Verification Analysis of Lower Limb Rehabilitation Based on Data Mining For Muscle Strain Identification

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ABSTRACT: *Muscle strain is a common sports injury that significantly impacts patients' lives and work. Early detection and intervention of muscle strain are significant for preventing and treating muscle strain. However, traditional medical diagnostic methods often have certain limitations and cannot meet the needs of large-scale, fast, and accurate diagnosis. Therefore, this study aims to use data mining technology to identify muscle strain and combine it with lower limb rehabilitation technology to provide new means for early detection and intervention of muscle strain. This article studies the validation analysis of lower limb rehabilitation for muscle strain recognition based on data mining. The feasibility and effectiveness of this method were verified by collecting patient motion data, using data mining technology to identify muscle strain, and combining it with lower limb rehabilitation technology.*

Keywords: Data Mining Algorithm, Anatomic Information, EMG Signal, Identification

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1. Introduction

Muscle fatigue refers to a state of muscle after excessive exercise and the continuous contraction of muscles. When the movement reaches a specific time, the muscle cannot provide contraction according to the requirement of nerve consciousness [1]. There are two reasons for muscle fatigue. One is exercise fatigue, which is more common among sports athletes; because of frequent sports training, athletes' muscle fatigue appears in training [2]. Another is static muscle fatigue, which refers to the fatigue of the muscles when the body maintains a certain position for a long time. This paper mainly introduces the principle and method of motor muscle fatigue identification [3]. To study muscle fatigue identification, it is necessary to understand the essence of muscle fatigue. At present, there are two kinds of theories about muscle fatigue in academic circles; some scholars believe that muscle fatigue is mainly the result of chemical process, that is, excessive consumption of human ATP and excessive accumulation of metabolic waste cause the fatigue, resulting in changes in electrical signals of nerves and muscles [4]. More scholars believe that chemical processes cause nerve impulses and muscle fatigue causes exhaustion. In contrast, centripetal impulse inhibits the motor center, decreasing the number and frequency of motor nerve impulses. The signals on the surface of muscles also change accordingly [5]

2. Current Status

At present, the *EMG* signal acquisition system at home and abroad is divided into two types; one is to use the front-end signal conditioning module combined with the *PCI* acquisition card. This kind of system relies on the *PC* machine, through the data acquisition card of the *PCI* interface, collects multi-channel *EMG* signals and then completes the follow-up characteristic calculation and analysis of the *EMG* signal using the advantages of the processing speed of the *PC* machine [6]. At the same time, this system also integrates the function of *EMG* stimulation feedback, electromyography printing and so on. Since the research time is earlier, the platform is unified, and the function is relatively complete. Therefore, the electromyography acquisition system based on *PC* display and analysis is the most mature program and is the first choice of clinical rehabilitation medical equipment in major hospitals. The other kind of *EMG* acquisition system uses a *PDA* to replace the *PC* machine to realize the real-time display and analysis of *EMG* signal to reduce the volume and cost of the whole collection system; at present, there are a series of products, such as 16-channel wireless *EMG* signal acquisition system of German's BIOVISION` Noraxon wireless myoelectric telemetry system in the United States and a series of multi-channel myoelectric acquisition instruments provided by the Canada Company [7]. Taking ME6000 as an example, the acquisition device is designed with a dedicated handheld terminal, storing and displaying the collected myoelectric signal data on the handheld terminal, at the same time; it can transmit data to the *PC* terminal through wireless communication, and carry out the analysis and processing of the electromyography signal.

3. Methodology

3.1. Identification Algorithm for Muscle Fatigue

The identification of muscle fatigue studied in this paper based on *EMG* is mainly used to obtain the state of muscle fatigue during the rehabilitation exercise of the patients in the lower limb rehabilitation platform; when this happens, it reminds patients that the muscles in rehabilitation exercise have reached fatigue state, and muscles need rest to achieve the best rehabilitation effect. The methods of detecting muscle fatigue are generally divided into two categories, one of which is the direct detection method; that is, the maximum impedance of the muscles is measured directly. The ability of muscle impedance is embodied in the free contractile muscle strength's work power of muscle and forced contractile muscle strength of the muscles under the condition of electrical stimulation. The other is indirect identification, which indirectly evaluates muscle fatigue by monitoring the other physiological characteristics of muscles during muscle fatigue. The physiological characteristics frequently monitored during muscle fatigue include Surface *EMG*, twitch superimposition load duration, etc. This paper mainly introduces the implementation of the algorithm for identifying the state of muscle fatigue by using the electrical signal of the surface muscle. The organization of sports physiology found that the essence of muscle fatigue is the changes in the activities of the central nervous system; these changes are reflected in the physiological intensity of motor unit activity, the level of muscle fibre recruitment, and the velocity of muscle fibre conduction (*CV*) related to cell acidosis. When the *CV* is reduced, the muscle fatigue state can be identified; at present, the detection technology of *CV* is not yet mature. Therefore, we often use the method of extracting the characteristic parameters that can reflect the size of the *CV* value in the surface electromyography signal to get the change of the *CV* value indirectly. Stulen et al conducted in-depth research through the change of the *CV* value and established a set of EMG signal mathematical models; the model shows that the power spectral density of the surface *EMG* signal with differential mode input is a function variable of muscle fibre conduction velocity *CV*, that is, the power spectral density of electromyography can reflect the change of *CV* and reflect muscle fatigue information. Based on the relationship between the power spectral density of *EMG* and the *CV* of muscle fibre conduction velocity, we proposed an algorithm that uses characteristic parameters based on frequency domain values related to the power spectral density of *EMG* signals to identify muscle fatigue. This algorithm focuses on changes in the average power frequency (*MPF*) and the median frequency (*MF*) of the surface *EMG* signal during muscle fatigue. The formula for calculating the average power frequency is shown in formula (1) and formula (2).

$$MPF = \int_0^{+\infty} fp(f)df \,/ \int_0^{+\infty} p(f)df \quad (1)$$

$$MF = \frac{1}{2}\int_0^{+\infty} p(f)df \quad (2)$$

Among them, $p\ (f\ )$ the function is the power spectral density function of the surface *EMG* signal. Studies have shown that muscle metabolic acidosis induced by exercise load is the main reason for the change of *MPF*, which causes the change of *MPF* through the influence of the excitation conduction velocity and action potential waveform. According to the theory of muscle *EMG*, median frequency (*MF*) is a consistent estimator in a certain coefficient of proportionality of the muscle fibre conduction velocity *CV*, and it is not sensitive to noise, Therefore, *MF* can more reliably reflect the changes of *CV* than the average power frequency (*MPF*), so *MF* is suitable for online analysis. However, the statistical results after many tests show that *MPF* can measure the spectrum movement more steadily. Therefore, when the *SNR* is high, the average power frequency is generally used to identify muscle fatigue. The experiment also found that as the degree of muscle fatigue deepened, the downward trend of *MF* and *MPF* was more obvious. Therefore, in some studies, the descending slope of *MF* and *MPF* is usually defined as the index of muscle fatigue, which is used to evaluate the degree of muscle fatigue.

Muscle fatigue not only leads to the change of eigenvalues of surface electromyography, but the experiment shows that the amplitude of the *EMG* signal changes during the contraction of fatigue muscle. Therefore, an identification algorithm is proposed to identify the muscle fatigue state by the amplitude of the muscle surface *EMG* signal. In the algorithm of identifying the muscle fatigue state based on the amplitude of the electromyography signal, the average value of rectification (*ARV*) and the root mean square (*RMS*) of electromyography are usually used as the eigenvalues to identify muscle fatigue. The *ARV* and *RMS* calculated values are shown in formula (3) and formula (4) at a certain time interval of 0 to *T*.

$$ARV = \frac{1}{T}\int_0^T |x(t)|dt \tag{3}$$

$$RMS = \sqrt{\frac{1}{T}\int_0^T x^2(t)dt} \tag{4}$$

The study shows that the amplitude characteristic value increases with the degree of fatigue during muscle fatigue, and ARV is more sensitive than RMS to identify the muscle fatigue state. Therefore, it is a common muscle fatigue identification algorithm that uses the surface signal amplitude of the EMG signal to identify muscle fatigue. In the algorithm of identifying the muscle fatigue in the frequency-domain eigenvalue of surface electromyography, because of the classical power spectrum estimation based on Fourier analysis, there is a frequency leakage problem caused by windowing. In the algorithm of identifying the muscle fatigue in the frequency-domain eigenvalue of surface electromyography, because of the classical power spectrum estimation based on Fourier analysis, there is a frequency leakage problem caused by windowing. Therefore, there are many problems, such as insufficient signal length, low-frequency resolution and significant variance when dealing with random signals; modern spectral estimation can solve these problems well. Therefore, an autoregressive (AR) model is introduced to analyze EMG signals and complete the muscle fatigue identification algorithm. The algorithm is mainly proposed by Merletti and Paiss et al. By studying the surface electromyography signal model, it points out that the first AR coefficient, first reflection coefficient, and normalized energy of model error decrease over time during muscle fatigue. Chang et al., by studying the four-order AR model, found that the square sum of the model autoregression coefficient has a linear relationship with the muscle force. When muscle fatigue occurs, the linear relationship decreases. Therefore, the autoregressive analysis of the surface EMG signal is also a common algorithm for identifying muscle fatigue.

3.2. Identification Strategy of Muscle Fatigue based on Amplitude and Frequency Combination

The muscle fatigue identification algorithm based on frequency domain eigenvalue (MPF) is more effective in the statistical analysis; at present, the slope of MPF migration generally defines the muscle fatigue index, but the accuracy rate of fatigue identification is high in individual research, and requirements for a signal-to-noise ratio of muscle electrical signal are high, when the weak displacement of the electromyography electrode appears, it is easy to produce the identification error. While the identification based on the amplitude eigenvalue (RKIS) of EMG signal is more accurate in fatigue identification of individual research, but it cannot get the quantitative value of muscle fatigue only by the amplitude eigenvalue of EMG. Therefore, there is a certain error rate in the identification algorithms of muscle fatigue, whether based on frequency domain eigenvalue or amplitude domain eigenvalue. This paper presents an amplitude and frequency domain combined eigenvalue muscle fatigue identification method; in this method, by using the advantages of amplitude-based eigenvalue algorithm and frequency domain eigenvalue algorithm, we can compensate for each other's shortcomings and get relatively high accuracy of identification of muscle fatigue. The specific algorithm flow diagram is shown in the figure; the following steps were used for the fatigue identification process: the rehabilitation exercise was started, while the corresponding muscles' time and EMG signals were recorded.

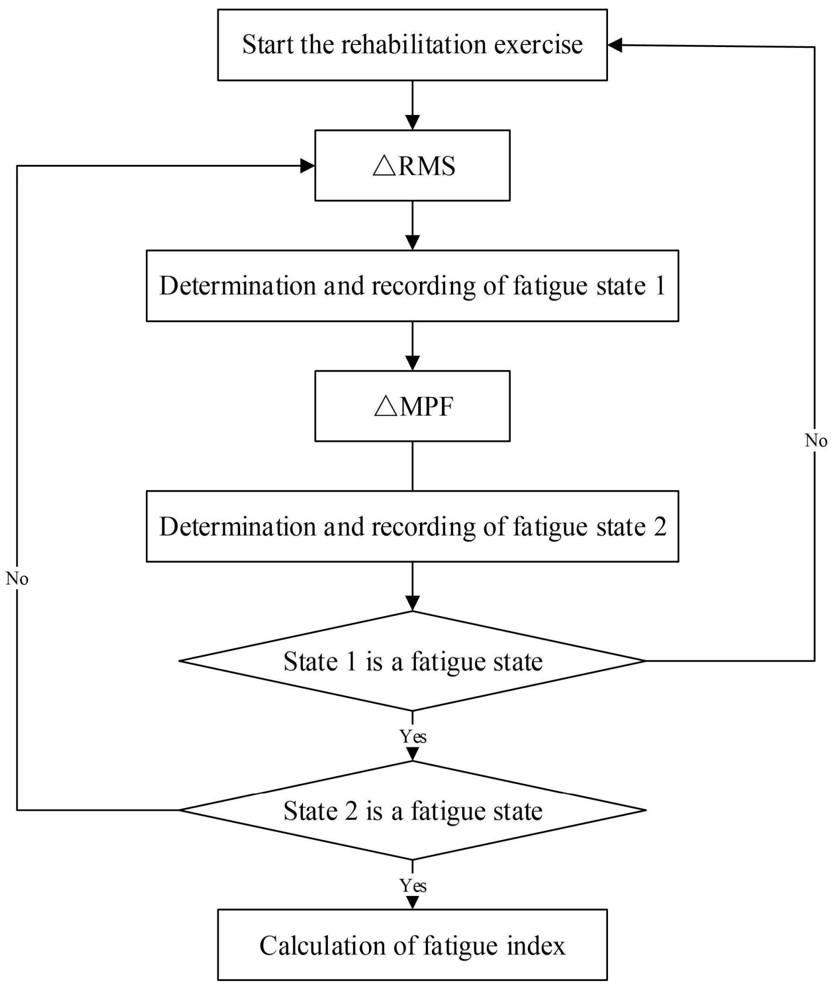

Figure 1. Joint identification of muscle fatigue amplitude and frequency domain

As shown in Figure 1, Delta *MPF* and delta *RMS* are, respectively, the variation of the eigenvalue parameter *MF* and the amplitude eigenvalue parameter *RMS* of the *EMG* signal. Amplitude and frequency domain combined identification strategy is shown in the figure,the following steps were used for the fatigue identification process, and the rehabilitation exercise was started, while the time and the *EMG* signals of the corresponding muscles were recorded, calculate and extract *EMG* signal frequency domain eigenvalue parameter *MPF* and amplitude eigenvalue parameter *RMS* in real time, preliminarily obtain the fatigue state 1 of muscle according to the variation of the amplitude eigenvalue parameters, if the identification result of state 1 is fatigue, the muscle fatigue state 2 is obtained by the change of the eigenvalue parameters in the frequency domain; If the identification result of state 2 is fatigue, the results of identification are muscle fatigue, at the same time; the muscle fatigue index is calculated by the variation slope of the frequency domain eigenvalue parameter *MPF*, if the state 2 is not fatigue, it shows that the state 1 may be wrong, and the muscle fatigue state needs to be regain; if the result of state 1 is not fatigue, and the identification result is not fatigue and can continue to carry on the rehabilitation exercise.

3.3. Wireless Transmission Mechanism of EMG Signal

The traditional surface electromyography signal acquisition system usually uses a serial port, *USB* interface or *PCI* interface to transmit the collected electromyography signal data to the host computer.

These wired transmission modes cause the electromyography signal acquisition system to be inconvenient to carry and the handheld design cannot be realized.

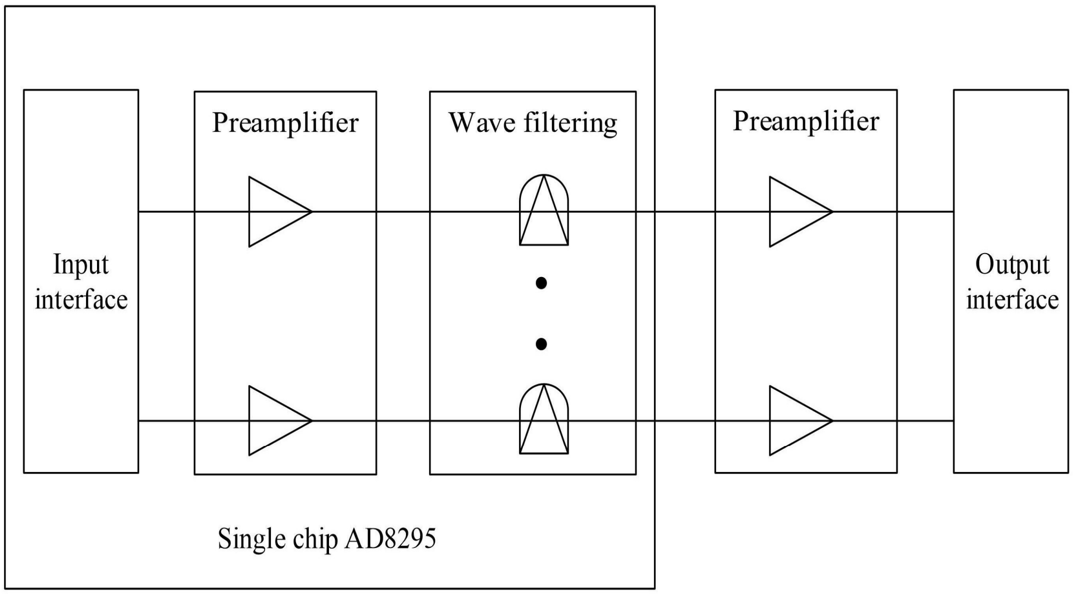

Figure 2. Schematic diagram of data signal transmission

The handheld electromyography acquisition system designed in this paper uses wireless communication to complete the transmission between the *EMG* signal data and the upper computer, such as Figure 2. Since the design requires the ability to collect four muscle channel signals simultaneously, a specific wireless transmission rate of *EMG* signals is needed. The effective frequency of the *EMG* signal is almost 300*Hz*. Meanwhile, the *ADC* module with 12-bit accuracy is adopted in the design; therefore, assuming that the sampling frequency of each channel is 2.5*Hz* and the four channels are sampling simultaneously, the concurrent rate of the electromyogram data is *P*, as the formula (5) shows.

$$P = 4*2.5K*12bit \tag{5}$$

The *P* value is about 120*Kbps*, so the wireless transmission rate in the system is at least 120*Kbps*. In addition, considering the expansion of channel number and system redundancy in the *EMG* signal acquisition system, the wireless transmission speed of the handheld *EMG* acquisition system should be no less than 300*Kbps*, which can better meet the requirements.

4. Result Analysis and Discussion

4.1. Effectiveness Test of Muscle Fatigue Identification Algorithm

To verify the effectiveness of the muscle fatigue identification strategy based on the combination of amplitude domain and frequency domain, a group of comparative experiments have been set up in this section. The experiment is mainly used to compare the algorithms that rely only on amplitude eigenvalues or frequency domain eigenvalues to carry out muscle fatigue, thus proving the effectiveness of the combined identification strategy. The handheld *EMG* signal acquisition system designed in this paper is used as the signal acquisition device for the experiment. The experimental muscle is a peptide two-head muscle. The experimental strategy is to collect myoelectric signals before and after muscle fatigue and save them as text files; then, we use Matlab programming to read, analyze and acquire the amplitude and frequency domain eigenvalues of *EMG* signals before and after fatigue.

Finally, the three identification algorithms were used to identify the muscle fatigue state, and the identification accuracy was compared. The specific muscle fatigue process is as follows: first, the initial position of the weightlifting arm is set up, and the characteristic value of the electromyography signal is recorded. The volunteers in the experimental group kept lifting the dumbbell 6*kg* uniformly and repeatedly and recorded the expected value of the electromyography signal when the arm could not be raised again and felt tired. The 5 volunteers repeated the fatigue process and recorded the eigenvalues of electromyography signals before and after fatigue, such as the following:

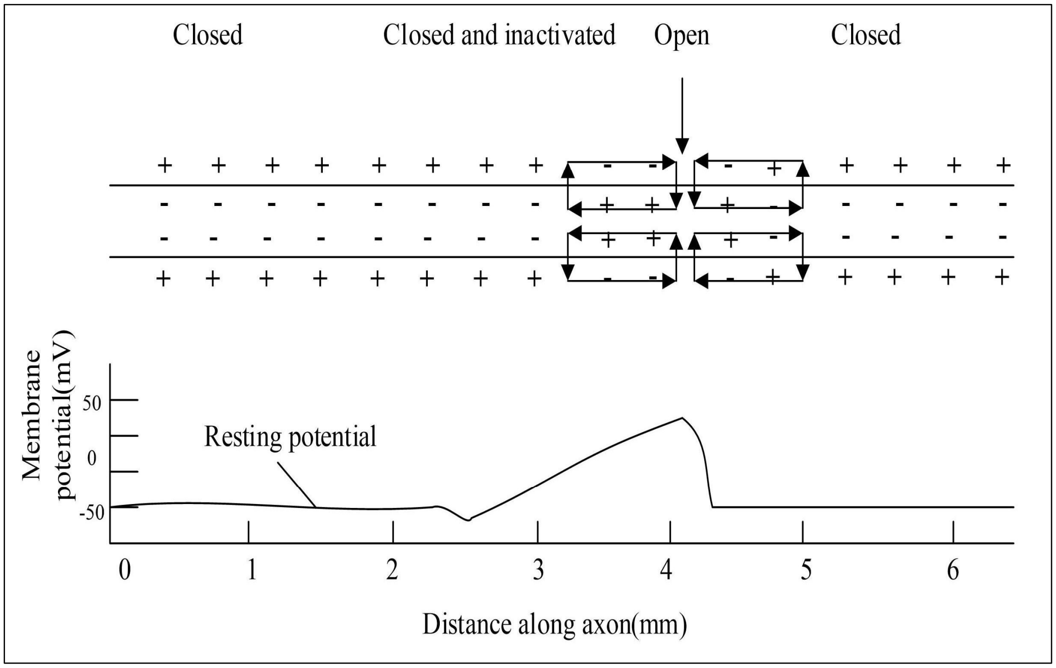

Figure 3. Principle of *EMP* generation

Experiments were conducted on several volunteers, and then three different muscle fatigue identification algorithms were carried out. The results are shown in Table 1 below.

Name parameter	Front	After	Front	After	Front	After	Front	After	algorithm 1	algorithm 2	algorithm 3
	IEMG		RMS		MPF		MF				
Volunteer 1	0.349	0.674	0.518	1.065	230.2	210.7	80.4	86.480	Y	Y	Y
Volunteer 2	0.403	0.727	0.621	1.119	182.8	202.4	79.0	81.425	Y	N	Y
Volunteer 3	0.349	0,661	0.543	1.025	209.5	206.3	86.9	84,178	Y	Y	Y
Volunteer 4	0.209	0.377	0.293	0.619	205.7	197.8	95.5	89.769	Y	Y	Y
Volunteer 5	0.419	0.328	0.616	0.662	230.9	227.3	73.0	100.02	N	Y	Y

Table 1. Identification Algorithm Results

In the table, the characteristics of the volunteers before and after the muscle fatigue were shown respectively. Algorithm 1 uses the *EMG* amplitude eigenvalue identification algorithm, algorithm 2 uses the *EMG* frequency domain eigenvalue identification algorithm, and algorithm 3 uses the amplitude and frequency domain eigenvalue combined identification algorithm. *Y* indicates that the identification is correct, and N indicates that the identification is wrong. As we can see from the table, the value of the integrated electromyography of the volunteer five is reduced, which causes the identification error of algorithm 1. The average power frequency of volunteer 2 is increased, which is inconsistent with the theoretical results, resulting in the identification error of algorithm 2, and algorithm three can get the correct identification results in thesecases. It can be seen that the muscle fatigue identification strategy based on the amplitude and frequency combined characteristic values is effective.

4.2. Application Test of Fatigue Identification in Rehabilitation Training of Lower Extremity

The strategy of combined identification of muscle fatigue has been proved effective in the last section. This section tests the application of muscle fatigue combined identification strategy in lower limb rehabilitation. The test was divided into two steps: the offline verification of the fatigue state of the individual muscles during the rehabilitation of the lower limbs and the test of the muscle fatigue identification system during the rehabilitation of the lower limbs. In the first test step, a handheld electromyography signal acquisition system monitors the *EMG* signals of single muscles of the lower extremities. The data storage function is used to carry out offline analysis of the collected data on the *PC* machine get the amplitude eigenvalues and the frequency domain eigenvalues, and make preliminary fatigue verification.

In the rehabilitation training experiment, firstly, monitor the *EMG* signals of the muscles to be trained the AT muscles after a certain time interval of rehabilitation exercise. The amplitude and spectrum characteristics of the muscle electrical signal are shown in Figure 4 and Figure 5; by comparing the amplitude changes of signals before and after rehabilitation exercise, the amplitude of *EMG* increases significantly after rehabilitation exercise, and by comparing the average power frequency (*MPF*) of signals before and after exercise, the trend of *MPF* decreases, which accords with the basic theory of muscle fatigue.

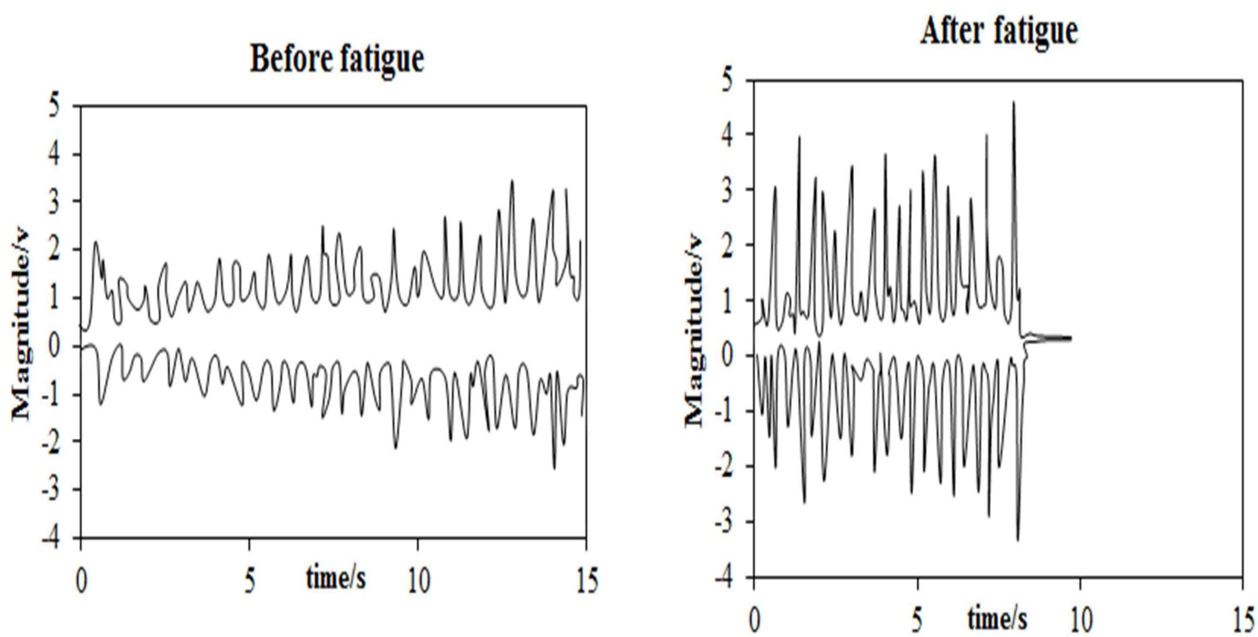

Figure 4. Amplitude of muscle rehabilitation before and after exercise

The second step is to combine the muscle fatigue identification function of the hand-held electromyography signal acquisition system and the multi-degree of freedom rehabilitation training robot system and further accomplish the application test of fatigue identification in rehabilitation training. In this step, we first need to perform rehabilitation exercises for lower limbs; in the process of rehabilitation exercise, we use a hand-held electromyography signal acquisition system to synchronously acquire the *EMG* signals of all the muscles in the lower extremities. At the same time, the muscle fatigue identification function of the handheld electromyography signal acquisition system was used to observe the state of muscle fatigue in real-time. The experimental results show that after a period of rehabilitation training, the amplitude of the *EMG* amplitude of the muscle increases, and the median frequency decreases, which is consistent with reality. Therefore, the muscle fatigue identification function of the handheld electromyography signal acquisition system is effective.

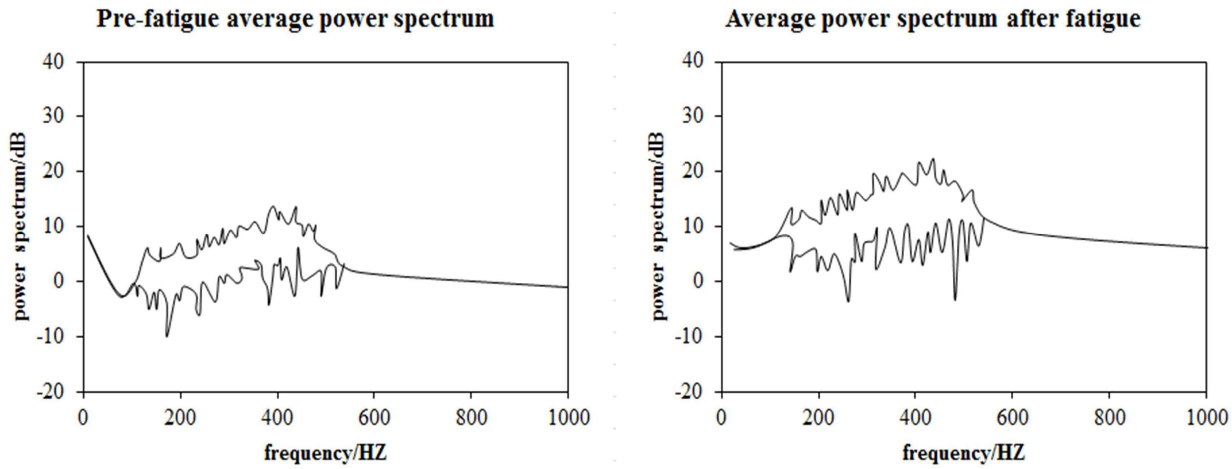

Figure 5. Spectrum characteristics before and after muscle rehabilitation exercise

5 Conclusion

When the human muscle contracts, it produces an electrical signal. Because the signal is closely related to the muscle state, to learn the human muscle function is important to the extraction and study of the surface EMG signal. Therefore, this paper studies the anatomical principles of the muscle movement process based on the data mining algorithm. This paper first introduces the concept of muscle fatigue and the causes of muscle fatigue and describes the application process of muscle fatigue identification in the lower limb rehabilitation robot project. Then, after analyzing the commonly used EMG-based muscle fatigue identification algorithms, a fatigue identification algorithm based on amplitude and frequency domain eigenvalues is proposed. Finally, we selected five eligible volunteers were studied; through the experiment, the accuracy of the new algorithm and the traditional algorithm in the identification of muscle fatigue were compared, indicating the effectiveness of the new algorithm but also completing the identification algorithm in the application of muscle fatigue rehabilitation on the platform of multiple degrees of freedom

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