

Application of Surface Electromyography (sEMG) in Smart Health Devices

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Abstract: As a non-invasive physiological signal detection technology, surface electromyography (sEMG) can reflect the state of muscle activity in real time. It has the characteristics of rich information, convenient collection, and high comfort. It is widely used in medical rehabilitation, sports health monitoring, ergonomics, and smart wearable devices. This paper focuses on the basic principles and characteristics of sEMG technology, and from multiple dimensions such as intelligent rehabilitation medicine, sports monitoring and training, ergonomic equipment, and smart wearable devices, it sorts out and analyzes its research status, application results, and technical bottlenecks in smart health equipment in detail. Through literature analysis, it is found that the current sEMG technology has challenges in equipment comfort, signal stability, individual difference adaptability, algorithm generalization performance, and data security, and further breakthroughs are urgently needed. At the same time, this paper also discusses the future development trend and research prospects of sEMG technology in multimodal physiological signal fusion, intelligent human-computer interaction, and personalized precision health management equipment development, in order to provide valuable reference for the future technology development and application in the field of smart health equipment.

Keywords: sEMG; smart health equipment; ergonomics; physiological signal fusion.

1. Introduction

With the deepening of population aging and the accelerated pace of modern life, people's demand for health monitoring and management is gradually increasing. As a non-invasive physiological signal detection technology, surface electromyography (sEMG) is widely used in many fields such as medical rehabilitation [1,2,3], sports science [4,5,6], ergonomics research, and smart health equipment development [7,8,9] due to its convenience, safety, and rich information content. Based on the relevant literature on surface electromyography technology and smart health equipment in recent years, this paper reviews the research status and trends of sEMG technology in smart health equipment from four aspects: medical rehabilitation, sports monitoring and training, ergonomic equipment, and smart wearable health equipment, aiming to provide a reference for research and application in related fields.

2. Overview of Surface Electromyography (sEMG) Technology

2.1. Definition and principle of surface electromyography signal

Surface electromyography (sEMG) is a bioelectric signal generated by muscle tissue contraction[10] and collected by electrodes placed on the surface of the skin. The generation mechanism of this bioelectric signal is closely related to the neuromuscular activity of the human body. When motor neurons transmit nerve impulses to muscle fibers, the potential of the muscle cell membrane changes, generating action potentials[11]. These action potentials are transmitted along the muscle fibers, causing muscle excitation and contraction. When a large number of muscle fibers are

activated synchronously or asynchronously, the potential changes are recorded by electrodes on the surface of the skin, thus forming the surface electromyography (sEMG) signal we are familiar with.

The amplitude of the surface electromyography signal is usually between microvolts (μV) and millivolts (mV), and its frequency is mainly concentrated in the range of 10-500Hz, depending on different muscle types and activity intensity. Usually, the sEMG signal exhibits random fluctuation characteristics, reflecting physiological information such as the strength of individual muscle activity, fatigue state, and muscle fiber recruitment pattern. Therefore, sEMG is widely used in biomedical engineering, human-computer interaction, rehabilitation medicine, sports science, and smart health equipment development. Compared with invasive needle electrode electromyography (iEMG), sEMG has significant advantages: it is a non-invasive technology that does not cause trauma or discomfort to the subject being measured, and is more easily accepted by patients or users. In addition, due to its easy operation, economical and practical, sEMG is particularly suitable for the development of smart wearable devices and long-term continuous health monitoring needs.

2.2. sEMG signal acquisition and processing method

The processing of surface electromyographic signals usually includes three stages: data preprocessing, feature extraction, and pattern recognition.

First, the main purpose of data preprocessing is to improve signal quality and remove noise and interference. Typical methods include bandpass filtering, high-pass filtering, notch filtering, and wavelet denoising technology. In particular, bandpass filtering is usually set to 20-500Hz, which can effectively eliminate low-frequency drift and high-frequency electromagnetic interference caused by human movement.

Secondly, the feature extraction process is used to extract parameters that can effectively reflect the state of muscle activity from the original electromyographic signal. Commonly used time domain features include root mean square (RMS), integrated electromyographic (IEMG), zero crossing rate (ZC), waveform length (WL), etc., frequency domain features include median frequency (MDF), mean frequency (MNF), power spectral density (PSD), etc., and time-frequency domain methods include short-time Fourier transform (STFT) and wavelet transform (WT) [12, 13].

Finally, there is the pattern recognition link, which involves machine learning and artificial intelligence algorithms, aiming to identify and classify muscle activity patterns or intentions. Currently, widely used algorithms include traditional machine learning (such as support vector machine SVM, random forest RF, linear discriminant analysis LDA) and deep learning (convolutional neural network CNN, long short-term memory network LSTM, etc.). Studies have shown that deep learning algorithms have better performance in complex motion pattern recognition and are suitable for more complex signal classification scenarios.

3. Application of sEMG in Smart Health Devices

3.1. Rehabilitation training equipment field

Surface electromyography plays an important role in the field of rehabilitation medicine, especially in prosthetic control and neuromuscular rehabilitation. By real-time monitoring of muscle activity status and assisting patients in active or passive training, Liu et al. developed a flexible sEMG acquisition system based on graphene and FPC technology, and successfully applied it to muscle strength assessment and hand rehabilitation training. Experiments show that the prediction accuracy of the system in the test set reached 98.81%, and it has good flexibility and wearing comfort, providing an efficient and convenient sEMG monitoring solution for the medical and scientific research fields [14]. Yu explored the rehabilitation effect of surface electromyography biofeedback combined with swallowing training on patients with dysphagia after cerebral infarction. The results showed that the combined intervention can effectively reduce the SSA score, improve the electromyographic activity level of the submental muscles, shorten the swallowing time, and reduce the incidence of complications. Studies have shown that this method can promote the recovery of swallowing function and provide a scientific basis for the rehabilitation treatment of dysphagia [15]. Chen et al. compared the surface electromyography (SEM) signal values of two groups of patients with lower limb spasticity after ischemic stroke: the control group and the observation group. The results showed that the lower limb muscle tension of the observation group was lower than that of the control group, and the patients' motor coordination ability was higher [16].

3.2. Sports monitoring and training field

sEMG technology can quantitatively analyze the activation and fatigue state of muscles during exercise, helping athletes better control the intensity and rhythm of training. Peolsson et al. used Doppler-based tissue velocity ultrasound imaging technology to study the muscle movement patterns of patients with shoulder and neck pain, and tested the muscle movement level of the neck and back through experiments [17].

Gopinath et al. used the sEMG-based time-frequency analysis method to non-invasively evaluate the muscle fiber composition of untrained people (UT) and sprinters (SP). The results showed that the signal characteristics of SP were more consistent with the characteristics of fast muscle fibers, while the changes of UT under fatigue were more obvious. The square duration was the key parameter to distinguish the two groups of signals. Studies have shown that this method is suitable for muscle fiber type analysis and can be further applied to sports training strategy optimization and sports biomechanics research [18]. Li et al. analyzed the effect of long-term basketball training on the isotonic contraction performance of male upper limbs based on sEMG indicators. Experiments showed that the F12B feature group can stably achieve high-accuracy classification under the SVM2 model, and can effectively distinguish between professional and non-professional basketball subjects. The research results provide a scientific basis for sports training monitoring and the formulation of personalized training programs [19]. Bai A et al. used sEMG and kinematic analysis to monitor the performance of roller skaters and compared them with elite athletes. The results showed that students with higher training levels were closer to elite athletes in terms of kinematics and muscle efficiency, but there was still an imbalance in muscle activation patterns. Beginners showed more instability. The research results provide a scientific basis for optimizing training methods, formulating personalized training plans, and preventing sports injuries [20].

3.3. Ergonomics Application Areas

Long-term desk work and poor sitting posture can easily lead to a high incidence of musculoskeletal diseases. sEMG technology is applied to ergonomic equipment to monitor muscle burden in real time and prevent occupational strain. Jing C et al. analyzed the ergonomic risk factors of manual handling tasks through surface electromyography and found that the load weight, handling speed and posture during handling have a significant impact on the spinal muscle load. The results show that the half-squat posture can effectively reduce muscle burden and provide better mechanical support compared with other handling postures, which helps to reduce the risk of injury and provide a scientific basis for safe handling operations [21]. The study of Balasubramanian K et al. showed that during material handling, the use of a trolley can significantly reduce muscle fatigue compared with manual handling, thereby reducing the risk of MSD. By optimizing the design of the trolley, such as adjusting the handle height, the biomechanical load during handling can be further improved. This study provides a scientific basis for muscle fatigue management in the workplace and provides a reference for the formulation of ergonomic optimization plans [22]. Trudeau et al. studied the changes in thumb movement performance during one-handed use of a mobile phone to help optimize specific thumb interaction movements to improve the user's one-handed interaction experience [23]. Weston et al. studied the differences in interactivity when an office chair is used in combination with a desktop computer and a touch-screen tablet computer. This study provides effective reference opinions for the optimization design of existing office chairs [24].

3.4. Wearable applications in smart health devices

With the development of wearable devices, sEMG technology has received widespread attention in the field of daily health monitoring. Through portable electromyographic sensors, muscle electrical activity can be monitored in real time to assess the health status of users. Rescio G et al. developed a smart sock SEMG monitoring system that integrates biocompatible hybrid polymer electrodes to improve signal acquisition quality and reduce impedance. Compared with traditional AG/AGCL electrodes, this system performs well in measuring lower limb muscle activity and has potential application value in fall risk, gait abnormalities and sarcopenia assessment. Experimental results show that the SEMG signals collected by this system are highly correlated with those collected by commercial electrodes. Future research will further verify its reliability and practicality in long-term use [25]. Moore A et al. proposed a wearable SEMG system consisting of a soft wearable garment (a pair of shorts and two calf sleeves) embedded with screen-printed electrodes and a stretchable track that can pick up and record the electromyographic activity of lower limb muscles. By integrating screen-printed electrodes and stretchable wires, gait freezing in patients with Parkinson's disease can be monitored and predicted. Preliminary tests showed that the system can detect a significant decrease in electromyographic signals 3 seconds before the onset of FOG, providing a scientific basis for the early identification and intervention of FOG. In the future, the system can further combine AI and multi-sensor technology to provide Parkinson's disease patients with a more intelligent and accurate gait monitoring solution [26]. Song K et al. proposed a digital biomarker measurement technology using surface electromyography (sEMG) electrical stimulation and wearable devices to conveniently monitor muscle function at home. When motor neurons and muscle fibers are electrically stimulated, stimulated muscle contraction signals (SMCSs) can be obtained using sEMG sensors. Experiments have shown that this method has high accuracy and practicality and can be effectively applied to home monitoring and evaluation of sarcopenia [27]. Jiang S et al. proposed a wrist-worn real-time gesture recognition wristband that integrates surface electromyography (sEMG) and inertial measurement unit (IMU) sensors. It can recognize 8 air gestures and 4 surface gestures, and supports recognition of 2 different levels of force. The experiment invited 10 healthy subjects to undergo an initial test, repeated test one hour later, and one day later. The results showed that the accuracy of mid-air gesture recognition was 92.6%, and the accuracy of surface gesture recognition was 88.8%, with no significant changes over time. This shows that wrist position can be used for reliable gesture recognition, providing an effective basis for achieving intuitive human-computer interaction in future wrist-worn devices such as smart watches[28].

4. Issues and Challenges

Although sEMG technology has broad application prospects, it still faces many challenges: (1) Signal stability and anti-interference ability: EMG signals are easily affected by skin conditions, electrode contact quality, and electromagnetic interference; (2) Optimization of signal processing and pattern recognition algorithms: How to improve the accuracy and generalization of recognition in

actual application environments; (3) Equipment wearing comfort and convenience: How to optimize equipment design to improve long-term wearing comfort and user acceptance; (4) Data privacy and security issues: How to effectively protect the privacy of users' physiological information.

In response to the above issues, future research needs to further optimize the software and hardware systems, improve the robustness and adaptability of signal processing algorithms, strengthen the ergonomic design of equipment, and ensure data security and privacy.

5. Summary

This article discusses the basic principles of surface electromyography (sEMG) technology and its current application status and development trends in the field of smart health devices. The application research of surface electromyography (sEMG) in smart health devices is booming and has shown great potential in the fields of medical rehabilitation, sports training, ergonomics and health monitoring, improving users' health management and quality of life. In the future, with the continuous breakthroughs and integration of signal processing algorithms, artificial intelligence technology, flexible electronics and wearable technology, the application of sEMG in the field of smart health will surely enter a new stage of greater accuracy, efficiency and intelligence.

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