An Active Rehabilitation System for Adhesive Capsulitis

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Abstract. Adhesive capsulitis is a stick of shoulder capsule that causes stick due to acute or chronic inflammation. It will cause serious impacts on patient’s daily life. Rehabilitation agencies used a shoulder abduction ladder, Pulley System for Upper Limb rehabilitation. Without electronics, networking is its drawback. The system digitizes an upper extremity rehabilitation equipment, and records the patient's rehabilitation information, such as the ability to lift the upper limbs, rehabilitation time and frequency, and so on. In addition, the system uses the Gray relational analysis to evaluate the rehabilitation efficacy. Physicians can know the patient's condition to improve his rehabilitation strategy. Patients can also know their rehabilitation effects so to encourage their rehabilitation psychology, so the arms can be recovered early.

Introduction
In the area of treatment of shoulder disease, the emphasis is on the reconstruction of the function of the shoulder to restore its mobility, such as shoulder extension, loosening (such as arthroscopic surgery) and physical therapy (such as ice packs, heat packs, ultrasound, Far infrared, etc.) and so on. Commonly used exercises rehabilitation [1] for Shoulder joint diseases are finger climbing wall movement, scapula activity, pendulum movement, end plate movement, pull rod movement, behind raised his hand movement; for patients who cannot lift the upper limbs, physicians or therapists will ask patients to perform rehabilitation using the Wall finger ladder and Shoulder abduction ladder [2,3].

The traditional shortening rehabilitation apparatus in Figure 1 has the following disadvantages: (1) It does not have the ability to lift the upper extremity, the number and time of rehabilitation and other immediate measurement display device. (2) Without the function of rehabilitating information record and monitoring. (3)Without the database function, the patient's rehabilitative data cannot be stored in the storage device for a long time. (4) It cannot provide quantitative indicators as a reference to assess the effect of rehabilitation.

The main purpose of this system is to construct a new set of active frozen shoulder rehabilitation systems to improve the above-mentioned shortcomings of conventional finger ladder rehabilitation equipment listed in Figure 1 to record the patient's rehabilitation information for a long time, such as the ability of the upper limbs to lift, the time and frequency of rehabilitation, and so on.

System Architecture
The main objective of this system is to improve some of the traditional ladder-like rehabilitation equipment, and to redesign a set of active frozen shoulder rehabilitation equipment with electronization and networking, which has the functions of rehabilitation of the upper limbs. The system architecture block diagram shown in Figure 2 has the rehabilitation of people standing in front of the rehabilitation platform, with the index finger or middle finger hard touching the bottom of the flat-panel button, and slowly moving up along the flat-panel buttons, upper extremities as much as possible, and then slowly scrolling back to the bottom flat button. Each flat button should be pressed and stay for a period of time to achieve Isometric contraction movement purposes.
Flat Button Mechanism

According to the rehabilitation requirements of the ladder in Figure 1, the fingers must be used to suppress the floor of each step ladder plate, and the system is based on aluminum extrusion connector and additional components to replace the ladder plate of Figure 1. As shown in Figure 3, four buttons are embedded in the four holes on the outside of the bottom plate, and are connected in parallel, and then a flat plate is added thereon to form a large flat plate button. When the finger presses the tablet, more than one button will be connected, and the LED lighting device will be on at the same time. Placement of 20 flat-panel buttons in the square-shaped aluminum castings results in a flat button mechanism as shown in Figure 4 with a pitch of 4.5 centimeters.

Lift Height Monitoring

Lift height tests for rehabilitation persons are implemented by the monitor control circuit in Figure 2. Monitoring control circuit consists of two parts: flat-panel button monitoring circuit and LED light-emitting device driver circuit. Flat-panel button monitoring circuit is used to detect whether the flat-panel button is pressed, and its number is sent to the embedded system (single-chip PIC18F4520). The embedded system then turns on the LED on the tablet button through the LED driver circuit so that the rehabilitation persons can know the current lift position of the arms.

Man-Machine Interface

In the system of man-machine interface design, the PC-side and single-chip microprocessor (PIC18F4520) side are using NI's LabWindows CVI and MPLAB C18 to develop. The therapist through the CVI program issues a command to the single-chip microprocessor to perform, and CVI program will monitor the rehabilitation message, which is presented on the screen.
Rehabilitation Efficacy Evaluation

The main purpose of the system is to raise the level of activity in the training of rehabilitation, and its movement track is up and down movement. The main efficacy of the system is to assess the two factors, each course of treatment on the highest position $M_p$ of the arm on the tablet and arm movement speed (average duration $T_{(avg)}$ of the treatment table). In the two assessment factors, the $M_p$ is greater than $T_{(avg)}$; moreover, each rehabilitation includes a number of courses of treatment, so they can be constructed into a matrix $R$ of $m \times 2$ rehabilitation data, in which $m$ is the actual number of courses for the rehabilitation person, the preceding $M_p$ or following $T_{(avg)}$: with $p = 1, 2, ..., m$.

$$R = \begin{bmatrix} M_1 & T_{(avg)} \\ M_2 & T_{(avg)} \\ \vdots & \vdots \\ M_m & T_{(avg)} \end{bmatrix} = \begin{bmatrix} x_{11} & x_{12} \\ x_{21} & x_{22} \\ \vdots & \vdots \\ x_{m1} & x_{m2} \end{bmatrix}$$

For the rehabilitation data matrix, the system uses the localized gray relational grade in the gray system theory [4] proceeds Gray multiple attributes decision-making. From the second course of treatment, the best rehabilitation is found from $m$ course of treatment as the efficacy of the rehabilitation evaluation index.

The basic steps of local gray incidence are as follows:

1. Find a reference series and a comparison series from the Rehabilitation Data Matrix.
2. Gray association generated

   The data processing and normalization of the sequence are called gray incidence generation. The commonly used methods are expected to be large-scale, small-sized and look-ahead type [5,6,7]. The greater he aforementioned maximum plate position $M_p$ the better, while the smaller the average treatment time $T_{(avg)}$ the better. Therefore, The-Larger-The-Better and The-Smaller-The-Better are used to generate gray correlation to meet the gray system comparability:

   (a) The-Larger-The-Better

   $$x_{ij}^* = \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}}$$

   (b) The-Smaller-The-Better

   $$x_{ij}^* = \frac{\max x_{ij} - x_{ij}}{\max x_{ij} - \min x_{ij}}$$

   wherein $x_{ij}$ is the original data of the rehabilitative data matrix $R$, and $x_{ij}^*$ is the data after the gray relation is generated, $\min x_{ij}$ is the minimum value in the item j, and $\max x_{ij}$ is the maximum value in the item j. Based on Formula (1), $i = 1, 2, ..., m$, $j = 1, 2$.

3. Calculate the gray relational distance $\Delta_{ij}$

   $$\Delta_{ij} = |x_{ij}^* - x_{ij}^*|$$

   where $X_{ij}^*$ is the reference series of gray incidence data.

4. Calculate Grey relational coefficient $r_{0ij}$

   The Gray correlation coefficient according to the definition of reference sequence can be divided into “Local Gray Correlation Measures” with only one reference sequence and Either sequence can be a "Holistic Gray Correlation Measures " with any reference sequence. The system uses the former.
\[
\gamma_{oj} = \frac{\Delta_{\min} + \zeta \Delta_{\max}}{\Delta_{oij}(k) + \zeta \Delta_{\max}}
\]

(5) Calculate Grey relational grade \( \Gamma_{oij} \)

\[
\Gamma_{oij} = \sum_{j=1}^{w_j} \left[ w_j \times \gamma_{oj} \right]
\]

wherein \( w_j \) is weight. Equal weight, Rank sum weight, Rank reciprocal weight, Eigenvector method, Entropy method and hierarchy Analytical methods (AHPs) are available for weighting [8], but the sum of all weights must be equal to one. There are two evaluation factors in this system, where \( M_p \) weight is greater than \( \overline{\tau}_{avg} \) weight, so the system default for the former weight 0.6 and the latter set as the weight 0.4.

(6) Arrange Grey relational ordinal

According to the sort of gray relational value calculated, the greater \( \Gamma_{oij} \) the better rehabilitation status.

Based on the above steps, it can be found in a rehabilitation that the best course of rehabilitation is used as the efficacy of the rehabilitation evaluation index. The lifting capacity and arm speed in Figure 5 are shown in Table 1, where for the lifting capacity, treatment course 2 is the best; for the arm speed treatment course 10 is the best; after gray correlation analysis, the treatment course 10 has highest Gray correlation value; therefore, it is set as the rehabilitation efficacy evaluation: The lift capacity is plate 15, and arm speed is 3.7 seconds. The actual number of treatment sessions for these two parameters and \( m \) treatments of the rehabilitation person are stored in the SQL database.

<table>
<thead>
<tr>
<th>Treatment type</th>
<th>Average time ( \overline{\tau}_{avg} )</th>
<th>Highest position ( M_p )</th>
<th>Gray correlation generated ( \overline{\tau}_{avg} )</th>
<th>Grey Relational Grade</th>
<th>Sort</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.4</td>
<td>11</td>
<td>0.5278</td>
<td>0.4667</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>5.1</td>
<td>16</td>
<td>0.5758</td>
<td>0.7455</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>4.0</td>
<td>14</td>
<td>0.8637</td>
<td>0.7582</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>6.7</td>
<td>12</td>
<td>0.3878</td>
<td>0.4404</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>7.5</td>
<td>14</td>
<td>0.3333</td>
<td>0.3526</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td>7.0</td>
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<td>0.3654</td>
<td>0.6071</td>
<td>4</td>
</tr>
<tr>
<td>7</td>
<td>4.6</td>
<td>13</td>
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<td>0.4073</td>
<td>7</td>
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<tr>
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<td>12</td>
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<td>0.4073</td>
<td>7</td>
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<td>7.3</td>
<td>13</td>
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</tr>
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<td>1</td>
</tr>
<tr>
<td>Reference sequence</td>
<td>3.7</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Total Assessment of Rehabilitation Efficacy**

After a period of rehabilitation (such as \( M \) rehabilitation treatments), the rehabilitation will be concerned about whether the rehabilitation makes progress. According to the above, after each rehabilitation, it can be obtained from the second course of the best lifting abilities and arm speed as a curative effect evaluation index; for the second rehabilitation effect, the gray system is also as the assessment tool, and the process is the same as the previous section. However, there are three evaluation factors: the number of rehabilitation courses, lifting capacity and arm speed. In the gray relational generation, the former two take “The-Larger-The-Better”, while the later one takes “The-Smaller-The-Better”; The number of treatment has a great effect on the rehabilitation effect. For the weight of the three, the system default orders are 0.45, 0.3 and 0.25. If the rehabilitation
person's recent gray relational values are not ranked at the anterior stage, the therapist must explore
the causes and alter their rehabilitation strategy.

Conclusion
The system entity is shown in Figure 6. The system does improve the shortcomings of the traditional
referral ladder rehabilitation equipment in Figure 1, and can record the patient's rehabilitation
information for a long time, such as the ability of the upper limbs to lift, the speed of the arm
movement and the number of rehabilitation times, which can reduce the human resource dispatch of
the medical staff burden. The system uses gray correlation to assess the rehabilitation efficacy so that
the therapist can know the rehabilitation status of the rehabilitation persons so that different
rehabilitation strategies can be adopted to allow the rehabilitation persons to resume their arms as
soon as possible. Meanwhile, the rehabilitation efficacy evaluation data is displayed on the screen, so
that those who immediately see their efficacy can inspire their rehabilitation psychology, restoring
the original function of the shoulder as soon as possible.

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