# A Novel Design and Development on Bioimpedance-Based Wheelchair Control

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## ABSTRACT

This article presents a novel design and development on bioimpedance-based wheelchair control for the disabled people and the elderly. We use three electrodes to measure two channels of bioimpedance from the trapezius muscle. Bioimpedance changes when there is a movement in the segment of trapezius muscle. We can classify six types of motions resulting in six operation capabilities for wheelchair control based on six types of shoulder movements, i.e. left shoulder up, right shoulder up, and both shoulder up for short time and long time. Our system is composed of the modified Howland current bridge circuit, which supplies the 0.5 mA ac current to the measurement system at the frequency of 50 kHz. NI PCI-6250 DAQ board was adopted to collect the data and Labview 8.2 was used to implement the signal processing and control system. Algorithms applied in the system are an automatic threshold value adjustment, which adapt its value to the measured signal. Pump value detection is used to detect the unexpected large change of the signal to avoid the wrong operation. Results indicate that the change of signal according to the shoulder movement is very stable. Moreover, we can use the shoulder movement to control LED on Labview8.2 with an accuracy of 100%.

## Categories and Subject Descriptors

C.3 [**Special-purpose and application-based systems**]: *Signal processing systems*

## General Terms

Algorithms, Design, Experimental.

## Keywords

Bioimpedance, wheelchair, motion design, shoulder movement.

## 1. 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 is in commercial application. However, wheelchair is also a very useful application. In this paper, we are focusing 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]. In the recent few years, researchers have started to study the use of bioimpedance on movement analysis [7]-[10]. 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].

## 2. THEORY

### 2.1 Four electrodes system

The four electrodes method 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 bio-impedance $z$ can be calculated by

$$z = \frac{V}{I}, \qquad (1)$$

where $V$ is the voltage and $I$ is the current.

## 2.2 The effective factor of bioimpedance

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

$$z = \frac{L}{\sigma_m S_m + \sigma_b S_b} = \frac{L}{\sigma_m S_m + \sigma_b V_b / L} \qquad (2)$$

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.

# 3. MATERIALS AND METHODS

## 3.1 Measurement system configuration

Figure 1 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.

## 3.2 Electrodes configuration and motion design

As the disabled people, such as 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, it is necessary to design the electrode location to be convenient use by these populations. As a result, the locations on the trapezius muscle are chosen as shown Figure 2. The electrode number 1 and 2 are used to supply the current to the tissue. In addition, each of them also is used as the voltage detecting electrode for a certain channel. Electrode no. 3 is the common end of the two channels.

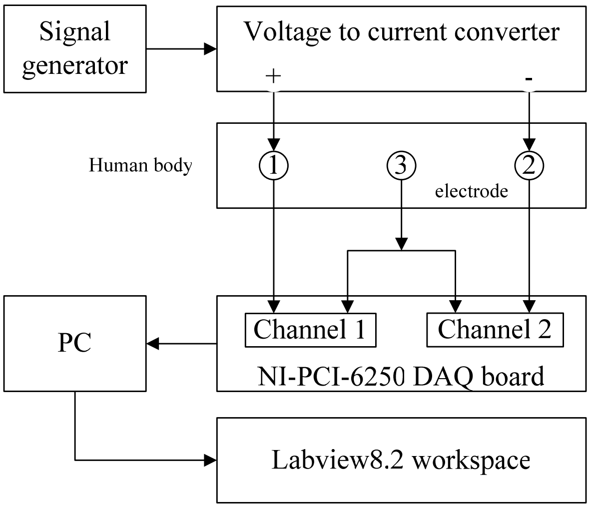

**Figure 1.** **Block diagram of the bioimpedance measurement for the control system.**

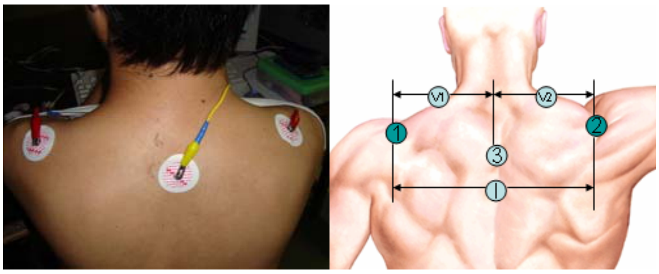

**Figure 2.** **Electrodes configuration**

Although the measurement is based on the four-electrode method, we made some improvement according to our specific application and the specific tissue segment. The conventional four electrodes method needs six electrodes for two channels but we design the new electrode configuration using just three electrodes as shown in Figure 2.

Bioimpedance can be nearly considered as the kinematic information because the bioimpedance change follows the segment movement [6]. This is an advantage of bioimpedance over EMG signal. Therefore, we can achieve more benefit when utilizing bioimpedance as a control signal compared to EMG.

**Table 1.** **Motion design for wheelchair control**

| **Electrodes' No.** | **Muscle** | **Segment** | **Action hold time ( $T_{hold}$ )** | **Motion No.** |
|---|---|---|---|---|
| (1,3) | Left trapezius muscle | Left shoulder | 300 ms < $T_{hold}$ < 1000 ms | 1 |
| | | | $T_{hold}$ > 1000 ms | 2 |
| (2,3) | Right trapezius muscle | Right shoulder | 300 ms < $T_{hold}$ < 1000 ms | 3 |
| | | | $T_{hold}$ > 1000 ms | 4 |
| (1,3) and (2,3) | Left and right trapezius muscles | Left and right shoulder | 300 ms < $T_{hold}$ < 1000 ms | 5 |
| | | | $T_{hold}$ > 1000 ms | 6 |

**Table 2. Operation descriptions of motion design**

| Motion No. | Wheelchair operation | Operation description |
|---|---|---|
| 1 | Turn left 10 degree | If there is a small curve corner, in order to adjust the running direction smoothly during wheelchair running, this command signal makes a 10 degree left side turn. |
| 2 | Stop<br>Turn left 90 degree<br>Run | If there is a sharp angle corner, in order to change the direction rapidly, this command signal will control wheelchair to do serial operation: stop, turn left 90 degree, and run. |
| 3 | Turn right 10 degree | If there is a small curve corner, in order to adjust the running direction smoothly during wheelchair running, this command signal makes a 10 degree right side turn. |
| 4 | Stop<br>Turn right 90 degree<br>Run | If there is a sharp angle corner, in order to change the direction rapidly, this command signal will control wheelchair to do serial operation: stop, turn right 90 degree, and run. |
| 5 | Stop/Run (Toggle) | This motion is used to toggle between stop and run the wheelchair. |
| 6 | Stop<br>Turn 180 degree | This motion will make the 'turn round' operation conveniently. Command signal will control wheelchair to do the following serial operation: stop and turn left 180 degree. |

In our design, two measurement channels of bioimpedance from three electrodes can make six types of motions resulting in six operation capabilities. The design of motions related to the segment and electrode configuration is shown in Table 1. In addition, Table 2 describes the operations related to each design of motions.

## 3.3 Motion classification algorithm

Motion classification algorithm based on bioimpedance consists of four steps:

1. Collect 50000 raw bioimpedance signals.
2. Filter the collected signals with a bandpass filter at the 49 kHz low cutoff frequency and 51 kHz high cutoff frequency.
3. Calculate the root mean square value of the 50000 filtered signals.
4. Classify motions using automatically adjusted threshold value.

Figure 3 shows the details of motion classification algorithm in the forth step. Details of the classification algorithm are as follows.

- First, the algorithm will judge if the current root mean square value is a pump value, i.e. an unexpected large change of the signal. If yes, the value cannot be used to determine the command signal and it will be discarded. If no, the current value is kept for classification.
- Second, the algorithm will check if the current period is preceded by a no movement period. If no, the nature threshold value will be the system threshold value. If yes, the no movement period threshold value will be transferred to the system threshold value.
- Third, the system threshold value will be used to compare with the current root mean square signal value to determine the command signal.
- Finally, the duration of the movement will be used to determine the command signal whether is a short period command signal or long period command signal. These two signals are the final command, which will be used to control the LED on software Labview8.2.

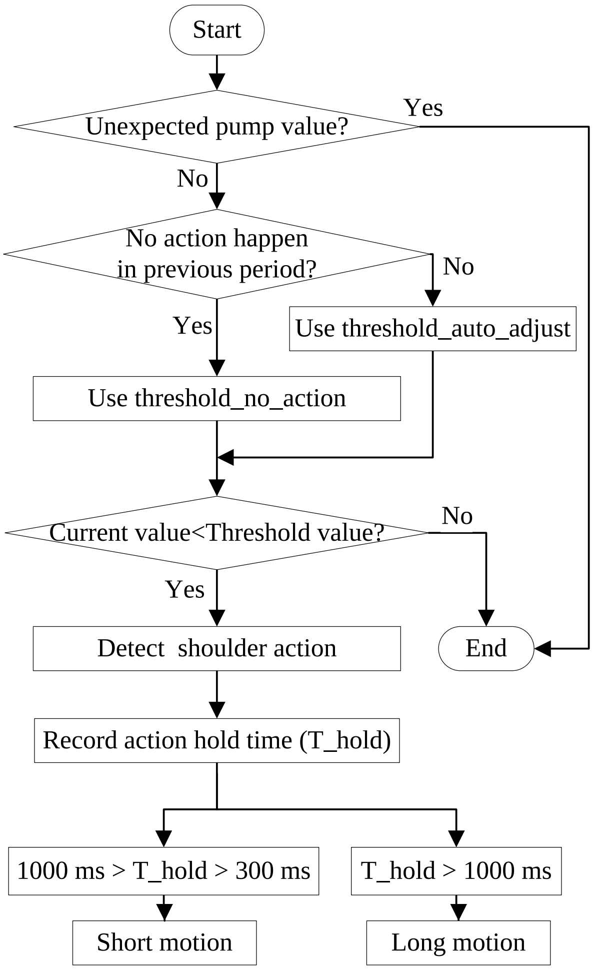

**Figure 3. Flow chart of motion classification**

## 4. RESULTS

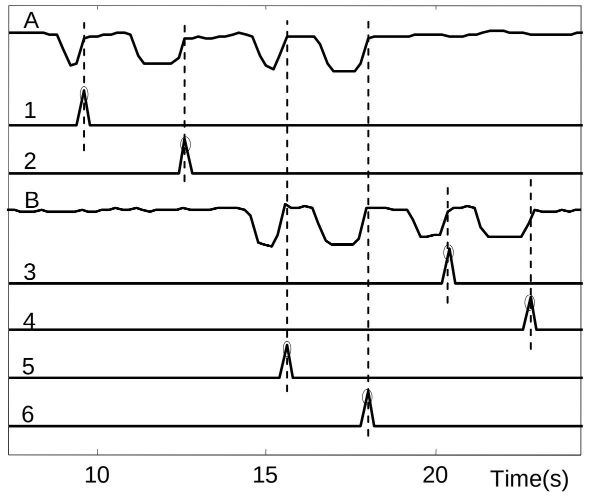

**Figure 4. Line A: The RMS value of filtered bioimpedance signal from left shoulder. Line 1: Left shoulder up with short hold time (Motion No. 1). Line 2: Left shoulder up with long hold time (Motion No. 2). Line B: The RMS value of filtered bioimpedance signal from right shoulder. Line 3: Right shoulder up with short hold time (Motion No. 3). Line 4: Right shoulder up with long hold time (Motion No. 4). Line 5: Both shoulders up with short hold time (Motion No. 5). Line 6: Both shoulders up with long hold time (Motion No. 6)**

Figure 4 shows the RMS values and the classified control command of filtered bioimpedance signal from six shoulder motions. The numbers (1, 2, 3, 4, 5, 6) placed in Figure 4 are from the motion's number appeared in both Table 1 and Table 2. We can clearly visualize and identify the shoulder movement from the RMS values. Obviously, the classified control command was preceded by the shoulder movement. In addition, we can use the shoulder movement to control LED on Labview8.2 with an accuracy of 100%.

## 5. CONCLUSIONS AND DISCUSSION

Impedance property of human tissue offers a promising possibility for detecting the segment movement. This opens an opportunity to enable bioimpadance-based wheelchair control to practical applications. We proposed to develop a novel human machine interface for the wheelchair control. Three electrodes are used two acquire two channels of bioimpedance from the trapezius muscle. Three shoulder movements, i.e. left shoulder up, right shoulder up, and both shoulders up, are used to generate control signals. In addition, bioimpedance almost can be considered as the kinematic information. Its change follows the segment movement. Therefore, it is possible to keep the change of impedance signal for certain duration. We make use of the time characteristic of bioimpedance to make more motions, i.e. short action ($300$ ms $< T_{hold} <$ $1000$ ms) and long action ($T_{hold} >$ $1000$ ms). As a result, six operation capabilities for wheelchair control are feasible. The proposed system is evaluated by controlling LED on a computer. Results show that 100% accuracy is obtained. Moreover, it is possible to make the proposed system to be a portable device. For example, the system and algorithm can be implemented in a FPGA chip or a microcontroller. Actually, the classified motion can be implemented in not only for the wheelchair control but also for other devices such as computers and some other portable electronic devices.

## 6. ACKNOWLEDGMENTS

This work is partially supported by NECTEC-PSU center of excellence for rehabilitation engineering and Faculty of Engineering, Prince of Songkla University.

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