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# A Rehabilitation Evaluation System Based on Electromyography Signals

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***Abstract*—This paper aims at the problem of designing a rehabilitation evaluation system based on electromyography (EMG) signals to provide an objective rehabilitation evaluation system for stroke patients in the rehabilitation process. In the design process of rehabilitation evaluation system, surface electromyography (sEMG) signals of specified movements of sick and healthy limbs were collected and features were extracted to calculate the difference between the two sides. Analytical Hierarchy Process (AHP) and Fuzzy Comprehensive Evaluation (FCE) methods are combined organically to build a rehabilitation evaluation model based on AHP-FCE method. The corresponding experimental results conducted on the stroke patients verified the feasibility and efficiency of the proposed evaluation system in practical clinical applications.**

***Keywords*—*surface electromyography(sEMG); AHP; FCE; rehabilitative evaluation;***

## I. INTUROUCTION

In recent years, the number of patients with upper limb motor dysfunction which is caused by stroke and peripheral nerve injury is increasing worldwide, and how to valuate their motor function and rehabilitation status in rehabilitation therapy to implement effective rehabilitation strategies is critical [1], [2]. However, the existing clinical evaluation methods mainly use qualitative evaluation methods such as scale. This method is limited by the human factors and the difficulty in comprehensive quantification, and the current clinical study did not establish a comprehensive rehabilitation evaluation database for comprehensive data collection and information analysis. Therefore, the research on scientific, reasonable and effective rehabilitation evaluation methods and the establishment of patient information database will have a very important significance and value in rehabilitation research.

Surface electromyography (sEMG) is the bioelectrical activity transmitted by skin muscle and related neurons. It can not only reflect the internal activity and state of muscle, but also reflect the movement intention of humans to a certain extent. Each person's sEMG signal is different, it is difficult to have an objective evaluation of the limb motor function of the patient depending on the sEMG signal of the affected side alone [3]. In this paper, the characteristics of diseased limbs and healthy limbs were compared. Analytical Hierarchy Process (AHP) and Fuzzy Comprehensive Evaluation (FCE) methods were combined to construct an upper limb rehabilitation evaluation model based on AHP-FCE method. In this paper, a scientific and effective evaluation method is proposed for the statistical and recorded of patient information. The proposed evaluation system is of great practical value to assist medical staff in analyzing the effect of a patient's limb rehabilitation and determining the treatment plans and rehabilitation targets.

## II. SYSTEM DESIGN

The measurement method of sEMG is convenient and simple. In general, a special surface electrode without injury to the skin is attached to the surface of the muscle to be measured. The original sEMG signal is very weak, but it is closely related to the function and state of the limb muscles in the process of human movement. It not only contains complex and changeable muscle activity information, but also can accurately reflect the human movement mode. Therefore, sEMG signals are now widely used in rehabilitation robots, life science, clinical diagnosis, evaluation and other related fields. SEMG has the following remarkable characteristics [4]:

1) Extremely weak: sEMG signal is very weak, and its amplitude is gendered in the range of 0-5mV;.

2) Low frequency: The signal frequency range is low, mainly in the range of 20-1000 Hz, and the main energy is concentrated between 50-150 Hz;

3) Strong noise background: Due to the complex composition of the EMG signal guided by the electrode, many interference signals together constitute a strong noise background;

4) Differentiation: The sEMG signal changes all the time and is non-stationary [5];

5) Weak disturbance resistance: Signal acquisition is easy to be interfered by the surrounding electronic equipment

Alternating Current (AC) magnetic field, impedance coupling and other interference. Signal stability is not strong.

Aiming at the characteristics of sEMG, this paper proposed a rehabilitation evaluation system based on sEMG. The overall structure block diagram of the proposed system is depicted in Fig. 1. The proposed system includes the four modules: sEMG signal acquisition module, sEMG signal processing module, evaluation module and history storage module of evaluation data. The working process of the system is as follows: the patient generates sEMG signal through the specified movements of the upper limbs, and the sEMG collection device collects sEMG; After the signal is amplified and digitized by the digital analog-to-digital converter, it is sent to the signal processing module through Bluetooth. The signal processing module analyzes the SEMG and extracts its features. After the evaluation module accepts the features, it evaluates and grades the features, obtains the evaluation results and stores them in the database.

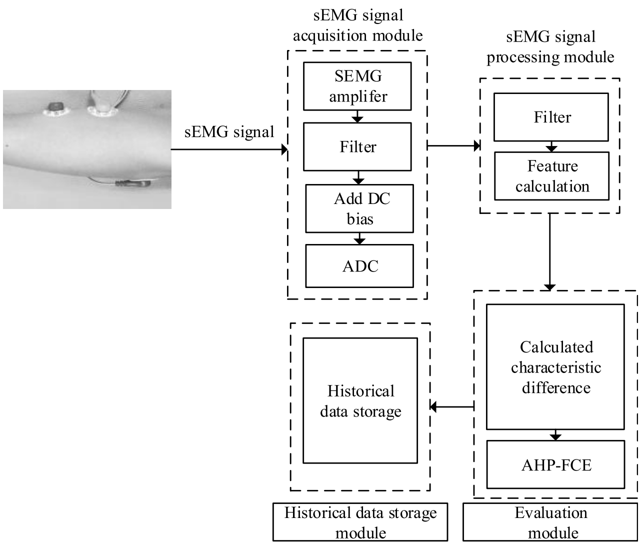


Fig. 1. a rehabilitation evaluation system based on sEGM signals

## A. System Composition

As mentioned above, the system is composed of four modules: sEMG signal acquisition module, sEMG signal processing module, evaluation module and historical data storage module.

### 1) sEMG signal acquisition module

This module is mainly used for the acquisition of sEMG. The acquisition of sEMG is the first step and the most critical part of the system. The integrity of the collected sEMG has a great impact on the subsequent modules. In this module, STM32F103ZET6 is the main control chip, and functions of amplification and filtering are constituted by integrated operational amplifier and peripheral circuit. Bluetooth BLE4.0 is used as the way for this module to communicate with the PC. The structure block diagram of the sEMG signal acquisition module is shown in Fig. 2.

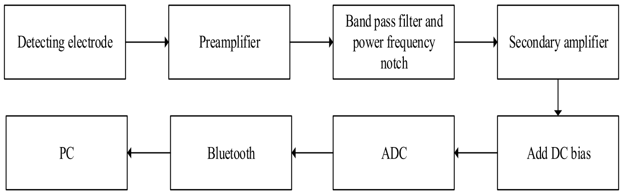


Fig. 2. sEMG acquisition module system diagram

### 2) sEMG signal processing module

As the key part of the whole system, this module is used to complete signal filtering and feature extraction. Only by selecting effective features can the evaluation be completed better.

#### a) Signal filtering

The signal is unbiased, and then a band-pass filter and power frequency notch is designed for the low frequency of sEMG to remove the influence of electrode motion artifact [6], ECG signal and other interference [7]. A band-pass filter with a sampling signal of 5000Hz is shown in Fig. 3.

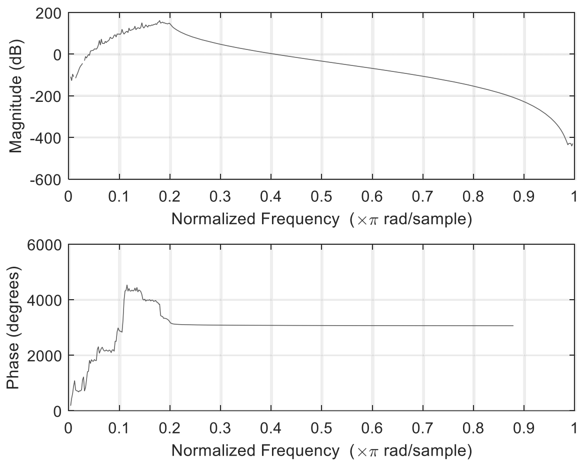


Fig. 3. The amplitude and phase response of the filter

#### b) Integrated electromyogram

Integrated electromyogram (iEMG) is the total amount of motor discharge per unit of neuromuscular activity over a certain period of time, which can reflect the fluctuation of the Electromyogram signal over time [8]. It is defined as follows:

$$iEMG = \frac{1}{N}\sum_{n=0}^{N-1}\left|x(n)\right| \tag{1}$$

Among them, $x(i)$ is sEMG, $(i = 0,1,2, \dots, N-1)$, N is the length of the data.

#### c) Root mean square

Root Mean Square (RMS) describes the average change of the signal amplitude, represents the average value of the signal, and has physical significance [9]. Although it can reflect the change of EMG amplitude with time in the time dimension, it cannot reflect the change of EMG in detail just like iEMG. It is defined as follows:

$$RMS = \sqrt{\frac{1}{N}\sum_{n=0}^{N-1} x^2(n)} \tag{2}$$

*d) Mean power frequency*

Mean power frequency (MPF), and can be referred to as the average Frequency Spectrum and the center frequency, the calculation is the focus of a time signal Power Spectrum Frequency, its size and uniformity, level of motor unit action potential, conduction speed, such as association, $P(k)$ is the signal power spectrum, it can describe the EMG signal Frequency characteristics [10], its computation formula is as follows:

$$MPF = \frac{\sum_{k=0}^{N-1} f(k)\cdot P(k)df}{\sum_{n=0}^{N-1} P(k)} \tag{3}$$

$f(k)$ is the frequency value of the k point in the sequence of frequency values, $f(k) = kf_N / N$, is the Nyquist frequency sampled. Numerically equal to half of the sampling frequency.

*e) Median frequency*

Median Frequency (MF) calculates the frequency at the midpoint of the power spectrum of a signal [11], so that the total power less than that Frequency is equal to the total power greater than that Frequency. The median frequency MF is $f_{median}$. It is usually associated with muscle fatigue [12]. Its calculation formula is as follows:

$$\sum_{k=0}^{f_{median}/2} P(k) = \frac{1}{2}\sum_{k=0}^{N-1} P(k) \tag{4}$$

*3) Evaluation module*

Evaluation of a patient's motor ability is one of the indispensable links in the process of patient rehabilitation. Rehabilitation evaluation is indispensable to the setting of rehabilitation goals and the improvement of rehabilitation effects for patients with upper limb motor dysfunction. In the process of rehabilitation evaluation, it is necessary to sort out the etiology and rehabilitation evaluation results and other relevant data, reasonably develop individual adaptive rehabilitation training plans according to the condition, track and evaluate the effect of rehabilitation treatment, and put forward targeted rehabilitation guidance [13]. For example, the Brunnstrom motor function recovery staging table is shown in Table 1.

TABLE I. BRUNNSTROM MOTOR FUNCTION RECOVERY STAGING TABLE

| installment | Spasticity |
|---|---|
| I | Flaccidity |
| II | Synergies some spasticity |
| III | Marked spasticity |
| IV | Out of synergy less spasticity |
| V | Selective control of movement |
| VI | Isolated/coordinated movement |

Although the detection technology and other contents of these clinical assessment methods have been very perfect, their qualitative or semi-quantitative assessment of patients often relies on the experience of rehabilitation doctors and is subject to great subjective influence of doctors, which makes the accuracy of test results low and difficult to quantify [14]. Therefore, it is the research content of this paper to design a set of comprehensive, objective and quantitative evaluation methods based on clinical evaluation criteria.

The difference between the characteristics of the affected side and the healthy side was calculated as the input characteristics, and the formula was shown as follows:

$$D = \frac{|C_1 - C_0|}{C_1 + C_0} \tag{5}$$

where D is the difference between the characteristics of the healthy side and the affected side. $C_0$ and $C_1$ are characteristic of the affected and healthy side, respectively.

AHP-FCE is a comprehensive evaluation method combining AHP and FCE, which solves the shortcomings of traditional clinical evaluation methods influenced by physicians' subjective factors and low evaluation accuracy [15]. AHP-FCE is an evaluation method combining qualitative and quantitative methods. AHP method determines the weight of indicators, and FCE method and AHP multi-level index weight are combined to determine the evaluation results, which can comprehensively and accurately evaluate the actual situation of the target problem [16]. Because the rehabilitation evaluation is a multi-level, multi-factor problem, involving the subjective and objective, qualitative and quantitative combination of comprehensive problems, so on this basis, this paper constructs the rehabilitation evaluation system.

*a) Modeling steps of the AHP-FCE method*

The modeling flow chart of AHP-FCE method is shown in Fig. 4. The specific steps of the model are as follows:

*b) Determine evaluation indicators*

The evaluation content of motor function rehabilitation of upper limb of target layer can be divided into two parts: motor function and coordination function, which constitute the second-level fuzzy evaluation factors [16]. Among these evaluation indexes, the motor function includes muscle strength and muscle tension, and the coordination function includes muscle coordination. Criterion layer of the first three evaluation index level fuzzy evaluation, respectively, calculated and corresponding criterion layer movement, balance and coordination functions of the evaluation results, the rule layer again the two evaluation results as the target layer of upper limb movement function for evaluating the effect of rehabilitation, the secondary fuzzy evaluation, the final evaluation results, the hierarchy chart of motor function rehabilitation evaluation structure diagram as shown in Fig. 5.

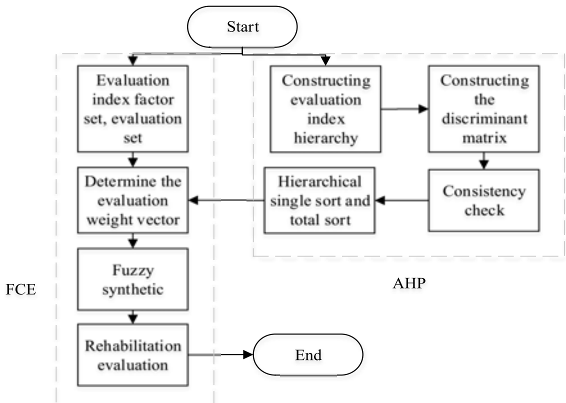


Fig. 4. Modeling steps of the AHP-FCE method

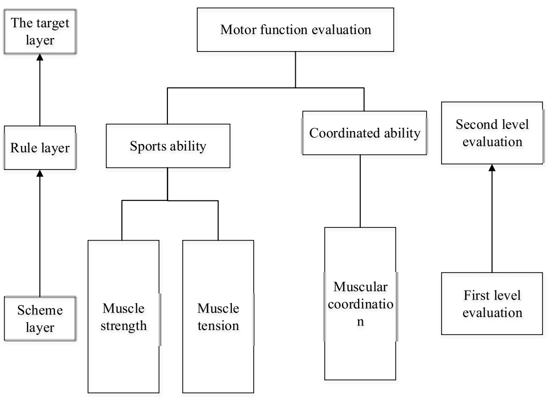


Fig. 5. Hierarchy chart of motor function rehabilitation evaluation

### 4) Historical data storage module

MySQL is used as a database development tool. According to the role and function of the upper limb rehabilitation system, the system database contains patients, rehabilitation evaluation, treatment plans and other relatively important data. The patient's historical data can be pulled out and the rehabilitation evaluation curve can be drawn, which has an important reference value for the patient's recovery.

## III. EXPERIMENTS AND RESULTS

To evaluate the efficiency and effectiveness of the proposed system, 11 patients who comes from Shandong Provincial Hospital of Traditional Chinese Medicine were selected for the evaluation experiment. Before the experiment, the subjects were informed of the specific process of the whole experiment. Each subject need complete 20 tests of this experiment, including 10 exercises on the affected side and 10 exercises on the healthy side. The time schedule of one trial is shown in Fig. 6.

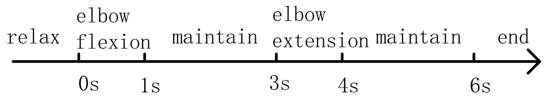


Fig. 6. time schedule of one trial

### A. Experimental Steps

1) Wipe and disinfect and clean the measured part with alcohol cotton pads;

2) The electrodes are attached to the corresponding part of the subject;

3) Each subject was tested in 20 groups, and each group was about 120S;

4) During the experiment, the subjects followed six stages: relaxation, elbow flexion, hold, elbow extension, hold, and end;

5) After the experiment is completed, the measured part of the subject is cleaned.

### B. Experimental Results and Analysis

A total of 11 patients were tested in this experiment, among which the rehabilitation rating of S4 and S10 patients was unknown (replaced by "*"), and the data of S5 patient was abnormal due to the large muscle strength beyond the measurement range set by me. This system maps the grading of rehabilitation evaluation to 1-9, and the higher the rating score, the better the rehabilitation results. Among them, 1-3 are poor recovery; 4-6 Restore general; 7-9 Good recovery. The experimental results are shown in Table 2.

TABLE II. EXPERIMENTAL RESULT

| **Subjects** | **Rehabilitation rating** | **Results of EMG signal evaluation** |
|---|---|---|
| S1 | BrunnstromⅣ | 6 |
| S2 | BrunnstromⅢ | 4 |
| S3 | BrunnstromⅢ | 3 |
| S4 | * | 2 |
| S5 | BrunnstromⅣ | 3（data exception） |
| S6 | BrunnstromⅣ | 5 |
| S7 | BrunnstromⅣ | 6 |
| S8 | BrunnstromⅢ | 4 |
| S9 | BrunnstromⅣ | 6 |
| S10 | * | 8 |
| S11 | BrunnstromⅢ | 4 |

Excluding S4, S5 and S10, according to the experimental results and the evaluation results given by the hospital, the evaluation accuracy of the experiment is 87.5%, indicating the feasibility of the rehabilitation evaluation system established in this paper. With the increase of the number of tests, the validity and accuracy will change, and more experiments and results are needed to verify.

## IV. CONCLUSION

With the continuous development of biological signal acquisition and processing technology, researchers have gradually introduced bioelectrical signal analysis method into the field of rehabilitation function evaluation to provide more comprehensive and accuracy evaluation system. In this paper, sEMG information was combined with clinical rehabilitation evaluation indexes to study the feasibility of sEMG in upper limb rehabilitation evaluation, and a rehabilitation evaluation system based on AHP-FCE method was constructed to realize comprehensive and quantitative rehabilitation status evaluation and database system. The corresponding experiments conducted on the stroke patients demonstrated the efficiency and effectiveness of the proposed evaluation system.

Rehabilitation evaluation is a complex problem involving multiple factors and levels. Further research and development should be put on the following areas: enriching more patients' data to build the patients' datasets; extracting more effective features; improving the robustness of the evaluation system, et al.

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