate dynamics associated with emotional states, enabling accurate emotion recognition.

Similarly, EEG signals, which reflect the electrical activity of the brain, exhibit distinct patterns associated with different cognitive and emotional states. Specific brain rhythms, such as alpha, beta, theta, and gamma waves, have been identified as correlates of various mental states and emotional experiences. The novel method of brain rhythm sequencing (BRS) offers a promising approach to EEG-based emotion recognition, allowing for the classification of rhythmic sequences using dynamic time regularity (DTW) algorithms.

This paper aims to provide a comprehensive overview of the current state of wearable emotion recognition technology, highlighting the significance of HRV and EEG rhythm as physiological markers. The research reviewed here encompasses studies investigating the use of these signals for emotion recognition tasks, ranging from experimental designs involving emotional stimuli presentation to sophisticated machine learning algorithms for feature extraction and classification.

In terms of methodology, this paper adopts a review approach, synthesizing findings from existing literature to elucidate the potential of wearable devices in emotion recognition. By examining various studies and methodologies employed in the field, this paper seeks to identify trends, challenges, and future directions for research in wearable emotion recognition technology.

In summary, this paper contributes to the growing body of literature on wearable technology and its applications in emotion recognition. By shedding light on the utilization of HRV and EEG rhythm as physiological markers, this research underscores the potential of wearable devices in enhancing our understanding of human emotions and promoting mental health and well-being.

2. How heart rate variability recognizes emotion

Heart Rate Variability (HRV) is a physiological measure that reflects the variation in time intervals between consecutive heartbeats. It's an indicator of the autonomic nervous system's influence on the heart and is often used as a marker of emotional states due to its sensitivity to changes in emotional arousal.

Heart rate variability (HRV) is associated with mood by measuring fluctuations between successive heartbeat cycles. In emotion recognition, HRV analysis involves extracting various features from the heart rate signal. For example, there is time-domain indices (e.g., standard deviation of NN intervals, root mean square of successive differences), frequency-domain indices (e.g., low-frequency power, high-frequency power), and non-linear dynamic methods (e.g., Poincare plot analysis, Lyapunov exponent). These features capture different aspects of heart rate dynamics associated with emotional states.

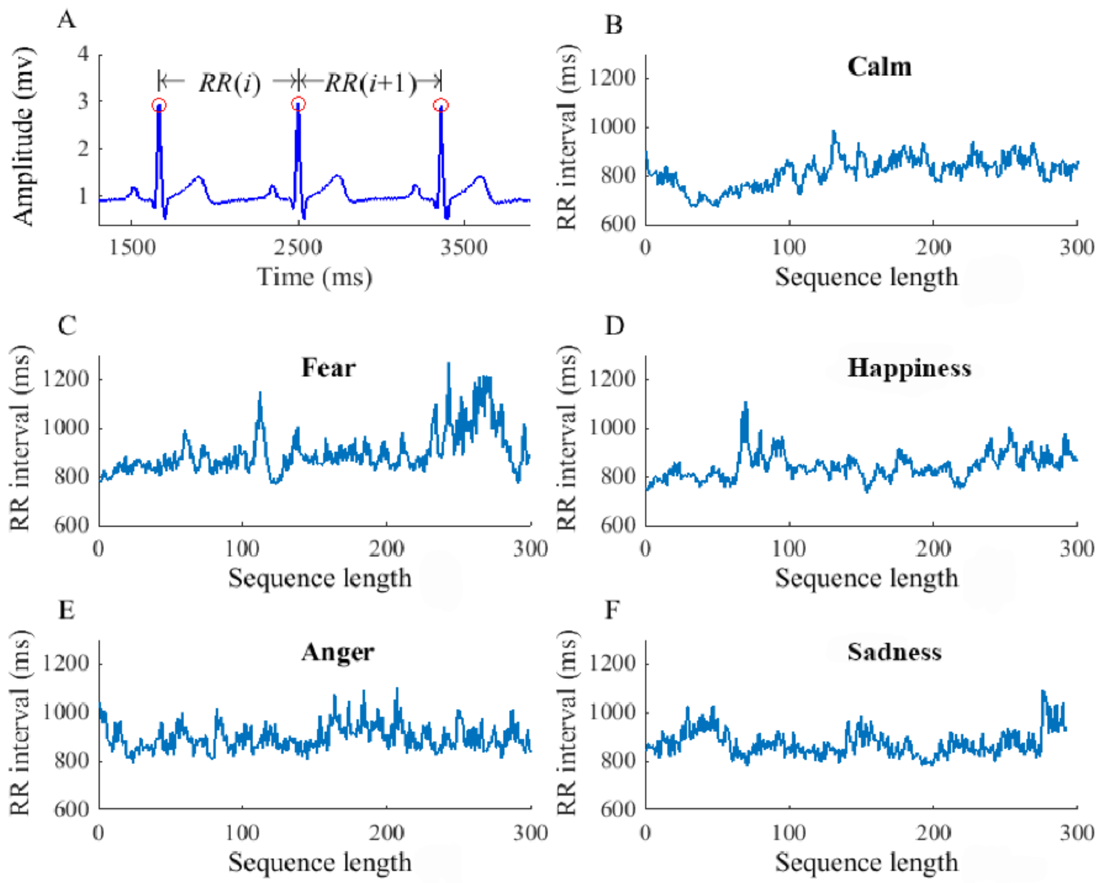

Figure 1. Construction of HRV series from the consecutive RR intervals in ECG signal (A) and the examples of HRV series under calm (B), fear (C), happiness (D), anger (E) and sadness (F)

conditions from a healthy subject [1]

The research indicated by figure1 conducted an experiment in which participants presented various emotional movies, audio or images and then measured their heart rate variability to understand their physiological responses across emotional states.

Figure 1 demonstrates the HRV series under different emotion states (calm, fear, happiness, anger and sadness), and it also indicates that the humans' emotions can be measured by HRV.

In details, HRV can recognize emotions based on Feature Extraction, Machine learning algorithms' classification models and other wearable devices. There is an emotion recognition system based on HRV and the block diagram following demonstrates it.

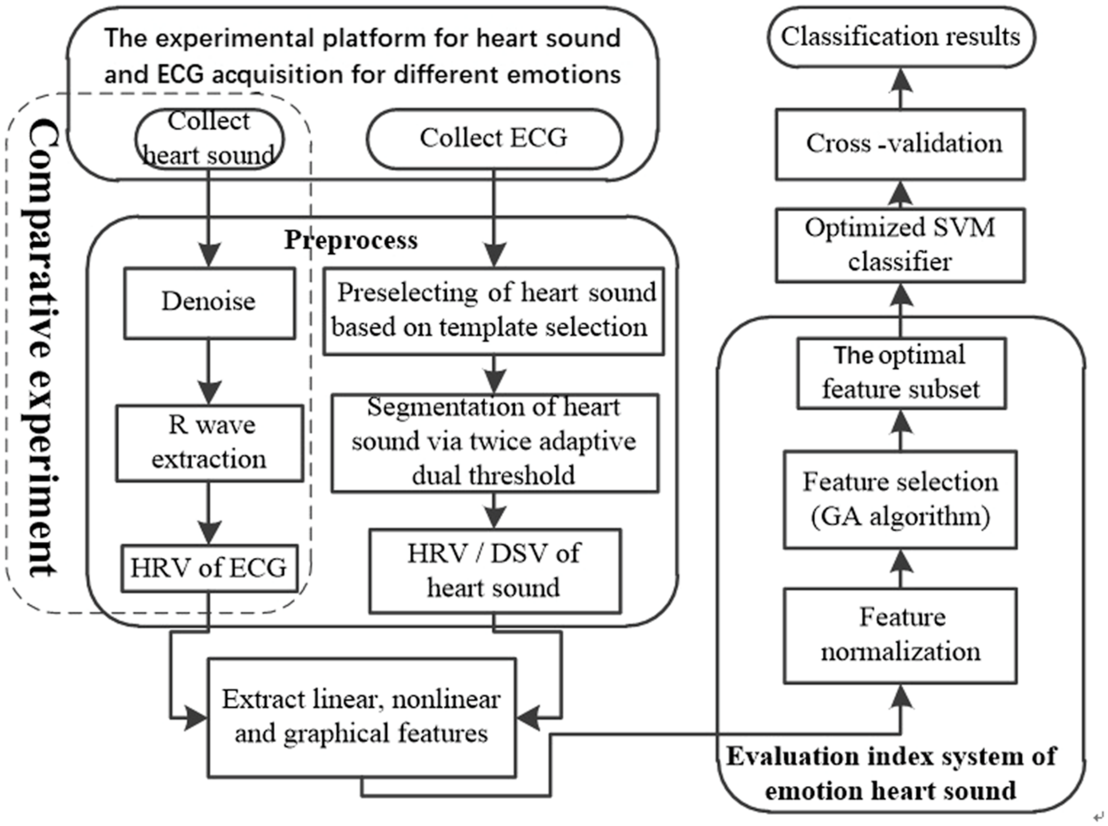

Figure 2. Overall block diagram of the emotion recognition system based on heart sound [2]

The system mainly consists of heart sound collecting, ECG synchronous acquisition module, signal preprocessing module and emotion recognition module [2]. The system first establishes a unique emotion heart sound database based on experimental data, extracts features from the dataset, and performs emotion recognition based on the extracted feature values.

As to the establishment of the Emotion Heart Sound Database, the system collects heart sound signals and preprocesses them to filter out noise interference unrelated to emotions initially. This preprocessing involves segmenting the lengthy (300 seconds) heart sound signals into distinct segments corresponding to different emotional states, ensuring the independence and accuracy of each segment. By labeling and analyzing the collected heart sound signals, a comprehensive database encompassing various emotional states such as relaxation, happiness, sadness, and anger is constructed. These datasets are then utilized for subsequent emotion recognition tasks.

Feature Extraction: In the domain of feature extraction, the system extracts various linear and nonlinear features from the heart sound signals, including heart rate variability (HRV), heart sound variability (DSV), among others. Additionally, HRV features from corresponding emotional states of electrocardiogram (ECG) signals are extracted.

Emotion Recognition: The final step involves emotion recognition based on HRV. This is achieved by analyzing and comparing the extracted features, employing techniques such as cross-validation. The system compares the features of heart sound signals and ECG signals across different emotional states to determine their effectiveness in emotion recognition.

This approach integrates data collection, preprocessing, feature extraction, and emotion recognition, leveraging both heart sound signals and ECG signals to facilitate accurate emotion recognition.

As to the innovation of the system, this system lies in utilizing heart sound signals as indicators for emotion recognition. This approach innovatively incorporates heart sound signals as one of the indicators for emotion recognition and extracts multiple features for analysis. Traditionally, emotion recognition mainly relies on physiological signals such as electrocardiography (ECG); thus, introducing heart sound signals into the domain of emotion recognition holds significant innovative potential.

Another innovation pertains to the methods of feature extraction and analysis. The system employs various feature extraction and analysis methods, such as heart rate variability (HRV), heart sound variability (DSV), among others. By comparing the variations in features across different emotional states, effective emotion recognition is achieved. Particularly noteworthy is the introduction of the SD12 feature to compare the differences between heart sound signals and ECG signals, offering a novel perspective and approach to emotion recognition.

3. How EEG rhythm recognizes emotion

EEG signals reflect the electrical activity of the brain, which varies with different cognitive and emotional states. It has been established that specific brain rhythms, such as alpha, beta, theta, and gamma waves, are associated with distinct mental states and emotional experiences.

There is a new method for emotion recognition, known as the brain rhythm sequence (BRS). Electroencephalography (EEG) was resolved by explaining the dominant brain rhythm with the maximum instantaneous power at each 0.2-second timestamp. The rhythmic sequence was then classified using dynamic time regularity (DTW). By evaluating the rhythmic sequence of the emotion recognition task, representative channels that produce excellent accuracy can be found to achieve single-channel selection.

The study utilized methods such as synchronization likelihood (SL) for channel selection and feature extraction, ReliefF-based channel selection, and normalized mutual information (NMI) for channel selection in EEG-based emotion recognition.

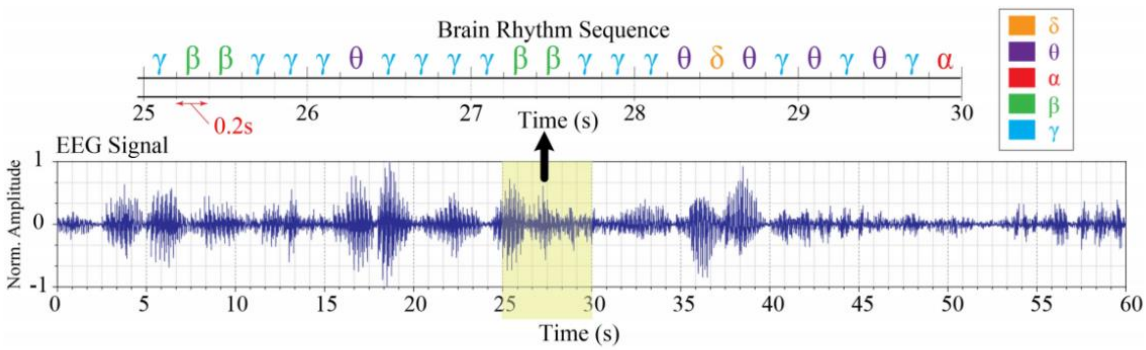

Figure 3. BRS was proposed by a dominant brain rhythm having the maximum instantaneous power at each 0.2 s timestamp of EEG (FP1 channel, Subject S1, DEAP) [3]

Jia Wen Li et al found that single-channel selection for EEG-based emotion recognition can achieve accuracies ranging from approximately 70% to 82% for different test sets when using brain rhythm sequences generated from a selected representative channel at an appropriate 10-second time segment [3][4]. This indicates that focusing on single-channel selection can lead to significant improvements in emotion recognition accuracy.

At the same time, J. W. Li et al proposes a method for EEG-based emotion recognition using brain rhythm sequencing and dynamic time warping for similarity measurement [4]. The methodology involves generating sequences of dominant brain rhythms from EEG signals and analyzing single-channel data segments of 5 seconds. The innovation of the method lies in its ability to achieve classification accuracies of 72%–75% by identifying the representative channel and appropriate time segment for each subject, outperforming previous works in accuracy and data sources used. This highlights the significance of individual characteristics in emotion recognition and the potential for developing portable emotion-aware devices.

4. Specific research work on identifying mood by wearable devices

Wearable devices are designed for ease of use, comfort, and improved signal quality, which makes them more convenient to be carried out in order that the devices can detect high-quality signal successively for users in all places and at all time. This has brought immeasurable commercial value and development significance to the development of wearable emotion recognition devices.

In the first place, wearable emotion recognition devices can collect a large number of individual emotional data, combined with machine learning and other technologies for analysis, and provide users with personalized emotion management suggestions and interventions. Emotion recognition technology can help people better understand their emotional state, find and deal with emotional problems in time, and help prevent and manage mental health problems, such as anxiety and depression. Especially for some people with affective disorders, this device can provide real-time monitoring and intervention that can help to improve their quality of life. In addition, the data of emotion recognition devices can also be used as a reference for adjuvant medical diagnosis and treatment, especially for some emotion-related diseases, such as autism, post-traumatic stress disorder, to provide more objective data support, which can help doctors to diagnose and treat more accurately.

G. Valenza et al in the PSYCHE project, using the Smartex S.R.L, which is a wearable monitoring platform [5]. The Smartex S.R.L includes lithium battery power supply, micro SD card data storage, micro USB and Bluetooth data communication, and sensors for monitoring electrocardiogram and respiratory signals. The platform uses a comfortable T-shirt with integrated electrodes and sensors to monitor the ECG and respiratory activity. Data acquisition, processing, and interpretation procedures are used to extract important information on emotion recognition in patients with bipolar disorder. The system includes a rescaling program based on past emotional states and a support vector machine for pattern recognition.

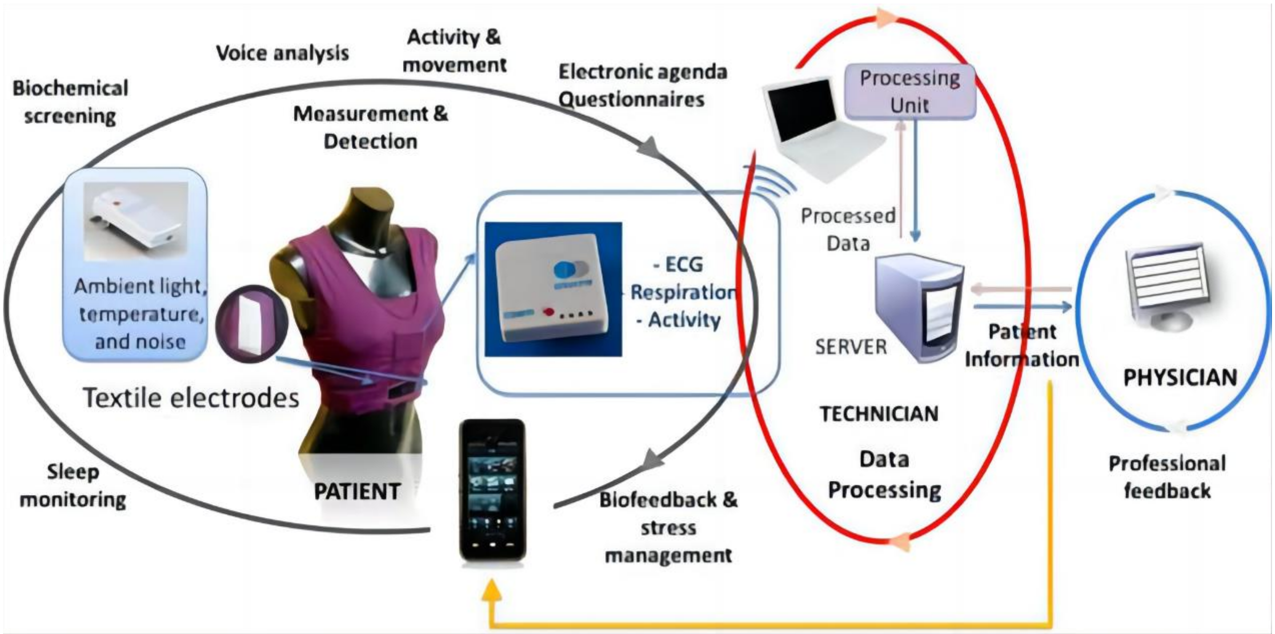

Figure 4. Overview of the PSYCHE system as a global platform serving as decision support system for bipolar disorder management [5].

5. Conclusion

In summary, the research presented herein delves into the realm of wearable emotion recognition technology, focusing on the utilization of heart rate variability (HRV) and EEG rhythm as key physiological indicators. Through the analysis of HRV, this research demonstrates the method's efficacy in discerning various emotional states, offering a nuanced understanding of emotional arousal. By integrating heart sound signals alongside traditional ECG signals, the study introduces an innovative approach that enhances the accuracy of emotion recognition systems, particularly in patients with bipolar disorder.

Moreover, the investigation into EEG rhythms sheds light on their association with cognitive and emotional states, with brain rhythm sequences proving to be instrumental in classification tasks. The emphasis on single-channel selection in EEG-based emotion recognition underscores the significance of individual characteristics, leading to notable improvements in accuracy.

The impact of this research on the academic landscape of emotion recognition technology is substantial. By leveraging wearable devices and physiological signals, such as HRV and EEG, the study contributes to the advancement of methodologies for emotion recognition. Furthermore, the integration of heart sound signals expands the scope of physiological indicators, paving the way for more comprehensive and accurate emotion recognition systems.

Looking ahead, the future of wearable emotion recognition technology appears promising. Continued research and development efforts are expected to further refine existing methodologies and explore new avenues for application. The integration of advanced signal processing techniques, machine learning algorithms, and wearable device design will likely lead to more sophisticated and user-friendly emotion recognition systems. Such advancements hold significant potential not only for academic research , but it also for practical applications in mental health. These application includes mental health intervention, personalized emotion management, and medical diagnosis and treatment.

In summary, the research presented in this paper contributes valuable insights to the field of wearable emotion recognition technology, showcasing the potential of HRV and EEG rhythm as key physiological markers. With ongoing innovation and exploration, wearable devices are poised to play an increasingly vital role in understanding and managing human emotions.

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