Preliminary Study on Upper Limb Movement Identification Based on sEMG signal

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Abstract – Stroke has become a very prevalent disease, especially in elder people. Many researches have focused on developing advanced and intelligent robotic system to assist the treatment of patients. For this field, Electromyography (EMG) is widely used for its benefit to get valuable information about the neuromuscular activity of a muscle. In this paper, wavelet packet decomposition method which is a kind of time-frequency domain is used for movement identification. Appropriate coefficients between three important movements for ADLs and sEMG signal will be extracted with wavelet packet decomposition method. These coefficients could be used as the input of BP neural network for movement identification. Experimental results proved that this method is effective off-line. Whereas the on-line identification rate should be improved in the future works.

Index Terms – sEMG; Wavelet Packet Decomposition; BP neural network; Virtual arm;

I. INTRODUCTION

According to the World Health Organization, 15 million people suffer stroke worldwide each year. Of these, 5 million die and another 5 million are permanently disabled [1]. Nowadays, there have many kinds of rehabilitation robotics system that assist persons who have a disability with necessary activities. Since 1980s, some best-known clinically tested upper-limb therapy robot systems have been developed. The mirror image movement enhancer (MIME) system used a Puma-560 robot arm to assist in movement of patient’s arm[2]. Guo and Song developed an active rehabilitation system. In this system, patients operate a haptic device and an inertia sensor to perform a tracking task in virtual environment with coordination training [3]. In 2010, Guo and song also developed a new upper limb exoskeleton rehabilitation device (ULERD). It is lighter and suitable for home-rehabilitation [4]. Recently years, the development of EMG biofeedback has more benefit compared with other sensors. Electromyography (EMG) is a technique for evaluating and recording the electrical activity produced by skeletal muscles [5]. In other word, EMG signal provides a method to directly “look” into the muscle. The EMG signals are important information to understand how the human subject intends to move. Consequently, the EMG signals can be used as input information for the robotic systems [6][7]. There are two methods to detect the EMG signal [8]. One is invasively by inserting a needle electrode through the skin. Another is non-invasively by mounting a surface electrode on the skin overlying the muscle, which is also called sEMG. According to the model of sEMG, Motor Unit Action Potentials (MUAPs) originating from surface muscles has higher frequency and magnitude than those from deeper muscles. In this paper, we detected and processed the sEMG signal.

The processing of EMG signal mainly includes four phases: signal acquisition, signal segmentation, feature extraction and classification. However, due to the complexity of the EMG signals, an important requirement for application is to improve the accuracy of pattern classification. There are many methods proposed many years ago. In general, they can be separated into three types: time domain, frequency domain and time-frequency domain according to analysis methods [9]. Time-domain method main include Integrated EMG (IEMG), Mean Absolute Value (MAV), Root Mean Square (RMS), and so on [10][11]. Frequency domain method main include Auto-Regressive coefficients (AR), Modified Frequency Median (MFMD) and so on [12][13]. The wavelet packets method is a time-frequency domain which is a generalization of wavelet decomposition that offers a richer signal analysis. Especially, wavelet packets method is much smarter in that the number of filters is adapted by considering signal entropy to find the best tree.

In this paper, three important upper limb movements for Activities of Daily Living (ADLs) will be analyzed. And wavelet packets method is used to find effective coefficients between movements and EMG signals. After it, a BP neural network which is suit for dealing with non-linear signal will be used for movement classification during a continuous movement. In order to ensure this method is safety when used on the real rehabilitation device in the future, a (Virtual Reality) VR arm model built by OpenGL is used just to check the accuracy rate at last. At the last part of this paper, some conclusions and future works are carry out.

II. EXPERIMENTAL IMPLEMENT
A. Proposed Rehabilitation System

Upper Limb Exoskeleton Rehabilitation Device (ULERD) (Fig1) which is a new rehabilitation device is proposed. It is designed to provide assistance to a patient’s impaired upper limb including elbow extension or flexion, forearm pronation or supination, and wrist flexion/extension. Especially, it is wearable and suit for home-rehabilitation [14].

![Fig1. Upper Limb Exoskeleton Rehabilitation Device](image)

For some stroke patients, they have no ability to move his/her arm easily. That is to say, conventional inertia sensor cannot work which detects the angle or velocity. EMG information can record the electrical activity produced by skeletal muscles. That means although the injured arm can not move itself, while, the ULERD can give assistant after recording the EMG signal and correct movement identification. If interactive machines can detect human behaviors and understand their intention, the machines can provide adequate supports. However, there has a problem that if the identification rate is not ideal, it will be very dangerous for patients even small error. Although the ULERD design is evaluated by physical therapists with rich experience.

Next, several important part for EMG identification include signal acquisition; feature extraction and signal classification will be introduced.

B. Signal acquisition

![Fig2. Signal acquisition system](image)

Fig2 shows the signal acquisition system used in our research. The Personal-EMG equipment was developed by Japan’s company in Osaka. It has eight channels used to extract the EMG signal. Surface EMG is chosen, since it is non-invasive and can be conducted by personnel other than technical medical doctors. Personal-EMG also provides a hardware filter function. MTx sensor shows in Fig2 which is a kind of inertial sensor called MTx sensor. At the same time of signal acquisition, it is used to record the movement angle. The angle information can used to calibrate the motion and provide output target for Artificial Neural Network (ANN).

For the experiment, we main consider about several important movements for Activities of Daily Living (ADLs) which is a term used in healthcare to refer to daily self-care activities within an individual’s place of residence, in outdoor environment, or both.

The final purpose of rehabilitation for stroke patients is to reinstate his/her ADLs. There are several important abilities for ADLs include elbow flexion/extension; forearm pronation/supination and wrist flexion/extension (TABLEII).

Each motion was detected with a pair of electrodes mounting on given places after antiseptis. The detected sEMG signal were amplified and then converted by A/D converter with 1 kHz frequency using Interface PIC 3165. There have five subjects (TABLE I) participated in this experiment. They did not report any physical injury or neurological illness that would impair movement function.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Sex</th>
<th>Age</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>Male</td>
<td>29</td>
<td>Healthy</td>
</tr>
<tr>
<td>S2</td>
<td>Male</td>
<td>24</td>
<td>Healthy</td>
</tr>
<tr>
<td>S3</td>
<td>Male</td>
<td>22</td>
<td>Healthy</td>
</tr>
<tr>
<td>S4</td>
<td>Male</td>
<td>21</td>
<td>Healthy</td>
</tr>
<tr>
<td>S5</td>
<td>Male</td>
<td>24</td>
<td>Healthy</td>
</tr>
</tbody>
</table>

They are required to perform motions mentioned above without any constraint on their limbs. The position of dry electrodes was put on given position shown in TABLE II following different motions (Fig4).

<table>
<thead>
<tr>
<th>Motion</th>
<th>Muscles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elbow extension</td>
<td>Bicipital muscle</td>
</tr>
<tr>
<td>Elbow flexion</td>
<td>Triceps muscle</td>
</tr>
<tr>
<td>Palmar flexion</td>
<td>Extensor carpi ulnaris muscle</td>
</tr>
<tr>
<td>Dorsal extension</td>
<td>Flexor carpi radialis muscle</td>
</tr>
<tr>
<td>Wrist pronation</td>
<td>Flexor carpi ulnaris muscle</td>
</tr>
<tr>
<td>Wrist supination</td>
<td>Extensor carpi ulnaris muscle</td>
</tr>
</tbody>
</table>
In elbow extension/flexion experiment, every subject was required to lift his forearm from vertical plane to horizontal plane, and keep forearm stable for a while and then extended forearm back to vertical plane (1) and (2). In forearm pronation/supination motion, every subject should start from Fig4 (4) and pronation to Fig4 (3) and turn back to Fig4 (4) and then supination to Fig4 (5). In palmar flexion and dorsal extension, every subject was required to start form Fig4 (7) and follow the same regular as forearm during all of experiments. The motions of upper limbs were detected with inertia sensor (MTx sensor). Every movement was required to do fifteen times with same method.

Experimental results were filtered with the hardware filter providing by Personal-EMG and converted by A/D board for the next processing.

![Fig4 Three ADLs motions of upper limb](image)

C. Signal feature extraction method (WPT)

The sEMG signal acquisition contained some noises, which should be filter. The frequency of sEMG is usually within 0-500Hz. Otherwise, dominant EMG signal energy focus on the frequency of 10-150Hz. Some important information will lost in the frequency domain using Fourier analysis. Compared with it, the wavelet transformation method can cut a signal into shifted and scaled versions of the original wavelet (or mother wavelet). Wavelets can determine if a quick transitory signal exists, and localize it. This feature makes wavelets become an effective method for EMG processing [15]. In this paper, Wavelet packet transform is employed here to decompose the signal into different frequency ranges for further research. It is much smarter than filter banks in that the number of filter is adapted by considering signal entropy to find the best tree. Information in high frequencies can be analyzed as well as in low frequencies in wavelet packet transform (Fig 5).

![Fig5. Decomposition tree and the level of decompositions](image)

After the processing of Wavelet Packet Decomposition, several levels were received. However, it is important to judge which level contains more information about upper limb motion using the best tree method. TABLE III shows the results screened with statistics method. These wavelets are most happened during motion.

<table>
<thead>
<tr>
<th>Motion</th>
<th>Wavelet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elbow extension</td>
<td>u2 and u3</td>
</tr>
<tr>
<td>Elbow flexion</td>
<td>u2 and u3</td>
</tr>
<tr>
<td>Palmar flexion</td>
<td>u0 and u1</td>
</tr>
<tr>
<td>Dorsal extension</td>
<td>u2 and u3</td>
</tr>
<tr>
<td>Wrist pronation</td>
<td>u0 and u1</td>
</tr>
<tr>
<td>Wrist supination</td>
<td>u0 and u1</td>
</tr>
</tbody>
</table>

![Fig6. u0, u1 and angle value of elbow extension and flexion](image)

The EMG signal should be detected before the start of movement. EMG detects the electrical potential generated by muscle cells when these cells are electrically or neurologically activated. While u2 and u3 got by best tree cannot reflect this feature obviously. Instead of u2 and u3, u0 and u1 are analyzed next showed in Fig6. It shows the connection between movement angle and wavelet packet decomposition coefficients. It can be known that before the start of elbow flexion, the information can be obtained from the EMG signal in bicipital muscle.

![Fig7. u2, u3 and angle value of palmar flexion and dorsal extension](image)

With the same method used for elbow extension and flexion, another two movements were also been calculated.
These results can reflect that the signal processed by wavelet packet decomposition contains the information of movements. Fig7 and Fig8 just show two typical examples.

Fig8. $u_0$, $u_1$ and angle value of wrist pronation and wrist supination

In this part, wavelet packet decomposition is used to achieve EMG feature analysis of human upper limb movements. Considering the best tree method, EMG information of human upper limb movements most contains in low frequency level. However, these analysis results have difference among different volunteers.

D. Signal classification method (The Feed-Forward Neural Network Model)

Different kinds of neural network models of muscle activations have been applied to classify the human body motion pattern frequently in which the feed-forward back-propagation neural network is adopted mostly [16]. To construct a complex nonlinear model such as EMG signal, artificial neural network also seems to be a good choice. In this part, a three-layer BP Artificial Neural Network (ANN) method is used for classification. The BP neural network is trained to simulate the pattern recognition procedure. Fig9 shows the experimental process of BP neural training of elbow extension and flexion using Matlab. Training used input data was random selected from three groups within total fifth groups of one person. Experiment data first proceed with the Wavelet Packet Decomposition and then low frequency levels were selected. These levels are most happened frequency with best tree method mentioned above. In this training, 70% data were used to train the net, 15% were used as validation, and the last 15% were used for testing. The middle layer is chosen twenty. The MTx sensor could get the angle within experiments. Every data can be cut into four parts according to the angle. From D1 to D4 (start position; flexion; stop from flexion; extension) just describes different stage of the whole flexion/extension motion in Fig10. And then these separated data were used as the input value of neural network. The targets of ANN are four conditions form D1 to D4.

Another two movements which are palmar flexion/dorsal extension and wrist pronation/supination also be got with same method (Fig11 and Fig12).

III. EXPERIMENT RESULTS

I. Results of the motion identification
From the training confusion Matrix results, some information about motion identification could be obtained. Red block means percentage of misjudge. In the country, green block represents the correct judgment. The identification results are almost close to 100%. However, it is just the off-line classification rate. If it is used in real rehabilitation system, on-line rate is more important.

In this part, BP neural network is used to achieve human upper limb movement identification with EMG signal. The identification rate of thee movement is proved high. However, it cannot identify the movement angle or velocity. Another problem is that, the net trained by one volunteer is not suit for the other volunteers. So, at the beginning of training, a new dedicated net should be trained first. We have developed an on-line training system used for it. It has several functions from EMG signal extraction; train a net and on-line identification.

C. VR BASED CHECKING SYSTEM

Until now, identification of upper limb's three motions with ANN has realized. In this part, a VR system was built using OpenGL aiming at checking the on-line classification rate. This is very important to verify whether the identification rate or this kind of EMG processing method is suit for real rehabilitation device or not. After several experiment with elbow flexion and extension experiment, it is found that the results are not very perfect, sometimes error would happen.

IV. CONCLUSIONS

In this paper, the raw EMG signal firstly filtered by hardware filter of Personal-EMG device. In order to realize the upper limb motion pattern identification, signal feature method was used. Among lots of feature extraction method, the wavelet packet decomposition was choosen for the reason that it offers a riher range of possibilities for revealing signal information. BP artificial neural network was used to do the classification. A VR checking system was proposed to prove the feasibility for the future use on real rehabilitation device. After several VR experiments, it is found that if the ANN is adopted for on-line identification, the results are not so perfect. But it can be known that wavelet packet decomposition method is feasibility and effective used for motion identification for its high off-line identification rate. In the future, several plans are implemented. 1) Improve the on-line motion identification rate. 2) Instead the virtual arm with Upper Limb Exoskeleton Rehabilitation Device on the premise of safety.

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REFERENCES


