EMG Controlled Wheelchair Movement based on Masseter and Buccinators Muscles

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Abstract — *There are many elderly people who lack the control of movement of their upper or lower limbs. There are also many people affected and who are paralyzed. For this reason, the wheelchair is very important for these people to help them daily. The aim of this work is to present a control method of wheelchair movement in five directions: (forward, reverse direction, turn left, turn right, and stop condition) based on the signals of electromyography (EMG), where the EMG signals are collected from the masseter and buccinators muscles, and then extracted features of the autoregressive model (AR model) 4-order, and classify it by using the K-nearest neighbor classifier (KNN) and use it as a control signal for the wheelchair's movement. The rate of classification was a maximum when the value of K=1 and K=2, where the accuracy of the proposed method was as the following: double blowing 98.1, double clenching 97.3, single blowing 96.5, and single clenching 98.1.*

Keywords — *Intelligent Wheelchair, EMG, AR model, K-nearest neighbour classifier.*

I. Introduction

The Electric Power Wheelchairs (EPWs) are becoming increasingly critical inside assistive technological and rehabilitation devices. It is very important to improve the daily lives of the elderly and people who have amputated hands over the last twenty years [1] where there are many elderly people have difficulties in controlling their arm and leg movements. Typically, EPWs are usually controlled by a joystick. Nevertheless, it is not always well suited for impaired people that have been lacking in controlling of their upper or lower-limbs.

However, there are many methods for controlling wheelchair movement, such as: eye moment [2], bio-potential signals interface [3-6] head gesture [7] voice recognition [8] movement of shoulder muscles [9] forehead muscle [10] and the wrist and ankle muscle [11] The Electromyography (EMG) signals are very easily obtaining from the skin's surface of the muscles by using surface electrodes, the EMG signal is a biomedical signal that measures electrical currents generated in muscles during its contraction representing neuromuscular activities, where the nervous system always controls the muscle activity (contraction/relaxation)[12].

The procedures of collecting the EMG signals can be done by two methods, namely non-invasive and an invasive manner. For the invasive method, the electrodes are injections inside muscles for recording the signals of muscles, but this method is not comfortable for the subject and because many risks could occur during the surgery. For non-invasive method, the electrodes are directly placed on the surface of the skin without any surgical procedures and the procedure of fixing the electrodes on the skin to the muscles is very easy. Some of the previous research used the signals of the upper and lower muscles as the method for controlling the wheelchair's movement and focused upon how to use the intermittent commands of controlling for the electric power wheelchair without any focus on the contraction of the muscles that be changing level.

In this work focuses on how to collect the signals of masseter and buccinators muscles and extracted the feature of the AR model fourth-order from the signals, and classify it with the K-nearest neighbor classifier to use it as a control signal to control the movement of the wheelchair in five directions.

II. Methodology

The EMG signals is collected from the buccinators and masseter muscles of the subjects not disabled, by placing the surface electrode on the skin muscles after that processing the signals and extracted the features of AR model from each signal of to classify it with K-nearest neighbor classifier and used it as a control signals of the wheelchair movements in a five direction (forward, reverse direction, turn left, turn right, and stop condition).

A. EMG Data Acquicition

The EMG is a device used for recording the electrical activity of EMG muscle signals, where the EMG signal is a biomedical signal measures the electrical currents that are generated in the muscles during its contraction representing neuromuscular activities. The signal of the EMG controlled by the nervous system is also based on the physiological and anatomical properties of the muscles.

However, in this work, the EMG data is collected from the buccinators and masseter muscles by placing surface electrodes on the skin muscles of the subject. However, before collecting the EMG signals from the muscles, the skin of the muscles must be prepared so as to obtain a good quality EMG signal as this can considerably reduce the skin's impedance. Dead skin cells such as a hair must be completely removed from the location where the EMG electrodes are to be placed. All the moist of the skin muscles must also be removed, and then cleaned with alcohol in order to eliminate any type of wetness or sweat on the skin in order to increase the attachment between the skin of the muscles and the electrodes.

The recording of EMG signals was collected from the masseter and buccinators muscles of subjects not disabled, where the operation of data collecting occurs by utilizing the EMG device (Bioradio 150) and fixing the EMG electrodes on the skin muscles. The EMG electrodes that are used in this work was a Silver – silver chloride (Ag-AgCl) electrodes, because the (Ag-AgCl) electrodes are more comfortable for the subject when placed on the surface of the muscle skin without any need inject the skin of the subject's muscles. In this research, two channels of EMG device are used for recording the data from the masseter and buccinators muscles.

After placing the electrodes on the skin of the masseter and buccinators muscles, at first, the subject will blow as single blowing, where this data represented the signals of single blowing. After recording the data of single blowing, the subject takes a rest for ten seconds to avoid muscle fatigue, and then records the data of double blowing. The signals of single and double blowing are recorded from the buccinators muscles, as the buccinators muscles are responsible for blowing. After that the subject also take a rest for ten seconds, and then records the signals of single clenching from the masseter muscles, and recording the signals of double clenching. The signals of single and double clenching are collected from the masseter muscles, as the masseter muscles are responsible for the movement of clenching. The time of recording each signal is five seconds only. The data was collected from 15 subjects not disabled for four movements, through 10 trials for each movement. Fig 1 shows the placement of electrodes on the skin of the buccinators and masseter muscles of the subject.

Fig. 3 The placement of the electrodes on the buccinators and masseter muscles, where **A** the electrodes placement of the masseter muscles and **B** the electrodes placement of the buccinators muscles.

B. EMG Signal Processing

The raw data of EMG is generated from the muscle fiber that is innervated by the motor neuron. That means it contains the intention of the users. The nervous system always controls the muscle activity (contraction/relaxation) [13]. Hence, the EMG signal is a complicated signal, which is controlled by the nervous system and is dependent on the anatomical and physiological properties of muscles. However, the raw data of the EMG is very noisy, its frequency ranges from 0 to 2,000 Hz, its amplitude is very limited, 0 to 10 mV, according to the contraction of the muscles [14]. The activation of the muscles can be detected by measuring the amplitude of it, where the amplitude of the EMG signals directly increases with increasing the contraction force of the muscles. However, after the skin muscles had been prepared and cleaned, some of characteristics were considered as follows: sweat of the skin, muscle fatigue and the location of the electrodes, where the physical characteristics of the EMG signals had already changed even when it was measured from the same subject. After placing the electrodes on the surface of the skin muscles, the data of masseter and buccinators muscles was collected as shown in Fig 2. The data collected then filtered with a Band Pass Filter (low pass filter = 450 Hz, high pass filter = 20 Hz) to be more suitable [15] and then get the maximal voluntary contraction (MVC) for the clenching and blowing signals, and normalization it.

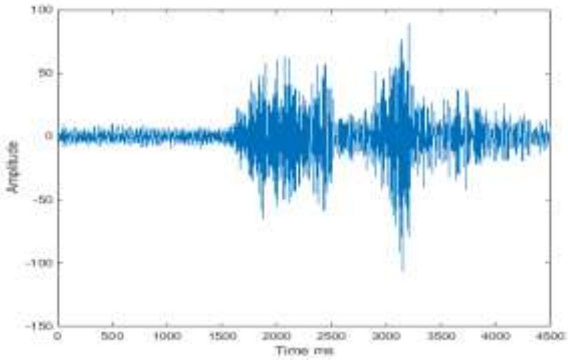

Fig 2 (a) Time series Double Blowing

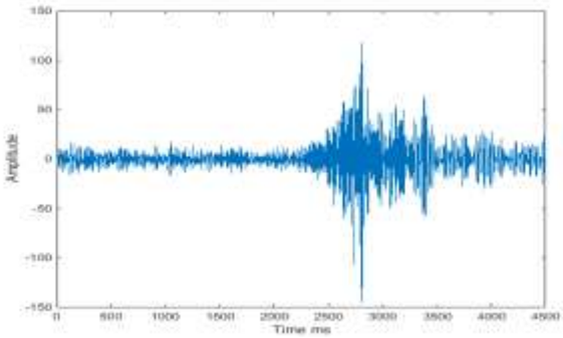

Fig 2 (b) Time series Single Blowing

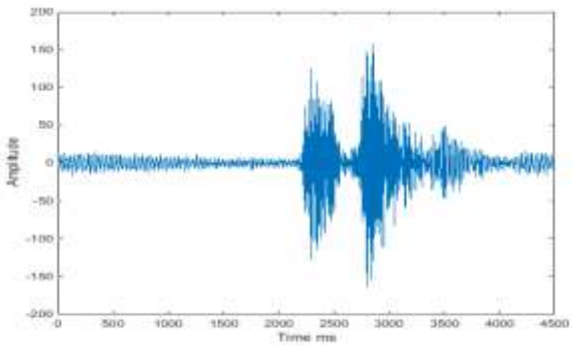

Fig 2 (c) Time series Double Clenching

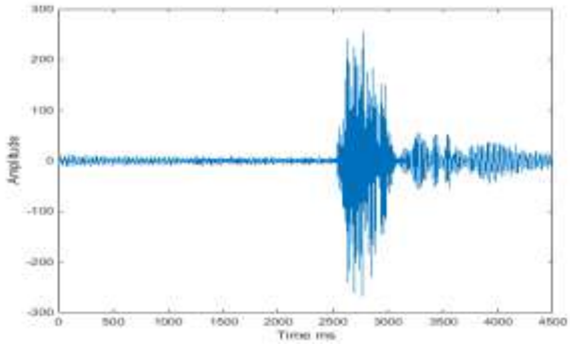

Fig 2 (d) Time series Single Clenching

Fig. 2 Time series of EMG signals for movement of buccinators and masseter muscles.

Fig. 4 shows the raw data of EMG signals, without any filtering, whereas Fig 2(a) and Fig 2(c) represented the data of the buccinators muscles for single and double blowing. Fig 2(b) and Fig 2(d) represented the data of the masseter muscles for single and double clenching.

After getting the normalization of the EMG signals of the masseter and buccinators muscles must be test the validity of the signals by using the Analysis of Variance (ANOVA) test to check it. In this research work has been used one way ANOVA test to check the validity of the normalization signals, where the ANOVA is a statistical model using to analyze the difference between the different groups and their associated procedures as the variation between the groups. In ANOVA test has been calculating the sum of the square deviation from the total mean of normalization data, where the value of $p < 0.05$ that means the validation of the raw data is good for all classes. Table 1 shows the result of ANOVA.

TABLE 1: THE RESULT OF ANOVA TEST THE SIGNALS OF MASSETER AND BUCCINATORS MUSCLES.

source	**Sum of squares**	***p* -value**
Columns	440.42	0
Error	2195.39	
Total	2635.81	

Form Table 1 it can be observed that the value of *p*-value is less than 0.05, that means the validation of the normalization EMG signals is acceptable to use it in the procedures of controlling of the wheelchair movements.

C. Feature Extraction

The EMG signals are very important in the method of controlling. There are also many features of the EMG signals in time domain, frequency domain, and time-frequency domain. However, the stage of feature extraction is very important for the pattern recognition system. The feature of the EMG signals extracted from the AR model four-order in time-frequency domain [16], the reason of choose the AR model four-order in this research work because of the experimental shows the accuracy of classification is very high with AR four-order compared with the other result with using another order of AR model [17], where the algorithm of an autoregressive model is used to extract the feature of signals, also the fourth-order of AR model is used to analyze the EMG signals, by using the mathematical expression as shows in Equation :

$$x(n) = -\sum_{k=1}^{p} ak \ \ x(n-k) + w(n)$$

Where $x(n)$ represent the current sampling value of the EMG signals . $w(n)$ is the current incentive value, *i.e.*, the residual of the white noise. p is the order of the model. ak is the kth coefficient of the AR model. The meaning of the Equation is that $x(n)$ is generated by the linear combination of several past values $x(n-k)$ and the current incentive value $w(n)$. The chosen of p is very critical, where if the order be very low, the result will be smooth, while if the order be high, the result will contain a dramatic and vibration.

D. Classification

The K-nearest neighbourhood classifier is widely used in pattern recognition classification methods [18] where the pattern recognition is very good as the method of controlling the wheelchair movement, and the accuracy of the pattern is very high after classification. In this paper has been used the K-nearest neighbourhood (KNN) classifier for classification the EMG signals, where the KNN classifier represents the simplest type of the classifiers and is more effective, also it is efficient classifiers [19]. The KNN takes into consideration a distance function that is computed between the features of the EMG signals belonging to the pattern of the EMG in the test set. Also, the neighbouring of the EMG pattern in the training set, the pattern of the EMG of the test set that is classified depended on the class labels of closer EMG pattern [20]. At first, by using AR model start from order one to ten to test the accuracy of KNN classifier, and the value of K is fixed as one only in order to choose the best order of AR model. In Fig 3 the accuracy of KNN classifier with AR order model is charted.

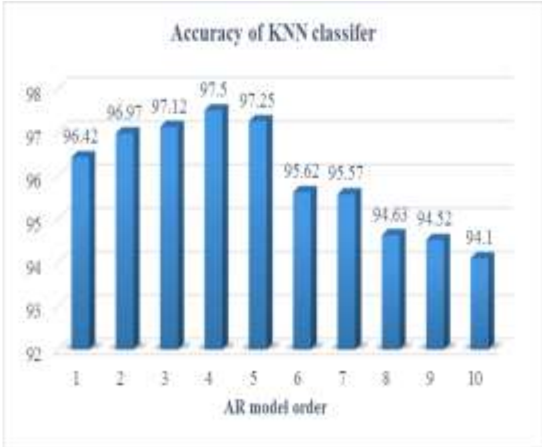

Fig 3 The accuracy of KNN classifier with AR model.

From the Fig 3 it can be observed that the accuracy of KNN classifier is high when the AR model order is four compared with the other result of accuracy, therefore in this research work, fourth-order of AR model has been used as features input to the KNN classifier and used as a control signals of the wheelchair movements. In the process of classification has been used 70% of the data for each class for training and 30% of the data for each class used for testing, the accuracy of the KNN based on the pattern, the Euclidean distance and the suitable value of K (Neighbor) for getting best accuracy. In this method, we used different “K” values ranging from 1 to 5 to choose the best value of “K”. Table 2 shows the accuracy of classification when the order of the autoregressive model is four as follows:

TABLE 2: THE ACCURACY OF KNN CLASSIFIER WITH AR model 4-ORDER AND VALUE OF “K” from 1 TO 5.

Accuracy of KNN classifier					
Pattern	K=1	K=2	K=3	K=4	K=5
Double blowing	98.1	98.1	95	95.8	88.3
Double clenching	97.3	97.3	95.8	95.8	85.8
Single blowing	96.5	96.5	90.8	90	88.3
Single clenching	98.1	98.1	94.1	92.5	89.1

From Table 2, it can be observed that the maximum classification performance when the value of K is equal to 1 and 2 when compared with the other classification accuracy for different of K.

III. CONTROLLING METHOD

The controlling method is based on collecting the signals of the masseter and buccinators muscles of the subjects and then classify it by using KNN classifier to use it as a control signal for the wheelchair's movement. The operation of controlling the movement of the wheelchair was offline in a five directions: "forward", "backward" (reverse direction), "turn left", "turn right", and "stop". This method of controlling is very easy, comfortable and suitable for elderly and paralyzed people. It also does not need any effort during the operation of controlling. The signals of buccinators muscles are collected for two movements: single blowing and double blowing. The signals of single blowing are used as a control signal to control the wheelchair movement to turn it toward the right side, and the signal of double blowing is used to control the wheelchair movement to turn it toward the left side. The signals of the masseter muscles are collected for two movements: the signals of single jaw clenching are used as a control signal to control the wheelchair movement in a forward direction and used for the stop condition at the same time, the signals of double jaw clenching are used as a control signal to control the wheelchair movement in a reverse direction (backward).

After processed the EMG signals of the masseter and buccinators muscles and extracted the features of AR model four-order, made classification, at first made classification (training and testing) over all classes for the EMG signals in the Matlab program to check the classification accuracy, after that apply the data on the wheelchair, where at first made train over all classes one time only, then made test for each class by using the push button of the interface.

The signals that be collected from the buccinators muscles were responsible for the wheelchair movement in a left and right direction. The signals that be collected from the masseter muscles were responsible for the wheelchair movement toward the forward, backward and stop conditions. The signals that be collected from the masseter and buccinators muscles of the subjects not disabled are processed and extracted the features of the AR model then classified it with KNN classifier and then interfaced the classification of the EMG signals with the system by using mini-computer, where the collected signals of the EMG is stored in a mini-computer built in the wheelchair, and the controlling method was offline by using the mini-computer. The interface of the controlling program of the wheelchair movements is viewed via a small LCD display fixed on the wheelchair that be connected with the mini-computer as shown in Fig 4.

Fig 4 (a) Prototype of the electric wheelchair

Fig 4 (b) Explains the interface of the wheelchair controlling program

Fig 4 The electrical power wheelchair and the interface of the controlling method.

The user of the wheelchair is controlled on the wheelchair directly from the interface of the controlling program that view on the LCD display that is fixed on the wheelchair as shown in Fig 4(a).

During the procedure of testing the wheelchair, the user click on the push button of Forward command, the wheelchair is moving toward the forward direction, and the user click on the push button of Stop command, the wheelchair is stopping directly. After that the user click on the push button of Right command, the wheelchair directly turn to right side by 90 degree, and when the user click on the push button of Left command, the wheelchair will turn to left side by 90 degree. After that testing the command of Backward, where the user click on push button of Backward command, the wheelchair directly turn 180 degrees. Each push button is responsible on executing test classification on the desired direction, for example if the user want to move the wheelchair in a reverse direction, just click on the Back push button, where this button responsible on the test classification of the double jaw clenching signals that be responsible on moving the wheelchair in a reverse direction by 180 degree, where directly the result of classification will sends to arduino board that control on the motor of each wheel of the chair.

IV. RESULT AND DISCUSSION

In this work, the data of EMG is collected from 15 subjects for 4 movements, where the data collected from the masseter and buccinators muscles through 10 trials for each movement. The type of movement was as follows: double blowing, single blowing, double clenching, and single clenching. Each movement response was one movement of the wheelchair, except that the signals of single jaw clenching were used to control the wheelchair movement in a forward direction and also were used for the stop condition at the same time. The sum of 600 EMG signals was used for the method of controlling, where the feature gets by using the Autoregressive model. The result of the features of AR model fourth-order are grouped and then applied for training and testing set for classification of the movement of the masseter and buccinators muscles using EMG signals. The performance of the classification can measure the accuracy of it, where Table 2 shows the rate of classification 4 order of AR model and different value of K from 1 to 10. In this work, the accuracy of the method of controlling the wheelchair movement based on the accuracy of classification, where during using AR order = 4, value of K = 1 and K=2, the accuracy of the classification was very high compared with the other value of K. The maximum classification rate was 98.1, where it was obtained on the double blowing and single clenching movement. The classification rate of double clenching was 97.3, and the accuracy classification of single blowing was 96.5. However, the rate classification of all movement was 97.5 when the AR model order be 4 and the value of K be 1 or 2.

V. CONCLUSION

The classification of EMG signals by using a KKN classifier is very effective to use it as a control signal for the wheelchair movements. The main aim of this work is to use the signals of EMG in controlling the intelligent power-assisted wheelchair movement in five directions based on the data that is collected from the masseter and buccinators muscles. However, most researchers have collected the EMG signals from the upper or lower limbs and then used it as a control signal for the wheelchair movement. In this work, the data collected was from the masseter and buccinators muscles only by using two channels only. That means this work is very comfortable for elderly people and amputated hands or people with tetraplegia because the procedure of collecting the data from the masseter and buccinators muscle is suitable for these people. Furthermore, the method of controlling is very easy and has high accuracy and performs reliably when it is applied on the wheelchair.

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