Robot mobile control based on three EMG signals using an artificial neural network

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Abstract. The EMG signals can be produced from the human muscle activity. This paper explains the control system of the robot mobile which uses the EMG signal from three muscles contraction such as the jaw muscles, the right arm muscles, and the left arm muscles. The peak values of the EMG signal was used as the input to the ANN system using the Backpropagation algorithm, and it produces the output which has nine target conditions; the forward, then turn right and then turn left where each of them has the variations such as the slow, the medium and the fast. The ANN has been trained with 270 of the training data, and it has been tested with 135 of the testing data from 15 respondents who performed muscle contraction activities. Based on the test result, there are only two unrecognizable data with the rate of the system accuracy is 98.52%. The movements of the robot mobile can be controlled based on the recognized movement patterns with the specified target conditions.

1. Introduction

Every signal that comes from the biological and the medical sources is called the biosignal [1]. The biosignal which is the subject of this research is Electromyogram (EMG). The EMG signal is a biosignal corresponding to human muscle contractions [2]. The muscle contraction produces the voltage which the value depends on the muscle physiological, the muscle anatomy position, the electrode type, the electrode dimensions, and the electrode placement. Many methods have been developed to detect, process, decomposition and classify the EMG signal, such as Double Threshold Detection, Wavelet Transformation, Wigner-Ville Distribution, Artificial Neural Networks (ANN), Fuzzy Logic System, Higher-Order Statistics (HOS), Bayesian and Support Vector Machine (SVM) [3]. Based on its ability to detect and records the muscle electrical activity, The EMG signal has contributed not only in the biomedical field [4]-[5], but also in the applications related to the Human-Machine Interface (HMI) [6]-[8] and the control application tools such as the wheelchair control, the computer control and the robot control [9].

Some research which related to the EMG signal and its applications of the controlled robot, such as in the research [10], the robot manipulator is controlled by the left arm using the EMG signal and the encoder. In the research [11], the robot arm control system is designed by using the EOG signal to move the angle of the robot arm based on the eye movement and the EMG signal to hold the object. In the research [12], the robot arm is controlled by the EMG signal using Fuzzy algorithm method. Also, the EMG signal of the leg muscle contractions can also be used to design the prosthetic leg which can apply to the people who have amputated at the knees [13].
There are many older adults and disabled people who are difficult to walk or move, so they need a wheelchair to facilitate them to move and walk. Based on this reason, some researches about the EMG signal on the wheelchair control application has developed, such as in the research [14], the wheelchair control based on the EMG signal of the forearms muscle with the grasping movement using the ANN method of multilayer perceptron type. In the research [15], the wheelchair control based on the EMG signals of the masseter and the buccinators muscle, then it was extracted with the autoregressive model feature (AR model) 4-order, and it classifies with the K-Nearest Neighbor classifier (KNN).

The EMG signal has also been developed on the control computer application to help the disabled people who can not operate the computer freely when they use it. In the research [16], the system was designed to control the mouse cursor using the EMG signal with the ANN method. In the research [17], the EMG signal was induced by the wrist movements using the ANN method, so that the users could move the cursor, the click button, and the text typing on the computer.

In this research, we used the EMG signal from three muscle contractions, such as the jaw muscle contraction, the right arm muscle contraction, and the left arm muscle contraction. The EMG signal was processed using Artificial Neural Network (ANN) method. The ANN is a computational model inspired by the neural system of the living things [18]. The ANN method was able to process the actions, recognize the patterns and make decisions based on the conditions. The input of the ANN system was the signal peak data, and the output of the ANN system was in the form of the movement recognition patterns to control the robot mobile based on the target conditions given. The robot mobile could move back and forth, it could turn right and turn left and also it could stop with slow, medium, and fast variation of each movement. This research aims to design the motion control system for the robot mobile, and it could also be used as an alternative wheelchair for disabled people who do not have the legs, the hands, and the fingers.

2. Method
2.1. System architecture
The system detects and records the signal of muscle contraction using a device is called an electrode. The electrode was used by attaching to the skin. In this research, we used seven electrodes, such as Channel 1 (CH1), Channel 2 (CH2), Channel 3 (CH3), Ground (G) and three for Reference (R) in each channel. The EMG signals were detected by the electrodes; then is forwarded to the signal processing circuit. The signal processing circuit divided into two; such as the amplifier circuit and the filter circuit. The amplifier circuit functioned to amplify the signal so that the signal could be read clearly, while the filter circuit functioned to reduce the noise so that the signal could be held and forwarded to the particular frequency area, therefore we could get the desired signal. The EMG signals that have been amplified and filtered, then it sent via Analog pins to the data acquisition device which is a product of National Instrument (NI USB-6008).

The EMG signals processed on the computer and are presented in the real time through the GUI in the Visual Studio 2010 equipped with the library NI-MAX. Then, the peak value of the EMG signals was used as the input of the ANN system. The output of the ANN system was used as the parameter to control the robot mobile. The robot mobile was controlled through the Arduino IDE program that has been uploaded to the Arduino Microcontroller. The illustration of all systems is shown in Figure 1.
2.2. The EMG signal

In this research, the EMG signal used comes from three different muscle positions, i.e., the jaw muscle, the right arm muscle, and the left arm muscle. Each position of the muscle was placed two electrodes which are channel electrode and a reference electrode. Also, an electrode as the Ground was placed on the back of the neck. The position of all electrodes can be seen in Table 1. The EMG signals from the arm muscles consisted of contraction and relaxation activity, while the EMG signals from the jaw muscle consisted of biting and relaxation activity.

Table 1. The electrode positions and the muscle contractions.

| The Muscle Positions | The Electrodes | The Electrode Positions | The Muscle Contraction       |
|----------------------|----------------|-------------------------|-----------------------------|
| The jaw              | CH3            | The Cheek               | Relaxation -                |
|                      | Reference to CH3 | The Forehead           | Chewing/Biting              |
| The right arm        | CH1            | The right bicep         | Relaxation – Contraction    |
|                      | Reference to CH1 | The right forearm      |                             |
| The left arm         | CH2            | The left bicep          | Relaxation – Contraction    |
|                      | Reference to CH2 | The left forearm       |                             |

The Variables used in the EMG signal processing were threshold value and the peak value of the signal. The threshold value functioned to detect the muscle contraction. When the EMG signal passed the threshold value, then the contraction would be detected, while the EMG signal was in the below of the threshold value, then the muscle would be in the relaxation condition. Therefore, the threshold value has designed as much as 0.5 mV to distinguish the relaxation activities and the muscle contractions. Figure 2(a) shows the EMG signal from three times contractions.

After the contraction had detected, the system would have set the peak values of the EMG signals. The peak values were obtained by absolutizing the EMG values so that it had positive values. The largest value has been taken as the peak value. These values become the representation of the EMG signal on the system to control the robot mobile. Figure 2(b) shows the form of the three contraction signals that have been absolute.
2.3. The ANN

2.3.1. The architecture and the algorithm of the ANN

The backpropagation is a network architecture to process the peak value data of the EMG signal. The backpropagation is a multi-layer network consisted of three neuron layers, i.e., the input layer, the hidden layer, and the output layer. In this research, the network was built with three of input units (x), five of hidden units (z) and one of output unit (yk). The weight between the input layer and the hidden layer were v, and the weight between the hidden layer and the output layer were w. Two of input units were also added on the network, i.e., the bias b1 and the bias b0. The network architecture is shown in Figure 3. The Backpropagation consisted of two stages, such as the learning/training stage and the testing/using stage. In training, a stage provided the training data and the targets. The training process of this network was the supervised learning, where the input and the target values of the network have been determined and minimize the errors of the network output. Then, the ANN architecture that has been built was given the testing data.

The training with the backpropagation consisted of three phases, i.e., the feedforward, the backpropagation and the modification of the weight and the bias. In the feedforward phase, every input units received the input signals in the form the peak values of EMG signal; then forward calculations were performed from each layers using the binary sigmoid activation function with the function of value between 0 and 1 to get the output. The output compared to the target to determine the
error. In the backpropagation phase, calculations and propagation were performed to reduce the magnitude of the errors. In the modification of the weight and the bias aim to update the weight and the bias of each layer. These three phases were repeated continuously until the stopping condition had fulfilled so that the network training could be stopped. The stopping condition was determined by limiting iterations and limiting errors (Mean Square Error).

The testing with the backpropagation can be done after the network had finished the training. After the training was over, the network had considered smart; therefore if the network was given the new input, so the network produced the output as desired. The algorithm of the training and the testing of the ANN is shown by Figure 4.

![Figure 4. The algorithm of the ANN](image_url)

2.3.2. The ANN to recognition of the movement patterns

Three inputs of the ANN system represented the EMG signal that recorded in every channel. CH1 as the input of X1, CH2 as the input of X2, and CH3 as the input of X3. When one of channel detected the EMG signal, then the other channel would be 0, or it was no contraction. The input of the ANN system was the EMG signals which its peak values have been determined, then the process of the network training and testing was done, so that we got the output of the movement patterns recognition that would be used as the parameters to control the robot mobile based on the target conditions that have been determined. The target was represented by a number (1-9) because the data type of the ANN should be in the form of numbers. The output of the ANN system became the instructions to control the robot mobile, such as the turn right, then turn left and the forward according to the target conditions.
Table 2. The input, the output and the target of the ANN

| Channel | The Input | The Output Representation | Target | Target Conditions |
|---------|-----------|----------------------------|--------|-------------------|
| CH3     | 0 0 ✓     | Forward                    | 1      | The slow down     |
|         | 0 0 ✓     |                            | 2      | The medium forward|
|         | ✓ 0 0 ✓   |                            | 3      | The fast forward  |
| CH1     | ✓ 0 0     | Right                      | 4      | The slow right    |
|         | ✓ 0 0     |                            | 5      | The medium right  |
|         | ✓ 0 0 ✓   | Left                       | 6      | The fast right    |
| CH2     | 0 ✓ 0     |                            | 7      | The slow left     |
|         | 0 ✓ 0 ✓   | Left                       | 8      | The medium left   |
|         | 0 ✓ 0     |                            | 9      | The fast left     |

3. Experimental design
The experiment was conducted on 15 respondents. Each of the respondents was asked to do the movements, such as the contraction of the right arm muscle, the contraction of the left arm muscle and the chewing/biting movement on the jaw muscle with each movement consisted of the slow, the medium and the fast variation. Every variation was done like three times so that each of the respondents made 27 movements with the total number of data obtained was 405 data. The data consisted of 135 data of the right arm muscle contractions, 135 data of the left arm muscle contractions and 135 data of the jaw muscle contractions. Every 135 data contractions, each of them is determined 90 data for training data and 45 data for testing data so that in the training and the testing of the network used 270 of the training data and 135 of the testing data.

3.1. The training and the testing of the ANN
The ANN network training in the Matlab using the nntool toolbox. In the nntool toolbox, the network training has been created according to the network architecture as Figure 5. The network training needed the input data and the target data. The input data was the peak data of EMG signal from the muscle contraction was 270 data (the training data), while the target data consisted of 9 data that was represented by the number 1 to 9. Then the data was entered into a Matlab program to train. Every the layer of the network had the weight and the bias value. The initiation of the weight and the bias on the training were arranged as randomly by the Matlab system.

![Figure 5. The training network of the Matlab](image)

In the training process, the number of the minimum iterations was 1000 times iterations in each the training. In the nntool toolbox, the training would stop automatically on the certain iterations when the error value obtained has reached 10^-7. After the data have been trained, then we got the network performance graph shown in Figure 6. In the graph, the network training has stopped at the 491^{st} iteration but it has achieved the best performance at the 485^{th} iteration with the value is 0.0098211. After the network training has finished, we get the update of the weight and the bias values.
After the training of the network was done, then it would have continued to the testing of the network. The testing of the network was done by entering the new input data into the training program in Matlab. The new input data was 135 of testing data: the weight and the bias initiation of the testing adjusted with the weight and the bias of the training result. After the testing process has finished, then the network could recognize the movement patterns and obtained the output which is the parameter to control the robot mobile.

3.2. The robot mobile control

The robot mobile had four wheels using two motors 12V DC on the rear wheels as the driving wheel and two Omni wheels on the front wheels. The robot got the electrical energy from the battery with voltage 12V. Figure 7 shows the robot mobile designed in this research.

The ANN has been able to recognize and detect the movement patterns after the training and the testing, then the motor of the robot mobile is controlled through the Arduino IDE program that has been uploaded to the Arduino microcontroller. In the Arduino IDE program, the conditions that have been given were adjusted to the output value and the target data that was in the form of numbers 1 until 9. This condition would give the command to the robot to do the movement; the forward, the right and the left with the slow, the medium, and the fast variations. Also, the conditions other than target conditions were also given in the form of s and x characters to control the backward and the stop movements. The command of the backward and the stop movement had gotten from two muscle contractions simultaneously.
4. Result and discussion

4.1. The result of training and testing ANN

The ANN training in Matlab results in an update of the weight and the bias values. The weight and the bias values of the training results are initialized on the ANN testing to get the output values. There was two type of the weight and the bias values obtained, i.e., the weight and the bias values from the Input layer to the hidden layer and the weight and the bias values from the hidden layer to the output layer as shown in Tables 3 and Table 4.

| Table 3. The weight and the bias values from the input layer to the hidden layer |
|---------------------------------|----------------|----------------|----------------|----------------|----------------|
| x1                             | 5.7938         | -11.9423       | -0.8152        | 0.115          | -12.7807       |
| x2                             | -11.4718       | -15.8106       | 15.3034        | 0.5673         | 15.3139        |
| x3                             | -8.0505        | 154.6298       | 64.8671        | -4.4037        | 31.0026        |
| 1                              | -22.7653       | 11.8369        | 72.0113        | -9.2526        | 26.187         |

| Table 4. The weight and the bias values from the hidden layer to the output layer |
|--------------------------------|----------------|
| Y                              | z1  | z2  | z3  | z4  | z5  |
| z1                             | -0.0004 |     |     |     |     |
| z2                             | 0.0004  |     |     |     |     |
| z3                             | -1.5239 |     |     |     |     |
| z4                             | 0.3099  |     |     |     |     |
| z5                             | 1.5236  |     |     |     |     |
| 1                              | -0.746   |     |     |     |     |

The ANN testing was done to observe the results of network training whether it has been able to recognize the movement patterns or not. There are two errors from 135 of testing data. The errors occurred in the slow forward data (target 1), where the test results were not suitable with the target conditions, and it was closer to the advanced medium data (target 2). The test results obtained were not in integers, so the rounding the number of the results of the testing against the target was applied because each target was represented by the number (1-9) to every movement variation. Thus, 135 of the testing data were only two data which were not suitable with the target, and it had the error percentage of 1.48%. The system accuracy rate of testing could be seen in Table 5. Based on the error percentage, the ANN could recognize and detect movement patterns.

\[
Error = \frac{The\ Error\ Data}{The\ Overall\ Data} \times 100\% = \frac{2}{135} \times 100\% = 1.48\%
\]

| Table 5. The system accuracy rate of the ANN |
|--------------------------------|----------------|----------------|----------------|----------------|
| The Channel | The Movement Patterns | The Accuracy Rate | Fast |
| CH3         | Forward              | 13              | 15             | 15             |
| CH1         | Right                | 15              | 15             | 15             |
| CH2         | Left                 | 15              | 15             | 15             |
4.2. The output calculation to control the robot mobile movement

The output value \( y_k \) was calculated using the visual studio 2010 program by declaring the weight, and the bias values (Tables 3 and Table 4) and the calculation were done by applying the equations:

\[
\begin{align*}
    z_{inj} & = vO_i + \sum_{i=1}^{3} x_i V_i \\
    z_j & = f(z_{inj}) = \frac{1}{1 + e^{-z_{inj}}} \\
    y_{in} & = w_{0k} + \sum_{j=1}^{5} z_j w_{jk} \\
    y_k & = f(y_{-in}) = \frac{1}{1 + e^{-y_{a1}}}
\end{align*}
\]

(1) (2) (3) (4)

| The Channel | The Range Value of The Muscle Contraction (mV) |
|-------------|---------------------------------------------|
| CH3         | 0.5 - 1.2, 1.2 - 2, >2                      |
| CH1         | 0.5 - 1.5, 1.5 - 3, >3                      |
| CH2         | 0.5 - 1.5, 1.5 - 3, >3                      |

The robot mobile would control the movements based on the instructions given as shown in Table 7. Every instruction that was done produced the EMG signal was recorded by each electrode channel with the value of the contraction range from the peak of the EMG signal as could be seen in Table 6. The contraction value should be greater than the threshold, and it was in the range of the contraction value. In the visual studio 2010 program, the range value of the muscle contractions and the output values \( y_k \) was used as the condition to control the robot mobile; then it sent to the Arduino Microcontroller which is read through the serial ports to give the commands to the robot mobile to do the movements.

| The Instructions                          | Serial ports | The Robot Command |
|-------------------------------------------|--------------|-------------------|
| Chewing/biting on the jaw muscles         | 1            | The slow down     |
|                                           | 2            | The medium forward|
|                                           | 3            | The fast forward  |
| Contracting the right arm muscles         | 4            | The slow right    |
|                                           | 5            | The medium right  |
|                                           | 6            | The fast right    |
| Contracting the right arm muscles         | 7            | The slow left     |
|                                           | 8            | The medium left   |
|                                           | 9            | The fast left     |
| The combination of the right arm muscle contraction and the biting movement simultaneously | s            | The backward     |
| The combination of the right and the left arm muscle contraction simultaneously | x            | Stopped           |

Table 7. The robot mobile control
5. Conclusion

The robot mobile control system using three muscle signals have been built using the ANN method. The research uses the right arms muscles, the left arms muscles, and the jaw muscles. The ANN has three inputs, five neurons in the hidden layer and one output. The robot mobile could do the movements in 11 conditions, such as the turn right, then turn left and the forward in each slow, medium and fast variation, the backward movement, and the stop motion. The rate of the accuracy system reaches 98.52%.

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