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# Design of Brainwave Controlled Electrical Wheelchair Using Wavelet Transform and Neural Network

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***Abstract:*** *Thoughts identification via EEG signals is an interesting problem because of its potential application. This paper proposes the design of electric wheelchair controlled by brainwaves to support people with mobility and physical impairments. Through brainwave communication, electric wheelchair system can recognize some patients' commands like move forward, back, left, right, stop. Besides, wheelchair system can also recognize some other patients' requirements as eat, drink, call for relatives. The experiment result shows that the system works with high reliability and could be used in practice.*

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## I. Introduction

For people with mobility and physical impairments, certain activities or interaction with the world mostly depend on relatives or doctors. This would prove burdensome to the national socio-economic development.

The urgent problem is to develop a device helping people with mobility and physical impairments to move, enabling them to take care of themselves or contribute to the family and society. Wheelchairs are an effective solution for this problem. With a wheelchair, the disability people can travel themselves and participate in community activities. These activities help them to be more active, and also reduce the burden on the family and society. However, wheelchairs are currently just suitable for people with only foot disabilities, not those with both arms and legs, or body disabilities. Because most electric wheelchairs today are controlled manually.

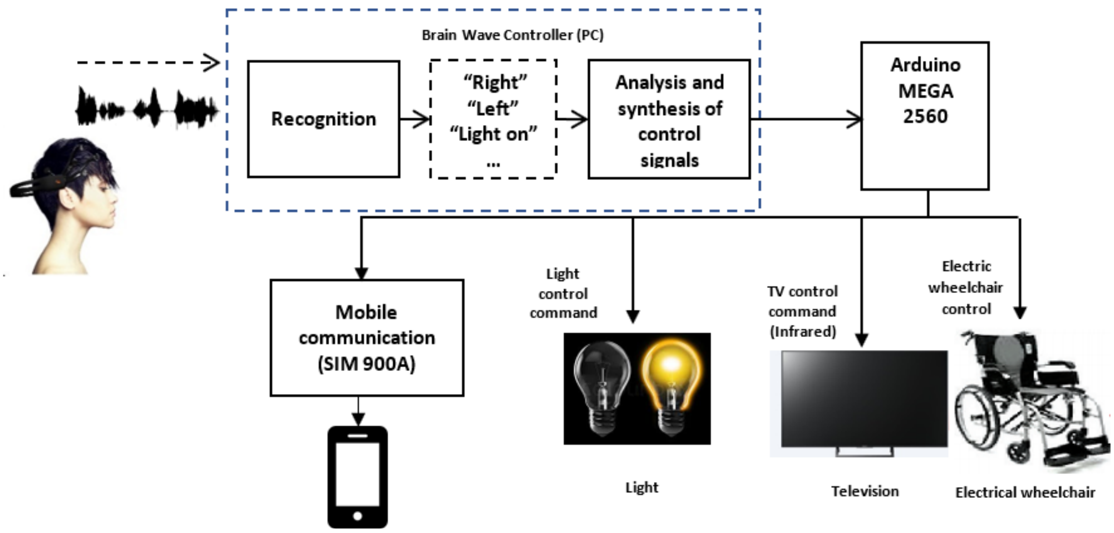


**Figure 1.** Diagram of an electric wheelchair controlled by a brainwave

With the goal of mastering technology and reducing product costs, in this paper we propose a design of the electric wheelchair. The decoding system is integrated to recognize and implement a number of basic control requirements as well as the essential requirements of people with disabilities via brainwave. People with disabilities can control the wheelchair move forward, back, left, right, and make some requests such as turning on / off the lights, turning on / off the TV (automatically controlling the system) or eating, drinking, sleeping, using the toilet, or calling the caregiver through a speaker or smart phone (Figure 1).

The wheelchair operating process consists of following steps:

- Step 1: User make command via thought.
- Step 2: Brainwave is collected by Emotiv Epoc+ headset, filter noises and send to recognition module.
- Step 3: Recognize the wheelchair control, communication, I/O device control commands. If the command is valid (correct) system moves to Step 4, else move back Step1.
- Step 4: Synthesize the correspond control information package and send it to I/O device through communication module.

## II. System Design

The design of each function block mentioned in Figure 1 is as follows:

**Electrical wheelchair**

**Figure 2.** Electric wheelchair product

Basically, wheelchair is a mean of transportation, but only travel on the roads for disability. However, the mobility and physical impairments make disability people less flexible in controlling the mean. This leads to the need of the automatic and smart electrical wheelchair. The most four most important requirements are:

- Allow to recognize the control signal from different signal sources to unlimit the user objects. The signal sources can be the joystick handlebar, voice, eyes movement, or head movement…
- Dynamic control for 2 wheels must ensure stability and speed. On the trajectory the vehicle may be deflected due to uneven road surfaces or the slip of 1 in 2 wheels. The controller needs to automatically detect and control these errors. In other words, unless there is a control command, the mechanical system and the power electric system must always keep the vehicle in the right trajectory. If this is done well, the human activity requirement will be minimized.
- Security system for the wheelchair: early detection and warning system. This system must be able to predict the the collision, out-of-battery, uneven road surface, accident possibilities…to support the users, or automatically control the wheelchair to minimize the risk.
- Emergency call system for malfunction: This module will automatically detect the emergency situation when the wheelchair is broken, collapsed, or user mismanipulation. In these situations, the emergency call will be automatically made and the system will provide the wheelchair location to relatives.

Figure 2 shows the designed electric wheelchair, which fully meets 4 requirements mentioned above. Including, from left to right, top to bottom are finished products, power control module, actuator with rotation angle sensor (MPU6050) equipped, microcontroller (Arduino MEGA 2560), the communication with controller is through Bluetooth Module (HC-05). Experiments showed that the wheelchair can work with the load up to 150 kg.

**Collect and pre-process brain signals**

We use the Emotiv EPOC+ wireless headset to pick up the EEG signal of people with disabilities. This cap has 16 electrodes positioned based on the international standard for the 10-20 electrode system. Figure 2 shows the headset and the position of 16 electrodes. It has 14 electrodes located at AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4 and 2 reference electrodes. This cap is moistened to improve conductivity [2].

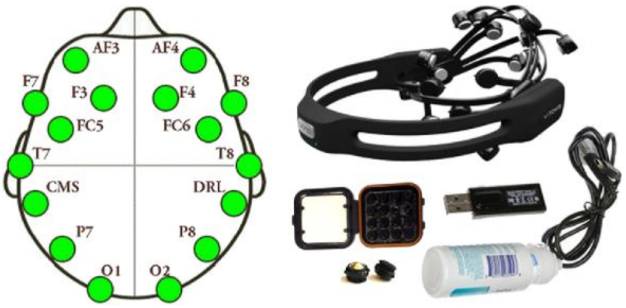


**Figure 3.** Emotiv Epoc+ headset and position of 16 electrodes

**Interactive controller by brainwave**

We use a PC to do this task. This PC integrates a number of software that is responsible for receiving EEG signals obtained from the Emotiv Epoc+ headset, extracting features according to Wavelet, minimizing the number of characteristic vectors by Principal Component Analysis (PCA) algorithm, classification using MLP neural network, transferring commands to the Arduino MEGA 2560 microcontroller in a wheelchair via Bluetooth communication.

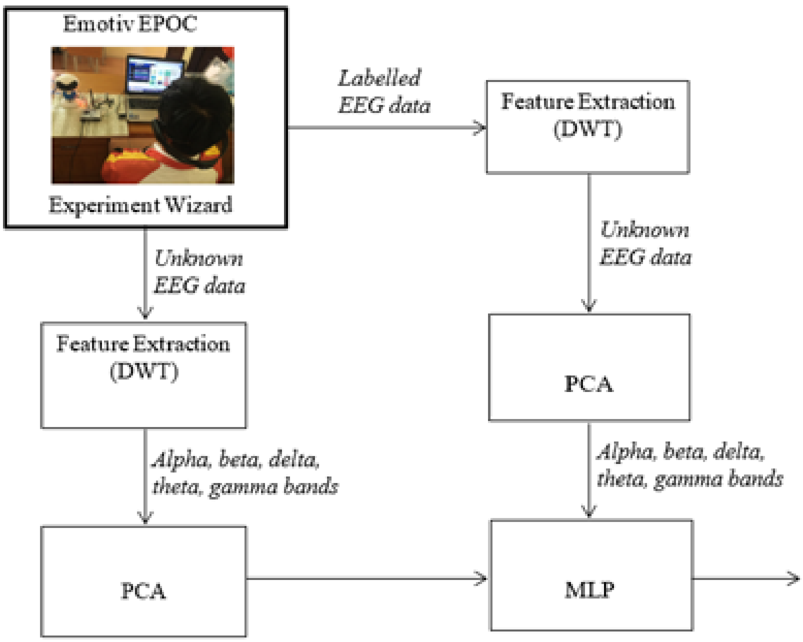


**Figure 4.** Diagram of functions in control software[8]

*Receive EEG signals:*

We used the Emotiv SDK software tool to retrieve raw EEG data from the Emotiv Epoc+ cap. This software is provided by Emotiv and is very useful for experimental design, preparation and multimedia configuration. The software also helps to collect EEG data in a structured and systematic manner.


**Figure 5.** Receiving EEG signals with Emotiv SDK software[2]

*EEG signal characteristics extracting*

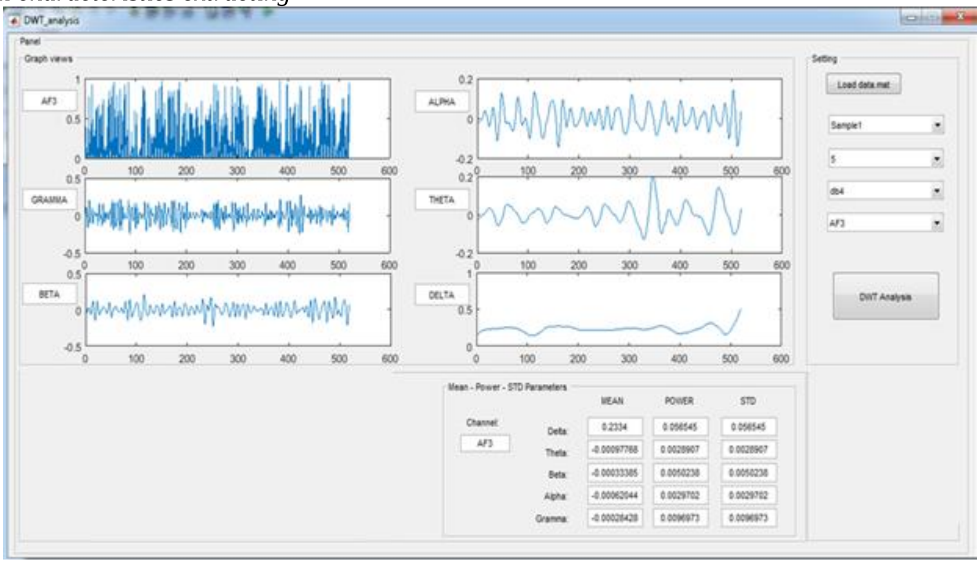


**Figure 6.** Feature extraction using DWT

Figure 6 depicts the use of Debuchies4 wavelet to extract the characteristics of the EEG signal. By this method, each signal obtained from an electrode will be separated into 5 basic wave components: Delta, Theta, Alpha, Beta and Gamma. For each basic wavelet component, we calculate three characteristic parameters such as: The power of the signal, the mean value, the standard deviation. With a total of 14 electrodes we obtain a characteristic vector of 210 parameters [5].

*Reduce the dimensions of feature vector by PCA*

The size of the characteristic vector obtained after applying the wavelet transform on the EEG signal is 210. If this vector is directly applied to the MLP network, the training time for the network will be very large. Besides, among 210 parameters, there are some parameters whose influence is very small compared to other parameters. Therefore, in order to reduce the number of specific vector dimensions to 70, we used the PCA method with the implementation steps described in Figure 7 [9].

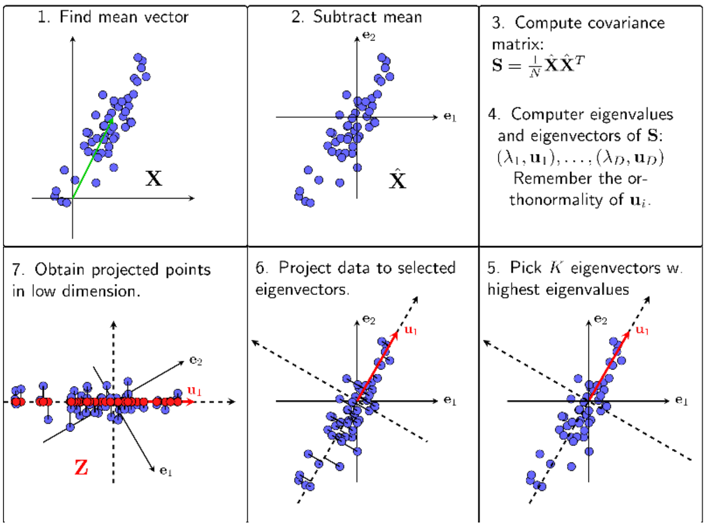

**Figure 7.** Dimensional reduction of feature vectors using PCA [9]

*EEG signal recognition using MLP neural network*

The system is expected to allow users to use 12 control commands via brainwave. If only one MLP network is used, it should be able to distinguish 12 layers [8]. Therefore, it is difficult to have high accuracy. To increase accuracy, we divide the patient control process into 2 steps. First, the operator will select one of four command groups including “wheelchair control”, “equipment control”, “living assistance” and “main menu” (in case of wrong choice). With the wheelchair command group, users can choose one of 5 commands such as forward, backward, left, right, main menu (neutral). The group of device control commands consists of 4 commands: turn on / off the light, turn on / off the TV, and return to the main menu. The living support order group also includes 5 commands such as eating, drinking, sleeping, going to the toilet, and returning to the main menu.

Therefore, to classify the three control command groups, we use MLP neural network with the architecture as in Figure 8. To learn the four commands in each group, we use the MPL network with the structure illustrated in Figure 9.

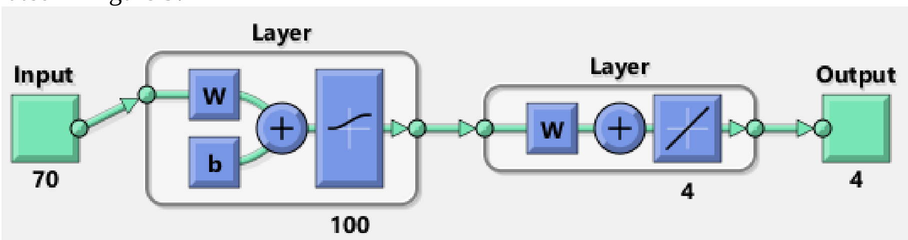

**Figure 8.** MLP neural network architecture for command group selection

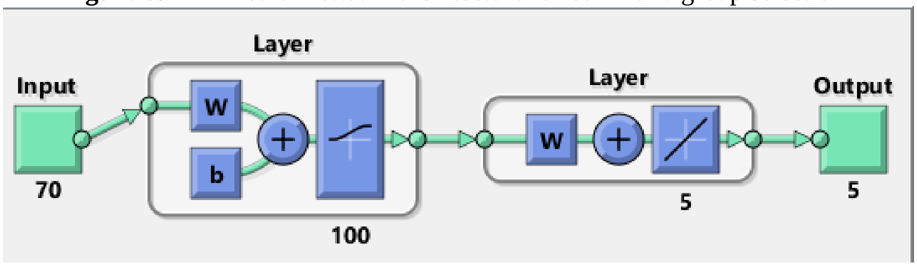

**Figure 9.** MLP neural network architecture for each command in the group

During network training, the labeled EEG data (data from a known operator's request) is recorded and sent to the MLP neural network to train the model for thought recognition.

In the identification stage, unknown EEG data will be fed into the trained MPL network to make a decision on the most appropriate command. The number of neurons in the input layer is equal to the length of the input characteristic vectors (70). We conducted a trial and error test to determine the best configuration for the neural network in terms of: the number of neurons in the hidden layer and the maximum number of epochs as follows:

- The number of neurons in the hidden layer = 100.

- Maximum number of iterations (epoch) in the learning process = 1000.
- Activation function is sigmoid function, learning rate is 0.1

The network training will stop when the maximum epoch number reaches 1000 or the average square error reaches a value as small as 0.001.

In order to prepare the network training sample and evaluate the identification results of the MLP network, users are asked to look at the images on the PC interface, focus their thoughts for 10 seconds so that the software collects specific vectors. The data samples are computed in correlation with the previous samples (in the same order class) to recommend that users decide to choose as a standard sample for identification.

Each control command (left, right, forward, backward) is practiced 250 times on the same person. The recorded data is divided into two groups, 80% for network training and 20% for testing. Thus, each order will have 200 samples for network training and 50 samples are used to check the accuracy of identification.

**The communication modules**

*Bluetooth and infrared communication module:*

Bluetooth module (HC-05) allows transmission command code between PC and Arduino MEGA 2560. Infrared module (IR-T940) for controlling TV on / off

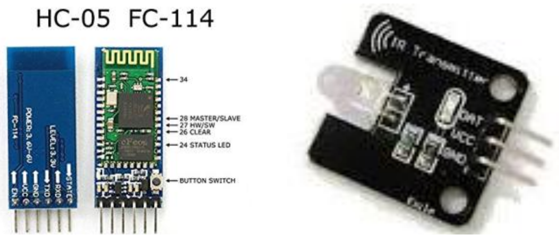


**Figure 10.** Bluetooth module (HC-05) + Infrared (IR-T940)

*Light control module*

The principle of operation of the light control module is described in Figure 11. Arduino MEGA 2560 will send control commands to the relay module. It consists of 8 small relays for standby purposes.

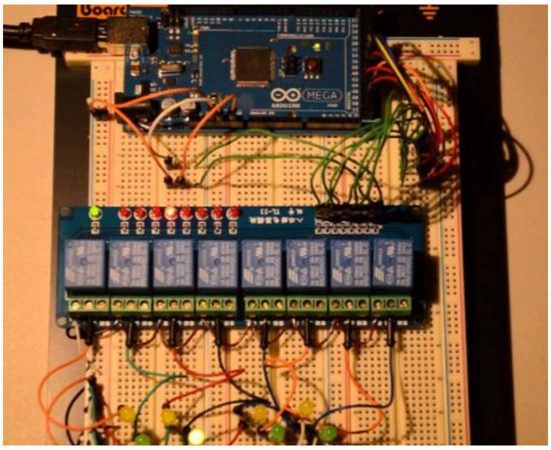

**Figure 11.** Relay Module for light control

*Mobile communication module*

This module is enabled to send a message to the support person when the patient wants to eat, drink, sleep, go to the toilet. For simplicity, we use the Sim900A module.

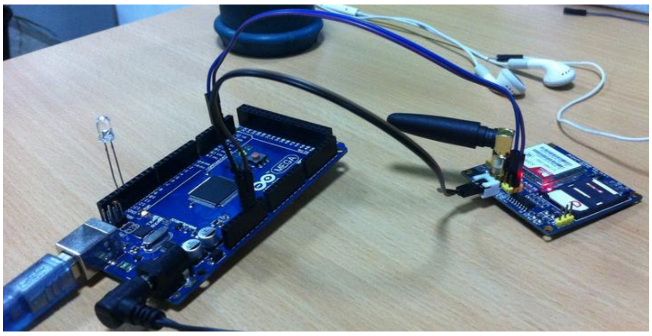

**Figure 12.** SIM900A module sends SMS to mobile phone

## III. Results And Discussions

We have built hardware and software for wheelchair controlled by brainwave. Figure 13 shows the finished product.

**Figure 13.** Wheelchair system controlled by EEG signal

Figure 14 shows the interface that allows the user to choose whether to build a set of commands or to perform device control.

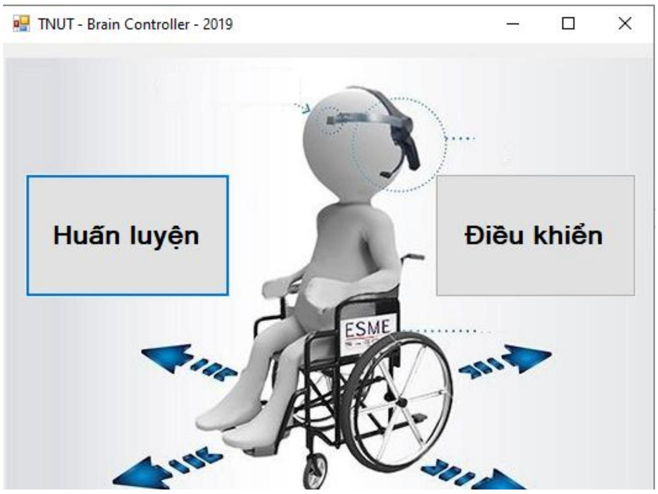


**Figure 14.** System software interface

Figure 15 illustrates the interface for choosing the three groups of commands. Figures 16, 17, and 18 describe in detail the training for each command.

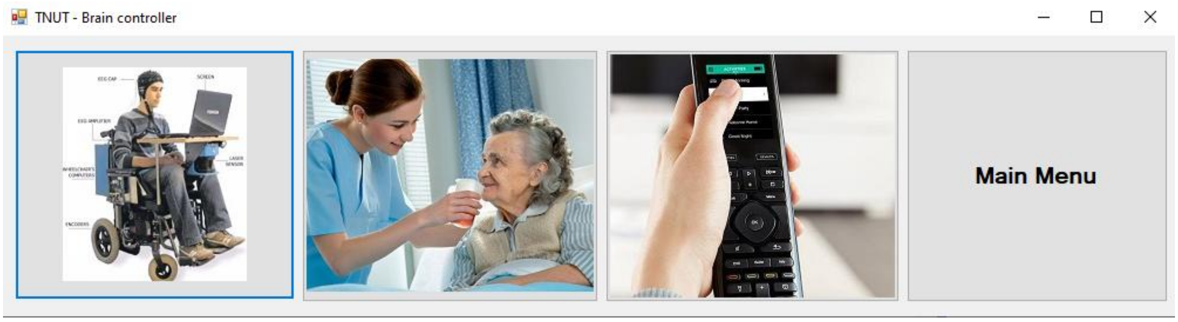


**Figure 15.** Command group selection interface

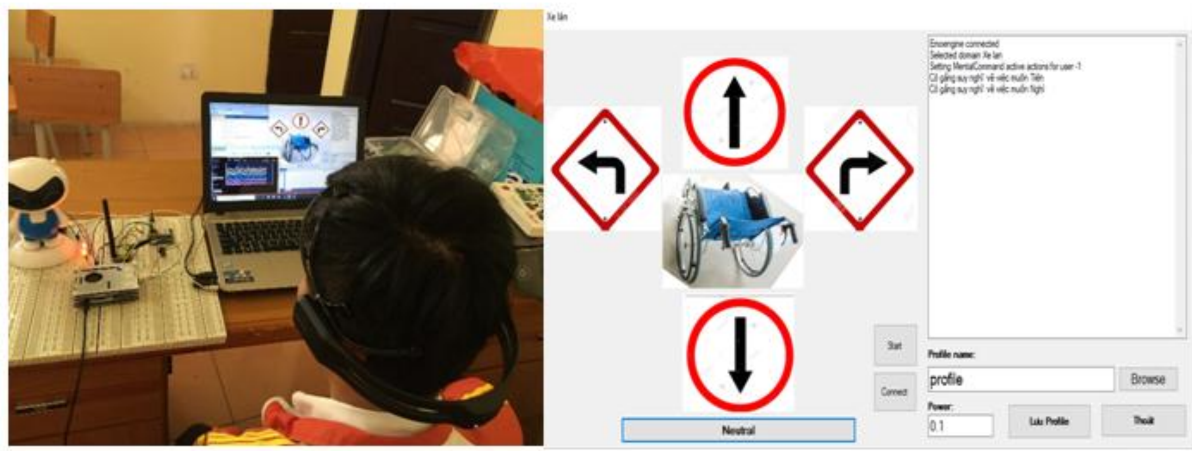


**Figure 16.** Command group for wheelchair control

As depicted in Figure 16, in order to train the wheelchair control commands, the user must connect the device, select the command to learn, and focus on thinking for 10 seconds. The sample received will be saved in a database for neural network training. The process is similar for the command groups described in Figure 17 and Figure 18.

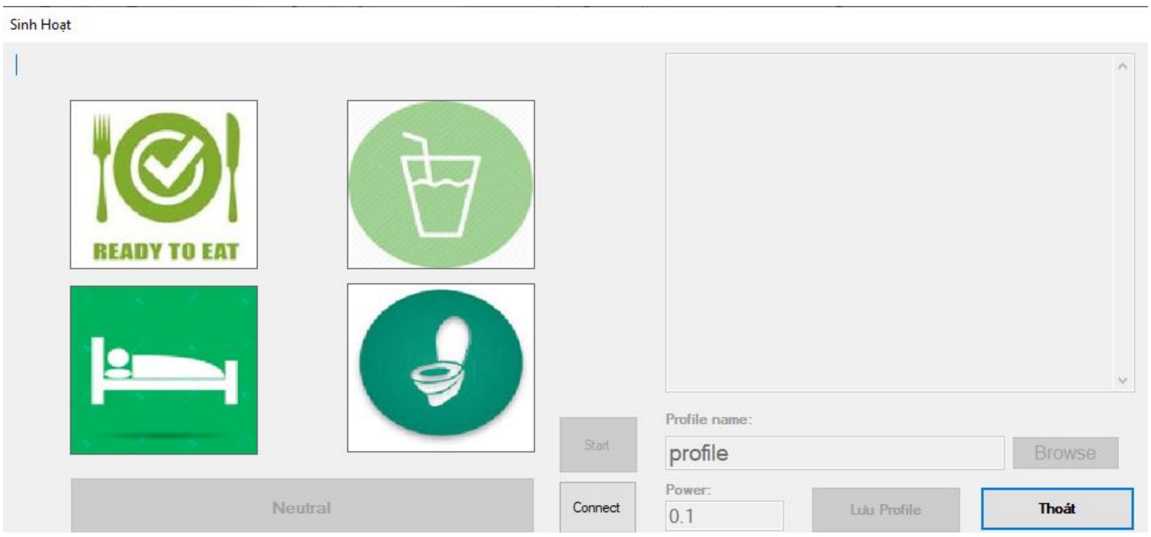


**Figure 17.** Group of commands to support living communication

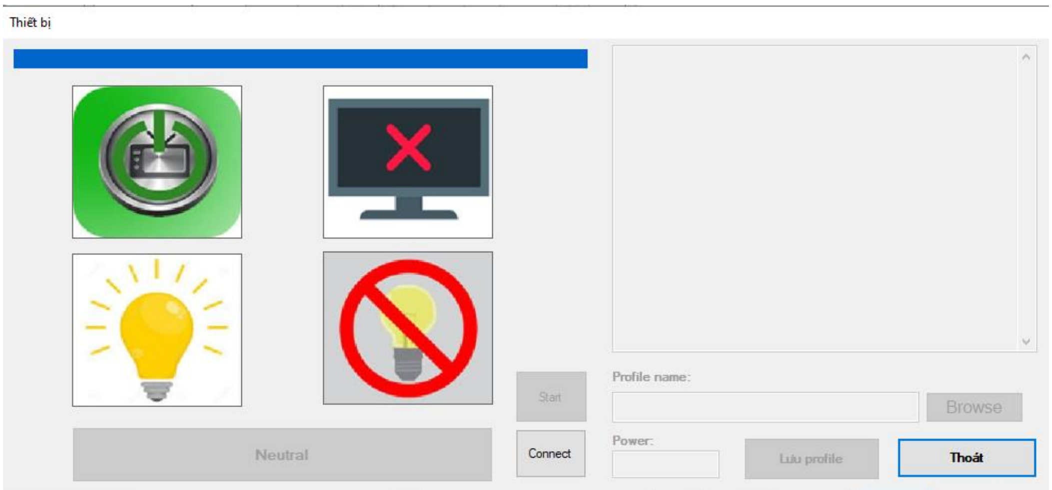


**Figure 18.** Group of commands for device driver

To test the accuracy of this system, we tested 50 samples for each command. The results are shown in Table 2.

**Table 2.** Some test results

| Command | **Number of test samples** | **Number of correct identifications** | **Accuracy rate (%)** |
|---|---|---|---|
| Eat | 50 | 43 | 86 |
| Drink | 50 | 42 | 84 |
| Sleep | 50 | 43 | 86 |
| Go to toilet | 50 | 45 | 90 |
| Light on | 50 | 43 | 86 |
| Light off | 50 | 42 | 84 |
| TV on | 50 | 41 | 82 |
| TV off | 50 | 43 | 86 |
| Forward | 50 | 42 | 84 |
| Backward | 50 | 43 | 86 |
| Turn Left | 50 | 41 | 82 |
| Turn Right | 50 | 46 | 85 |

It can be seen that the system operates with high accuracy. However, this is only the result of testing on the same object. For another object, we have to perform sampling and neural network training from the beginning. This will affect the system performance in real life because it is difficult for patients to perform well neural network training. In the future, we will find a way to acquire common sense traits for everyone. In addition, during the test, we found that the system had difficulty with the control command latency.

## IV. Conclusion And Future Work

Identifying EEG signals is a very complex problem, but this problem will be solved if we use the appropriate tools for signal acquisition, feature extraction and classification. In this paper, we describe how to build a system (both hardware and software) for controlling electric wheelchairs and supporting communication via brainwave. On the hardware side, this system captures brainwave data with the Emotiv Epoc +, recognizes the patient's thoughts, passes the code to the Arduino MEGA 2560 microcontroller and finally to the actuator. The software installed on the PC collects EEG signals, extracts features by DWT, reduces the number of feature vector by PCA and using MLP neural network for recognition. The system works with high accuracy and It can be deployed in practical applications such as, controlling wheelchairs, controlling devices for smart homes ... This is also our future work.

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