IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received March 26, 2020, accepted April 5, 2020, date of publication April 9, 2020, date of current version April 30, 2020.

Digital Object Identifier 10.1109/ACCESS.2020.2986800

Intelligent Medical Rehabilitation Training Instrument Based on Movement Coordination

YANFENG SU[1] **AND LIANG SU**[2]

[1]Institute of Physical Education, Xinxiang Medical University, Xinxiang 453003, China
[2]Department of Sports, Henan University of Finance and Economics, Zhengzhou 450000, China

Corresponding author: Yanfeng Su (081029@xxmu.edu.cn)

ABSTRACT This study designed an intelligent medical rehabilitation training system based on motion coordination, which is mainly aimed at patients with balance functions and motion coordination disorders. The system consists of training beds, pedal components, manual control devices, main control computers and corresponding training software. Biofeedback control through the brain is combining physical and psychological treatment of patients, artificial intelligence judgment and adjustment, analysis and evaluation of biofeedback. The rehabilitation device adopts the structure mode of the upper and lower computers. The lower computers take DSP as the core and cooperate to complete the functions of weak EMG signal detection and feedback, stimulation signal output and data transmission. The weak electrical signals remaining in the limbs of stroke patients are processed by the host to form a closed-loop biological feedback electrical stimulation system. According to the intermittent distraction joint method and aerobic training method, an intelligent medical rehabilitation device is designed, including a rehabilitation device for training the rotation function of the wrist and a rehabilitation device for training the flexion and extension function of the wrist. In order to meet the rehabilitation needs of the spasm and recovery periods, both wrist rehabilitation devices have three rehabilitation modes, namely passive rehabilitation mode, assisted rehabilitation mode and damping rehabilitation mode. The intelligent medical rehabilitation training instrument system can realize the combination of patient adjustment force and hand control training to achieve the matching of lower limb, lower limb movements and visual information, so as to promote the patient's balance function and coordinate rehabilitation training. The system sets visual and auditory feedback, and increases the interest of training by adjusting the training speed and training difficulty, which has important clinical application value.

INDEX TERMS Rehabilitation training, rehabilitation apparatus, movement coordination, intelligent, rehabilitation model.

I. INTRODUCTION

Movement coordination is related to factors such as balance ability, ability to control upper and lower limbs, proprioception ability, visual perception ability, and auditory perception ability. For patients after stroke or head injury, balance dysfunction and lower limb motor dysfunction are the most common functional problems. At the same time, these patients often have motor coordination dysfunction related to these functional problems, which seriously affects the patient's rehabilitation and quality of life. Therefore, it is of great significance to carry out effective exercise coordination training at the same time as patient balance training.

The associate editor coordinating the review of this manuscript and approving it for publication was Naveen Chilamkurti.

Scholars at home and abroad have reported on the training and testing of lower extremity balance. The lower extremity balance ability of stroke patients has been trained and achieved good results [1]–[4]. AMES.MEGNA and others have performed static balance training on brain trauma patients, and tested and evaluated them. Their lower limb control ability has been greatly improved. At present, the balance function training products used at home and abroad also use MTD (Mettles-Toledo International LTD) German MTD balance training device, Australia Ultracar [5]–[9]. Company's balance training tester, Japan's Anim company's human body balance training center of gravity detector, American Biode, medical system company's Biode, balance test training system, etc., but these rehabilitation training instruments only have balance training test The function instrument has a single function and its use range is greatly limited. Most instruments are only suitable for patients with strong motion coordination ability. For patients with poor lower limb mobility, multifunctional training cannot be performed. Biofeedback technology has been used as an adjuvant treatment method for the treatment of post-stroke hemiplegia and the rehabilitation of neuromuscular function for more than 40 years. With the advancement of science and technology, biofeedback technology treatment measures have been greatly improved and gradually become stroke rehabilitation [10]–[14]. One of the comprehensive measures is for effective treatment [15]–[18]. Because biofeedback technology has the advantages of no damage, no pain, no drug side effects, simple methods, and obvious reduction of the huge economic and social burden caused by disease prevention, it has been valued by many countries. The rapid development of cognitive neurobiology [19], [20] has obviously promoted the research and understanding of the biofeedback technology mechanism, significantly improved the healing effect of the biofeedback technology for stroke, and provided new ideas and benefits for the treatment of stroke. prospect. Biofeedback therapy [21]–[25] The gyro mouse collects the trajectory information of the robot movement in the rehabilitation exercise of the upper limbs and transmits it to the virtual scene in the computer. The virtual reality system receives the position information of the patient in the rehabilitation movement and controls the pinball rehabilitation scene. The movement of the baffle and the rotation of the tank turret in the tank battle scene will display the processed information as virtual images and virtual sounds in the virtual reality system on the computer and feedback to the patient. The patient can directly interact with the virtual environment and understand himself Rehabilitation training. A total of rehabilitation exercises that can be achieved by the upper limb rehabilitation robot of exercise learning therapy [26]–[29] are: flat motion of the upper arm / forearm, forward flexion and extension of the upper arm / forearm, flat motion of the elbow, and internal rotation of the shoulder motion. Among these actions, the therapist can choose an appropriate exercise and virtual training scene, and choose the appropriate rehabilitation difficulty level of the virtual reality scene in advance according to the patient's upper limb hemiplegia. The patient is immersed in the virtual scene selected by the physician while receiving rehabilitation treatment. To achieve the purpose of interaction between patients and patients in the virtual environment, improve the subjective initiative and relaxed mood of patients' active rehabilitation. Rehabilitation equipment has begun to show the development trend from hospital rehabilitation equipment to home rehabilitation equipment [30], [31]. Market research organization predicts that by 2011, the output value of semiconductors for medical electronics will exceed 4 billion U.S. dollars. Among them, the household market has the fastest growth rate, with an average annual growth rate of 12%. Rehabilitation equipment is now one of the important components of this growth [32]–[35]. The general rehabilitation institutions adopt the traditional rehabilitation model [36], which mainly focuses on the artificial rehabilitation of physicians, and uses simple rehabilitation equipment to assist the treatment when necessary. There is no doubt that the traditional rehabilitation model has been difficult to meet the rehabilitation needs of patients, so the development of better and more intelligent rehabilitation equipment is imminent [37]–[39]. In order to change this hand-held rehabilitation training mode, improve the efficiency of rehabilitation training, and improve the effect of rehabilitation treatment, in recent years, a variety of rehabilitation robots have been successfully made [40]–[42], but unfortunately these rehabilitation robots lack clinical, and Has not reached the level of large-scale use. Therefore, the combination of clinical use and design of rehabilitation equipment is the focus of current research. The development of intelligent rehabilitation equipment will involve many disciplines, such as mechanical, electrical, medical, computer, etc. Therefore, close cooperation in various fields and disciplines will have the opportunity to design relatively comprehensive rehabilitation equipment [43]–[46]. Various institutions and rehabilitation institutions need to cooperate closely in order to design high-quality intelligent medical rehabilitation instruments. In terms of the development of rehabilitation equipment, a variety of rehabilitation equipment has been put into use abroad [47]–[49], and many scientific research institutions have begun to develop intelligent medical rehabilitation training equipment with better treatment effects, but most of the intelligent rehabilitation equipment are not enough The patient's autonomous movement is designed as the core [50], [51]. Rehabilitation equipment combined with rehabilitation therapy is based on medical treatment, and the design of rehabilitation equipment is a substitute for rehabilitation methods for doctors [52]. Therefore, this article will propose a complete set of rehabilitation methods based on the pathological mechanism and pathological characteristics of different rehabilitation periods, and then integrate the rehabilitation method into the development of rehabilitation equipment, and finally design an intelligent medical rehabilitation training instrument based on motion coordination.

This study designed a set of intelligent balance rehabilitation training system based on motion coordination. The system mainly consists of training bed, pedal assembly and manual control device. The system can realize that the patient can adjust the force in real time while maintaining the standing posture, combined with hand control training, and complete feedback to the patient to complete various games, so that the patient can reasonably train the patient's coordination ability while training balance, and realize upper limb, Leg movements were matched with visual information. The rehabilitation therapy instrument adopts the structure mode of the upper and lower computers. The lower computers take DSP as the core and cooperate to complete the functions of weak EMG signal detection and feedback, stimulation signal output and data transmission. The weak electrical signals remaining in the limbs of patients with stroke can be obtained, and after processing by the host, a closed-loop biological feedback electrical stimulation system is formed.

Through the computer's artificial intelligence scheduling of patients, rehabilitation training treatment programs, analysis and evaluation is of the effectiveness of rehabilitation training, the completion of the development of bio-feedback-based intelligent nerve rehabilitation therapy instrument, to achieve the purpose of promoting the simultaneous training of patients' balance function and coordination function.

II. DESIGN OF QUANTITATIVE REHABILITATION TRAINING APPARATUS BASED ON DATA ANALYSIS OF MOVEMENT COORDINATION

In order to adapt to patients with balance dysfunction such as stroke, Kinson's disease, traumatic brain injury, and other spinal cord injuries of various severity, the system design uses training beds. The patient can be trained while lying on the bed, and the bed design can be rotated (0-90) to achieve various degrees of weight loss for the patient. The parameter settings are based on the basic characteristics and needs of the human body. To meet the needs of clinical and medical research Technical parameters meet: Left and right lower limb plantar pressure centers (cop. Distance range: 270mm-330mm; Patient weight loss range (0-100%).

A. REHABILITATION TRAINING EQUIPMENT DESIGN

The mechanical design of the balance rehabilitation training device is mainly composed of a training bed, a pedal assembly, a manual operation console, and the like. The training bed is composed of a bed base, a bed frame and a bed board. The bed frame is installed on the bed base and is rotatably connected to the bed base. A pedal assembly is connected to the front end of the bed frame, and left and right foot pressure sensors are provided on the pedal assembly Device, a manual control device is arranged on one side of the bed frame. The manual control device has a folding and retracting function, which is realized by turning the crossbar and the like, which is convenient for patients to get out of bed. At the same time, the manual device has functions of adjusting left, right, front, back, and up and down positions to suit various patients with different heights and arm lengths.

The control system of the balance rehabilitation training device is controlled by human-machine dialogue, manual control detection, motor drive control and plantar pressure control detection and other functions as shown in Figure 1:

As shown in Figure 1, the control of the entire bed and the collection of signals are based on computer control. The sensor signals are collected through the foot pressure sensor of the foot device, and the signals are amplified, filtered, sampled and held, and entered into the data acquisition card. The control center processes the signals, so that the force levels of the left and right feet are displayed in real time, and the patient adjusts the force of the limbs to control the position of the center of gravity of the person and realize virtual training. The manual control device includes a manual training operation handle and two buttons and related interface circuits. The patient pushes the training operation handle to the relevant weapon selection gear, completes the training weapon type selection, performs weapon launch operations according to the training operation handle, and generates related control signals Send to the host computer in real time through the USB port to participate in the training process. Two buttons complete the training start and end of training respectively, which is convenient for patient control. Emergency stop, limit and other switching signals directly pass through the acquisition card, which is convenient for the bed to deal with emergency situations such as emergency stop, overshoot and so on. The data evaluation results are displayed on a dual display screen, where the main display screen is placed on the operating table for use by medical staff; the patient display screen is located in front of the patient during training and displays the training process, training participation process, and training results. Patient mastered. The computer integrates a two-axis motion control module, and the linear stepping motor in the angle adjustment mechanism of the bed plate is driven by the motor drive control module. The bedplate is rotated by synchronously controlling the stepper motor to make it forward and reverse, so as to reach the bedplate. -The effect of 90-degree arbitrary tilt realizes the tilt of the body to reduce weight.

B. MOVEMENT COORDINATION MECHANISM

Movement coordination refers to a properly coordinated relationship between various elements. It is a very common phenomenon existing in human society and nature. There is a synergy between various elements in various systems for a common goal [53]. Coordination of movement is a coordination phenomenon existing in each element of a complex biological system during movement. Propose motion coordination as a subject concept or research category. They believe that the core issue of motor coordination is how the central nervous system coordinates the activities of various elements of the motor organ system, so that the body realizes a certain movement, and it is very easy for the elements of the organism's motor organ system to move in a specific way. The system is composed of very large elements with one or more independent motion attributes, including multiple rigid bodies, multiple joints, and a large number of muscles and muscle fibers. The number of degrees of freedom it contains far exceeds the amount required to determine the movement. Following this, kinematic coordination is defined as the process of controlling the redundant degrees of freedom of the organs and organs of a living organism, transforming it into a controllable system [54].

In the study of motion coordination using dynamic system theory, the vector analysis method and continuous relative phase method are often used to calculate the relative phase angle [55]. The advantage of this type of quantization method is that it can clearly express the relationship between the degrees of freedom of movement, and the research results are easy to analyze and interpret. However, they are only suitable for quantifying the relationship between two degrees of freedom of movement, and cannot show the overall relationship between multiple degrees of freedom of movement.

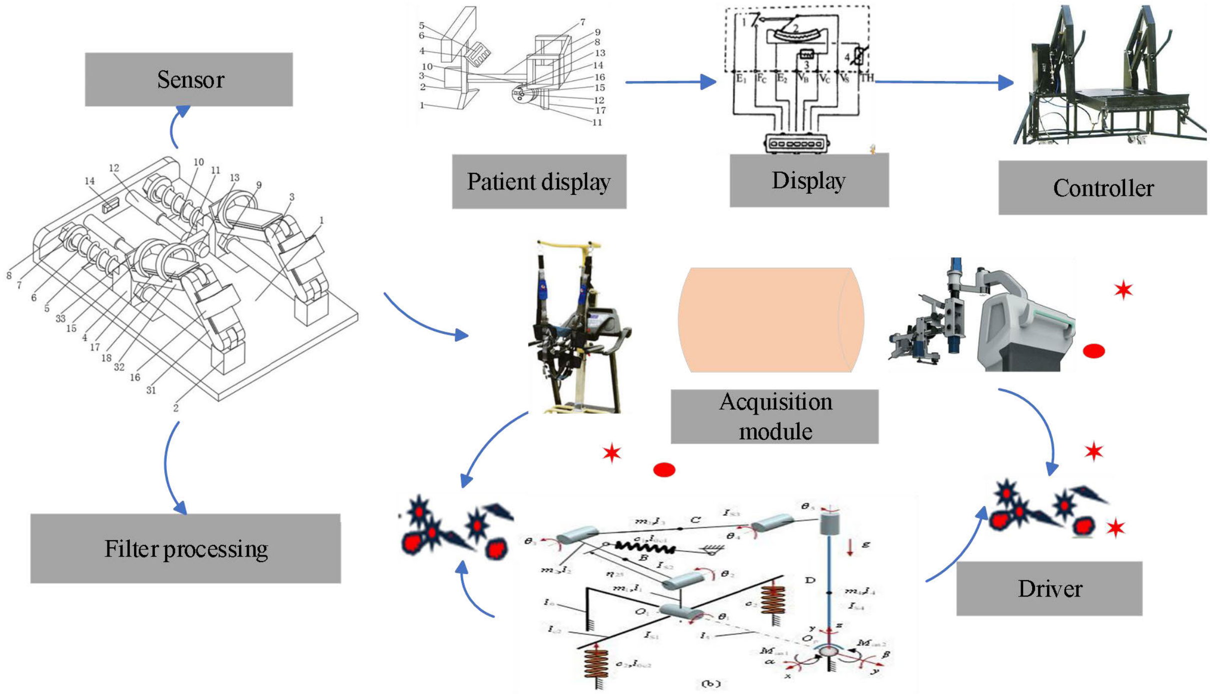

FIGURE 1. Control system of balance rehabilitation training device flowchart.

After all, the degrees of freedom of movement are in mutual connection.

The matrix factorization method is suitable for quantifying the relationship between multiple degrees of freedom, and it can show a low-dimensional, multi-degree-of-freedom aggregation, independent structure, which reflects the basic characteristics of motion coordination. Commonly used matrix factorization methods for quantifying motion coordination among multiple degrees of freedom include principal component analysis, factor analysis, non-negative matrix factorization, and independent component analysis. These methods have similar theoretical models.

$$x = \sum_{i=1}^{n} c_i w_i + \varepsilon \tag{1}$$

Among them, x is the original variable vector; c_i is the main component score; w_i is the weight coefficient vector; ε is the random error vector.

In these matrix factorization methods, the degree of freedom of movement is regarded as a variable; the vector of principal component weight coefficients is regarded as a motion coordination element, which represents the degree of coupling of each degree of freedom of movement; Represents the degree of participation of various sports coordinators. In some studies, the score of the principal component is also considered as a common motion pattern, which reflects the movement instructions output by the central nervous system; the weight coefficient vector of the principal component is regarded as a set variable, which reflects the basic elements of the received movement instruction.

In practice, some motion freedom variables are all positive values (for example, EMG, synthetic linear displacement and speed, etc.). However, it is difficult to explain the score of the principal component as a negative independent variable value after dimensionality reduction. In addition, due to:

$$M = C_1 \times W_1 + \ldots C_n \times W_n \tag{2}$$

The score of the principal component (C_i) is regarded as the relative contribution of each motion coordinator (W_n) to the original variable vector (M), which is called the activity coefficient of each motion coordinator. It can be seen from this that the higher the absolute value of the principal component score, the greater the influence of its corresponding motion coordination element, which means that its activity level is also higher. However, in the theoretical explanation, the speed variable is normalized (using the mean plus or minus the standard deviation) as an example. A higher positive speed principal component score means a higher speed value at this time, but a negative speed principal component score. The higher the absolute value is, the smaller the speed value is at this moment, and the latter matches the concept of the motion coordination element activity coefficient. In addition, when the non-negative matrix factorization method is used, the values in the principal component matrix and the weight coefficient matrix are both positive values, which makes the inverse coordination between the degrees of freedom of movement small and can be quantified. However, this is a common, more important ways to coordinate sports.

C. MOTION COORDINATION FUNCTION QUANTITATIVE METHOD

The time series method uses the ratio of the difference between the time points of the respective important features in the muscle-skeletal system DOF time series to the total time to determine the phase angle. Technical signs point in time and so on. Among them, the phase difference angle and the standard deviation between individuals are used as a mode of motion coordination and its variability. For example, when quantifying the coordinated movements of flexion and extension of the supporting leg and knee in the subtalar joint during the running support phase, the ratio of the relative time to the support time when the knee is flexed to the maximum and when the subtalar valgus is maximized To determine their phase difference angle. The specific calculation formula is as follows:

$$\varphi = \frac{t_1 - t_2}{T} \times 360^\circ \tag{3}$$

In this formula, φ is the relative phase angle, t_1 refers to the moment of maximum knee flexion, and t_2 refers to the moment of maxillary valgus joint; T is the total time of support. The phase difference angle is 0 ± 360. The range varies when the phase difference angle is 0 ± 30. At this time, the coordination of motion between the limbs is called in-phase coordination, and the other is out-of-phase coordination.

Functional principal component analysis is a method of functional data analysis, which is to reduce the dimension of the functional variable matrix. Among them, functional data refers to data presented in the form of functions, which has the characteristic that the dependent variable changes with the independent variable in a specific form. The theoretical model of functional principal component analysis is:

$$X_i(t) = \sum_{k=1}^{K} c_{ik}\varepsilon_k(t) + \varepsilon_i \tag{4}$$

$X_i(t)$ is the i-th function variable; c_{ik} is the score value of the i-th function variable function variable under the k principal component; $\varepsilon_k(t)$ is the weight function under the k principal component; ε_i is the random error.

In functional data analysis, the observed value of the sample is a small discrete value in traditional statistical methods, but a numerical state with a process. In this way, in the functional principal component analysis, the data processing is performed by using the traditional vector as the sheep position and the function as the sheep position. Its characteristics are: 1) This method treats the observed values as a whole with continuous characteristics, which makes the information in the data analysis richer. 2) In this method, the internal structure of the observations rather than the external form is used as the basic sheep position, which is conducive to revealing deeper information. 3) Constraints on the prerequisites for principal component analysis of functional data are small, and the results obtained are easy to interpret professionally.

The calculation of the principal component function is mainly to solve its weight coefficient function $\varepsilon(t)$. According to some prerequisites, after deriving by algebraic method, the principal component weight coefficient function is the characteristic function of the original function variable variance matrix characteristic equation. The specific equation is as follows:

$$\int v(s,t)\varepsilon(t)d_t = \lambda\varepsilon(s) \tag{5}$$

Among them, v(s, t) is the variance function of the original function variable, the variance matrix with large principal components, and $\varepsilon(t)$ is the feature function. By solving the characteristic equation of the matrix, the characteristic value and characteristic function corresponding to each principal component can be calculated. The weighted weight coefficient function of the principal component is a characteristic function that takes the characteristic value of the principal component as a weight. Specific calculation formula:

$$w(t) = \varepsilon(t) \times \sqrt{\lambda} \tag{6}$$

Finally, based on the weight coefficients, the score of each original function variable $[X_i(t)]$ in each principal component can be calculated. The specific calculation formula is as follows:

$$c_i = \int \varepsilon(t)x_i(t)d_t \tag{7}$$

In functional principal component analysis methods, the main statistics include eigenvalues, contribution rates, weight coefficient functions, and scores for principal components. Among them, the weight coefficient function and the score of the principal component are two important statistical indicators of functional principal component analysis. They can show some important characteristics of the analyzed object, such as the type of curve or important changes. The weight coefficient function reflects the degree of influence of the principal components on the function variables, and the score of the principal components indicates the degree of consistency between the original function variables and the principal components.

III. GENERAL RESEARCH OF INTELLIGENT REHABILITATION THERAPY APPARATUS

The intelligent rehabilitation therapy instrument can very sensitively detect the extremely weak EMG signal sent by the paralyzed patient through the detection electrode. After denoising and amplifying the signal, the instrument will compare it with the automatically set threshold value. When the signal amplitude reaches or exceeds the threshold, the instrument emits electrical stimulation to the paralyzed muscle, causing the paralyzed muscle to have a functional contraction. After the stimulation is over, the instrument will collect and detect the patient's EMG signal again, and repeat the above treatment process. If the patient's spontaneous myoelectricity level increases, the instrument will increase the

TABLE 1. List of technical indicators.

EMG amplifier section	Constant current source stimulator
Amplifier gain: 5000-50000 times Common mode rejection ratio: CMRR> 100dB Bandwidth: 40Hz-2000Hz Input signal range: 2uv-200uV Output signal range: 0-5uV A / D conversion accuracy: 10 bits	Waveform: square wave, triangle wave, exponential wave Frequency: l0Hz-100Hz Pulse width: 100us--450us Stimulation interval time: 0.5s-10s Questions about continuous stimulation: lmin- 60min Maximum stimulation current: 3mA / cm^2

TABLE 2. Gain allocation table

	Preamp circuit	High-pass filter circuit	Gain selection circuit	Intermediate stage amplifier circuit	Low-pass filter circuit	50Hz Notch Circuit	Last stage amplifier circuit
Gain distribution	10	2	1 3 6 10	5	2.9	3	12

threshold accordingly to achieve the purpose of gradually recovering muscle function.

A. FUNCTIONS AND INDICATORS OF INTELLIGENT REHABILITATION THERAPY INSTRUMENT

1) Real-time acquisition and storage of EMG signals.

2)Completing the computer artificial intelligence judgment and adjustment of the threshold of stimulation stimulus.

3)Control the multi-parameter electrical stimulation waveform output.

4)Use the serial port to communicate with the host computer.

List of technical indicators as shown in table 1.

According to the system to achieve the main functions and technical indicators, this rehabilitation instrument uses the upper and lower position structure mode, the lower position uses DSP and CPLD as the core to build a hardware system, and cooperates to complete the weak EMG signal detection and feedback, stimulation signal output and data transmission functions. The block diagram of the system structure is shown in Figure 2, which is mainly composed of four parts:

As shown in Figure 2, completes the amplification and filtering of the electromyographic signals detected by the electrodes. DSP-based data acquisition and transmission controller: collects and processes the amplified and filtered myoelectric signals, and implements manual scheduling according to the set threshold, controls the stimulator gear selection port to achieve stimulus output, and cooperates with the upper Machine communication. Constant current source stimulator based on multi-parameter complex stimulation waveform based on the combination of DSP and CPLD: to realize the output of stimulation pulse wave with adjustable stimulation waveform, stimulation frequency, stimulation pulse width, stimulation amplitude and duty cycle. Software design of host computer system: Realize database management of medical record files and dynamic display of stimulation waveforms and myoelectric waveforms.

The preamplifier circuit uses the AD620 precision instrumentation amplifier produced by AD. According to the AD620 gain relationship:

$$G = \frac{49.4K\Omega}{R_G} + 1 \tag{8}$$

In this design, G = 10, and CMRR = 100dB, $R_G = 5.5K\Omega$ at this time. This not only ensures that the pre-stage gain is not too large, but also provides sufficient common mode rejection ratio. The differential input resistance of the AD620 can reach $10G\Omega$. According to the design specifications, a $20M\Omega$ resistor is connected in parallel to the positive and negative input terminals of the AD620, so that the input impedance of this EMG amplifier is about $20M\Omega$.

$$\begin{aligned} A_{vp} &= 1 + \frac{R_f}{R_1} \\ A(S) &= \frac{(SCR)^2}{1 + (3 - A_{vp})SCR + (SCR)^2} \\ Q &= \frac{1}{3 - A_{vp}} \\ f_0 &= \frac{1}{2\tau RC} \\ A_v &= \frac{A_{vp}}{1 - \left(\frac{f_0}{f}\right)^2 + \frac{1}{Q}\left(\frac{f_0}{f}\right)} \end{aligned} \tag{9}$$

B. DESIGN OF INTERMEDIATE STAGE AMPLIFIER CIRCUIT AND FINAL STAGE AMPLIFIER CIRCUIT

After pre-amplification, band-pass filtering, and gain-selection amplifier circuits, the voltage still fails to meet the technical specifications. Therefore, two stages of intermediate stage amplification and final stage amplification have been added to the design to ensure the amplitude of the output signal.. The circuits all use the same comparison operation circuit.

The intermediate stage amplifier circuit and the front stage use a capacitor combination, and the gain of this stage is set to 5.

$$\begin{aligned} f_0 &= \frac{1}{2\tau RC} \leq 40Hz \\ R_{15} &= 47K\Omega, \quad R_{16} = 235K\Omega \\ R_{29} &= 51K\Omega \end{aligned} \tag{10}$$

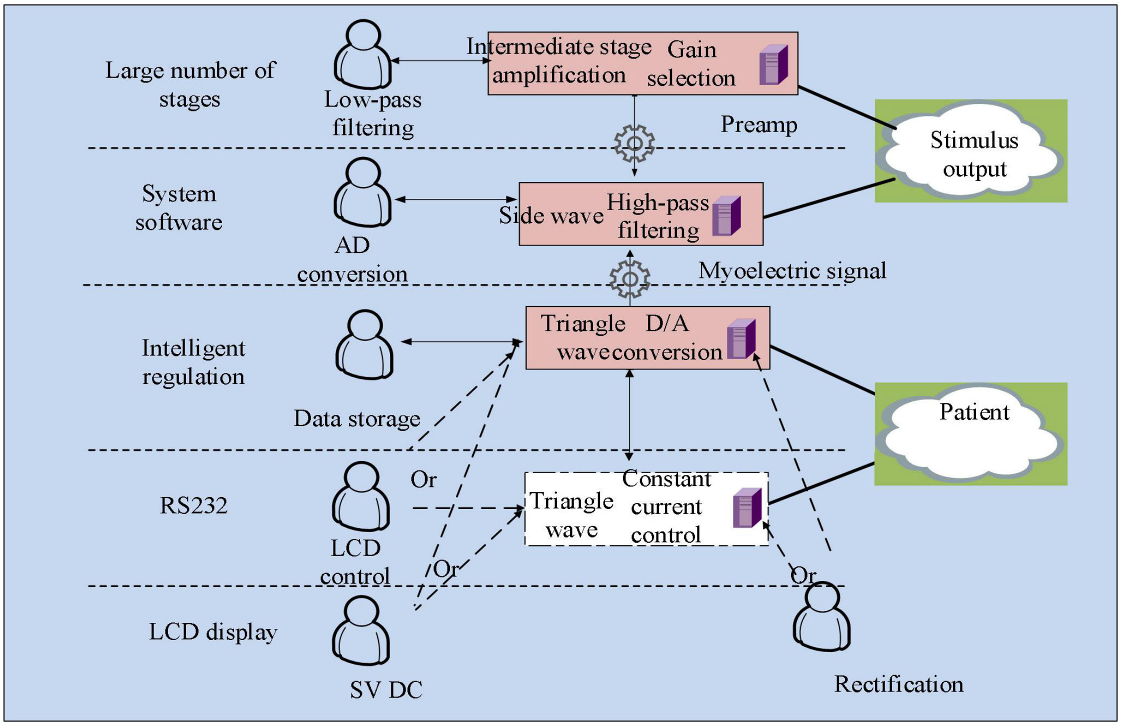

FIGURE 2. System structure block diagram of intelligent rehabilitation therapy instrument.

From Table 2, the total gain of the myoelectric amplifier circuit can be obtained:

$$A = \begin{cases} 10 \times 2 \times 1 \times 2.5 \times 2 \times 10 = 5000 \\ 10 \times 2 \times 2 \times 2.5 \times 2 \times 10 = 10000 \\ 10 \times 2 \times 5 \times 2.5 \times 2 \times 10 = 25000 \\ 10 \times 2 \times 10 \times 2.5 \times 2 \times 10 = 50000 \end{cases} \quad (11)$$

DSP like other microprocessor, requires a crystal oscillator to provide a clock in order to work. The TMS320LF2407 chip provides two clock access methods: single-ended and double-ended. The single-ended input method is mainly used for integrated crystal input; the double-ended input method uses the internal oscillation circuit of the DSP chip and an external crystal to generate a clock signal. The integrated crystal oscillator encapsulates the oscillation circuit and crystal, so you only need to add power to get a stable clock signal at the output.

The internal instruction cycle of the DSP is high, and the main frequency of the external crystal is insufficient. The phase-locked loop (PLL) circuit can multiply the clock source frequency by a specific coefficient to obtain an internal CPU clock. The PLL multiplication factor is controlled by the DSP's 16-bit system control and status register (SCSR1) PLL clock pre-scale selection bit. These three pairs of inputs always select the PLL multiplication factor as shown in Table 3.

The main purpose of the interface circuit design is to display the parameters such as mode, timing time, waveform, waveform frequency (wave frequency), pulse width, pulse frequency (pulse frequency), amplitude, stimulus duration and interval time (intermittent) on the LCD screen (The parameter setting is shown in Table 4), and the three keys are used to control the display, to select parameters, and to confirm the gear position.

TABLE 3. PLL clock predetermined selection bits for system clock frequency selection.

CLKPS2	CLKPS1	CLKPS0	System clock frequency
0	0	0	4 x fin
0	0	0	3 x fin
0	1	1	1.43 x fin
0	1	1	2 x fin
1	0	1	0.9 x fin
1	1	0	0.86 x fin
1	1	1	0.77 x fin
1	0	0	0.6 x fin

The constant current source stimulator has up to 41 general-purpose, bidirectional digital I/O (GPIO) pins, most of which are basic functions and general I/O multiplexing pins. The digital I/O port module adopts a flexible method to control the functions of dedicated I/O and multiplexed I/O pins. All I/O and multiplexed pin functions can be controlled by nine 16-bit control registers. To set, these registers can be divided into two categories:

(1) "I/O port multiplexing control register: used to control the selection of I/O port as a basic function or general I/O pin function.

TABLE 4. List of parameter settings.

Waveform	Triangle wave	Exponential wave	Side wave	Sine wave
Pulse width	150	250	350	450
Amplitude	4/16	8/16	12/16	16/16
Pulse frequency	15	25	35	45
Wave frequency	0.2	0.4	0.6	0.8
timing	15	35	55	65
duration	4	6	8	10
Intervals	5	6	7	8

TABLE 5. Digital I/O control register address allocation.

Address	Storage register	Description
7090h	MCRA	I / O multiplexing control register A
7092h	MCRB	I / O Multiplexed Control Register B
7094h	MCRC	I / O multiplexing control register C
7098h	PADATDIR	I / O port A data and direction registers
709Ah	PBDATDIR	I / O port B data and direction registers
709Ch	PCDATDIR	I / O port C data and direction registers
709Eh	PDDATDIR	I / O port D data and direction register
7095h	PEDATDTR	I / O port E data and direction registers
7096h	PFDATDTR	I / O port F data and direction registers

(2) Data and direction control register R: When the I/O port is used as a general I/O pin function, the data and direction control register can control the data and the data direction to the bidirectional I/O pin. These registers are directly connected to the bidirectional I/O pins.

Table 5 is the register unit available for the digital I/O module. Together with other 240xA peripherals, these registers are memory mapped into the data space with addresses from 7090h to 709Fh. The bit reserved in the register unit is invalid. It is 0 when read. It has no effect on write.

C. SOFTWARE IMPLEMENTATION OF INTELLIGENT MEDICAL REHABILITATION TRAINING INSTRUMENT

Hand-foot coordination rehabilitation fun training software is a set of training software for landing and destroying aircraft. The function fun training module provides different levels of virtual reality training process. The training activity point design is based on the gravity center being set as an activity point, which is displayed on the picture of our fighter plane. The patient adjusts the force of both feet to make the image move in real time to achieve training participation. The hand action design is based on the training handle for weapon launch and weapon gear selection, increasing the flexibility and fun of fun training. The software function also has a training difficulty selection and a comprehensive assessment of the results. The difficulty is determined by the descending speed of the enemy aircraft and the generation speed and the weapon. The faster the descending speed and generation speed, the harder the training. The comprehensive evaluation of training results includes the health value of our aircraft, the number of enemy aircraft that have been shot down, and the player level. Among them, the player level consists of the score obtained and the life lost by our fighter, and then the training difficulty is automatically set to low, intermediate, and Advanced methods, gradually increase the difficulty, and gradually, to achieve the requirements of patients gradually rehabilitation training.

Coordination function of lower limb rehabilitation fun training method software is developed based on VC. The training implementation and evaluation process includes data acquisition and data storage processes. The hardware is based on the data acquisition device design. The acquisition device provides library functions. Based on the library functions, the acquisition device class is developed and all actions of the acquisition device are managed. The acquisition signal is set to single-ended, software timing sampling mode, the center of the screen (initial position) is taken when the left and right limbs are equally stressed, the acquisition data is temporarily saved to the memory buffer, and the acquisition is completed. In the directory, the above program explains that after the patient data file name and file save mark are given to the collection device class library, turn on the data collection device, set the voltage sampling range, configure the sampling channel, and correspond to the left and right lower limb pressure sensing device groups on the screen Display the information of our fighter aircraft, then record the training start time and set the sampling clock 1. Every 50ms, call the sampling module program, read all the sampling channel data and separate the sampling data to control the aircraft's up, down, left and right movement. Set the sampling clock 2 and read the USB port data every 50ms to get the handle operation information. The information includes weapon selection and launch operations plus detection of launch operations, execution of the bullet firing process, and determination of whether the training time is up to the end of the training module program call.

Coordination function the various parameters involved in the lower limb rehabilitation training software are automatically opened by calculation according to the set test time, and refreshed at a certain time. The buffer space can store data for a certain collection time. When the training is stopped, The data is automatically saved on the hard disk in a file format, which is convenient for the calculation and invocation of each sub-module, and then the algorithm of each parameter placed in the program is used to run from the computer background. The algorithms in the program are implemented through dynamic link library programming, which is convenient for upgrading and content expansion.

The software design of rehabilitation therapy instrument is composed of DSP and CPLD. DSP software design mainly includes system initialization software, keyboard LCD display module software, AD acquisition and processing module software design; CPLD software design mainly completes the design of multi-parameter stimulation waveform generator, including stimulation waveform generation module, pulse modulation control module Software design of DA, DA parallel conversion module, stimulation timing and stimulation interval control module. The system software process is shown in Figure 3.

The physical meaning of the amplitude histogram statistics is: Count the frequency of the amplitude of each sampling point, and then draw a statistical histogram; the amplitude histogram uses the form of a histogram to represent the frequency of the EMG. In the statistical processing process, the following quantities are required: peak-to-peak, average rectified voltage, root mean square value RMS, and turning count per second.

For each measurement point, the statistical processing is performed according to its magnitude. For sampling points whose values are less than Amax or greater than Amax, limit processing is performed at both ends; the method of peak-to-peak amplitude processing is to find the positive and negative maximum amplitude values over the entire interval, and the algebraic sum is the peak-to-peak value obtained. Amplitude; the average rectified voltage is generally to obtain the rectified effective value. For the sake of convenience, you can also find the rectified values of all the measurement points in a given interval (that is, take the absolute value), and then perform statistical average.

For this measurement with the same precision, perform statistical calculations according to the following calculation formula to find the root-mean-square value σ.

$$\sigma^2 = \frac{\sum_{i=1}^{M} (X_i - X)^2}{n-1}$$
$$X = \frac{1}{n}\sum_{i=1}^{M} X_i \tag{12}$$

In order to quickly find the root mean square, we transform the formula equivalently to:

$$\sigma^2 = \frac{Q \frac{1}{n} S^2}{n-1}$$
$$Q = \sum X_i^2, \quad S = \sum X_i \tag{13}$$

Because this system does not have strict requirements for the specific waveform of the EMG signal (mainly to see the peak value), and mainly depends on the overall EMG signal amplitude, it is used in the processing of the EMG signal after amplification and filtering. Based on the method of domain analysis and the analysis of the amplitude histogram of myoelectric signal, a simple and intuitive method of dynamic threshold processing is proposed, which includes ideas such as mean processing and zero-crossing calculation.

Its processing method includes the following 4 steps:

a. Take the average value E of the collected N data;

b. Find the difference B(i) between the amplitude A(i) and the mean E of each collection point, and round off the points where B(i) is less than 0, increase the zero to the average level, and get a value greater than the mean Points N1;

$$N_1 = \sum_{i=1}^{N} N_{1i}, \quad N_{1i} = \begin{cases} 1, & B(i) \succ 0 \\ 0, & other \end{cases} \tag{14}$$

c. Set the threshold value T, find the difference C(i) between the value corresponding to the point greater than the average value and the threshold value (T);

$$N_2 = \sum_{i=1}^{N1} N_{2i}; \quad N_{2i} = \begin{cases} 1, & C(i) \succ 0 \\ 0, & other \end{cases} \tag{15}$$

d. Calculate the zero-crossing rate: Calculate the ratio of N1 and N2 to get a reasonable percentage (n%), which is used as a threshold judgment comparison. If N1 / N2 is greater than n%, it is considered that stimulation is achieved when the stimulus level is reached; otherwise, stimulation is not given, and by lowering the threshold, continue to collect data and judge the threshold again.

In addition to the above steps, considering the difference in the range of the EMG gain in the hardware structure design of the program-controlled part, the difference in the amplitude range of the EMG signal, in the software design, the data processing part of the collected muscle The electrical data is subjected to predetermined standard processing, and the data entering the data processing module is adjusted to the same range, so as to provide the same reference level for threshold determination.

(1) Software implementation of waveform generation module

The waveform generation module is used to generate adjustable square, triangle, sine, and exponential waves.

In the design, VHDL language programming is used to achieve frequency selection by dividing the system clock. The design of waveform generation uses an average of 64 data in time during a complete waveform cycle. Among them, the design of sine wave and exponential wave uses table look-up method to fit the waveform, that is, in the period of a sine (exponential) wave, 64 phases are averaged over time, and the sine (exponential) value of the corresponding phase is calculated. Range, maximum 1023, minimum 0), and use the corresponding phase as the address, store the corresponding sine (exponential) value data in the table, and then generate address information by phase accumulation, read the phase value at the current time in the table Corresponding value to generate the required waveform; the design of the square wave is to count the input clock from 0 to 31, the square wave amplitude is 1023, from 32 to 63, the square wave amplitude is 0, and the triangle wave design The first addition is performed in the first half cycle, and the amplitude is increased from 0 to 32 in units of 10, and the subtraction

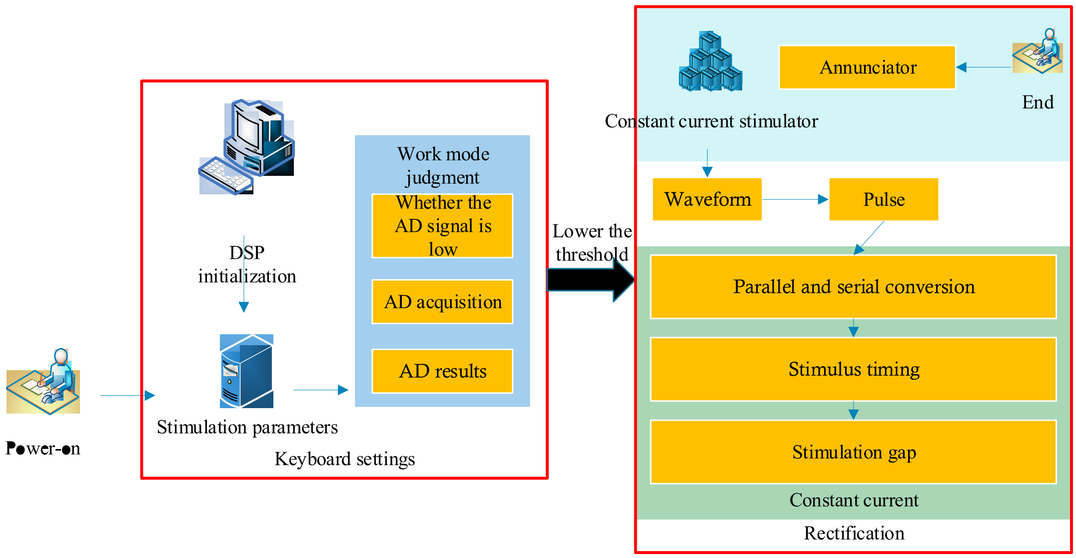

FIGURE 3. Software flow chart of intelligent rehabilitation training system.

is performed in the second half cycle, and the amplitude is decreased from 1023 to 32 in units of 0 to achieve.

(2) Software implementation of pulse modulation module

The pulse modulation module mainly uses a digital method to modulate the output signal of the waveform generator (square wave, triangle wave, sine wave, exponential wave), and changes the duty cycle of the carrier signal through pulse width selection and frequency selection. The modulation signal waveform is related to signal modulation. The modulation signal is digitally converted to change the output voltage amplitude before being sent to the D / A converter, thereby realizing the change of the stimulation intensity caused by the change of the duty cycle and the amplitude. Its software implementation is as follows:

1) Realization of duty cycle change: By dividing the clock signal and corresponding to different set values, low-frequency clock signals of various frequencies can be obtained, and this signal is used as the clock for modulating the square wave. The air ratio setting value uses a counter to determine the ratio of high and low levels in a square wave period, thereby adjusting the duty cycle of the carrier signal.

2) Implementation of amplitude change: Divide the data input to the D/A converter by an amplitude change coefficient to change the amplitude of the output waveform. Because the VHDL language requires that the divisor of the division operation must be a power of two, we choose the variables b×l, b×2, b×3, and b×4 as 1/2 amplitude, 1/4 amplitude, 1/8 amplitude, and 1/16 Value, by changing the linear combination of the variables b×l, b×2, b×3, b×4 (a total of 16 types, that is, 1/16 amplitude value 16/16 amplitude value), to achieve the purpose of changing the amplitude.

(3) Software implementation of stimulation timing control module and intermittent control module

TABLE 6. Low-frequency end transition band test.

Frequency (HZ)	120	110	80	60	40	38	36
Amplitude (mV)	0.25	0.25	0.2	0.22	0.16	0.15	0.05

The stimulus timing control module realizes the control of the overall working time of the stimulator, which is a global control; the stimulus intermittent control module is a control that generates or does not generate a stimulus pulse, and is a stimulus control in a local sense. The design ideas of these two modules are to accurately divide the 25M CPLD system input clock to ls, and then count in units of 1s to output timing and stimulation intermittent control signals. The enable control signal output by the timing module is matched with the clock signal, and the timing function is realized by controlling the presence or absence of the clock signal; the intermittent module outputs the square wave signal with different duty cycles and the modulated pulse signal, and passes the control. The presence or absence of pulse output is used to realize the intermittent function of stimulation.

IV. EXPERIMENTAL VERIFICATION

This test adopts the method of single-step debugging of the unit circuit, and selects the sine wave of 0.1mV, l00HZ, X1 gear for testing. As shown in Table 6.

The overall gain test results are shown in Table 7.

Taking square wave and triangle wave as examples, the simulation diagrams are shown in Figure 4 and Figure 5.

It can be seen from Figure 4 that the waveform output q value is 000 (representing a low level) and 3FF (that is, 1023 represents a high level), which proves that this design fully meets the characteristics of a square wave; analyzing the q

TABLE 7. Overall gain test results.

	□1（V）	Av	□2（V）	Av	□5（V）	Av	□10（V）	Av
0.02mV/60HZ	0.048	4780	0.09	9750	0.26	24500	0.48	490020
0.06mV/100HZ	0.246	4860	0.498	9950	1.25	24820	2.49	494600
0.1mV/200HZ	0.497	4980	0.996	9960	2.49	24860	4.96	498600

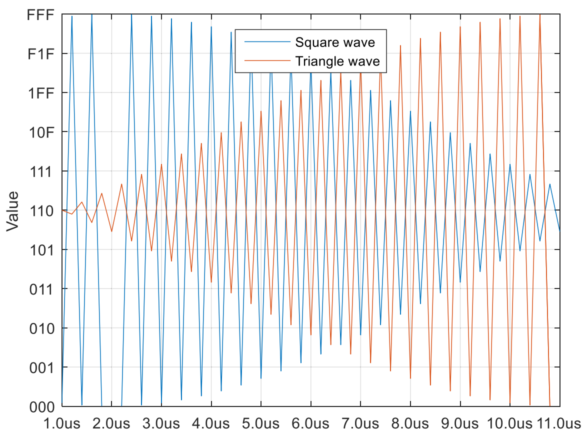

FIGURE 4. Square wave security picture.

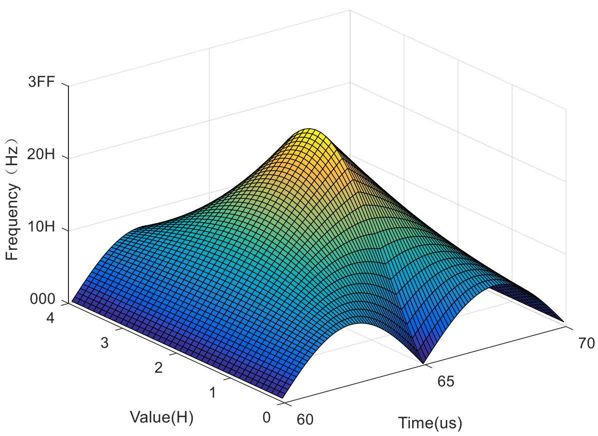

FIGURE 5. Triangular wave protection.

value of Figure 5 It can be seen that 3FF (1024) is the peak of the triangular wave. As the dividing point, the q value on both sides of 3FF is increased or decreased by 20H (32) respectively, and the periodic design of the triangular wave's waveform characteristics from 0 to the peak to 0.

As shown in Figure 6, in different stages of rehabilitation training, there are differences in the number of motion coordination units with high activity intensity. It can be seen from FIG. 6 that at the beginning stage, only the first principal component, the second principal component, and the fourth principal component represent the high intensity of the motion coordination element; in 10-50s, the second principal

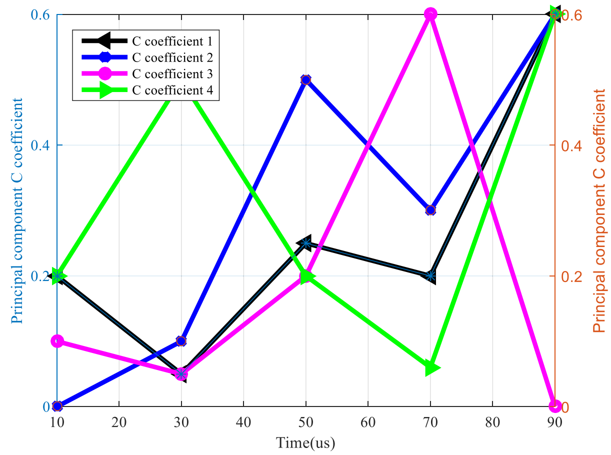

FIGURE 6. Schematic diagram of the weighting coefficients (C coefficients) of each principal component, the main active area and the peak time in the rehabilitation training action.

component and the fourth principal component The activity intensity of the indicated motion coordinator is high, and the two basically perform activities in order; in 50-90s, the activity intensity of the first, second, and third principal components is high, and most of the time in this phase The three are active simultaneously in the area. In the rehabilitation training movement, the movement of the second double support phase is relatively complicated, which has a high impact on the athletic performance of the rehabilitation training movement and has certain correlation with the complexity of the movement during the rehabilitation training phase. It can be seen that the number of participating motion coordination elements is larger than that in more complex action phases. Multiple sports coordination elements synchronize activities in a relatively strong degree. The superposition of their same functions can enhance this function to meet the needs of exerting the ultimate explosive power of the human body. The integration of different functions can meet the various tasks in sports, and require high-tech requirements to be completed in a very short time.

In the rehabilitation training movement, the number of motion coordination elements involved in the more complex movement phase is larger, but this does not make the number of motion coordination elements involved in the entire rehabilitation training movement process large. The activities of the same motion coordination unit can participate in

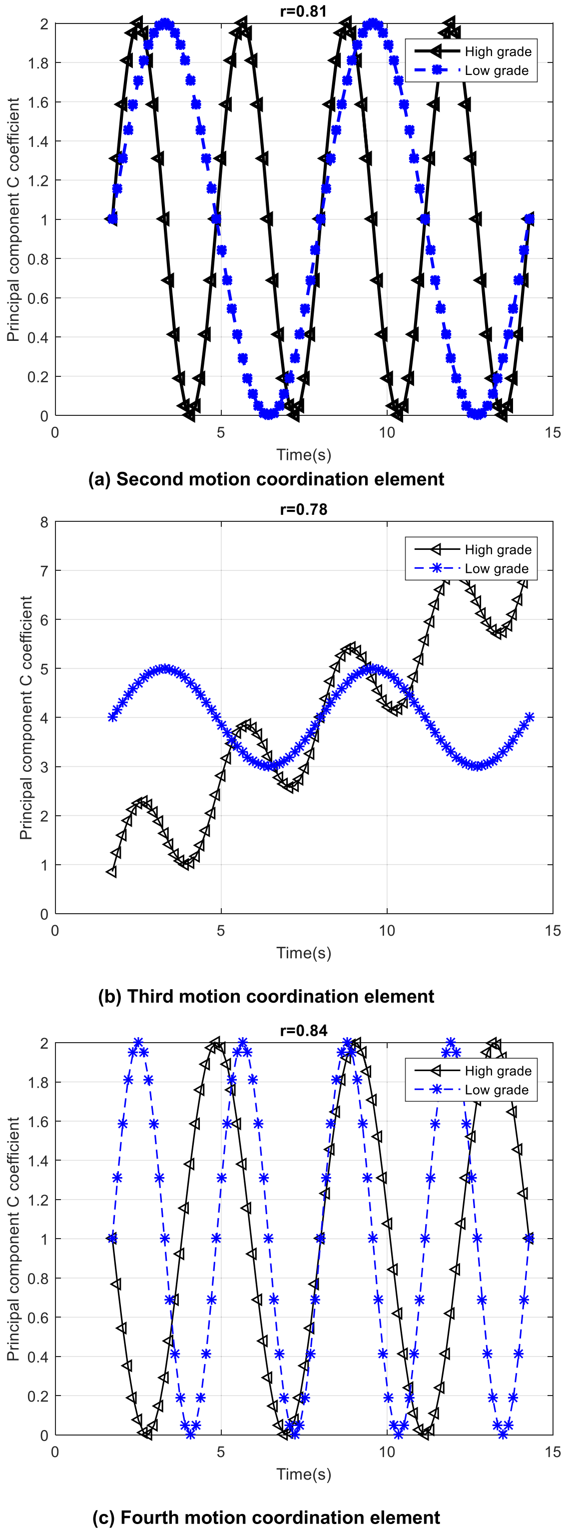

FIGURE 7. Schematic diagrams of the main variation forms of the principal component weight coefficients (C coefficients) that are significantly related to athletic performance in rehabilitation exercises.

the completion of motion tasks in different action phases. Figure 7 shows that the main active areas of the motion coordination elements represented by the second, third, and fourth principal components all cover more than two action phases. The main active areas of the motion coordination unit represented by the second principal component include the first single support phase, the second single support phase, and the second dual support phase; the main active area of the motion coordination unit represented by the third main component covers The first and second double support phases; the main active area of the motion coordination element represented by the fourth principal component covers the first single support phase.

By using the functional principal component analysis method, the weight coefficients of the principal components of each test muscle EMG were decomposed into a few major forms. There is a significant correlation between the performance of each rehabilitation exercise and its score in the first major form of the second, third, and fourth principal component weight coefficients (accounting for 46%, 52%, and 75% of the overall variability) Figure 7 shows the weight coefficients of these principal components when the athletic performance is higher (represented by a solid line) and lower (represented by a dashed line) in the rehabilitation training action, showing the activity coordination coefficients of each athletic coordination in different athletic performances The difference. The difference in the coefficients of various sports coordination meta-activities in high and low athletic performance rehabilitation training movements is as follows: in the high-performance sports rehabilitation training movement, the peak value of the second type of sports coordination meta-activity moves backwards, starting with the first single support. It reaches a peak after a short period of time and in the early stage of the second double support phase. In addition, the peak value is relatively high during these periods, especially in the second double support phase; the third type of motion coordination element is active in the first double support phase The peak value moves backward, and the peak value of activity in the second double support phase is higher; the peak value of the fourth type of motion coordination element activity obviously moves backward, appearing near the end of the first single support phase. It can be seen that with the changes in the athletic performance of rehabilitation training movements, the coefficients of various coordination elements that dominate each muscle activity will also change significantly, mainly as the peak coefficient and peak phase change. In addition, there were no significant differences in the weighting coefficients of the main components of the muscle EMG for each test (see Table 8). This shows that changes in the weight of rehabilitation training have no significant effect on the coefficient of motor coordination activity.

Figures 8 and Figure 9 show the "UCM" and "ORT" variability and the "UCM" variability ratios of the motion coordination meta-activity coefficients for the task variable human body weight and heart displacement during rehabilitation exercises. As shown in Figure 8, the average value of the variability ratio of the motion coordination meta-activity coefficient "UCM" in the rehabilitation training movement of the elite group is 0.63, which is higher than 0.57 in each

TABLE 8. Comparison table of the differences between the main coefficients of the main component weight coefficients in rehabilitation training.

	Principal component 1	Principal component 2	Principal component 3	Principal component 4
Major changes 1	n.s.	n.s.	n.s.	n.s.
Major changes 2	n.s.	n.s.	n.s.	n.s.
Major changes 3	n.s.	n.s.	n.s.	n.s.
Major changes 4	n.s.	n.s.	n.s.	n.s.

Note: n.s. means no significant correlation.

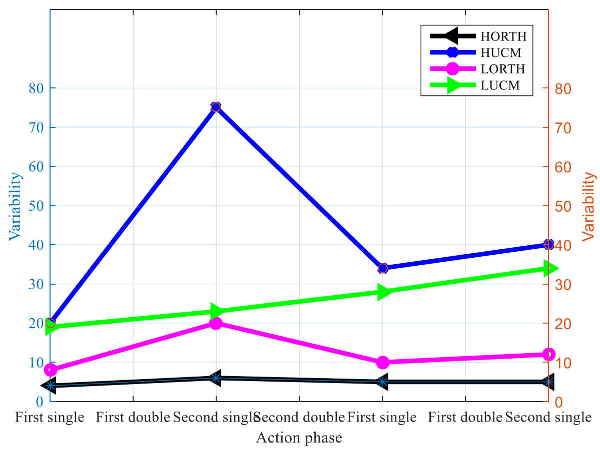

FIGURE 8. Coordination of meta-activity coefficient UCM and ORT variability for human body weight and heart movement during each phase of rehabilitation training in elite (H) and ordinary group (L).

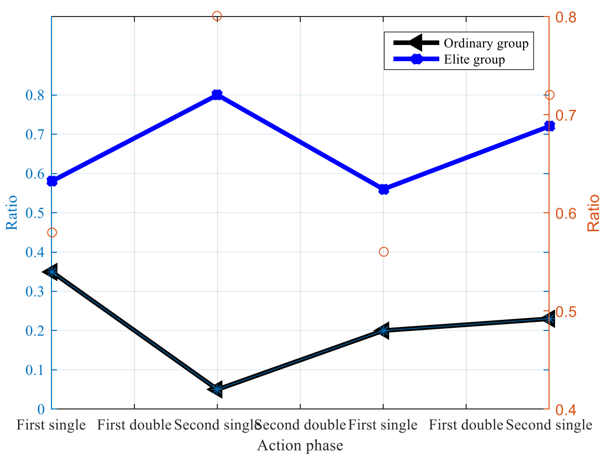

FIGURE 9. Entire process of rehabilitation training in the elite and ordinary groups (dotted line) and the ratio of the variability of the UCM coefficient of the coordinated meta-activity coefficient for the human body's weight and heart displacement during each stage.

stage of the exercise; ''The average value of the variability is 0.24, and the value of each action stage is between −0.01 and 0.32. The ''UCM'' variability ratio of the elite group in each stage of rehabilitation training is higher than that of the ordinary group, especially in the stage of large movement amplitude, the gap between the two groups is the largest. These indicators show that the elite group of rehabilitation training exercises Human body weight and heart displacement is an important task variable that the central nervous system needs to control when using the redundancy of the human motion system. The redundant degrees of freedom in the motion system will not affect the stability of the motion task. In the general group rehabilitation training, the central nervous system also takes into account the control of human body weight and heart displacement when organizing the redundant degrees of freedom of the motor system, but its degree is much lower than that of the elite group. Figure 9 shows that compared with the ordinary group, the ''UCM'' variation of the elite group The sex was 1.8 cm^2, 51.67 cm^2, 2.82 cm^2, 6.57 cm^2 higher in each action phase, and the variability of ''ORT'' decreased by 4.58 cm^2, 15.97 cm^2, 9.91 cm^2, 14.05 cm^2. It can be seen that the elite group was more the high ''UCM'' variability ratio is mainly due to its lower ''ORT'' variability.

V. CONCLUSION

Based on the body coordinated rehabilitation fun training method, clinical trials have shown that during the rehabilitation training of the balance disorder, the patient adjusts the force in real time to control the movement in up, down, left, and right directions, and controls the training operation handle by hand to select the weapon type and fire the projectile to hit the enemy aircraft, Dodge bullets and other related operations allow the patient to reasonably train the patient's coordination ability while training balance, and to achieve the matching of hand and foot movements with visual information. While improving the balance function, the ability to coordinate sports has been greatly improved. The training provides visual and auditory feedback so that patients can easily play training while rehabilitating, distract patients, and reduce patients' boring training. This method provides a training platform for the majority of patients who cannot be independent with the assistance of back support weight loss, and achieves the purpose of promoting balanced and coordinated rehabilitation training for patients. In a new way, combine myoelectric signals with neuromuscular electrical stimulation, perform biofeedback control through the brain, combine physical therapy and psychological therapy for patients, and conduct artificial intelligence biofeedback scheduling, analysis and evaluation, and fully mobilize Patient motivation, exercise paralyzed muscles. The structural equation model method used in this paper to verify the theoretical model is the first time that this method has been used to verify the basic theoretical problems of sports training, but the sample size has not reached the optimal number. In the future, we expect the support of the same and similar empirical studies of larger samples; The method of structural equation model also has certain limitations, such as only linear processing of research problems, which may cause the limitations and deviations of research results and conclusions.

Therefore, the research practice of basic theoretical problems of sports training Expect breakthroughs in research methods.

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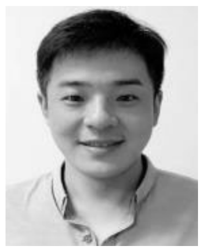
YANFENG SU was born in Xinxiang, Henan, China, in January 1977. He received the master's degree from Zhengzhou University, in 2008. Since 2002, he has been working with the Xinxiang Medical College for 18 years. During his lecturer position, he has published ten articles, including two SCI and five Chinese core journals. His research interest includes sports rehabilitation.



LIANG SU was born in Zhengzhou, Henan, China. He received the master's degree from Henan Normal University, in 2008, and the Ph.D. degree from Henan University, in 2018. He was worked as a part-time with the Henan Student Sports Association all the year round and has been engaged with the School Sports Management for many years.