Development of a bioimpedance-based human machine interface for wheelchair control

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Abstract—We present a new method, which is based on bioelectrical impedance of the trapezius muscles, to control wheelchair for the disabled people and the elderly. In our application, three electrodes were used for detecting the changes in movements of left and right trapezius muscles. The modified Howland current bridge supplies the 0.5 mA ac current for the measure system at the frequency of 50 kHz. NI PCI-6250 DAQ board were adopted to collect the data and Labview8.2 was used to implement the control system. The threshold value in detection algorithms applied in the system is automatically adjusted to the change in the measured signal magnitude. Pump value detection is used to detect an unexpected large change of the signal to avoid the wrong operation. As a result, we can find that the change of the signal according to the movement of the shoulder is very stable. Additionally, after some signal processing we can use shoulder movement to control LED on Labview8.2 with an accuracy of 100%.

I. INTRODUCTION

Recently, a large amount of rehabilitative devices is required by many populations who have diseases such as myelopathy, upper limb disabled, lower arm disabled, loss of skeletal muscle control from below the shoulders, and hand amputees. The limitations imposed by these diseases deprive the injured individuals from operating electronic devices. Besides the drastic quality of life reduction directly imposed by the impairments, individuals also face a communication shutdown as they are often incapable of operating devices that make possible to communicate with others (computer, cell phone, and PDA etc.). It is a worldwide concern to restitute disabled users communicative and control skills to improve their quality of life. Therefore, human machine interface comes with these reasons.

As we know, the main studies in this field are prosthesis and wheelchair. Prosthesis is the most important and only commercial application. However, wheelchair is also a very useful application. In this paper, we focus on human machine interface for disabled people applied on a wheelchair control. There are researchers who studied the EMG-based electric wheelchair control [1]-[4]. However, none of these studies have examined a bioimpedance-based wheelchair control. In our study, we proposed to use the bioimpedance from shoulders to analyze the human movement and develop a hand-free wheelchair control to help the disabled people with the high level spinal cord injury, quadriplegia and others who can not use their hands. In order to complete the basic function of the wheelchair operation, four classes of motions are required, i.e. run, stop, turn left, and turn right.

The main characteristics of segment movement analysis using bioimpedance are as follows:

1) When we excite a constant current, the bioimpedance change between the measuring electrodes is directly proportional to the intensity of segment movement.

2) Bioimpedance signals are time and spatial invariant on a given segment of limbs and the chest for healthy subjects at rest [5].

3) Bioimpedance almost can be considered as the kinematic information because its change follows the segment movement [6].

In the recent few years, researchers have started to study the use of bioimpedance on movement analysis [7]-[10].

II. THEORY

A. Four electrodes system

The four electrodes method shown in Figure 1 is a widely accepted technique used to measure the bioimpedance. The four electrodes method uses two electrodes to supply current to the tissue and another two electrodes to measure the bioimpedance. As a result, the bioimpedance $z$ can be calculated by

$$z = \frac{V}{I}$$  \hspace{1cm} (1)

where $V$ is the voltage and $I$ is the current.
B. The effective factor of bio-impedance

The human tissue can be seen as the parallel conductor model which consists of muscle and blood. Bioimpedance can be expressed by

\[ z = \frac{L}{\sigma_m S_m + \sigma_b S_b} = \frac{L}{\sigma_m S_m + \sigma_b V_b / L} \]  

(2)

where \( \sigma_m \) is conductivity of muscle, \( \sigma_b \) is conductivity of blood, \( S_m \) is sectional area of muscular tissue, \( S_b \) is sectional area of blood vessel, \( L \) is length of measured part, and \( V_b \) is volume of blood. Because \( L, \sigma_m, \) and \( \sigma_b \) are almost constant, bioimpedance is mainly determined by \( V_b \) and \( S_m \) [6]. It is reasonable that the change in bioimpedance is proportional to the movement.

III. MATERIALS AND METHODS

A. Measure system configuration

Figure 2 shows the block diagram of bioimpedance measurement for the control system. Voltage to current converter circuit converted the 50 kHz signal generated by a function generator to 0.5 mA ac current. Then, this current was injected to human tissue. NI PCI-6250 DAQ board was used to acquire the data at a sampling frequency of 600 kHz for each channel. The signal was stored and then processed with Labview8.2 software. Finally, we used the classified signal to control LEDs on labview8.2 software simulating the wheelchair control.

B. Electrodes configuration and motion design

The disabled people such as spinal cord injury, myelopathy, upper limb disabled, lower arm disabled, loss of skeletal muscle control from below the shoulders and hand amputees, cannot use their hands to operate the wheelchair. We need to design the electrodes location so that these populations are convenient to operate. As a result, the locations on the trapezius muscle are chosen as shown in Figure 3. For two channels, three electrodes were used. Electrode number 1 and 2 were used to supply the current to the tissue. Moreover, each of them also is one of the voltage detecting electrodes for a certain channel. Electrode number 3 is the common end of the two channels.

Four motions, i.e. run, stop, turn left and turn right, are designed for wheelchair operation. The design of motions related to the segment of human body is shown in TABLE I. In addition, TABLE II shows details description of the motions. It tells how motions transfer from one state to another state.

C. Bioimpedance classification algorithm

The control system was implemented on the Labview8.2 work space. Figure 4 is the block diagram of Labview8.2 program for the control system in our project. First, 50000 raw bioimpedance signals were collected through NI PCI-6250 DAQ board in real time. Second, the signal was filtered by

![Figure 2. Block diagram of the bioimpedance measurement for the control system.](image)

![Figure 3. Electrodes configuration.](image)

<table>
<thead>
<tr>
<th>Electrodes’ No.</th>
<th>Muscle</th>
<th>Segment</th>
<th>Motion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,3</td>
<td>Left trapezius muscle</td>
<td>Left shoulder</td>
<td>Left</td>
</tr>
<tr>
<td>2,3</td>
<td>Right trapezius muscle</td>
<td>Right shoulder</td>
<td>Right</td>
</tr>
<tr>
<td>(1,3) and (2,3)</td>
<td>Left and right trapezius muscle</td>
<td>Left and right shoulder</td>
<td>Stop/Run</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Motion No.</th>
<th>Operation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Turn left</td>
<td>Left shoulder up and down</td>
</tr>
<tr>
<td>2</td>
<td>Turn right</td>
<td>Right shoulder up and down</td>
</tr>
<tr>
<td>3</td>
<td>Stop / run</td>
<td>Both shoulders up and down</td>
</tr>
</tbody>
</table>
Raw bio-impedance signal

Bandpass filter

Root mean square algorithm

Auto threshold value modify

Pump value detect algorithm

Threshold algorithm

LED control

Figure 4. Block diagram of Labview8.2 program for the control system.

a bandpass filter at the 49 kHz low cutoff frequency and 51 kHz high cutoff frequency. Third, we calculated the root mean square value of the 50000 filtered signals. Fourth, the system adjusts the threshold value automatically. After the pump value was checked, we compare the current RMS signal value with the threshold value to determine the command type.

1) Auto threshold value adjustment.

The system modifies the threshold value every 50 RMS values (RMS value is calculated by 50000 signal sample) because the magnitude of the measured signal sometimes completely changes. The way to find the new threshold value is to store 50 RMS values in an array. Then, the threshold value can be calculated by

\[ \text{RMS}_{\text{Threshold}} = \frac{\text{RMS}_{\text{max}} + \text{RMS}_{\text{min}}}{P_{\text{sensitive}}} \]  \hspace{0.5cm} (3)

where RMS\text{max} is the maximal RMS signal value in the array, RMS\text{min} is the minimal RMS signal value in the array, Psensitive is the control sensitivity parameter for the control system. Psensitive is a very important parameter. It keeps the balance between the high facility of control and the low error rate of operation. It must be modified manually after:

- Subject change
- And/or electrode position change (not configuration change).

This is due to the fact that the changes in bioimpedance value vary individually. Even on the same subject, when the electrodes are attached at different time, the change in bioimpedance is also different.

2) Pump value detection.

Sometimes, the signal is interfered by some noise, which can make the signal RMS value change pump to be many times of the normal signal. In case of wrong operation, we use the equation (4) and (5) as a limitation of the signal value. If the signal meets one of the conditions, it is not used to determine the control command.

\[ \text{RMS} - \text{RMS}_{\text{max}} > X \times (\text{RMS}_{\text{max}} - \text{RMS}_{\text{min}}) \] \hspace{0.5cm} (4)

\[ \text{RMS}_{\text{min}} - \text{RMS} > X \times (\text{RMS}_{\text{max}} - \text{RMS}_{\text{min}}) \] \hspace{0.5cm} (5)

where RMS is the current signal RMS value, RMS\text{max} and RMS\text{min} are the same as in equation (3). X is the possibility times of the pump value to the normal value. In our experiment, it was 5.

IV. RESULTS

In the experiment, we implement the control system on the Labview8.2 work space and save the data at the same time. In our application, the signal magnitude change is enough to execute the control task. Therefore, it is not necessary to calculate the real bioimpedance value. As the frequency of our current source is 50 kHz, we designed a FIR bandpass filter (first cutoff frequency at 49 kHz and second cutoff frequency at 51kHz.) to filter the noises, i.e. (power line noise and dc noise. We use power spectral density (PSD) to analyze the frequency component in the signal. Figure 5 shows the original and filtered signal PSD of the measured bioimpedance signal from the shoulder. As we can see, the main noise appeared is the power line noise, and after filter, the frequency power of the filtered signal is mainly focused at 50 kHz.

Figure 6 shows the RMS value and classified control command of the filtered bioimpedance signal from both shoulders. It includes all of the movement: left shoulder up and down; right shoulder up and down; both shoulders up and down. From this figure, we can easily identify the shoulder movement from the RMS value by our eyes. Obviously, the classified control command followed the shoulder movement. In addition, we can use shoulder movement to control LED on Labview8.2 with an accuracy of 100%.

Figure 5. The original and filtered signal PSD of the measured bioimpedance signal from the shoulder. Line in size=1 is the PSD graph of original signal; line in size=2 is the PSD graph of filtered signal.
V. CONCLUSIONS AND DISCUSSION

Impedance property of human tissue offers a high possibility to detect the movement of human body segment. It will make interface based on the bioimpedance feasible in practical applications. In our study, we proposed to develop a new human machine interface for the wheelchair control. The new three electrode configuration works very well. It also can be applied with other segments of human body. We utilized 50 kHz current source in our system, which used by the former researchers. The constant current at this frequency flows almost throughout the tissue of muscle and blood [11]. Even this frequency performs well in our experiment, but we still doubt about it whether maybe some other frequency will be more suitable for the movement detection. We will make it clear in the future work.

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REFERENCES