Wireless EMG-based Human-Computer Interface for Persons with Disability

Myoung-Joon Lee, In-Hyuk Moon, Sin-Ki Kim and Mu-seong Mun

Korea Orthopedics & Rehabilitation Engineering Certer, Inchun, Korea
(Tel : +82-032-500-0597; E-mail: mjlee@iris.korec.re.kr)

Abstract: This paper proposes a wireless EMG-based human-computer interface (HCI) for persons with disabilities. For the HCI, four interaction commands are defined by combining three elevation motions of shoulders such as left, right and both elevations. The motions are recognized by comparing EMG signals on the Levator scapulae muscles with double thresholds. A real-time EMG processing hardware is implemented for acquiring EMG signals and recognizing the motions. To achieve real-time processing, filters such as high- and low-pass filter and band-pass and -rejection filter, and a full rectifier and a mean absolute value circuit are embedded on a board with a high speed microprocessor. The recognized results are transferred to a wireless client system such as a mobile robot via a Bluetooth module. From experimental results using the implemented real-time EMG processing hardware, the proposed wireless EMG-based HCI is feasible for the disabled.

Keywords: EMG, human-computer interfaces, shoulder elevation motion, double thresholds, Bluetooth

1. INTRODUCTION

Recently, as the silver generation has been exponentially increasing, the social demands for the quality of life (QOL) also have been increasing proportionally. As a part of the efforts to improve the QOL of the disabled and the elderly, robotic researchers have been trying to combine the robotic techniques into the rehabilitation systems. However, since the robotic system needs to guarantee both the safety and reliability, many recent studies proposed the human-in-the-loop control system for considering user's intention[1]. Since the human has a different information system from machinery system, human-computer interface (HCI) is regarded as one of key technologies in the human-in-the-loop control system.

Keyboard and mouse are often used as the HCI. However it needs much training for the disabled and the elderly who are not familiar with computer. With the advancement of the computer performance, many researchers tried to use computer vision and voice recognition techniques for the HCI. However, the voice interface is easily affected by noise and, the vision-based HCI should overcome the processing speed problem.

The HCIs using bio-signals such as electromyogram (EMG), electroencephalogram (EEG) [2], and electrooculograph (EOG) [3] were proposed. Because EMG signal has better properties of high amplitude and signal to noise ratio (SNR) than other bio-signals, it is often applied to the rehabilitation system such as the EMG-driven prosthetic hand. In [4, 5, 6] the EMG signal was used for monitoring user's intention and for controlling electric-powered wheelchair.

In this paper we propose a wireless HCI using EMG signals obtained from the Levator scapulae muscle (LSM) as shown in Fig. 1. User's intention is represented by shoulder elevation motions which are recognized by a novel double thresholds method. The recognized results are transferred to the remote system via a wireless Bluetooth module. For the HCI, four interaction commands are defined by combining three elevation motions of shoulders such as left, right and both elevations. An EMG processing hardware to acquire EMG signals and to recognize the motions is implemented. To achieve real-time processing, filters such as high-pass filter (HPF), low-pass filter (LPF), band-pass filter (BPF) and band-rejection filter (BRF), and a full rectifier and a mean absolute value (MAV) circuit are embedded on a board with a high speed micro- processor. Experimental results using the wireless EMG-based HCI and a robotic wheelchair show that the proposed method is feasible for persons with disabilities.

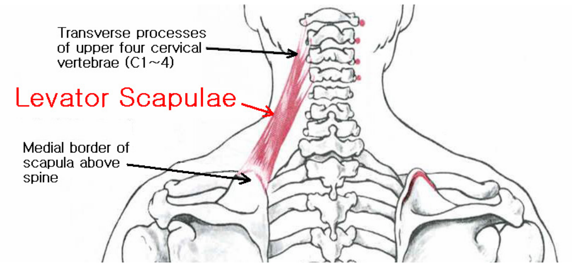


Fig. 1 Levator scapulae muscle

2. EMG SIGNAL PROCESSING

It is known that the principal frequency of the EMG signal is concentrated on 30Hz to 500Hz range, and that the amplitude by voluntary contraction is measured in 0 to 10 $mV_{P\text{-}P}$ range [7].

To acquire EMG signal on the LSM, we use DE-2.3 electrode (Delsys Co.) which is embedding the BPF with 20Hz to 450Hz cutoff frequency and a 60dB amplifier (see Fig. 2). The clavicle area is selected as the reference point because it is less affected from motion artifacts. The acquired EMG signal by DE-2.3 is then processed in the implemented real-time hardware. The 60Hz power line noise is filtered out by the BRF, and then MAV of the signal is obtained by a full rectifier and a moving average circuit. The MAV is expressed as follows:

$$MAV(t) = \frac{1}{T}\int_{t-T}^{t}|EMG|dt \,, \qquad (1)$$

where T denotes time constant for the moving average, and it is implemented by using a resister and a capacitor. Integrated absolute EMG (IEMG) signal is generated by 1Hz LPF. Finally,

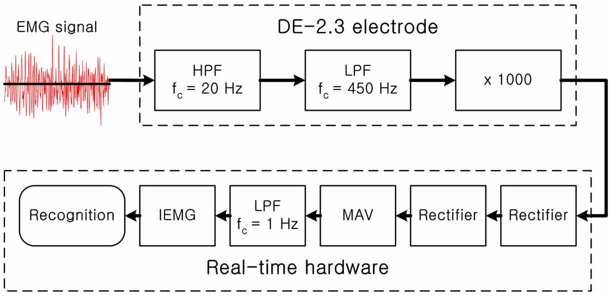


Fig. 2 EMG signal processing

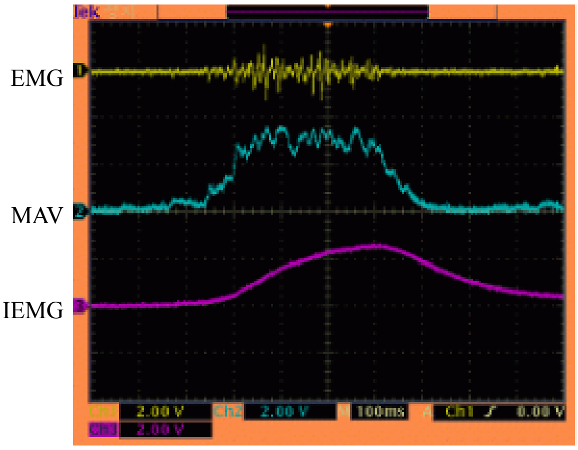


Fig. 3 Examples of shoulder EMG, MAV, and IEMG

the IEMG signal is sampled every 400 [μsec] and user's intention is recognized simultaneously by double thresholds method proposed in this paper. Fig. 3 shows a processing result using the implemented hardware. The first channel shows the EMG signal obtained by DE-2.3 electrode, and MAV and IEMG signals are shown in the second and third channel, respectively.

3. EMG-BASED HUMAN-COMPUTER INTERFACE

3.1 Definition of interaction commands by shoulder elevation motions

In this paper we use four interaction commands for a robotic wheelchair control. The commands are defined by combination of three elevation motions of shoulders such as left, right and both shoulders elevation. The elevation motion is recognized by comparing the IEMG signal with a predetermined threshold. Table 1 shows the commands defined, where `on' and `off' mean whether the shoulder elevation motion is valid or not. We first define two modes: 'move' and 'rotate' which mean moving to straight forward and rotating direction, respectively. Two modes are alternated whenever both shoulders are elevated. In 'move' mode, 'stop' and 'go forward' motions are occurred by left or right shoulder elevation, respectively. While the wheelchair is moving to forward, user can control the motion direction using the rotate commands.

3.2 Double thresholds method

By comparing IEMG signal with a threshold value, muscle activation is recognized. When IEMG is larger than the threshold, intended motion is recognized, which is denoted as 'on'. Otherwise 'off' denotes no intended motion occurred. Practical EMG-based HCI must recognize user’s intention quickly considering a time difference when both shoulders are elevated, and it should perform that one intentional motion is corresponding to one command only. To recognize EMG-based shoulder elevation motion, we use double thresholds method which has a primary threshold and an auxiliary threshold to be less than the primary threshold.

Table 1 HCI commands and states defined by shoulder elevation motions

left EMG	right EMG	state	command	
			move mode	rotation mode
on	on	1/0	mode change (move/rotation)	
on	off	2	stop	turn left
off	on	3	go forward	turn right
off	off	4	none	none

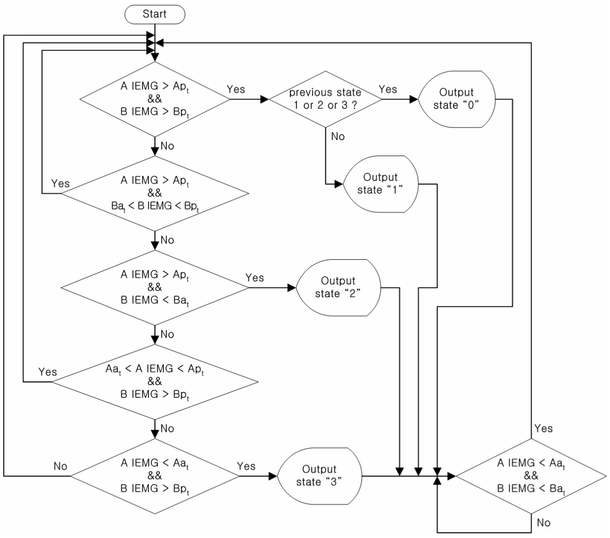


Fig. 4 Recognition procedure using double thresholds

Fig. 4 shows recognition procedure of user's intention using double thresholds. Let A_{pt} and B_{pt} be the primary thresholds and A_{at} and B_{at} be the auxiliary thresholds of two muscles, A and B, respectively. When muscle A's IEMG exceeds A_{pt} and muscle B's IEMG is less than B_{at}, muscle A is activated only. When muscle A's IEMG exceeds A_{pt}, and muscle B's IEMG is less than B_{pt} but larger than B_{at}, it has a possibility that two muscles are activated simultaneously. In this case the recognition result is reserved until muscle B's IEMG is less than B_{at} or larger than B_{pt}. When all IEMG exceeds the primary thresholds, A_{pt} and B_{pt}, all muscles are activated simultaneously. The output in this case may be state 0 or 1 in Table 1. When IEMG of muscle B is less than B_{at}, muscle B is not activated, and muscle A is activated only. This is state 2 or 3. Consequently, though a time difference of muscle activation is occurred, user's intention can be recognized well, and one intentional motion is corresponding to a command only. After recognizing muscle activity, the procedure waits until state 4.

4. EXPERIMENTAL RESULTS

4.1 Real-time hardware

Fig. 5 shows the block diagram of a real-time hardware for the wireless EMG-based HCI. All processing procedure as shown in Fig. 2 is implemented by hardware except for the

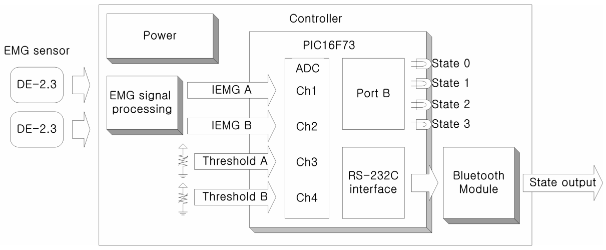


Fig. 5 Block diagram of real-time hardware for wireless EMG-based HCI

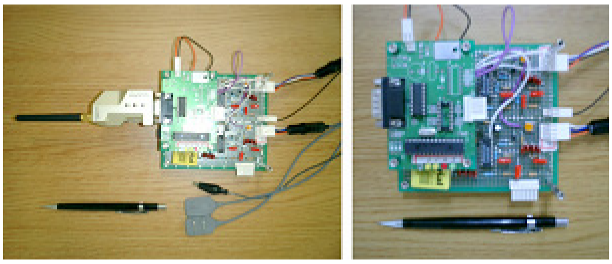


Fig. 6 Implemented hardware and DE-2.3 electrodes

motion recognition by the double thresholds. We set 50% of the maximum IEMG signal to the primary threshold, and the auxiliary threshold is set to smaller value than the primary threshold but it is larger than IEMG value by no movement. The recognized result is displayed by four LEDs, and simultaneously transmitted to a remote robotic wheelchair by a Bluetooth-based wireless communication.

As most EMG equipments have 2kHz sampling rate, they obtain digital data every 500μsec. The presented processing hardware in this study performs 400 instructions for the double thresholds method, so it can execute the recognition procedure at every 400μsec by 4MHz system clock. Consequently the procedure is executed faster than data acquisition speed, so we can regard it as real-time hardware. Fig. 6 shows the implemented mobile-type hardware operated a single 9 volt DC dry-type battery.

4.2 Rates of motion recognition

We performed experiments of shoulder elevation motion to five non-trained normal subjects. A series of elevation motions and corresponding interaction commands are as follows: change to rotation mode (both elevation), turn left (left elevation only), turn right (right elevation only), change to move mode (both elevation), go forward (right elevation only), and stop (left elevation only). The motions were iterated ten times for each subject (see Fig. 7).

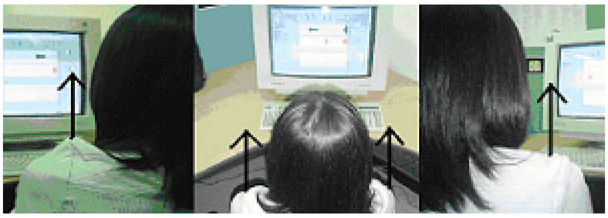


Fig. 7 Experimental setup for test of recognition rates

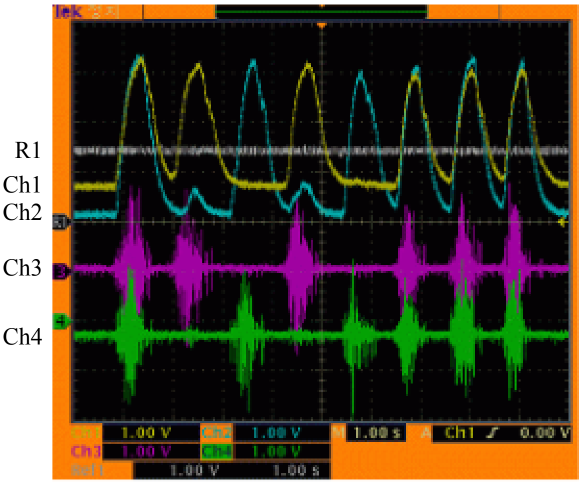


Fig. 8 Processing for measuring recognition rates

Table 2 Rates of motion recognition

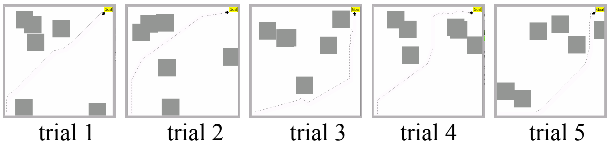
visual feedback	motion (state)	subjects					average
		A	B	C	D	E	
none	both (0/1)	100%	100%	100%	85%	100%	97%
	left (2)	100%	100%	100%	80%	100%	96%
	right (3)	100%	100%	100%	85%	100%	97%
average		100%	100%	100%	83%	100%	96%
given	both (0/1)	100%	100%	100%	95%	100%	99%
	left (2)	100%	100%	100%	85%	100%	97%
	right (3)	100%	100%	100%	95%	100%	99%
average		100%	100%	100%	91%	100%	98%

Fig. 8 shows an obtained result using the real-time hardware. Ch3 and Ch4 show EMG signals of left and right LSM, and Ch1 and Ch2 are output of IEMG, respectively. R1 is the primary threshold.

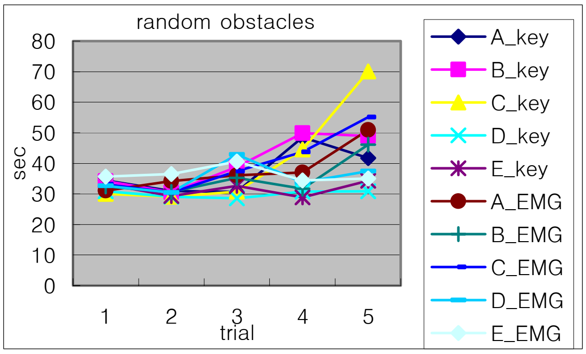
In the first experiments, subjects only occurred with the motion sequences without visual feedback. Then, the subjects performed the same motions as above while viewing computer screen. As shown in Table 2, the rates of motion recognition were 100 % except the subject D. The reason was that subject D's muscle was activated continuously by muscle fatigue. In the second experiments with visual feedback, the success rates were higher because subjects could contract his muscles more strongly by visual feedback.

4.3 Wheelchair control using wireless EMG-based HCI

We conduct two experiments using implemented HCI. The first is that user controls a virtual wheelchair to goal position without collision where six obstacles are created on random position. The second experiment is to pass a maze type environment with uniform corridor width. The shape of simulation environment is a rectangular area with 600 to 600 pixels. We set twice of the wheelchair's width to the corridor width, and the linear and angular speed of wheelchair is set to



(a) obstacle map for five trial



(b) elapse time by keyboard operation and EMG-based HCI

Fig. 9 Experimental environments and results by keyboard operation and EMG-based HCI

30 [pixel/sec] and 90 [deg/sec], respectively. If the wheelchair collides with any obstacles in navigation, it stops motion and waits the next control command. For assessment of the EMG-based HCI, we compared the elapse time between EMG-based HCI and keyboard operation.

We conducted experiments with subjects five times, and measured the elapse time from start to goal position. Fig. 9 and 10 show the experimental results. In the first experiments, the wheelchair direction does not need to be controlled accurately because the motion environment is larger than the maze type one. Therefore the result by the EMG-based HCI was similar elapse time to keyboard operation (see Fig. 9(b)).

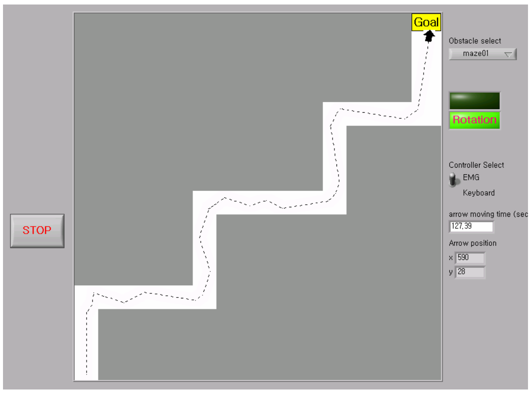
However, in the corridor navigation the motion direction is changed frequently. Accordingly Fig. 10(b) shows that the EMG-based HCI took more time than the keyboard operation.

4.4 Wireless control of electric-powered wheelchair

Fig. 11 shows pictures to control electric-powered wheelchair using implemented wireless EMG-based HCI. User can obtain the motion result by visual feedback, and the control commands by EMG-based HCI are sent to the wheelchair by Bluetooth module.

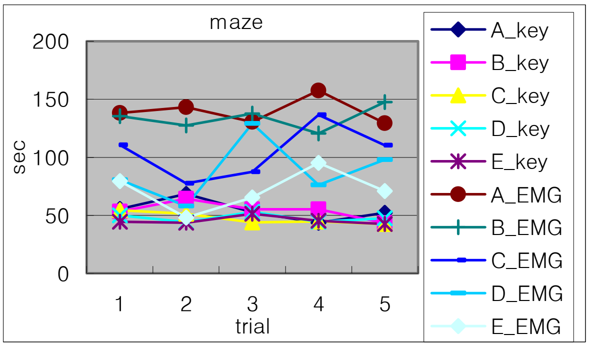
5. CONCLUSION

In this paper, we propose a wireless EMG-based HCI for persons with disabilities. For the HCI, four interaction commands are defined by combining three elevation motions of shoulders. The recognized results are transferred to a wireless client system such as a mobile robot via a Bluetooth module. From experimental results using the implemented hardware, the proposed wireless EMG-based HCI is feasible for the disabled.



Obstacle select: maze01
Controller Select: EMG / Keyboard
arrow moving time (sec 127,39
Arrow position
x 590
y 28

(a) maze type motion environment



(b) elapse time by keyboard operation and EMG-based HCI

Fig. 10 Experimental environments and results for maze type obstacle avoidance

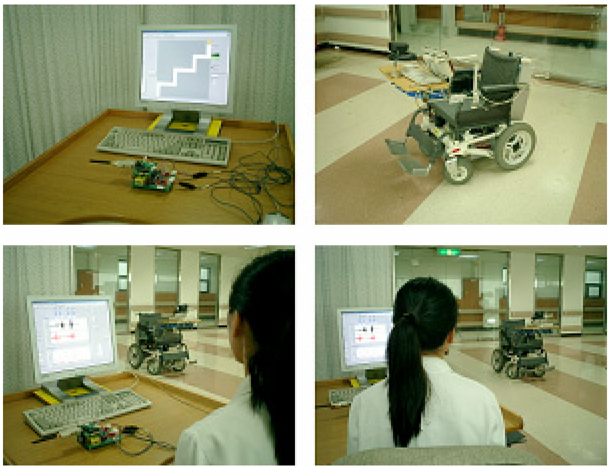


Fig. 11 Electric-powered wheelchair control using wireless EMG-based HCI

Currently it was only tested by normal person in laboratory environment, but it needs to test with the disabled. Automatic selection of double thresholds is very important to adapt changes of user's muscle condition. This is a future work.

ACKNOWLEDGMENTS

This study was supported by a grant of the Korea Health 21 R&D Project, Ministry of Health & Welfare, Republic of Korea. (02-PJ3-PG6-EV03-0004)

REFERENCES

[1] D. J. Kim, W. K. Song, Z. N. Bien, "Effective Intention Reading in Rehabilitation Robots", *2nd International Workshop on Human-friendly Welfare Robotic Systems (HWRS 2001)*, pp. 179-184, Taejon, Korea, Jan. 15-16, 2001.

[2] L. Kirup, A. Searle, A. Craig, P. Mclsaac, and P. Moses, "EEG-based system for rapid onoff switching without prior learning", *Medical and Biological Engineering and Computing*, vol. 35, pp. 504-509, 1997.

[3] J. Gips and P. Oliviere, "EagleEyes: An Eye Control System for Persons with Disabilities", *Proc. of int'l Cong. on Technology and Persons with Disabilities*, 1996

[4] Z. N. Bien, W. K. Song, D. J. Kim, J. S. Han, J. Choi, H. E. Lee, and J. S. Kim, "Vision-based Control with Emergency Stop through EMG of the Wheelchair-based Rehabilitation Robotic Arm, Kares", *Proc. of ICORR 2001*, pp. 177-185, Evry Cedex, France, 25-27 April 2001.

[5] J. S. Han, D. H. Stefanov, K. H. Park, H. B. Lee, D. J. Kim, W. K. Song, J. S. Kim, and Z. N. Bien, "Development of an EMG-based Powered Wheelchair Controller for Users with High-level Spinal Cord Injury", *International Conference on Control, Automation and Systems (ICCAS 2001)*

[6] I. H. Moon, M. J. Lee, J. C. Ryu, K. H. Kim, and M. S. Mun, "Intelligent Robotic Wheelchair with Human-friendly Interfaces for the Disabled and the Elderly*", Proc. of ICORR 2003*, pp. 23-25, April 2003.

[7] Carlo J. De Luca, "Surface Electromyography: Detection and Recording", *Delsys Incorporated*, 2002.