A Low Cost Surface Electromyogram (sEMG) Signal Guided Automated Wheel Chair for the Disabled

Taslim Reza, S.M.Ferdous, Md. Nayeemul Hasan, Md. Rokonuzzaman, Kazi Firoz Ahmed, A.Z.M.Shahriar Muttalib

Abstract— This paper discusses the exploratory research of a simple, effective and low cost design of a microcontroller based wheelchair using the sEMG signal collected from the neck muscles which will allow a disabled person to control the wheelchair only by using the movement of his neck. Among the different neck muscles, upper trapezius muscle has been chosen for collection of the sEMG signals which are used to move, control and navigate the wheel chair. The main purpose of the work is to design a cost-effective, easily affordable and accessible wheel chair for the disabled general masses where advanced attachments like on board computer, digital cameras, sophisticated sensors etc. are not being used, rather concentration has been paid on designing a more practical and simple but effective system using an electrically controlled differential drive with only two wheels.

Index Terms—Automated Wheel Chair, Bio-Electric Amplifier, Differential Drive controller, F/V converter, Myoelectric Signal processing, PID control, sEMG signal.

—————————— ◆ ——————————

1 Introduction

Over the years, the neurophysiology and biomechanics of muscle systems have been investigated quite extensively based on the research of surface EMG signal. Surface Electromyography (EMG) signals represent the electrical activity of a muscle during contraction [1]. The surface EMG signals are complex and non stationary time sequence that can be considered as direct reflection of the muscle activity [2]. In this work EMG signals collected from the muscles responsible for two types of movements of neck medically termed as – *flexion* (the movement in which the chin is lowered down toward the chest) and *lateral rotation* (rotation to the left or to the right towards the shoulder); are used as the controlling signal for the wheelchair movement. In the past decade, a number of simple yet effective hands-free human machine interfaces (HMI) are brought into applications using human physiological signals such as electromyography (EMG), electrooculography (EOG) and electro-encephalography (EEG).

- ***Taslim Reza*** *has obtained his Masters degree in Biomedical Engineering from Tamper University, Finland and Bachelor degree in Electrical and Electronic Engg from Islamic University of Technology, Bangladesh. Currently he is serving as Lecturer in Dept. of EEE of American International University of Bangladesh (AIUB), Dhaka, Bangladesh. E-mail: taslimreza@gmail.com*
- ***S.M.Ferdous*** *has obtained his Masters and Bachelor degree in Electrical and Electronic Engg from Islamic University of Technology, Bangladesh. Currently he is serving as Lecturer in Dept. of EEE of American International University of Bangladesh (AIUB), Dhaka, Bangladesh. E-mail: tanzir68@gmail.com*
- ***Md. Nayeemul Hasan*** *is currently serving as Lecturer in Dept. of EEE of American International University of Bangladesh (AIUB), Dhaka, Bangladesh. E-mail: nayeem01@yahoo.com*
- ***Md. Rokonuzzaman*** *is currently serving as Lecturer in Dept. of EEE of University of Asia Pacific (UAP), Dhaka, Bangladesh. E-mail: rokon_iut@gmail.com*
- ***Kazi Firoz Ahmed*** *is currently serving as Lecturer in Dept. of EEE of American International University of Bangladesh (AIUB), Dhaka, Bangladesh. E-mail: k.firoz@aiub.edu*
- ***A.Z.M Shahriar Muttalib*** *is currently serving as Lecturer in Dept. of EEE of American International University of Bangladesh (AIUB), Dhaka, Bangladesh. E-mail: sadi_eece@yahoo.com*

As can be seen in literature [1, 2], HMIs developed from these signals are used for hands-free control of electric-powered Wheelchairs. Li and Tan [3] propose a bimodal wheelchair control approach by integrating vision and speech controls. Matsumoto and Ino et al. [4] apply the recognition of head motion and eye gaze onto a locomotive wheelchair system. Ferreira and Silva et al. [5] proposed an HMI structure to control a robotic wheelchair by scalp EMG and EEG signals.

This paper presents a solution for those kinds of disabled people who are unable to spend a lot of money to buy a fancy wheelchair that requires on board computer and other expensive instruments. A simple structure and user friendly control system are used to control the wheelchair movement using only the movements of neck muscles. Generally this type of design would suit most to the people those who are totally disabled, that means completely unable to move their hand or leg. First part of the paper shows the extraction of EOG signal by elaborately analyzing the anatomy of the eye muscles and processing of those signals to make it compatible to use in conjunction with a microcontroller. Second part shows the structure and control mechanism of the wheelchair.

2 Sensing and Acquisition of sEMG Signals

Myoelectric signals or surface electromyograms (sEMG) are produced during muscle contraction when ions flow in and out of muscle cells. When a nerve sends the signal to initiate muscle contraction a potential is developed across the muscle due to the movements of electrolytes. This ionic current can be converted into electronic current with Ag-AgCl electrodes placed on the surface of the skin of the contracting muscle. A typical EMG signal has an amplitude level of *0-5mV* with a frequency range of *0-500Hz* where the dominating frequency lies in the range of *50-150 Hz*.

2.1 Electrode Placement

There total three electrodes placed on the different muscles as shown in Fig.1(a). For signal acquisition the upper trapezius muscle is chosen where two electrodes – R (right) and L (left) have been placed. To obtain a reference point (the point with respect to that the potentials are being measured) a third electrode is placed at point G. Any movement of the muscle specially contraction will generate an EMG signal as shown in Fig. 1(b), which can be sensed and acquired through electrodes.

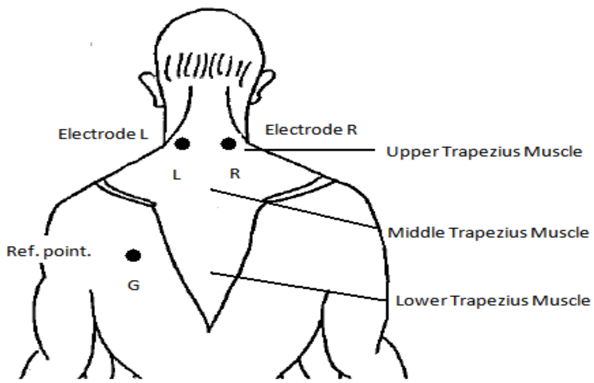


Fig. 1(a). Placement of electrodes on different points of neck muscle for signal acquisition.

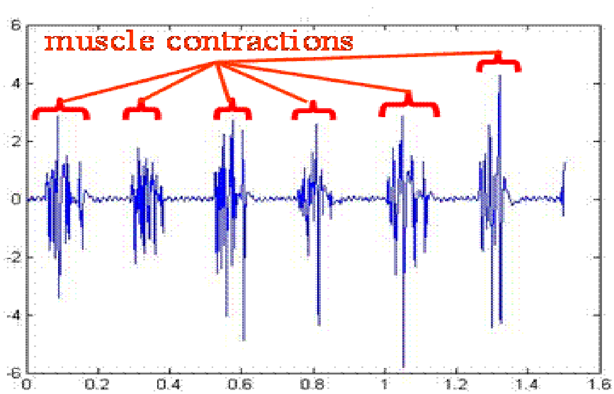


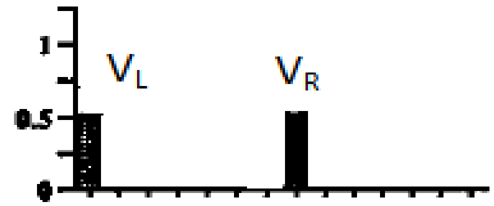
Fig. 1(b).Generation of sEMG signals when muscles are contracted.

2.2 Generation of sEMG signals from different movements of Neck Muscles

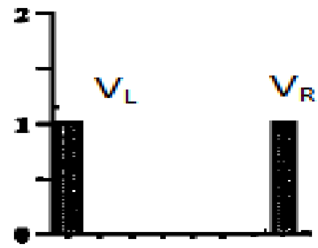
For navigating the wheel chair two types of rotation of neck muscle are considered- *Flexion* and *Lateral rotation*. From these movements four types of movement should be identified to control the motor. It has been observed that, different movements of trapezius muscle can produce voltages with different levels [6]. These are shown graphically with the help of following diagrams of Fig.2. [6].

2.3 Signal Acuisition

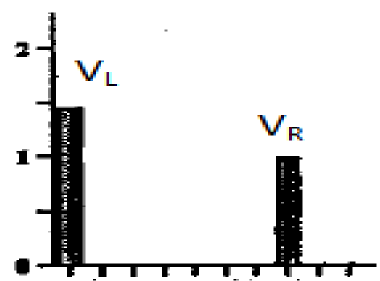
A signal acquisition model is developed to acquire the sEMG signal due to the movement of head. Acquired signals are processed, filtered and amplified to feed to a microcontroller which in turn will produce the necessary driving pulses of the motors to navigate the wheel chair. The functional blocks of the acquisition module and steps are shown in Fig. 3.



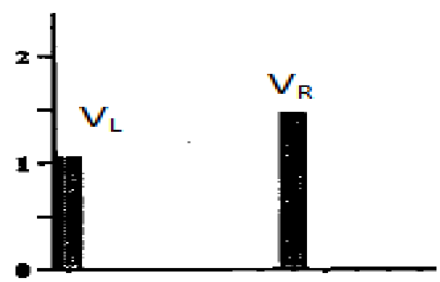
(a) Head at rest



(b) Head Flexion to 45º



(c) rotation of the head to the left



(d) rotation of the head to the right

Fig. 2. Measured sEMG signal for trapezius muscles during different movements of the head. V_L and V_R are the left and right electrode voltage respectively, plotted in logarithmic scale.
For Reference, 2 = $\log_{10}$ (100µV) [6]

With exactly same process two identical acquisition modules are used to collect signals from the neck muscles. Generally the noise components are in the frequency range of 0-10 Hz (low frequency motion artifacts) and 500+ Hz (movement between electrodes and skin surface). By using a HPF and a LPF unwanted noises are filtered out. A 0-5V input is required for operation of a microcontroller and hence a precision rectifier along with an amplifier with adjustable gain is introduced to convert the bipolar sEMG into unipolar signal. At the final

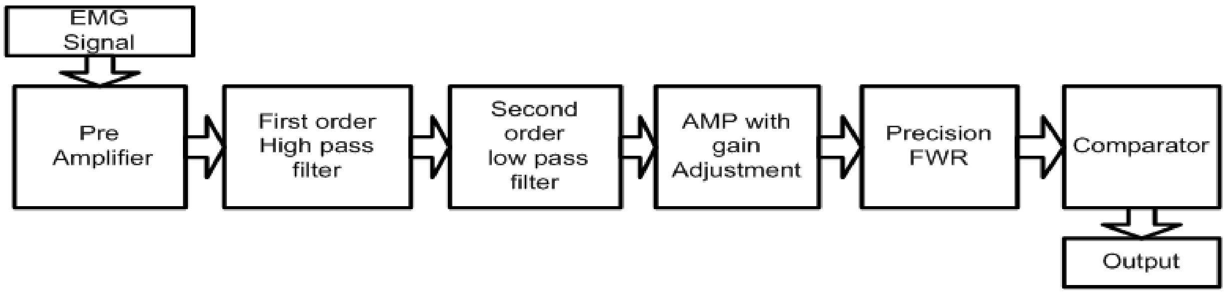


Fig. 3. Steps and components of EMG signal Acquisition.

stage, a comparator with a threshold voltage level of 3V is used to clearly distinguished between the two different head movements as both the electrode (right/left) would produce some voltages during lateral rotation. But the muscle of a particular side will be more contracted if it is the side at which the head has been moved, and then the voltage generated by the electrode of that side would be higher compare to the other one. Hence the comparator will produce an output voltage high if the corresponding electrode along with its amplifier generates a voltage greater than that. The circuit arrangements of the module and final acquired signal after processing are shown in Fig.4 and Fig.5 respectively.

3 System Design and Development

The system is capable of producing three movements- forward motion, left and right rotation. The wheelchair employs a differential drive system where the motion controller converts motor rotations into useful torques which are in turn mapped to wheel velocities. The differential drives used have two independent drive wheels on the left and right sides, enabling the chair to move at any desired directions. Casters on the front or back or both ends keep the chair level.

The layout of the chair showing all the components are shown in Fig.6. Two 12V, 5A (60W) PMDC motor is used to drive the wheelchair where the motors are connected with a Bevel gear arrangement which are finally connected with the axis of the wheel.

4 Wheel Chair Control and Navigation

Control for the two motors in the system is carried out by using an H- bridge motor controller. The driving signals are generated by the microcontroller which produces appropriate PWM signals for appropriate movement of the chair. Depending on the direction of movement of the head, the associated neck muscle will force the corresponding electrode output to go high.

4.1 Motor Control Algorithm

The complete movement of the motor depending on the movement of the head is summarized in Table.1. A simple but effective algorithm is developed and implemented using the microcontroller. Depending on the control algorithm the duty cycle of a particular motor is varied to obtain the desired response from the system.

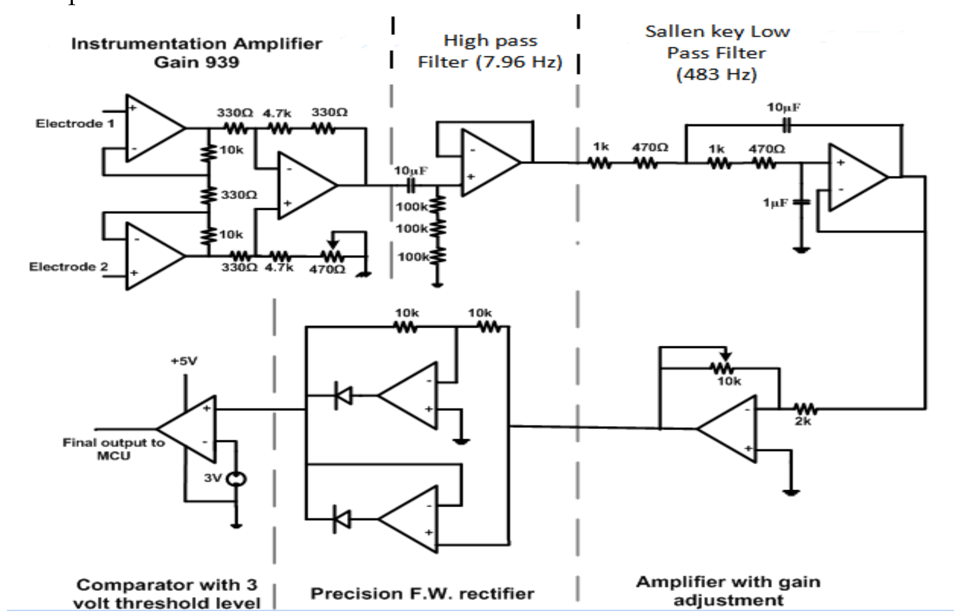


Fig. 4. Complete Circuit Diagram of EMG Signal Acquisition and Processing Unit (Bio-electric Amplifier)

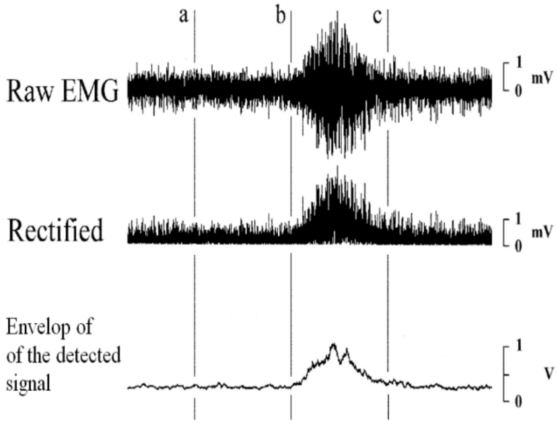


Fig. 5. Detected sEMG Output Signal.

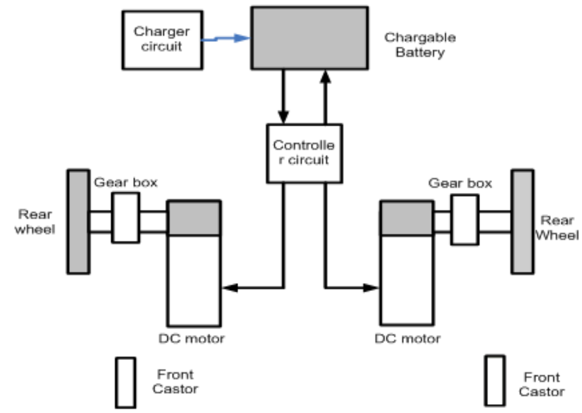


Fig. 6. Layout Design of the Wheel Chair

Based on the algorithm, next the controller is developed using the microcontroller. The control structure of the wheel chair is modeled in Fig. 7. To obtain a smooth and fast response a PID controller is applied in the system. The error signal, e_1 is generated depending on the direction of movement and is assigned with a value enlisted in Table.1. Next the value is compared with a pre-assigned reference value which in turn will generate the necessary duty-cycle for the PWM signals.
Duty-cycles are generated by following the equations [eq. (4) - eq. (7)]. The PWM signal will operate a motor controller IC which will furnish sufficient amount of current and voltage from the power supply to run the motor.

The reference voltages are set as follows-

$V_{ref} = 5$ .... (1)

$V_R = V_{ref} + e_1$.................................. (2)

$V_L = V_{ref} - e_1$.................................. (3)

For Right Motor (to rotate CW/ right)

Duty Cycle, $DC_R = 20V_R$; for $0 \le V_R < 5$....(4)

Duty Cycle, $DC_R = 0$; for $V_R \ge 5$......... (5)

For left Motor (to rotate CCW/ left)

Duty Cycle, $DC_L = 20V_L$; for $0 \le V_L < 5$.....(6)

Duty Cycle, $DC_L = 0$; for $V_L \ge 5$.......... (7)

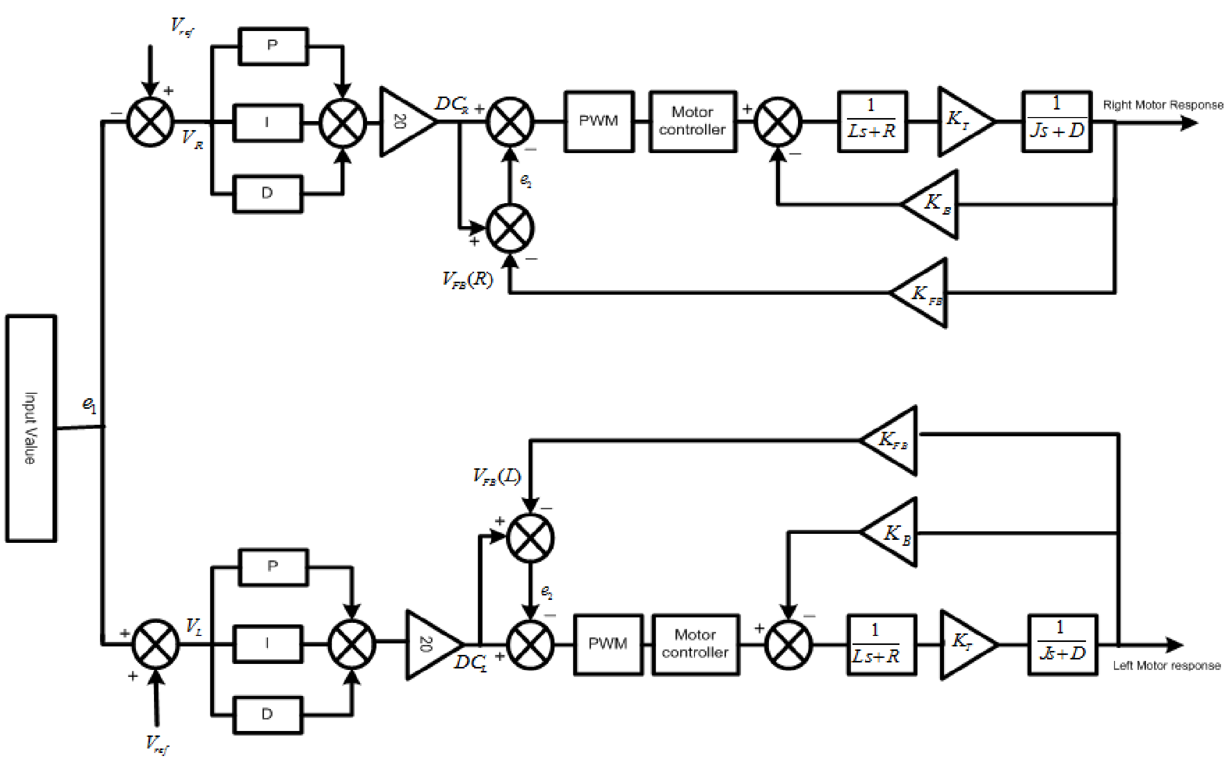


Fig. 7. Block Diagram Representation of the Wheel Chair Control System

TABLE 1
UNITS CONTROL ALGORITHM FOR THE MOVEMENT OF THE MOTOR

Right electrode output V_R	Left electrode output V_L	Position of Head	Wheel chair response	Assigned error value	Duty cycle (Right motor)	Duty cycle (left motor)
0	0	At rest	Forward	0	100%	100%
0	1	Rotating Left	Rotate counter clockwise	-2	60%	0%
1	0	Rotating right	Rotate clockwise	+2	0%	60%
1	1	Flexion (moving head downward)	START/STOP (depends on the previous state)	N/A	Turn ON/OFF the power supply to the motor	

4.2 Feedback Control

Feedback is employed to ensure accuracy of the system designing a closed loop controller. Depending on the set value the motor will run at a particular speed. The speed of the motor is sensed by an Infra red transmitter- receiver and a pulse generating circuit. These pulses are sent to a frequency to voltage converter which is calibrated to produce 5 volts when the input signal has a frequency of 25 Hz (i.e. 25 pulses per second). The output voltage of an F/V converter is fed to microcontroller where it is sampled and stored using Analog to Digital converter. The Feedback signal, V_{FB} is then generated using the following equation implemented by the MCU.

V_{FB} = (25/ 128) x (ADC value)................. (8)

The total process of feedback signal acquisition is enlisted in Table 2.

TABLE 2
FEEDBACK SIGNAL ACQUISITION AND GENERATION OF V_{FB}

PWM signal (reference of set value)	RPM of the motor	Voltage generated by the F/V converter.	ADC value (generated by the MCU)	Respective value assigned according to ADC	Feedback voltage V_{FB}
0%	0	0	0	0	0
20%	300	1	102	1	20
40%	600	2	205	2	40
60%	900	3	308	3	60
80%	1200	4	410	4	80
100%	1500	5	512	5	100

To obtain a closed loop controller, a Feebback signal is needed to be generated and fed to the Microcontroller via the ADC port. A reflective tape can be placed on the rotating part of the motor or the shaft to count the RPM of the motor and through generated electrical pulses. These pulses can be fed to a Frequency to voltage converter circuit to generate a voltage proportional to the speed of the motor. Later on the generated voltage can be fed to the ADC port and processed accordingly to produce necessary feebback signal, V_{FB} for comparision and generation of error value. The total system can be represented with the help of a block diagram shown in Fig. 8.

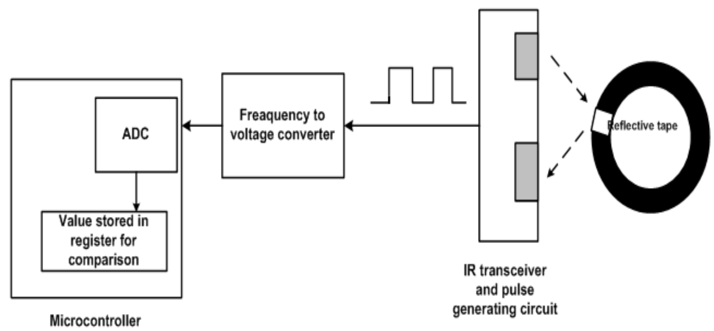


Fig. 8. Block Diagram Representation of Feedback Signal Acquisition

5 CONCLUSION

The design of the wheel chair along with its simple but effective algorithm suggests that, it can be a very good method to obtain system assisted mobility for the disabled. The accuracy and performance of the system depends greatly on the signal acquisition. So, the signal acquisition and processing module should be designed with great care. The simplicity of the system makes it a perfect candidate for practical implementation. In spite of its effectiveness still there is a lot of room for improvements. Intelligent control system like neuro-fuzzy controller, adaptive control may be introduced in the system to obtain a better performance from the system and make the system more versatile, dynamic and fast.

Acknowledgment

The authors wish to thank Mr. Ahmed Mortuza Saleque, Lecturer of EEE Department in American International University- Bangladesh (AIUB), for his valuable suggestions and cordial support during the entire time period of this Project Work.

References

[1] Madeleine M. Lowery, Nikolay S. **Stoykov, Allen Taflove, Todd A.**Kuiken, " A Multiple-layer Finite Element Model of the Surface EMG Signal, "IEEE Transaction on Biomedical Engineering, vol 49, no.5, May 2002, pp446-456.

[2] Research on the Surface EMG Signal for Human Body Motion Recognizing Based on Arm Wrestling Robot ; 12Zhen Gao, 1"2Jianhe Lei, 1"2Quanjun Song, 'Yong Yu, 'YunJian Ge; Proceedings of the 2006 IEEE International Conference on Information Acquisition August 20 - 23, 2006, Weihai, Shandong, China.

[3] Moon, I., Lee, M., Chu, J., Mun, M.: Wearable EMG-based HCI for electric-powered wheelchair users with motor disabilities. In: Proceedings of IEEE International Conference on Robotics and Automation, pp. 2649–2654 (2005).

[4] Barea, R., Boquete, L., Mazo, M., Lopez, E.: System for assisted mobility using eye movements based on electrooculography. IEEE Transactions on Neural Systems and Rehabilitation Engineering 10, 209–218 (2002)

[5] Tsui, C.S.L., Jia, P., Gan, J.Q., Hu, H., Yuan, K.: EMG-based hands-free wheelchair control with EOG attention shift detection. In: Proceedings of IEEE International Conference on Robotics and Biomimetics, pp. 1266–1271 (December 2007)

[6] V. Reggie Edgerton, Steven L. Wolf, Daniel J. Levendowski, Robert I. Jennrich, Roland R. Roy, "EMG Activity in Neck and Back Muscles During Selected Static Postures in Adult males and Females", Physiotherapy Theory and Practice (1997) 13, 179-195.

[7] Mohammad Rokonuzzaman, S.M.Ferdous, Rashedul Amin Tuhin, Sabbir Ibn Arman, Tasnim Manzar, Md. Nayeemul Hasan. "Design of an Autonomous Mobile Wheel Chair for Disabled Using Electrooculogram (EOG) Signals.", DOI : 10.1007/978-3-642-23244-2_6, Mechatronics-Recent Technological and Scientific Advances, Ryszard Jabłoński, Tomaš Březina (Editors), Published by Springer Berlin Heidelberg, ISBN- 978-3-642-23243-5 (Print) , 978-3-642-23244-2 (Online), DOI- 10.1007/978-3-642-23244-2, Springer Publication Date- Saturday, September 24, 2011.