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Optimal Layout of Wearable Intelligent Terminal Micro Sensor and Modeling of Elbow Movement Function Rehabilitation

HAIMIN ZHANG[1,2], WENXIAN XIAO[3], AND HONGBO JIANG[4]

[1]School of Physical Education, Henan Institute of Science and Technology, Xinxiang 453000, China
[2]Department of Physical Education, Pukyong National University, Busan 608-737, South Korea
[3]Network and Information Management Centre, Henan Institute of Science and Technology, Xinxiang 453000, China
[4]Recovery Centre, Third Affiliated Hospital of Xinxiang Medical College, Xinxiang 453000, China

Corresponding author: Haimin Zhang (zhanghaimin@hist.edu.cn)

ABSTRACT The layout of wearable smart terminal micro sensor and the rehabilitation training of elbow motion function were studied. The wearable wireless sensor network system designed in this paper is mainly used to reflect the motion trajectory of patients in real-time and collect the specific physiological parameters data in the process of exercise rehabilitation. The joint reconstruction of multi-sensor data based on distributed compressed sensing optimizes the layout of smart terminal micro-sensors, and then uses kinematics simulation of elbow joint to design the terminal node of motion rehabilitation monitoring system. The system can monitor physiological information such as electromyography (EMG) signals of patients in real time, process and analyze physiological information of patients in real time, and provide basis for medical workers to formulate and adjust rehabilitation training programs, so as to improve the effect of rehabilitation training.

INDEX TERMS Wearable, intelligent equipment, sensor optimization, elbow joint, rehabilitation training.

I. INTRODUCTION

Elbow joint is one of the most important components of upper limb, including lower humerus, ulna and upper radius. It connects the middle part of the arm and forearm and plays a key role in upper limb activities [1]. However, with the frequent occurrence of various diseases and accidents (such as stroke, fracture, etc.), the incidence of elbow motor dysfunction is getting higher and higher, which seriously affects the daily life and work of patients, and brings great physical and mental pressure and serious economic burden to patients [2], [3]. Therefore, elbow motion dysfunction has become an urgent problem in medical field.

Clinical treatment of elbow dyskinesia can be divided into three stages: early stage, middle stage and late stage. Later rehabilitation training is the key stage of the longest time span and the best effect recovery [4]. Rehabilitation training mainly restores the normal self-care function of patients' joints through some intelligent and effective training methods. It is an important means of rehabilitation medicine to achieve the therapeutic effect of physical and mental rehabilitation. At present, most hospitals in China adopt the method of combining traditional Chinese and Western medicine to treat elbow joint diseases, such as surgery, cervical traction-natural reduction, fixed-point directional joint dislocation suture [5], [6]. Elbow rehabilitation training methods mainly include physical therapy, exercise therapy and occupational therapy, while there are two main methods to assist elbow rehabilitation training [7], [8]. The first is that the doctor and the patient carry out one-to-one, and the doctor gives the instructions. The patient completes the corresponding actions actively or passively according to the instructions. The second is to use the corresponding rehabilitation training system, such as upper limb intelligent feedback training system. Through wearing the mechanical arm, the systematic game training and post training are completed according to the rehabilitation training program, so as to achieve the goal of rehabilitation training [9].

Most of the traditional rehabilitation evaluation methods are based on the clinical experience of rehabilitation physicians before and after the rehabilitation training of patients, using measuring instruments to evaluate the range of active joint motion and muscle strength recovery grade of patients respectively [10]. In the whole process, the whole program

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relies too much on doctors' medical level and experience, and there is no accurate and effective data to reflect the applicability of the exercise program in real time during the implementation of the exercise rehabilitation training program [11], [12]. There is an urgent need to develop a real-time, effective, low-cost rehabilitation monitoring and evaluation system that can objectively and accurately reflect the recovery of limb motor function.

In this environment, the use of sports rehabilitation training monitoring equipment to real-time monitor the patient's body data. From simple pulse monitors, portable hall monitors, complex and expensive implantable sensors. In the past few years, there has been a significant increase in the number and variety of health monitoring devices [13]. However, in the existing system, it is still limited by the lack of portability, intelligence and expensive.

With the development of wireless network, microelectronics integration and miniaturization, sensor development and Internet technology, we can fundamentally change and optimize the existing human-centered monitoring equipment for sports rehabilitation training. The communication network is composed of network elements related to human body (including personal terminals, distributed on human body, sensor nodes embedded in human body, networking equipment, etc.) [14], [15]. These smart sensor nodes include sensing, computing and communication modules, which can form a network synergistically, and process and fuse the collected information through specific network technology and send it to the user terminal. Therefore, the wireless body area network technology provides a good means to achieve an efficient, real-time, objective, accurate and low-cost sports rehabilitation monitoring and evaluation system [16].

In this paper, the layout of wearable smart terminal micro sensor and the rehabilitation training of elbow motion function are studied. The main arrangement of the paper is as follows: the first part introduces the research background, research significance and research status at home and abroad; the second part introduces the relevant theoretical knowledge, including: elbow joint physiological characteristics and rehabilitation training, joint reconstruction of multi-sensor data based on distributed compressed sensing and kinematics simulation of elbow joint; the third part mainly talks about the terminal node of the motor rehabilitation monitoring system; the fourth part carries on the system test and the result analysis; the fifth part is the research summary and the prospect of the full text.

II. RELEVANT THEORIES AND METHODS

A. PHYSIOLOGICAL CHARACTERISTICS AND REHABILITATION TRAINING OF ELBOW JOINT

The elbow is one of the most important joints of the upper limb, which is the "link" between the arm and forearm. The upper limbs need elbow joints to participate in the movement and it consists of scapula, humerus, ulna, flexor and hand bones. In people's daily life, the activities of upper limbs are more frequent. Each joint and bone cooperate with each other to coordinate and complete the corresponding movements. Among them, shoulder joint, elbow joint and wrist joint are the three major components of the upper limb, and elbow joint is the middle link of the upper limb. The bones connected to the elbow include the humerus, ulna and radius. The internal physiological structure of the bones is shown in Figure 1.

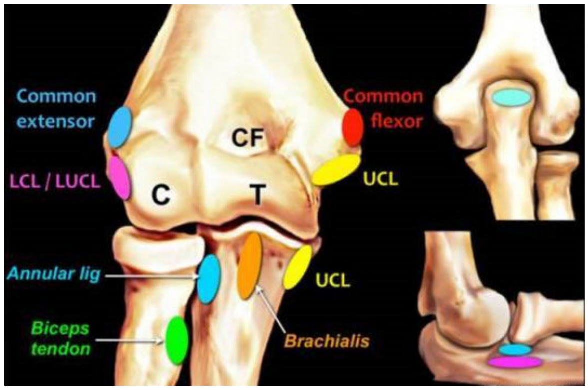

FIGURE 1. Physiological structure of elbow joint.

TABLE 1. Elbow joint motion and joint muscles.

Form of motion	Participating muscles
Buckling	Brachialis, biceps brachii, brachioradialis, pronator teres and wrist flexors
Stretch	Biceps brachii, elbow and extensor carpi
Pronation	Pronator teres, pronator quadratus, brachioradialis, elbow and flexor carpi
Supination	Supinator, biceps brachii, abductor pollicis longus, brachioradialis and extensor radialis longus

Elbow joint is a complex composite joint, which contains many fragile and important structures, such as coronal process, trochlea, radial head, synovium and annular ligament. When the elbow joints perform flexion, extension, pronation and supination, the skeleton, ligament and muscle of the elbow joints are divided and cooperated, as shown in Table 1. Because the elbow joint capsule and ligament are very weak and the elbow joint mobility is large, people are prone to joint injury and dislocation in the process of exercise, which leads to elbow joint dyskinesia [17]. People of all ages are prone to diseases of elbow joint, which lead to dysfunction of elbow joint movement. Therefore, elbow rehabilitation evaluation and training are carried out after clinical examination and treatment.

Rehabilitation assessment refers to objective, qualitative and quantitative assessment of the nature, scope, severity and development trend of elbow dysfunction, which lays a solid foundation for the formulation of rehabilitation treatment plan. Elbow joint function refers to the most basic ability to meet the daily work, study, life and social activities.

After elbow joint disease, if we want to restore the physiological function of normal people and achieve a state that does not affect daily life, it needs a systematic, scientific, effective and long-term stable rehabilitation evaluation and training process. Because the pathology of different diseases of elbow joint is different, the degree of injury of the same disease is different, but there is a certain regularity in rehabilitation evaluation and training [18], [19]. Usually elbow rehabilitation assessment and training is a cyclic process, which starts with rehabilitation assessment and ends with rehabilitation assessment. Through evaluation, elbow motor dysfunction was identified, and appropriate treatment plan was formulated according to the evaluation results. Among them, there are five main methods of elbow rehabilitation treatment: exercise therapy, occupational therapy, physical therapy, psychological therapy and rehabilitation engineering. Rehabilitation therapy can be divided into three stages: early stage, middle stage and late stage [20].

In the three rehabilitation processes mentioned above, patients gradually change from passive training to assistant training, and finally to active training to complete treatment [21]. Among them, assistant and active training mainly relies on medical equipment to set corresponding goals, and patients' elbows are repeatedly flexed and stretched. However, rehabilitation therapy usually evaluates its effectiveness in a dynamic way. When evaluating and training elbow rehabilitation, it is necessary to modify the treatment plan appropriately and determine the evaluation objectives and contents. In order to evaluate the efficacy of rehabilitation training, a certain scale is needed. If the evaluation index is improved, it is considered effective; if the evaluation index is unchanged or worsened from the previous stage, it is invalid. The main flow chart is shown in Figure 2.

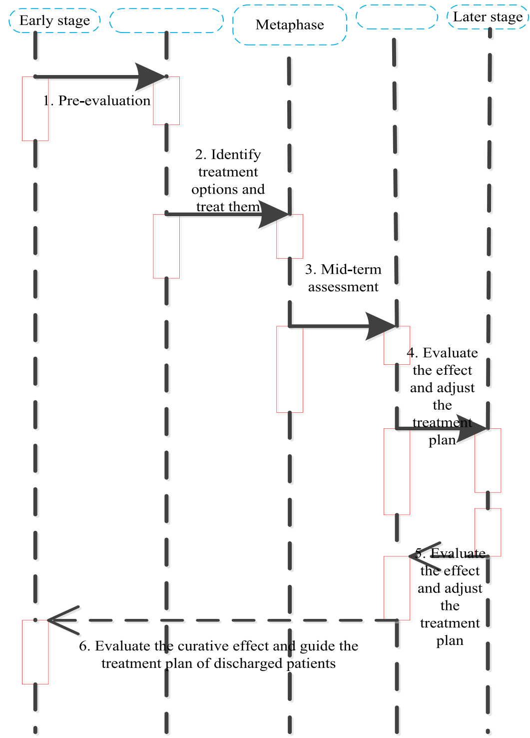

FIGURE 2. Treatment course of elbow rehabilitation evaluation.

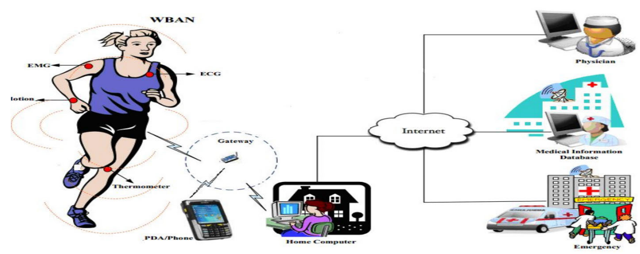

FIGURE 3. System overall framework diagram.

The sports rehabilitation wireless sensor network is mainly used for real-time collection of patient motion parameters and physiological parameters during rehabilitation training, and sends the parameters to family members and therapists. It facilitates real-time health monitoring and facilitates the development and evaluation of exercise rehabilitation programs for patients. Therefore, the system is required to have real-time, accuracy, security, stability and low power consumption. The purpose of the motion rehabilitation-oriented wireless sensor network system is to obtain the motion parameters and physiological parameters of patients in real time by using the wireless sensor nodes worn on the patients' bodies, and to do preliminary data processing for the motion parameters and physiological parameters, so as to provide objective and accurate reference for the whole rehabilitation training process [22].

According to the analysis of system requirements, the system is mainly composed of terminal node system, proximal monitoring system and remote monitoring system. In this paper, the first two systems are studied and implemented, and the remote nodes are analyzed. The terminal node system is composed of multiple wireless sensor nodes wearing on patients. Self-organized wireless mesh network is established between the nodes. The communication is based on IEEE 802.15.6 protocol, which gathers the motion parameters and physiological parameters to the wireless sensor network gateway node. The monitoring system consists of remote monitoring system and proximal monitoring system. The proximal monitoring system is developed based on Android system and communicates with gateway node through Bluetooth. The remote monitoring system is used to analyze the physiological parameters data packet in the gateway node, analyze and process various physiological parameters, and finally display the waveform intuitively, and has the function of emergency reminder in emergencies. The remote monitoring system is used to build a database of multi-patient and multi-physiological parameters to facilitate physicians to observe the effect of rehabilitation training remotely and formulate rehabilitation training programs. Figure 3 shows the overall framework of the system.

The terminal of sports rehabilitation monitoring system consists of three parts: sensing board module (motion and physiological parameter acquisition sensor board), data processing module and data transmission module. The whole terminal node is designed as a multi-layer structure. From bottom to top, it is used as a sensor board module, battery data processing module, data transmission module and antenna. Sensor board module needs to install or wear nodes in the appropriate position of the patient's body to collect the required signals of the human body. In signal selection, according to the previous analysis, the system mainly collects motion position, electromyography (EMG), electrocardiogram (ECG) and body temperature signals, and reserves interfaces for other signals. In the design of hardware nodes, it is mainly composed of sensors for specific physiological signals and signal conditioning circuits such as amplification and filtering.

On the one hand, data transmission module realizes the aggregation and encapsulation of data encapsulated by data processing module. On the other hand, data transmission between nodes in wireless sensor networks is realized. According to the above analysis of networking needs, and to meet the needs of patients in the process of rehabilitation training mobility. After the designed networking application program is written into the controller chip of each node, the data transmission between nodes of wireless sensor network can be realized. The system has the characteristics of low power consumption, self-organization, load balancing and robustness.

B. JOINT RECONSTRUCTION OF MULTI-SENSOR DATA BASED ON DISTRIBUTED COMPRESSED SENSING

In the non-stationary random process of time-varying sensor acceleration data in wireless body area network, the short-term stationarity can be maintained, and the spatial correlation of sensor nodes can be maintained. Using distributed compressed sensing technology, the multi-sensor acceleration data compression and coding of wireless body area network can be transmitted to reduce the amount of data transmission. At the same time, the spatial-temporal correlation of multi-sensor data is used to realize the joint reconstruction of multi-sensor data. Based on the above ideas, a multi-sensor acceleration data joint reconstruction system framework based on distributed compressed sensing is proposed, as shown in Figure 4. The basic ideas are as follows: first, the distributed source coding technology is used to compress the sensor nodes and transmit the compressed coded data to the coordinator node for data fusion. Then, the MBSBL algorithm is used to reconstruct the compressed data jointly, that is, to decode the encoded data and restore the original multi-sensor data, so as to provide reliable data for subsequent diagnosis and treatment. This paper focuses on the compression and joint reconstruction of multi-sensor acceleration data. Below is a brief introduction of distributed compressed sensing technology.

Distributed compressed sensing is a generalization technology of traditional compressed sensing theory. This technology combines distributed source coding technology with traditional compressed sensing technology, and uses the spatio-temporal correlation of data to reduce redundant information between data, effectively solving the problem of distributed data compression and reconstruction. Its technical implementation includes three parts: data sparse representation, distributed compression coding and joint reconstruction. Data can be sparsely represented as:

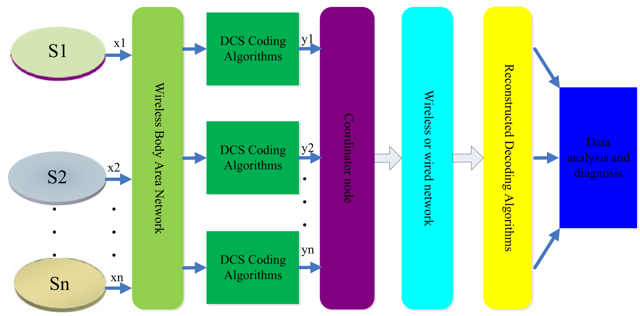

FIGURE 4. Multi-sensor data association based on distributed compressed sensing.

$$x_j = \psi \cdot \theta_j, \quad j \in \{1, 2, \cdots, J\} \tag{1}$$

Among them, $x_j \in R^N; \theta_j \in R^N; \psi \in R^{N \times N}$ and θ_j are vectors representing sparse coefficients, whose nonzero elements have the same positions but different values. The data structure is represented as $\Omega \subset \{1, 2, \cdots, N\}$. If $|\Omega| = K$, it is said that distributed data has the same K-sparsity, i.e. joint sparsity, which is a priori of distributed compressed sensing theory.

DCS distributed compression coding mainly uses different measurement matrixes $\Phi_j \in R^{M_j \times N}$ $\left(M_j < N\right)$ to compress each data x_j, that is to say

$$y_j = \Phi_j x_j = \Phi_j \psi \theta_j \tag{2}$$

The measurement matrix Φ_j satisfies the RIP (Restricted Isometry Property) property. Commonly used measurement matrices are independent and identically distributed random Gauss matrices, Bernoulli matrices, sparse binary matrices, etc.

The sparse coefficient is usually solved by the following optimization problems:

$$\arg\min \|\theta\|_{l_0}, \quad s.t.\ Y = \Phi\psi\theta = A\theta \tag{3}$$

$A \in R^{M \times N}$ is the perception matrix. Since this problem is a NP-Hard problem, the above-mentioned solution is usually converted to l_1 norm solution, that is, to solve it.

$$\arg\min \|\theta\|_{l_1}, \quad s.t.\ Y = \Phi\psi\theta \tag{4}$$

When considering that the system contains noise, equation (3) can be expressed as:

$$\arg\min \|\theta\|_{l_0}, \quad s.t.\ Y = A\theta + Z \tag{5}$$

$Z \in R^{M \times N}$ denotes the observed noise.

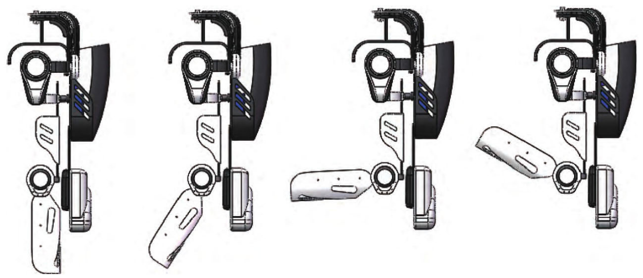

FIGURE 5. Simulation process of elbow flexion/extension.

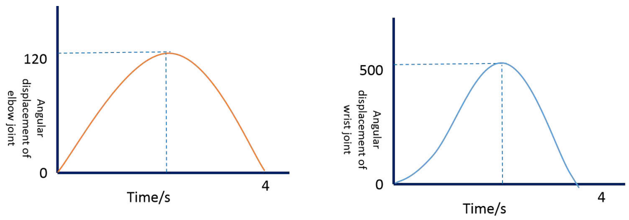

FIGURE 6. Angular displacement curve of elbow (left) and wrist (right).

C. KINEMATICS SIMULATION OF ELBOW JOINT

Considering the rehabilitative training requires the affected limbs to move gently and slowly (no sudden change of movement, etc.), in order to prevent secondary injury. In the motion simulation module Motion of SOLID WORKS, the elbow joint is taken as the origin of coordinates, and a motor is added at the elbow joint. The motor's motion mode is set as oscillation, the oscillation frequency is 0.25 Hz, and the maximum angle of motion is set to 120 degrees (that is, the average speed of elbow joint is 10 r/min, and the motion period is 4 s). Motion simulation of forearm buckling/stretching in sagittal plane driven by motor is carried out in Motion. The buckling process of forearm is shown in Figure 5 (stretching is the inverse process in the figure).

In the process of forearm movement, the forearm can be simplified as a connecting rod rotating around the elbow joint, while the wrist joint (the end of the forearm bracket) can be regarded as another end of the simplified connecting rod, and its displacement data can reflect the overall situation of forearm movement (whether the displacement is smooth). After the motion simulation, the angular displacement curve of the elbow joint and the linear displacement curve of the wrist joint can be generated by using the ''results and diagrams'' in solid works motion. The corresponding curve will be automatically generated by the system. Users can modify the relevant properties of the curve. It can also generate the corresponding EXCEL spreadsheet to record the relevant motion data in the whole motion process, and draw curves by using these data through EXCEL. This way can intuitively see the specific values of each data point, at the same time, it can be more convenient for users to edit and process the curve. Therefore, this method is used to generate the angular displacement curve of elbow joint and the linear displacement curve of wrist joint in this motion cycle, as shown in Figure 6.

As shown in Figure 3, the curve of angular displacement and linear displacement of exoskeleton mechanism driven by motor is smooth, which indicates that the whole movement transition is smooth and close to the normal motion of human body. It proves that the design of exoskeleton elbow mechanism is reasonable and conforms to the law of human motion. It can effectively assist users in training and prevent secondary injury.

Considering that the planned training mode of wearable upper extremity exoskeleton rehabilitation robot includes elbow joint independent training, shoulder joint independent training and shoulder and elbow joint joint linkage training. After the Motion simulation analysis of elbow joint independent training and shoulder joint independent training, the simulation analysis of shoulder and elbow joint linkage training mode is added to verify the movement effect of this training mode.

Through the wrist and elbow joint motion curve of shoulder-elbow joint training, we can see that the elbow and wrist joint displacement curve of skeletal robot in shoulder-elbow joint training is smooth. The wrist curve depression is due to the elbow limit angle of 120 degrees. After 90 degrees, the elbow position tends to the shoulder as the origin of the simulation system. The sudden change in the position that is unlikely to cause secondary damage proves the rationality and safety of the institution.

III. ADAPTIVE CONV DESIGN OF TERMINAL NODE OF SPORTS REHABILITATION MONITORING SYSTEM

A. OVERALL DESIGN OF TERMINAL NODE

The terminal node of the motion rehabilitation monitoring system (hereinafter referred to as the terminal node) is the information source of the whole system. It is composed of several wearable nodes. The wireless Mesh network is built independently among the nodes. The network is based on the IEEE 802.15.6 protocol and transmits the motion parameters and physiological parameters to the gateway node of the wireless sensor network. The system includes three parts: sensor board module, data acquisition and processing DSP module and data transmission module. The overall hardware design block diagram of the terminal node is shown in Figure 7.

The whole software system is a closed-loop system. After the parameters are processed by adjusting circuit and data software, they are sent to the monitoring software through wireless sensor network (near-end through Bluetooth). The monitoring software can also send control commands to the node through wireless sensor network to control the on-off of each module in the node and which physiological parameters need to be collected.

B. DESIGN OF MOTION POSITION TERMINAL NODE

The final application of the motion rehabilitation monitoring system is in the rehabilitation training process of patients, so the patient's motion trajectory is a necessary monitoring object. In this paper, the motion trajectory of the patient's arm is mapped in real time by collecting the parameters of different positions during the movement of the patient's arm.

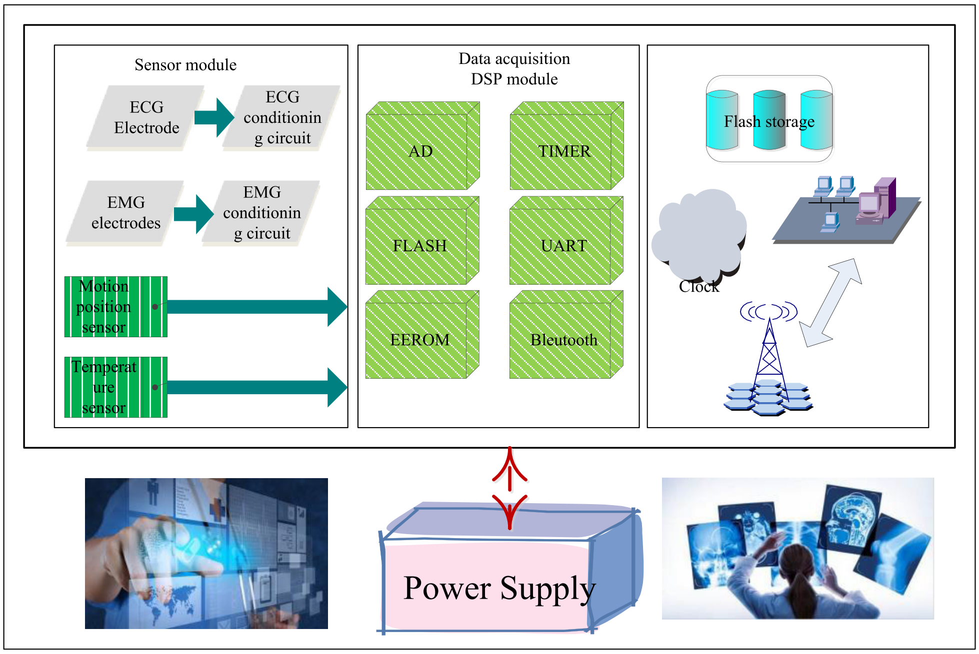

FIGURE 7. Block diagram of terminal node design.

In this paper, MPU9250 attitude monitoring sensor module is used, which integrates acceleration sensor, geomagnetic sensor and gyroscope sensor to compensate for the monitoring angle deviation of a single sensor.

MPU9250 attitude monitoring sensor is a digital sensor, which can be directly connected to the DSP. Its data frame contains three-axis (X, Y, Z) angle information. The sensor is connected to DSP through I2C bus, and the communication rate is up to 1Mbps. MPU9250 sensor module acquires three-axis operation attitude angle, converts it into digital form, and obtains rotation vector through gyroscope.

X represents the angle of X axis from Z axis, Y is the angle of X axis from Y axis, Z is the angle of Z axis from Y axis, W is the speed vector of local coordinate system and R is the speed vector of global coordinate system.

When the local coordinate system (LSC) is transformed into the global coordinate system (GSC), its rotation vector is R (6), as shown at the bottom of this page.

Variation rate of rotation vector in kinematics:

$$\frac{dr(t)}{dt} = w(t) \times r(t) \tag{7}$$

whereas $w(t)$ is the rotation velocity vector of the local coordinate system obtained from the gyroscope, and $r(t)$ is the rotation velocity vector of the global coordinate system.

Its integral form is:

$$r(t) = r(0) + \int_0^t d\theta(t) \times r(t) \tag{8}$$

When the direction is changed, it can be obtained from the cosine matrix.

$$r_{GSC}(t+dt) = r_{GSC}(t) + r_{GSC}(t) \times d\theta(t) \tag{9}$$

Finally, it can be concluded that:

$$\begin{aligned} \theta_z &= -\sin^{-1}(R[3,1]) \\ \phi_z &= \tan^{-1}(R[3,2]/R[3,3]) \\ \psi_z &= \tan^{-1}(R[2,1]/R[1,2]) \end{aligned} \tag{10}$$

When θ_z is time dt, X axis deviates from Z axis, ψ_z is X axis deviates from Y axis, and ϕ_z is Z axis deviates from Y axis.

C. DESIGN OF EMG TERMINAL NODE

EMG signal is a kind of human electrical signal produced in the process of muscle activity, which contains a variety of physiological information about muscle activity. The EMG signal collected by EMG electrodes is very weak, only tens to thousands of microvolts, the frequency range is $1 \sim 500$ Hz, and mainly concentrated in $10 \sim 200$ Hz. EMG signal is easily affected by environmental noise. Differential mode interference occurs between the human body and the signal lines at the front end of the differential amplifier. Therefore, a good conditioning circuit is needed to get an effective EMG signal.

EMG signal acquisition sensor board is mainly composed of EMG electrodes, front-end amplifier circuit, filter circuit, rear amplifier circuit and so on. According to the

$$R = \begin{bmatrix} \cos\theta\cos\psi & \sin\phi\sin\theta\cos\psi - \cos\phi\sin\psi & \cos\phi\sin\theta\sin\psi + \sin\phi\sin\psi \\ \cos\theta\sin\psi & \sin\phi\sin\theta\cos\psi + \cos\phi\sin\psi & \cos\phi\sin\theta\sin\psi - \sin\phi\sin\psi \\ -\sin\theta & \sin\phi\cos\theta & \cos\phi\cos\theta \end{bmatrix} \tag{6}$$

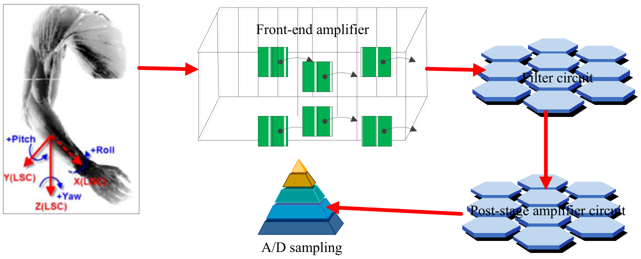

FIGURE 8. EMG signal acquisition sensor board.

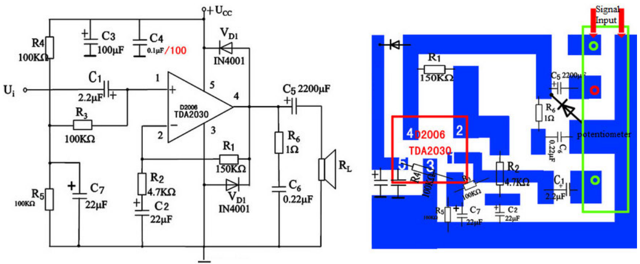

FIGURE 9. The circuit principle diagram.

characteristics of EMG signal and the requirement analysis of ECG signal acquisition sensor board, it is necessary to amplify the EMG signal by about 2000 times. In this way, it has the advantages of good filtering effect, high common mode rejection ratio and strong anti-interference ability. The composition of EMG signal acquisition sensor board is shown in Figure 8.

Surface electromyogram (SEMG) signals collected by surface electrodes are very weak and contain a lot of noise. It is necessary to design a conditioning circuit for processing to meet the sampling requirements. The signal must be amplified first by a preamplifier circuit. Considering the polarization voltage and the saturation of the subsequent circuit, the preamplifier gain should not be too large. The original EMG signal after amplification is accompanied by a variety of noises, which seriously interfere with the quality of the signal. Therefore, an effective filter is designed to filter the signal according to the characteristics of the EMG signal.

The magnified and filtered EMG signals are at the MV level, so it is necessary to amplify the EMG signals at the second level. Considering the performance power ratio, the OPA2335 chip integrated with two operational amplifiers is powered by a single power supply. It has the characteristics of low noise, low input bias current and low power consumption. The secondary circuit diagram is shown in Figure 9. The gain is:

$$G_1 = 1 + \frac{100k\Omega}{R_G} \approx 19 \tag{11}$$

In addition, empirical mode decomposition (EMD) algorithm is used to extract EMG features. The purpose of EMD is to decompose an arbitrary signal into a cost eigenmode function, so that the instantaneous frequency obtained by

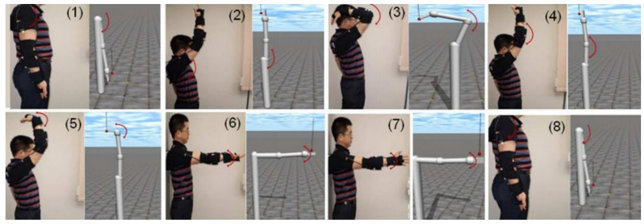

FIGURE 10. Motion simulation diagram.

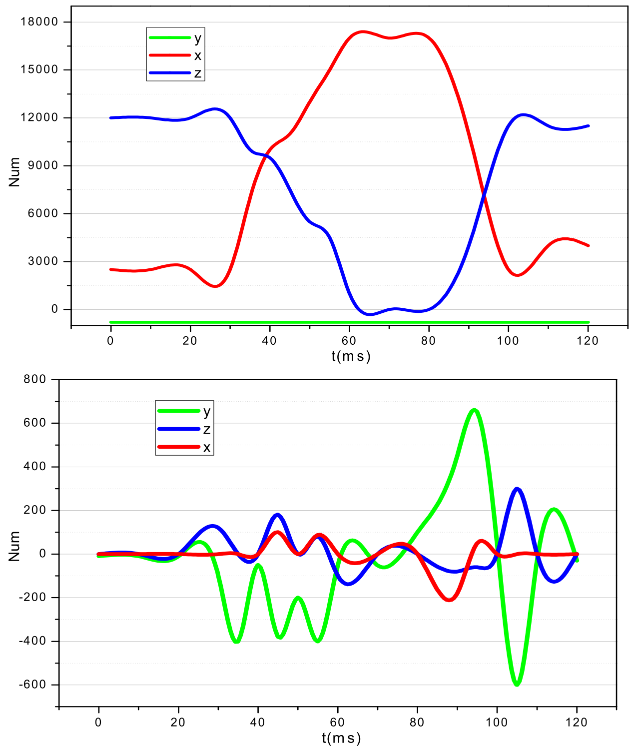

FIGURE 11. Motion position waveform.

the Hilbert transform can reflect the physical mechanism of the signal. Let the input signal be:

$$f(t) = \sum_{n=1}^{N} c_n(t) + r_N(t) \tag{12}$$

In the formula $c_n(t)$ is the IMF component obtained by the nth decomposition and $r_n(t)$ is the residual obtained by the decomposition.

IV. EXPERIMENTS AND RESULTS

A. MOTION POSITION NODE TESTING

In order to verify the performance of the node, it is defined that the horizontal movement is X-axis, the horizontal movement is Y-axis, and the vertical movement is Z-axis. Figure 10 is the motion simulation diagram. Figure 11 gives two groups of motion sensor parameters.

It can be seen from the Figure 11 that the data collected by the sensor can be simulated to be close to the original trajectory.

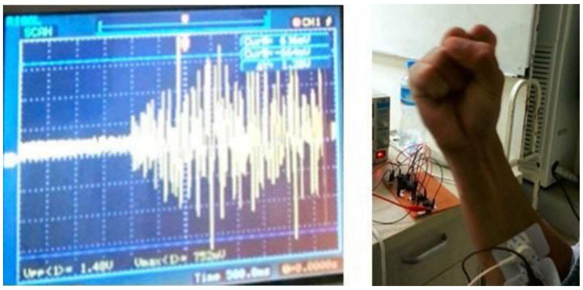

FIGURE 12. EMG signal acquisition waveform.

B. EMG TERMINAL NODE TEST

The testing method of EMG signal is similar to ECG signal. The difference lies in the different types and patching methods of medical electrodes. According to the patching method mentioned above, the electrodes are patched well and the access circuit is tested. The waveform of EMG signal collected from the condition of arm relaxation to tightness is shown in Figure 12.

For the EMG signal, this paper uses the Symlet wavelet system to perform five-layer decomposition and denoising. In this paper, symbolic wavelets are used to denoise continuously acquired EMG signals. Although the algorithm is implemented on DSP, in order to facilitate the observation of test results, the algorithm is implemented in the matlab environment. The wavelet coefficients and detail coefficients of each layer of EMG signals decomposed by Symlet wavelet in Matlab environment. The experimental results show that the myoelectric signal after denoising is smoother.

C. SYSTEM PERFORMANCE TESTING

By establishing a wireless sensor network, data transmission between sensor nodes and nodes, between nodes and gateway nodes is realized. According to the analysis of networking requirements in the previous article, the objectives of networking test for wireless mesh network of the system are as follows:

1) Whether all nodes except gateway nodes have routing function;
2) Whether each node has the function of ad hoc network and has high stability;
3) Whether wireless sensor networks have strong network self-healing capability;
4) Whether the gateway node has high gateway reliability.

Figure 13 shows the experimental topology of wireless sensor networks based on TinyOS. In the experiment, three sensor nodes are used as sensor terminal nodes to collect physiological parameters, and one sensor node is used as gateway node. Three terminal nodes connect the physiological parameters acquisition sensor board, and transmit the physiological parameters collected by the sensor to the gateway node through the wireless Mesh network. The gateway node sends the data to the PC through USB. Finally, on the PC, the received data packet is analyzed by MoteView

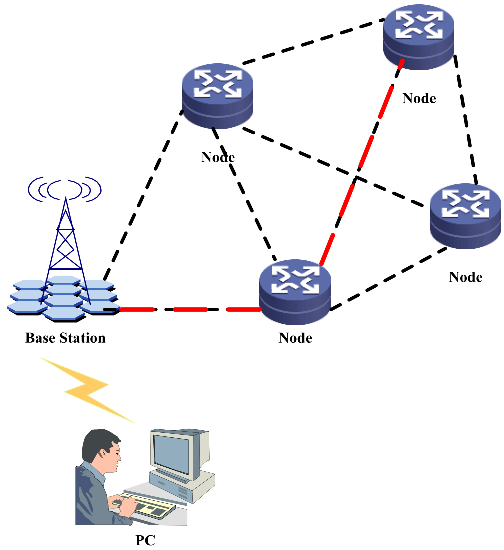

FIGURE 13. Network experimental topology.

software provided by Crossbow platform, and the node topology information is displayed. In the node topology diagram, the green connection line between nodes indicates that the link is normal, and the grey connection line indicates that the link has been disconnected. The function of the network can be verified by observing the changes of node topology.

According to the requirement analysis of wireless sensor networks, the wireless sensor network system needs to build a multi-hop network. That is to say, each terminal node has two functions of data acquisition and routing. When the cost of sending data directly between nodes and gateway nodes is high, forwarding is implemented by other nodes. Or when the path is blocked, forwarding is performed by other nodes.

In the following Figures, GW represents the gateway node, and 1, 2 and 3 are the three terminal node numbers. The nodes are placed in different locations: nodes 2 and 3 are placed near the gateway node; nodes 1 is placed on the same side of node 2, but it is far away from the gateway node. Power is turned on after deployment and the constructed node topology is shown in Figure 14. As can be seen from Figure 14, nodes 2 and 3 can be directly connected to gateway nodes due to their different placement positions. Node 1 can not connect with gateway node, so node 2 needs to forward. Experiments show that the nodes in this system have the ability of routing and forwarding.

The purpose of network self-organizing capability test is to construct a reasonable network topology between nodes when the network environment or the state of nodes changes. When three nodes are placed near the gateway node, the three nodes will automatically change the routing according to the difference of signal intensity caused by different locations. Figure 15 shows that Node 1 communicates directly with the gateway node at this time, as compared with Figure 14, without requiring other nodes to act as routing nodes.

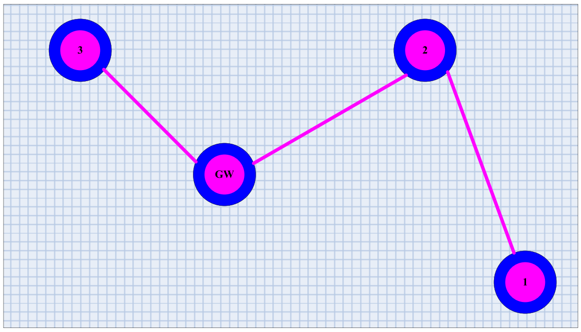

FIGURE 14. Node topology diagram.

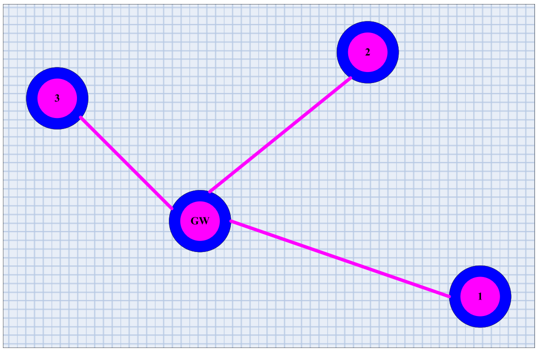

FIGURE 15. Network topology after resetting location.

The experiment proves that the wireless sensor network designed by this system has the ability of network self-organization.

Although a good channel allocation strategy can be used to allocate non-overlapping channels to different channels of wireless sensor networks to avoid internal interference between wireless sensor networks. However, the channels and frequencies of wireless sensor networks and WiFi will be identical, and may overlap with other wireless devices in the same frequency channel. Therefore, when wireless sensor networks coexist with WiFi, performance interference may occur. Therefore, the main application of wireless sensor network in this paper is 2.4 GHz. In the case of constant frequency, improving performance interference can only start from the node itself and channel. Therefore, the main work focuses on MAC protocol optimization and channel hopping mode setting.

MAC protocol is designed to facilitate multi-reflection communication between nodes in unregulated frequency bands. This network capability is achieved at the cost of reducing data throughput between individual sensor nodes, so sensor nodes have to wait for a random period of time to transmit a packet. The MAC protocol is improved by instructing the transmitter to send whenever the wireless transceiver buffer is full. In order to avoid the long-term interference of the channel, this paper designs the timing hopping of the channel, that is to say, when the hopping interrupt is triggered, the wireless sensor network changes in a downward

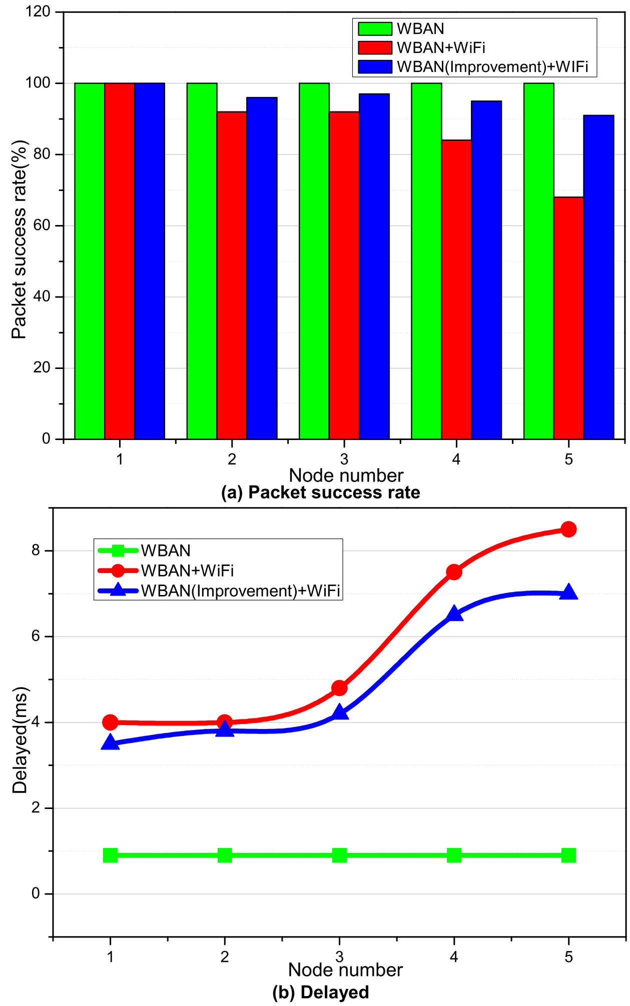

FIGURE 16. Data diagram of anti-jamming capability.

TABLE 2. Packet success rate.

	WBAN	WBAN+WiFi	WBAN(Improvement) +WIFi
1	100	100	100
2	100	92	96
3	100	92	97
4	100	84	95
5	100	68	91

cyclic way. The packet success rate is shown in Table 2. The data chart of anti-jamming capability test for wireless sensor networks is shown in Figure 16.

V. CONCLUSION

Aging is inevitable, but it can delay aging. Modern science has shown that through effective and specific training, physical function can be effectively enhanced, and the damaged limbs can gradually recover part of their functions in the process of rehabilitation treatment. When making rehabilitation training plan, medical workers need to monitor some or some physiological information of patients in real time in order to evaluate the effect of rehabilitation training and timely training program. In this context, the wearable wireless sensor network system designed in this paper is mainly used to reflect the motion trajectory of patients in real time and collect specific physiological parameters data in the process of exercise rehabilitation. Motion trajectory reflects the fitness, acceptance and rehabilitation degree of the training program in the process of exercise rehabilitation training; physiological parameters reflect the indicators of the elbow joint in the process of exercise, and the degree of the elbow joint to reflect the exercise program.

The system can monitor physiological information such as EMG signals of patients in real time, process and analyze physiological information of patients in real time, and provide basis for medical workers to formulate and adjust rehabilitation training programs, so as to improve the effect of rehabilitation training. The rehabilitation system is a certain degree of assistance to daily life. It needs to combine rehabilitation training with daily life assistance. In the design of monitoring software, this paper focuses on the display of physiological signals, and only carries out simple feature extraction and algorithm optimization for physiological data. In the future research and development process, more data processing and analysis functions can be considered to facilitate medical staff or target users to observe physiological conditions more clearly and conveniently. During the experiment, it was found that the elbow joint would move with the shoulder joint and wrist joint. The next step is to use the tracking registration and real-time rendering method based on the direction sensor to better support the elbow rehabilitation evaluation and training.

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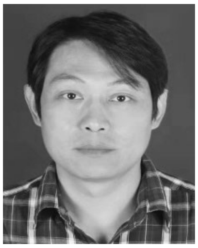
HAIMIN ZHANG was born in Juancheng, Shandong, China, in August 1983. He received the bachelor's degree from the Henan University of Science and Technology, in 2007, and the master's degree from Zhengzhou University, in 2012. He is currently pursuing the Ph.D. degree with the Department of Physical Education, Pukyong National University. He is currently a Lecturer with the School of Physical Education of Henan University of Science and Technology. He has authorized invention patent one, authorized utility model patent two, participated in compiling two national unified undergraduate textbooks, published 16 articles, and SCI 1. His research interests include physical education and training, sports nutrition and rehabilitation, and sports psychology.



WENXIAN XIAO was born in Nanyang, Henan, China, in August 1975. He received the bachelor's degree from The PLA Information Engineering University, in 2000, and the master's degree from the Huazhong University of Science and Technology, in 2011. He is currently an Associate Professor with the Network and Information Management Centre, Henan University of Science and Technology. He has published more than 20 articles, published four books, and participated in a dozen provincial and ministerial meetings. His research interests include network technology application and computing methods.

HONGBO JIANG was born in Xinxiang, Henan, China, in June 1980. She received the Ph.D. degree from Zhengzhou University, in 2017. She is currently the Deputy Chief Physician with the Third Affiliated Hospital of Xinxiang Medical College. She has authorized two invention patents, authorized seven utility model patents, participated in compiling one national unified undergraduate textbook, obtained six scientific research projects, five scientific research appraisals, two provincial scientific research awards, published 26 articles, nine core journals, and four SCIS. Her research interests include neuronutrition and rehabilitation.