The design and preliminary implementation of low-cost brain-computer interface for enable moving of rolling robot

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***Abstract*—We introduce the design and preliminary implementation of low-cost brain-computer interface (BCI) to enable movement of a rolling robot. This system will accept and execute basic commands that are generated from three brain condition normal, relax, or happy. The brain condition is determined by brainwaves known as alpha, beta, and gamma waves. The brainwaves are detected using Mindflex, connected with Arduino Uno, and sent data transmission to computer via USB connection. Algorithm is developed using Matlab to analyze the data and send three simple commands to a rolling robot through Wi-Fi connection. We conducted experiment for fifty times using 100 data for training and 50 data for testing, and obtained 62% of accuracy. This result shows that brainwave commands can be processed successfully for forward, turn left, and turn right movements. We have concluded that the system can be developed further to assist disabilities performing motions using their minds.**

***Index Terms*—Brainwave, Mindflex, Disabilities, Paralysis, Arduino Uno.**

I. Introduction

Paralyzed people can be found anywhere in every country. People with this physical disabilities are often considered as useless people, even though they have other ability that might be more than ordinary people. According to NHS, the four most common causes of paralysis is stroke, head injury, spinal cord injury and multiple sclerosis. It is estimated in United States based on study [1], nowadays there are almost 7 million people are suffering of paralysis. Usually people with mobility impairments are required helping tools to perform his or her activities. The most common tool is wheelchair which is powered either by hand or electric. However, in special case, some people are not able to use wheelchairs with common way, for example they have no hands for moving the wheelchair or pushing the button of the wheelchair. This condition could be an opportunity for brain-computer interface to solve the problem.

The communication model built by brain-computer interface (BCI) system overrides the normal pathway which uses neural and muscular. A BCI system computes activity of brain which is represented by brain waves, and convert into corresponding command to trigger the certain applications. One application that utilized the BCI system is the control of rolling object using mind wave [2].

In this research we try to design an implementation of BCI using low-cost devices. As the initial experiment we use a small rolling robot that receive motion commands that are transmitted by brainwave. Three basic commands are generated from three brain condition: normal, relax, or happy. The brain condition is determined by the combination of brainwaves known as alpha, beta, and gamma waves. The brainwaves are detected using dry EEG sensor Mindflex, connected with Arduino Uno, and sent data transmission to computer via USB connection. Artificial neural network (ANN) algorithm is developed using Matlab to analyze the data and send the commands to a rolling robot wirelessly. We conducted experiment and repeat the experiment for fifty times each. The result shows that brainwave commands can be processed successfully and the rolling robot can move forward, turn left and right.

II. Related Works

Initially, Brain Computer Interface (BCI) is designed for toys and game controllers. However, this technology become interesting part, not only for game companies and end-users but also for researcher in field of thought-controlled sensors. This ability is inspiring innovations such as allow phone calling by simply thinking about them, or even more complicated task such as moving objects without physically touching or holding them. Mattel's Mindflex, Neurosky, and Emotive EPOC headset are some mind-controller devices that can be found easily in the market.

The pioneer of BCI research is the University of California Los Angeles (UCLA) in 1970. The UCLA had grant from the National Science Foundation, continued with a contract from DARPA [5], [6], to do research in this field. The published papers after this research demonstrated the initial effort in the research of expression brain-computer interface. Until now there are many researchers are working in the BCI research for various fields including robot motions and advanced research in mind-controlled devices [7], [8], [9], [10].

In the application community, we can find Tan Le [3], the founder & CEO of Emotiv. She implemented a headset that reads brainwaves that making them possible to control objects using minds. There are also interesting brain-controlled applications has been developed [4] such as for composing and play music, screen mobile phone calls, 3-D object creation, drive a car and "Bionic" Limbs and many others.

Searching the literature, we can find limited research that are related to the usage of Mindflex and Arduino Uno as devices for controlling robot using brain commands. Our work is focused on the preliminary design of implementation of those low-cost devices so it can be implemented especially for people in developing countries.

III. System Design

There are three essential components in our system: Mindflex, Arduino Uno, and Matlab. Mindflex, connected with Arduino Uno, is used for capturing brainwave signals. Arduino Uno will translate the signals and transmit to the computer via USB channel. Wave signals will be processed using our developed artificial neural network (ANN) algorithm implemented in Matlab. Logic analysis based on the wave characteristics will generate output (decision) as motion command which is sent through Wi-Fi communication to the rolling robot

A. Design Goals

One may thing that low-cost devices correspond to low functionality. In our system we try harder to oppose that opinion. We have previous experiences in optimizing assistive technology by combination of hardware and software which will result synergism that finally will come up with the maximal result. To reach that goal we develop the following decision targets as follows: (1) *Easy to learn/use*. Due to its complexity, other mind reader devices are not easy to use, such as using a special kind of helmet with many cables, and required special handling to use it [11] (2) *Comfortable and robust*. Mindflex has belt that can easily put in the forehead. User will be comfortable to use it. In addition, there are many Mindflex games and toys found in the market. (3)*Responsive and accurate*. These are the characteristics that we focused on developing algorithm to optimize the response and accuracy.

B. Research Methodology

Specify the conditions and types of brain waves. This step is done to control a wheeled robot. In our case we decide to choose three condition: *normal, happy, and relax* to control three movements: *forward, turn left, and turn right*. Each condition is determined by the value of two brainwaves: alpha wave and beta wave. Those have been selected due to more easily produced when the subject awake, so that the data collection process will be easier.

Gather brain wave data and threshold selection. This is done by the process of scanning the brain waves of the subject using Mindflex. The signals are captured using sensors located above left eye and above left ear. Subjects given order to condition himself to be taken samples of the wave brain in normal conditions, happy, and relax. The process of data collection will not utilized all components of the data read from Mindflex. Of the eleven values were detected, only the values that represent selected brain waves will be taken as the experimental data. The data then processed to produce a threshold for each condition which has been selected.

Perform training data and select best architecture. This is performed using a special method of training artificial neural networks known as backpropagation. Selection is done based of maximum accuracy resulted from the neural network architecture.

Develop computer program and conduct experiment. In this stage we create and develop a wheeled robot control program using brain waves with neural network and conduct experiment. Our system is using Matlab as programming environment.

C. Hardware

Mind-reader device. Mindflex in non-battery operate mind-reader device that captured brain signals named alpha, beta, and gamma waves [12]. Alpha wave generally dominates the other brain waves when someone close his eyes but not in a state of fatigue or drowsiness. Beta wave is associated with normal waking state, means when someone undergoes daily activities with the conscious mind. Gamma wave is implicated with the ability to represent an object in the human brain based on color and shape (the binding problem). Mindflex consists of a set of units controlled and wireless EEG headset. Mindflex EEG headset is a simple form of EEG which aims to read brain waves. Mindflex headset can translate brain waves into a CSV (Comma Separated Value) data.

Processing device. For processing the signals we use Arduino Uno [13]. Arduino Uno is a micro-controller board based on the ATmega328 that has a 14 pin input/digital output (6 of which can be used to pulse with modulation outputs), 6 analog inputs, a USB connection, 16 MHz ceramic resonator, an ICSP header, a power jack, and a reset button. Arduino Uno is different from previous electronic circuit boards manufactured by Arduino. Arduino Uno does not use the USB FTDI-to-serial driver chip, but use Atmega16Ua programmed as a USB-to-serial converter.

Output device. In our system, the output device is a simple wheel robot [14] that has Wi-Fi connectivity and accept motion command.

IV. Experiment

A. Setup

Figure 1 shows the system setup for the experiment. Before making connection between Mindflex with the Arduino Uno and computer, we have to perform the driver installation for

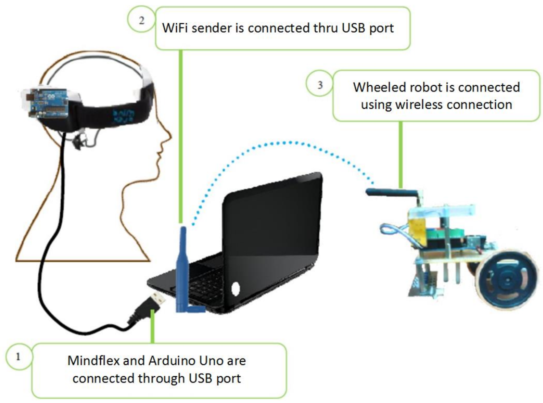

Fig. 1. System Implementation Overview.

the Arduino Uno with a USB Wireless Modem Ricochet type on the computer. Once the driver is installed, search the port used by Mindflex. If the port has been found then we are able to detect brain waves using that port. Then we can submit a command to determine the name of the variable brain wave data storage and baudrate. Baudrate is the standard data transfer rate between the Mindflex computer, in this research baudrate is set to 9600. The following Matlab code represents the steps to check the connectivity of Mindflex to computer.

```
>>varName=Serial('Mindflex Serial Port')
>>set(varName,'Baudrate',speed)
>>fopen(varName)
>>fscanf(varName)
ans =
200,0,0,847885,846444,171212,334811,69905,
488997,181833,1325365
```

The eleven numeric values represent values of signal strength (0-200), attention, meditation, delta, theta, low alpha, high alpha, low beta, high beta, low gamma, and high gamma.

Brainwave Data Collection and Threshold Selection.
The movement of a wheeled robot to the forward direction, turn right, and turn left require different input generated from Mindflex brainwave. Each command is represented by the condition that must be achieved by the subject. In this research, each condition is determined by the value of two brainwaves, alpha and beta. For each condition we made 50 attempts to obtain desired threshold so we have 50 alpha and 50 beta values to analyze and to obtain threshold value. We didn't do deep analysis for determining the sample size. However, this can be considered as the appropriate and large enough sample size for our experiment due to complexities of data gathering. Table I shows the first 10 alpha and beta values for each conditions.

From the table we can see that there are overlapped values between those two waves for each brain state. This situation become a challenge to find the threshold value for each condition. To support the threshold selection, the distribution of alpha-beta brainwave values are visualized in chart of

TABLE I
SAMPLES OF BRAINWAVE VALUES FROM MINDFLEX. TOTAL DATA ARE 50 WHICH ARE AVERAGED FORM LOW AND HIGH VALUE OF EACH WAVE.

No	Normal (α, β)	Happy (α, β)	Relax (α, β)
1	118250, 205090	122736, 148688	198324, 209248
2	98205, 78342	130092, 156787	198247, 209843
3	55430, 89012	101029, 236580	254638, 168273
4	100090, 120008	50281, 276488	220938, 150493
5	97604, 146000	120736, 198685	190332, 191901
6	123400, 300908	40290, 118768	250091, 183763
7	139877, 20304	101792, 176987	223124, 200045
8	77677, 304000	50090, 220586	200023, 128992
9	127000, 50900	99980, 154367	176352, 201738
10	196500, 70900	110875, 182379	151029, 183457
11	...	...	...
...	...	...	...
50	...	...	...

scatter plot and showed in Figure 2. This is done to see the distribution more clearly.

B. Results

By analyzing the data values collected from previous step we get minimum and maximum values of each wave for each condition. It is displayed in the Table II as follows:

TABLE II
ANALYZING RESULT OF COLLECTED BRAINWAVE (THRESHOLD VALUE)

Condition	α $(Min - Max)$	β $(Min - Max)$
Normal	$11000 - 150000$	$13000 - 150000$
Happy	$50000 - 150000$	$150000 - 300000$
Relax	$150000 - 260000$	$150000 - 250000$

Data Training and Testing to Select the Best ANN Architecture.
In data training we select the 100 brainwave data and submit them to a neural network with target to obtain three group matrix for representing each condition. The matrix are [100] for normal condition, [010] for happy condition, and [001] for relax condition. Then we perform two strategies for data testing, first using the same data, and second using 50 other different data. We utilized 6 variance of neural network architecture using backpropagation and *logsig* function. The variance is differed on the number of hidden layer and the number of neuron on each layer. Table III shows the result of data testing.

TABLE III
EXPERIMENTAL RESULT OF SELECTING ANN ARCHITECTURE

No.	# HL	# neuron	Epoch	Error	# max err	% acc.
1	2	8, 2, -, -	1000	10^{-10}	1000	94%
2	2	10, 2, -, -	1000	10^{-10}	1000	99%
3	3	8, 2, -, -	1000	10^{-10}	1000	98%
4	3	10, 2, 2, -	1000	10^{-10}	1000	96%
5	4	8, 2, 2, 2	1000	10^{-10}	1000	96%
6	4	10, 2, 2, 2	1000	10^{-10}	1000	95%

The best accuracy is the second experiment with 10 hidden layer and 2 neuron for each hidden layer. The best artificial

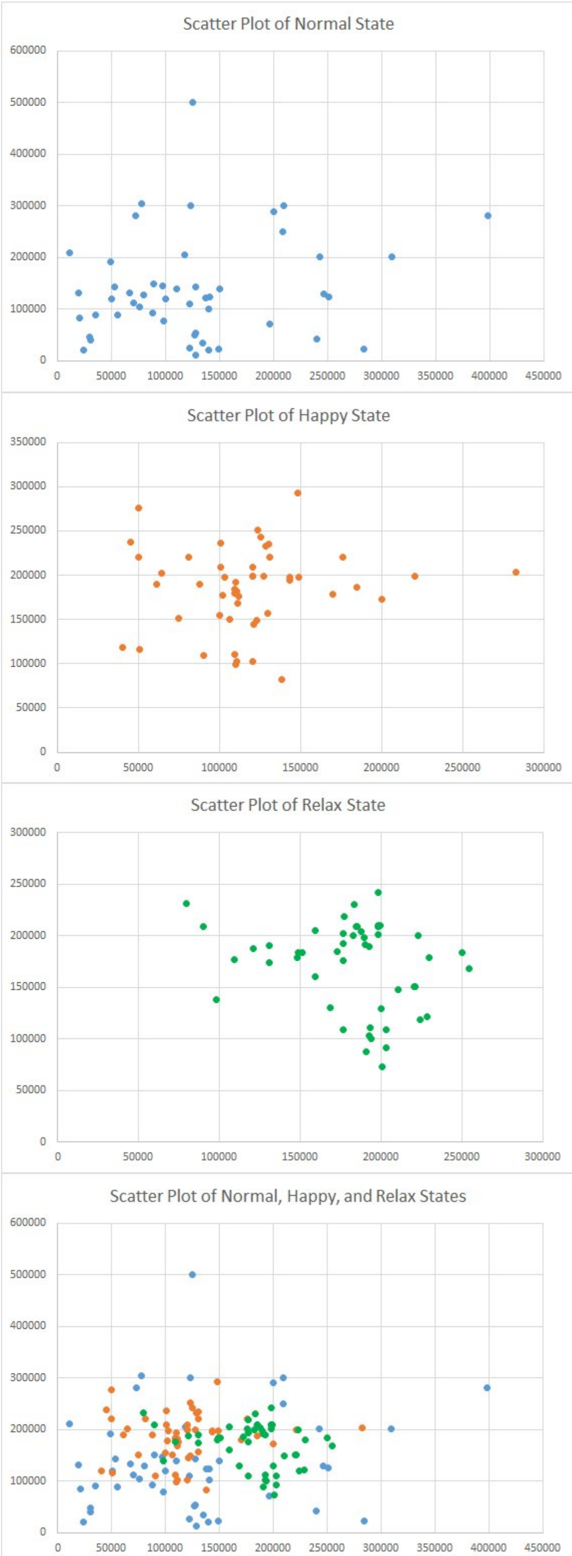

Fig. 2. Plot of Alpha-Beta Brainwave Values. There are several outlier values that we don't use in the experiment.

neural network is selected and displayed in the Figure 3.

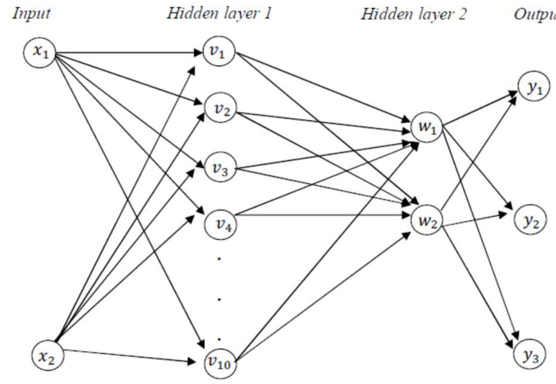

Fig. 3. The Best Accuracy Artificial Neural Network

Experiment of Moving Robot using Brainwave.
Experiment has been conducted to move robot using brainwave command (Figure 4). We perform 50 times with various conditions that should acted by the subject person. We have come up with 62% success result, which means

Fig. 4. Experiment to move robot using brainwave

31 of 50 conditions have commanded the robot to move accurately.

V. Discussion

Though preliminary, our research contributes to the literature on wearable devices and be a model for improving access to the physical world for the paralyzed person. The hardware implementation is using low-cost devices that might be affordable for many people especially people from developing countries. The developed algorithm shows the feasibility of our approach as initial success of our work. Doing this research depicted important technical issues that we must consider. Additionally, to obtain more accurate result other brainwaves that come out from the sensing device must be counted. In our study we found difficulties in brainwave data collection due to persons ability to act with desired condition. Clearly, however, more work is needed. Below, we discuss our preliminary findings and opportunities for future work.

Brainwave Data and Brain Condition.
Mindflex output has many different waves data, however in this research we used only two waves: alpha and beta.

Both waves are analyzed to obtain the threshold for three simple condition: normal, happy, and relax. We plan to extend the experiment by considering other wave data and more condition. We will gather the brainwave data, generated by expert actor, so the groundtruth data will represent more real condition. We expect that by using comprehensive brainwave data we can get more accurate result and do more various movements.

Low-cost yet more Accurate Brainwave Sensor.
The term low-cost is essential to our research. For this reason we try to find the public domain devices and do some enhancement to be use in our experiment. For current time, we utilized Mindflex as mind wave sensor and Arduino Uno as wave processing unit. However, technology of brainwave sensors are keeping up to date, so in the future we try to explore other devices which is better than the previously used devices but still in the context of low-cost devices. In the implementation side, in the future we are planning to use our system with real larger moving robot such as wheel chair, car, etc.

Algorithm for various movements and brain states
We successfully implemented our system in three simple motions, however, this is not reflected a real situation. We are planning to explore more brain states to move the robot, such as backwards, fast or low speed motion, etc. The decision that must be made based on the brain states are evaluated to develop more intelligent algorithm including optimization steps so the algorithm can be ported into portable hardware or even as internet of thing device.

Sample Size for Experiment
In this experiment we didn't do specific analysis for determining the sample size. We collected 50 data values for each brain wave alpha and beta. The data gathering process is not easy to perform due to subject difficulties to perform any condition in stable manner. In the future, the data gathering can be perform using more sophisticated device therefore the data size can be collected more.

VI. Conclusion

This paper described the initial design of transmitting command to a robot based on brainwave data, collected via Mindflex and Arduino Uno. Three brainwave states are selected to command the wheeled robot to move forward, turn left, and turn right. We focused on the alpha and beta brainwave which are processed using backpropagation artificial neural network. We came up with a conclusion that the system can be extended to move wheeled chair or other rolling devices.

Even though the implementation of the method has been already available but not in massive production. This paper can be referenced as an alternative solution to develop and to build a low-cost brainwave-controlled device which can be considered as the contribution of this research.

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