On a Wavelet Transform and Neural Network for Motion Discrimination from Myoelectric Signal for Robots Aimed Robot Therapy

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A real-time performance and strictness is important to apply myoelectric signal for control of a well-fare robot such as a prosthetic hand, rehabilitation and robot therapy. Past researches also has tried to discriminate a human motion from myoelectric signal in a moment for real-time performance, so that the signal can be apply to robot control. There is a paper to describe a method to discriminate six motions from myoelectric signals within 100ms. It’s probability, however, of some motions are less than about 80 %. In order to apply myoelectric signal to robot control, it is serious to discriminate a human motion correctly. Moreover it should be 100 % as close as possible. Additionally there is a paper to report that the accuracy of motion discrimination falls when myoelectric signal comes through couple neighboring muscles is analyzed by neural network method. Therefore, it might be said that to apply a neural network method for such a problem like past trials would have difficult to reach near 100 % accuracy of discrimination of human motions from myoelectric signal. The purpose of this paper is to develop a motion discrimination method from myoelectric signal within 80 ms data from start to measure, with almost 100 % probability for a real-time performance and strictness. In this paper, the myoelectric signal generated in muscles of a forearm of right hand is analyzed using combination of market wavelet analysis and three-layered neural network and the motions which are “Grasp”, “Flexion of wrist” and “Pronation” of a right hand are discriminated. A bipolar method is used to measure three kinds of myoelectric signal generated in three muscles related with each motion. Through the tests of 87 times for a subject and 300 times for another subject, the validity of the proposed method is confirmed. As a result, for a subject, all of three motions are identified completely without mistake, for another subject, the result showed very high identified completely without mistake, for another subject, the result showed very high identification ability of the proposed method such as 94 % for “Grasp”,100 % for “Flexion” except “Pronation”.

1. INTRODUCTION

Because of very strong correlation of a myoelectric signal with human motions, there are several reports that a myoelectric signal is going to be applied to many areas such as application for health care devices, control of teleoperated robot and virtual reality.

There are reports to apply myoelectric signal to a welfare apparatus and a manipulator [1]-[9]. In these studies, positions to measure myoelectric signal differ in a purpose of study, such that in a study, that signal is measured at face and neck [1], in other study, that is measured at forearm or around eyes [2], or at arm or forearm [3]-[10].

At the same time, in the case of actual application of myoelectric signal, there are many causes to make it difficult such as attached position of an electrode, a measurement method of a myoelectric signal, an effect from fatigue of muscle and mixture of myoelectric signal from many muscles into one electrode. Therefore, it is generally difficult to get a high relationship between a myoelectric signal and motions of a human without special analysis of the signal. Because of these problems, there is a report to refer that the probability of discrimination of motion from a myoelectric signal is decreased when the experiment is done continuously [3].

Therefore, a myoelectric signal generally includes nonlinear components. So far, in order to discriminate motions from these or such a nonlinear signal, a neural network has been widely used [1]-[10].

It is said that a visible motion of arm occurs about 30 ms to 100 ms behind after muscle start to being contracted by myoelectric signal [11]. Therefore, if time to discriminate a motion from a myoelectric signal exceeds 100 ms, a time delay between operation and response of an object device will not neglected. Obviously, the allowable time delay differs from systems. But the time delay should as small as possible.

There are papers focused on a real-time performance of motion discrimination from myoelectric signal, in that papers, myoelectric signal till only 75 ms or 100 ms from start to measure are analyzed by neural network method. In such a paper, however, the probability of discrimination for some motion is around 70 % to 80 %, still this accuracy is not enough to apply the signal to control [4], [7]. On a discrimination of motions using neural network, there is a report to say that the accuracy of motion’s discrimination decreases when contracting muscles are nearby [4].

In the case to apply system based motion discrimination from myoelectric signal to welfare apparatus, the motion discrimination system must work correctly. On the other hand, there is a case that a system which is able to respond quickly is considered as useful even if the probability of discrimination is around 90 %.
So, in this paper, Motions that contracting muscles are nearby are targeted, because accuracy of motion’s discrimination decreases by using neural network.

In order to realize high probability and real-time performance in motion discrimination from myoelectric signal, a new system which is combination method of a wavelet transform and three-layered neural network method is proposed.

2. TARGET MOTION AND ITS DISCRIMINATION SYSTEM

2.1 A motion discrimination system from a myoelectric signal

Fig. 1 shows a proposed discrimination system of myoelectric signal using combination of a wavelet transform and three-layered neural network.

First, a myoelectric signal within 80 ms from electrodes of 3 positions on an operator’s forearm of right hand is measured. Next, the measured signal is normalized by the maximum value. The normalized value is analyzed by the three-layered neural network. And then, motion correspond to an output value is chosen. Finally, the most frequently selected motion of all selected motion on each electrode position is decided to a discriminated motion.

2.2 Intended motions of discrimination and positions to get a myoelectric signal

The intended motions of discrimination are shown in Fig. 2. It denotes that “Grasp” is “Grasp”, “Flexion of wrist” is “Flexion” and “Pronation of forearm” is “Pronation” in Fig. 2. After this, the each motion is denoted as showing in Fig. 2. And positions to measure myoelectric signal are shown in Fig. 2. “Pronation 1” is on the constricting flexor digitorum superficialis at “Grasp”, “Position 2” is on the constricting flexor carpi ulnaris at “Flexion” and “Position 3” is on the constricting pronator teres at “Pronation”.

A myoelectric signal is measured from each point at sampling frequency 1000 Hz, voltage gain 2500 and cutoff frequency 1000 Hz.

3. A MOTION DISCRIMINATION METHOD FROM MYOELECTRIC SIGNAL

It is said that it takes about 30 ms to 100 ms to occur visible motion after a muscle received myoelectric signal and contraction of muscle started. Therefore, to dispose at nearly a real-time, in this study, signals within 80 ms from start to measure are analyzed.

3.1 Morlet wavelet transform

A wavelet transform in this paper is one of general wavelet transforms, so called morlet wavelet transform. The mother wavelet of the morlet wavelet \( \psi_{(t)} \) is follows;

\[
\psi_{(t)} = \frac{1}{\sqrt{a}} \left( e^{2\pi i f_0 t} - e^{-\frac{(2\pi f_0)^2}{2}} \right) e^{-\frac{t^2}{2}}
\]

where, \( t \) denotes the time and \( f_0 \) denotes the center frequency which is 0.849 in this paper as well as generally used.

Based on this mother wavelet transform, each parameters in this wavelet transform are defined as follows.

\[
t = \frac{(t - b)}{a}
\]

(2)

where \( a \) denotes a parameter to decide a range of a window of the wavelet and \( b \) denotes a parameter to decide a position of the wavelet.

By substitute equation (3) for (1)

\[
\psi_{\frac{(t-b)}{a}} = \frac{1}{\sqrt{a}} \left( e^{2\pi i f_0 \frac{(t-b)}{a}} - e^{-\frac{(2\pi f_0)^2}{2} \frac{(t-b)^2}{a^2}} \right) e^{-\frac{t^2}{2}}
\]

(3)

Additionally, for an input signal \( x_{(t)} \), \( x_{(t)} \) is transformed by using (3) and an output of the wavelet transform, \( T_{(a,b)} \), is as follows;
\[
T_{(a,b)} = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} x(t) \psi\left(\frac{t-b}{a}\right) dt
\]

(4)

In the propose method, first, obtain a absolute value of (4) and then normalizes each value by an absolute maximum value. And then, the characteristic of myoelectric signal is extracted by these results of analysis. In addition, the frequency wavelet transform is given by

\[
f = \frac{f_0}{a}
\]

(5)

In this paper, the time \( t \) in (2) is from 0 to 80 ms with 1 ms interval, and the position \( b \) in the wavelet is from 0 to 80 ms with 10 ms interval. Additionally, in (5), for \( a \) which is denoted the window range of the wavelet, \( f \) is changed from 50 Hz to 150 Hz with 10 Hz interval.

The results of the wavelet transform is 8 data due to transformation with 10 Hz interval about the frequency range from 50 Hz to 150 Hz. Therefore, a given data through due transformation with 10 Hz interval about the frequency range from 50 Hz to 150 Hz with 10 Hz interval. The results of the wavelet transform is 8 data due to transformation with 10 Hz interval about the frequency range from 50 Hz to 150 Hz with 10 Hz interval. Therefore, a given data through the wavelet transform is total 88 data at 10 times 8.

3.2 Three-layered neural network

Three-layered neural network to analyze myoelectric signal on each electrode position has 88 units in the input layer, 10 units in the hidden layer and 3 units in the output layer.

3.2.1 Input layer

The input signal of this three-layered neural network is 88 data. This input signal data is that is lined up normalized data given by data formula in 3.1 section in order from a component of high frequency to a component of low frequency.

The input signal \( X \) is (6).

\[
X = \begin{bmatrix} x_1 & x_2 & \cdots & x_{88} \end{bmatrix}^T
\]

(6)

3.2.2 Hidden layer

The units in the hidden layer are 10 units decided by trial and error. This is a square root of unit number of input layer and the number rounds out decimals.

Furthermore, the input signal in this layer is the \( X \) in (6). Output signal \( \sigma_{(y)} = [\sigma_{(y_1)} \ \sigma_{(y_2)} \ \cdots \ \sigma_{(y_{10})}]^T \) of the hidden layer is as follows;

\[
y = \begin{bmatrix} y_1 & y_2 & \cdots & y_{10} \end{bmatrix}^T = wX + \theta
\]

\[
\sigma_{(y)} = [\sigma_{(y_1)} \ \sigma_{(y_2)} \ \cdots \ \sigma_{(y_{10})}]^T = \left[ \frac{1}{1 + e^{-y_1}} \ \frac{1}{1 + e^{-y_2}} \ \cdots \ \frac{1}{1 + e^{-y_{10}}} \right]^T
\]

(8)

where \( w \) denotes weighting factor in the hidden layer (matrix of 10 times 88) and \( \theta = [\theta_1 \ \theta_2 \ \cdots \ \theta_{10}]^T \) denotes the threshold. \( \sigma \) is the sigmoid function and the outputs in hidden layer are value between 0 and 1.

3.2.3 Output layer

The unit’s number in the output layer is 3, because the number of the discrimination motions is 3 motions. The first unit judges “Grasp” motion or not, the second unit judges “Flexion” motion or not, the third unit judges “Pronation” motion or not.

The input in this layer is the output \( \sigma_{(y)} \) (column vector of 10 times 1) in the hidden layer in (7). The output signal \( \sigma'_{(x)} = [\sigma'_{(x_1)} \ \sigma'_{(x_2)} \ \sigma'_{(x_3)}]^T \) of the output layer is as follows;

\[
z = \begin{bmatrix} z_1 & z_2 & z_3 \end{bmatrix}^T = w'\sigma_{(y)} + \theta' = \frac{1}{1 + e^{-z_1}} \ \frac{1}{1 + e^{-z_2}} \ \frac{1}{1 + e^{-z_3}}
\]

(9)

\[
\sigma'_{(x)} = \left[ \sigma'_{(x_1)} \ \sigma'_{(x_2)} \ \sigma'_{(x_3)} \right]^T
\]

(10)

where \( w' \) denotes weighting factor in the output layer (matrix of 3 times 10) and \( \theta' = [\theta'_{1} \ \theta'_{2} \ \theta'_{3}]^T \) denotes the threshold, the output value in the output layer is a value between 0 and 1 because of the sigmoid function like as in the hidden layer. And, \( \sigma_{(y)} \) (column vector of 10 times 1) in (9) is the output value in the hidden layer in (8).

3.2.4 Learning of the neural network

A teacher signal of an input side for learning process, for a subject 1, is 30 data for each motion and for a subject 2 is 33 data for each motion. Therefore, number of the used signal for learning process is 90 data at the 3 motions for subject 1 and 99 data for subject 2.

When \( k \) denotes the unit number of the output layer, then the teacher signal of the output side is \( F_k \ (k = 1,2,3) \). In Table 1, the teacher signal for learning process is shown. In Table 1, when the teacher signal is the data of “Grasp” motion, the value of the first unit is 0.9 and other units are 0.1. When the teacher signal is the data of “Flexion” motion, the value of the second unit is 0.9 and other units are 0.1. When the teacher signal is the data of “Pronation” motion, the value of the third unit is 0.9 and other units are 0.1.

The weighting factors and the threshold value in this three-layered neural network are modified by the backpropagation algorithm using moment method in order to get the same output values as the given output values. Learning coefficients and coefficients of inertial terms in a moment method differ in subjects and electronode’s positions. These coefficients were
is data number of a teacher signal (for the subject 1, \( s = 90 \), for the subject 2, \( s = 99 \))., \( m \) is data number of a teacher signal, \( k \) is a unit number of a output, \( F^{(m)}_k \) is teacher signal of an output unit, and \( \sigma^{(m)}_{(z_j)} \) is output value in an output layer in (10). The convergence condition in the learning process paper is \( E < 0.0001 \).

### 3.2.5 A selecting method of motions

Firstly, the error between the output value of a corresponding unit to 3 motions and the value of teach signal given at learning process are calculated. Next, in order judge whether the entered signal is “Grasp” or not, the error is calculated by (13), and whether it is “Flexion” or not is judged the error calculated by (14), and whether it is “Pronation” or not, the error calculated by (15) is used to judge. And, the smallest error obtained by using (13), (14) and (15) is an estimated motion by the three-layered neural network. Finally, the discriminated motion by proposed system is that the most frequently selected motion at 3 electrodes positions.

When the selected motion is different at all of 3 positions, the signal treats as an unknown motion

\[
E_g = |0.9 - \sigma'_k| \tag{13}
\]

\[
E_f = |0.9 - \sigma'_k| \tag{14}
\]

\[
E_p = |0.9 - \sigma'_k| \tag{15}
\]

### 4. Discrimination Result and Consideration

#### 4.1 Experiment results of discrimination

In this paper, it is conducted that for subject 1, 87 myoelectric signals (29 times at each motion) are discriminated and for subject 2, 300 signals (100 times at each motion) are discriminated.

Estimated results of motion for subject 1 are shown in Table 4, and those of results for subject 2 are shown in Table 5. In Table 4 and Table 5, the line shows motion corresponded to myoelectric signal entered in the discrimination system, and the row shows an estimated motion by the discrimination system.

In Table 4, it is clear that this system is estimated exactly 3 motions, “Grasp”, “Flexion” and “Pronation”, from myoelectric signal without any error, though the experiment number, 29 times, may not enough to judge the effectiveness fairly. And in Table 5, the entered myoelectric signal of the subject 2 discriminated “Grasp” and “Flexion” with high probability except “Pronation”.

Since calculation time to the discrimination process is a few millisecond, this system can discriminate a motion from a myoelectric signal under 100 millisecond. Therefore, the proposed method which characterizes a motion by a wavelet transform, and based on the character, discriminate a motion by a three-layered neural network is effective as the discrimination of motion, at least within our testing. But, still the system is needed to improvement so that it doesn’t false to discriminate motion at all for practical purposes.

In this system, when the outputs of 3 positions are different respectively, the result of this system is “unknown”. However, for myoelectric signal of “Grasp” motion of the subject 2, this system discriminated the myoelectric signal of 6 % for “Grasp” as the other motion. And for “Pronation” motion, this system discriminate the myoelectric signal of 15 % for “Pronation” motion as the other motion. Therefore, when the system discriminate a measured signal of motion as another motion, same data exclusion method is necessary to add these data formula.
4.2 The number of units in hidden layer for three-layered neural network

The number of units in hidden layer is obtained by being rounded out the square root value of the number of units in input layer after the decimal point. Though for Subject 1, proposed method gets a good result, for subject 2, this method results in judge “Pronation” motion other motion with 15%. So, after the number of units in hidden layer is changed from 10 to 30, the distinguished result for subject 1 and subject 2 is changed as shown in Table 6 and Table 7 respectively.

In Table 5 and in Table 7 which shown the results for subject 2, “Grasp” motions of 6% which were distinguished as another motion in Table 5 were correctly distinguished in Table 7. And the wrong results were decreased to 3% from 15% for “Pronation” motion.

On the other hand, In Table 4 and Table 6 which shown the results for subject 1, though “Grasp” motions were correctly distinguished as shown in Table 4, the motion was distinguished by mistake 2 times (provability of mistake was 6.9%) in Table 6.

Therefore, it can be say that to select suitable number of units in hidden layer for a subject is important on the proposed method.

5. Conclusion

For “Grasp”, “Flexion” and “Pronation” motion, this paper proposed motion discrimination method with high speed and high possibility from measured myoelectric signal at 3 positions on the skin surface of the forearm, and the effectiveness of the system was verified.

(i) A method to discriminate the 3 motions from the myoelectric signal within 80 ms by the combination of a wavelet transform and a three-layered neural network was proposed.

(ii) 87 times (29 times at each motion) experiments to discriminate motions for subject 1 and 300 times (100 times at each motion) experiments for subject 2 were conducted. Through a result of that all of 3 motions, “Grasp”, “Flexion” and “Pronation”, of subject 1 were discriminated completely from myoelectric signal without any mistake, the effectiveness was exemplified. And also, it was suggested that same data exclusion method was necessary to add these data formula for the case of miss-discrimination. For the motion of subject 2, the results were 94% for “Grasp”, 100% for “Flexion” and 59% for “Pronation”.

(iii) When the number of units in hidden layer of three-layered neural network are changed from 10 to 30, the discrimination probability of “Grasp” motions for subject 1 shows a drop to 93.1% from 100%. But the probability for subject 2 shows a rise to 100% from 94% and the provability of “Pronation” motions for subject 2 rose from 59% to 71%. The number of units in hidden layer of three-layered neural network in the proposed method needs to set to suitable value.

REFERENCES


<p>| Table 4 The Discrimination Result for Subject 1 (The Number of Units in Hidden Layer is 10) |</p>
<table>
<thead>
<tr>
<th>Entered motion signal</th>
<th>Possibility of correct estimation [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grasp</td>
<td>100</td>
</tr>
<tr>
<td>Flexion</td>
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</tr>
<tr>
<td>Pronation</td>
<td>0</td>
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</tbody>
</table>

<p>| Table 5 The Discrimination Result for Subject 2 (The Number of Units in Hidden Layer is 10) |</p>
<table>
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<th>Entered motion signal</th>
<th>Possibility of correct estimation [%]</th>
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</thead>
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<tr>
<td>Grasp</td>
<td>94</td>
</tr>
<tr>
<td>Flexion</td>
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</tr>
<tr>
<td>Pronation</td>
<td>0</td>
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</table>

<p>| Table 6 The Discrimination Result for Subject 1 (The Number of Units in Hidden Layer is 30) |</p>
<table>
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<th>Entered motion signal</th>
<th>Possibility of correct estimation [%]</th>
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<td>Grasp</td>
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<td>Flexion</td>
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<td>Pronation</td>
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<p>| Table 7 The Discrimination Result for Subject 2 (The Number of Units in Hidden Layer is 30) |</p>
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<th>Entered motion signal</th>
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<tbody>
<tr>
<td>Grasp</td>
<td>100</td>
</tr>
<tr>
<td>Flexion</td>
<td>0</td>
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<tr>
<td>Pronation</td>
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