Proceedings of the 25th Annual International Conference of the IEEE EMBS
Cancun, Mexico • September 17-21, 2003

Human-Machine Interface for wheelchair control with EMG and Its Evaluation

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Abstract— **The objective of this paper is to develop a powered wheelchair controller based on EMG for users with high-level spinal cord injury. EMG is very naturally measured when the user indicating a certain direction and the force information which will be used for the speed of wheelchair is easily extracted from EMG. Furthermore, the emergency situation based on EMG will be checked relatively ease. We classified the pre-defined motions such as rest case, forward movement, left movement, and right movement by Fuzzy Min-Max Neural Networks (FMMNN). This classification results and evaluation results with real users shows the feasibility of EMG as an input interface for powered wheelchair.**

Keywords—**Powered wheelchair controller, EMG, the disabled, FMMNN, Evaluation**

I. Introduction

Independent mobility has significant importance for the quality of life of people with lower-extremities paralysis. Conventional joystick-controlled powered wheelchairs, however, are inappropriate for some categories of disabled people, especially, the disabled people with the high-level spinal cord injury, and quadriplegia. As an alternative to the joystick control, various input interfaces [1,2,3,4,5] such as a sip and puff [1], chin controller [1], ultrasonic non-contact head controller [2], head movement [3], and voice [4,5] controller, are developed to improve manipulability, safety, and comfortableness. Sip and puff, and chin controller are inconvenient to use, and ultrasonic non-contact head controller has relatively low accuracy. A voice controller presents delayed response to voice command and is not useful in noisy environment.

Head movement is a natural form of gesture and can be used to indicate a certain direction. Since the users can move their head even if they are the serious disabled people, electromyogram (EMG) may be utilizable for recognizing head movement.

EMG is the electric manifestation of neuromuscular activation contracting a muscle and can be measured from near neck muscle according to the head movement. In addition, the speed of wheelchair can be controlled by EMG signals since the amplitude of EMG has static relationship with force information [6]. We can also easily detect the emergency situation based on EMG signals [7].

This paper presents the development of an EMG-based powered wheelchair controller for the quadriplegic. The rest of the paper is organized as follow: In Section 2, the overall procedure for classification is explained. Experimental results and evaluation results are described in Section 3, and Section 4, respectively. Finally conclusion is given in Section 5.

II. Development of Classification Algorithm

EMG pattern recognition procedure is shown in Fig. 1. After measuring EMG signals on the proper locations (muscles), we reduce the noise such as motion artifact through designed filter. Each step will be explained in detail.

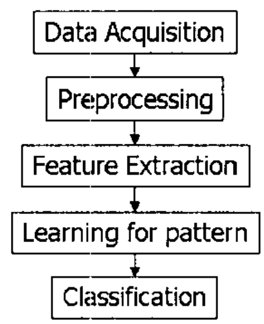


Fig. 1. EMG pattern classification procedure

A. Location of electrode for measuring EMG

To find the proper locations for measuring EMG is the first step to develop wheelchair joystick interface for the disabled. Especially, the disabled people with the spinal cord injury have a limited muscle alive; we must choose the proper locations. The target user for our system, people with spinal cord injury, especially, C4, can only control the upper muscle near neck. Therefore we selected the candidates for measuring EMG, which are shown in Fig.2. The candidate muscles are Stenocleidomastoid muscle (A) and Trapezius muscle (B). We measured EMG signal repeatedly during pre-defined motions, that is, forward movement, left movement, right movement, rest case. The representative results are shown in Fig. 3.

Candidate A (Stenocleidomastoid muscle) shows muscle contraction in each motion, but candidate B (Trapezius muscle) does not. Therefore we choose the Stenocleidomastoid muscle in each side as a location for measuring EMG. Fig. 4 shows the determined electrode locations.

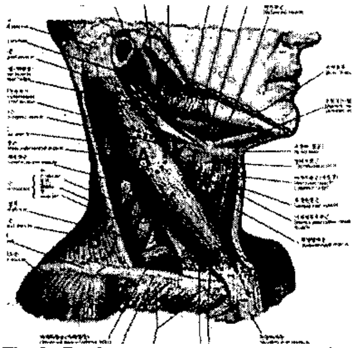


Fig. 2. EMG pattern classification procedure

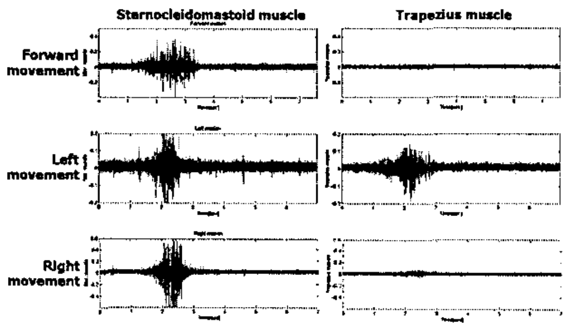


Fig. 3. Representative results for measuring EMG signals on each candidate muscle

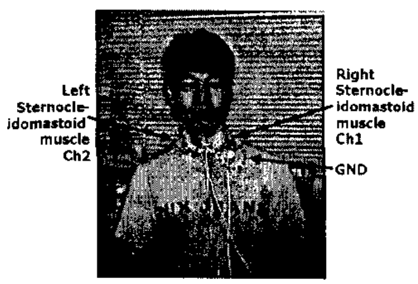


Fig. 4. Locations of electrode for measuring EMG

B. Feature Extraction

To choose good features, we first checked the separability of four features – Integral absolute value (IAV), Variance (VAR), Zero Crossings (ZC), Moving Average Root Mean Square (MARMS) [8,9]– between predefined motions. Fig. 5 shows the IAV, VAR, ZC and MARMS distribution in ch1. Since IAV and VAR show the good separability between motions while ZC and MARMS have low separability, we chose the IAV and VAR as a feature set.

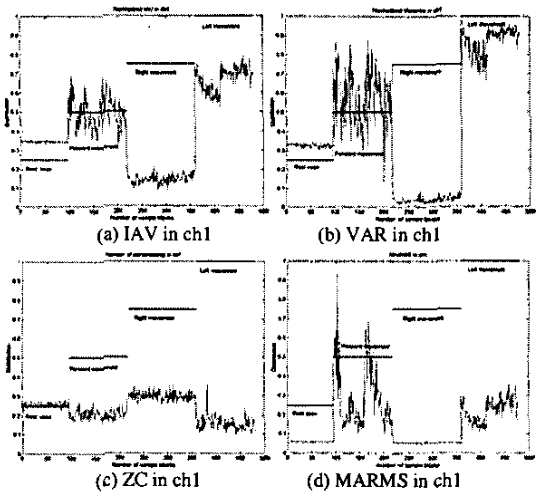


Fig. 5. Feature distributions in ch1.

C. FMMNN as a Pattern Recognizer

We adopt Fuzzy min-max neural networks (FMMNN) [10] for a pattern recognizer, which can adapt the variation of EMG signals due to its on-line adaptation function. FMMNN is supervised learning neural networks classifier that utilizes fuzzy sets as pattern classes. Each fuzzy set is a union of fuzzy set hyperboxes. Fuzzy set hyperbox is an n-dimensional box defined by a min point and a max point with a corresponding membership function. It is used as an input-output pair that extracted features, IAV, and VAR for learning in FMMNN.

III. EXPERIMENTAL RESULTS

A. Experimental Environment

To measure EMG signals, Ag/AgCl electrode and shielded cable are used to reduce the effect of noise in the environment. The measured EMG signals pass through 10Hz high-pass filter, 1kHz low-pass filter and 60Hz notch filter to be amplified by Grass Instruments Model 15 with 5000 V/V. The amplified EMG signals are converted by A/D converter, AD976 of Analog Device, with 2kHz sampling frequency and with 16 bit resolutions. Fig. 6 shows the overall system configuration.

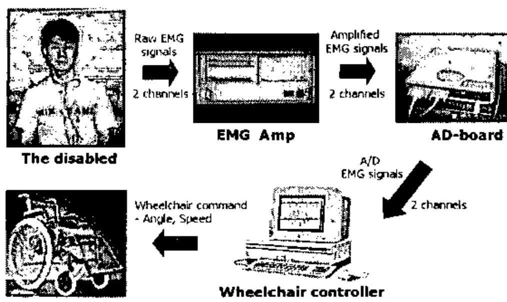


Fig. 6. Overall system configuration.

B. Pattern Recognition Results

After learning FMMNN with extracted features for each motion, we classified the pre-defined motions. Table 1 shows the classification results for training data and table 2 for test data. We claimed that EMG is a feasible input source for powered wheelchair controller from this classification results.

TABLE I CLASSIFICATION RESULTS WITH TRATINING DATA SET AFTER LEARNING

(Note: Total average success rate is 98.75% (474/480*100))

Classified result \ Motions	Rest case	Forward movement	Right movement	Left movement
Rest case	96	5	0	0
Forward movement	0	117	0	1
Right movement	0	0	141	0
Left movement	0	0	0	120
Average success rate	96/96* 100= 100 %	117/122* 100= 95.9 %	141/141* 100= 100 %	120/121* 100= 99.2 %

TABLE II CLASSIFICATION RESULTS WITH TEST DATA SET AFTER LEARNING

(Note: Total average success rate is 91.2% (439/480*100))

Classified result \ Motions	Rest case	Forward movement	Right movement	Left movement
Rest case	96	7	0	0
Forward movement	0	114	4	29
Right movement	0	1	137	0
Left movement	0	0	0	92
Average success rate	96/96* 100= 100 %	112/122* 100= 93.4 %	137/141* 100= 97.2 %	92/121* 100= 76.0 %

IV. EVALUATIION WITH REAL USERS

We performed a clinical evaluation with the user candidates who have a spinal cord injury. Among many candidates, our subjects consist of the quadriplegia with C4 lesion who can't move his arm at all and the quadriplegia with C5 lesion who have a difficulty to use his arm freely. Control of powered wheelchair was performed by using the developed EMG interface as shown in Fig. 7. To assess the performance of EMG interface objectively, we measured the total elapsed times, the number of collisions while driving along a predefined path while driving along a predefined path shown in Fig. 8. After experiment, we interviewed the users with questionnaire for subjective evaluation.

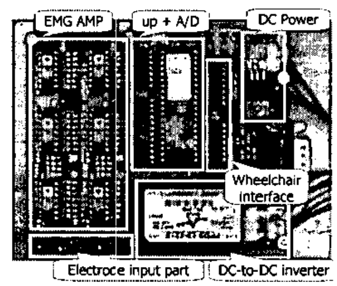


Fig. 7 The developed wheelchair interface

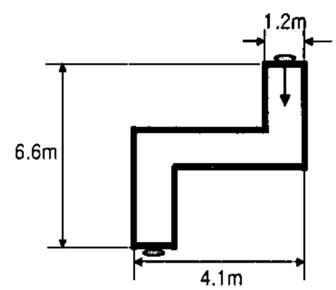


Fig. 8. Predefined path for wheelchair control

We tested two control modes as shown Table 3. The difference between Mode 1 and Mode 2 is a command for forward movement. In Mode 1 case, the wheelchair will go forward until a user keeps up forward command motion such as both shoulders up. In Mode 2 case, the same command will be executed by using a toggle switch which makes the wheelchair go straight or stop according to its current state. We attached four electrodes (two channels, bipolar type) for measuring EMG signals in both Trapezius muscles.

TABLE III MOTION COMMAND FOR CONTROLLING OF WHEELCHAIR

Motion	Wheelchair motion in Mode 1	Wheelchair motion in Mode 2
Initial state	Stop	Current state hold (forward/stop)
Both shoulders up	Forward movement	Forward/Stop (toggle)
Right shoulder up	Right movement	Right movement
Left shoulder up	Left movement	Left movement

After experimental we find that the forward command in Mode 1 has made the users to get tired because the users had to maintain forward motions till the wheelchair reached the target position ahead. The users, however, gave forward command easily in Mode 2 by both shoulders up. The difficulty of forward command usage in Mode 2 is the wheelchair response delay time. The wheelchair response delay time makes the user confuse whether the controller accepts the command correctly. After using this controller for a while, however, the user adapted to this delay time, and felt more comfortable than forward command in Mode 1.

The users also commented about electrode attachment and its outlook appearance. Some users disliked the procedure of electrode attachment (including skin preparation) to skins. Overall wheelchair control performance of the subjects is not as good as ordinary persons, but we ascertained that EMG interface based on the head movement or shoulder movement would be applied as a wheelchair controller to the users with spinal cord injury with lesion level C4 and C5. Fig. 9 and Fig. 10 shows subjective evaluation and experimental results for the EMG interface.

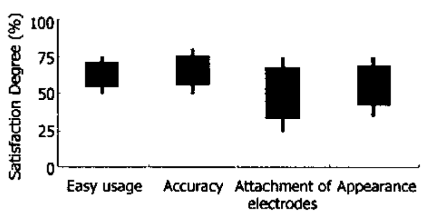
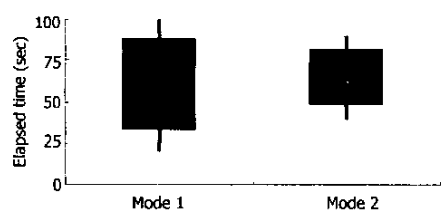
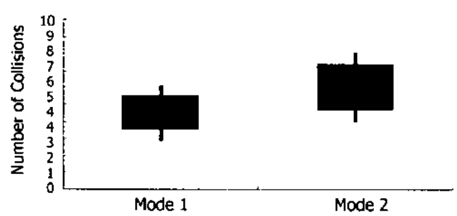


Fig. 9 Results from clinical evaluation for EMG interface



(a) Elapsed time



(b) Number of collisions

Fig. 10 Experimental results for EMG interface:

V. CONCLUSION

In this paper, we developed the powered wheelchair controller based on EMG signals for the serious disabled. The classification results showed the feasibility of EMG interface for powered wheelchair controller. We knew that EMG is one of alternative input interface for wheelchair from the evaluation with real users. To make the system low cost and small size, we also developed EMG AMP and its controller for powered wheelchair. We now have a second evaluation with EMG wheelchair interface which is modified based on user's comments.

ACKNOWLEDGMENT

This work is partially supported by of Critical Technology 21 program of the Ministry of Science and Technology of Korea and Human-friendly Welfare Robot System Engineering Research Center, KAIST.

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