EEG-based Controlling

Seminar IV Report
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1. History of the Course

The engineering seminar courses have been evolved. The purpose of the first engineering seminar is to gently force the students to survey their research field. Student had to read and to report 4 papers each week for about ten weeks of studying. Therefore, at the end of the semester, each student will read about forty papers in his field. The students handed in the conclusion of all papers they had read during the semester.

In the second seminar, students practice writing the quality paper. It began by an interesting assignment: reading novels written by Dog Mai Sod and noticed her style of storytelling. During the semester, students are assigned to write imaginary papers (i.e., a paper written from data obtain from imagining.) They read others students' paper and gave comments back so that he can improve the quality for the next revision.

The seminar style was changed again for the third seminar. For each week, one students lead the discussion. The discussion began by the leader presenting the papers, which is about two or three papers. Then, three questions were asked and the students discussed each question. At the end of the semester, each student handed in one report.

In the fourth seminar, we, students and professors, agree to divide into three groups. Each group work in one problem. By doing this, each student can do something they like aside from their research projects. Also, since the task is not relate to each student's research, it is likely that the other will be interested in the other group's work.

2. Mission

After we all agree with the theme of the fourth seminar, each students began to sell idea. Our group's original idea is to create a controller that response to human thought. For example, if we think "Left" then the object in the screen will go to the left side. We believe that it is possible because there is a commercial device that when put it into a finger, a different type of thinking can control the object on the screen.

However, after we talked with a faculty of engineering, Cherdkul, we thought that our idea seems to exists only in scientific novel. The electroencephalograph or EEG cannot read our mind. It was used mainly for diagnose people with brain disease. The electrodes are put on 32 position on the sculp and they produced 32 channels of waveform.

Arjarn Cherdkul recommended us to talk with arjarn Dr. Tayat Desudchit, who is a faculty of medicine. Dr. Tayard's project is to build a cheap EEG system using real-time Linux and circuit board developed in Thailand. He gave us a lot of details about the machine and suggested some method to use brainwave to control. One is to mediate and bring the brain to the alpha state. Then, we can control the amplitude of the alpha state. Different amplitude means different. However, it takes several minutes to be in the alpha state. Therefore, this approach might not be appropriate. Another approach is to.

Dr. Tayard gave us a URL that links to a Brainmaster (TM) project. The web site, http://www.brainmaster.com, contains resources about how to build a simple EEG machine. In this web site, we found a Pac-man games that can be control using different brain state.

3. Brain

Our huge brains make us distinct from animals. There are about 100 billion neurons in the adult human brain [1]. The brain consist of three parts: the cerebrum, the cerebellum, and the brain stem. The cerebrum is responsible for most high level brain functions. It can receive sensing information from organs and can send a motor signal to muscle or gland. The cerebellum coordinates the movement of the body by fine-tuning motor commands from the cerebrum. The brain stem is responsible for the basic function of life such as breathing. The motor control is crossover at this area. The right brain talks with the left half of the body and vice versa.

3.1 Motor Cortex

The cerebrum cortex is the outer layer of the brain. The motor cortex is located in the middle of each side of the brain. Because the pyramidal tract crosses over at the lower medulla, the left motor cortex controls the right side of the body and vice versa [2]. The muscles that it controls are mapped upside down. The part that sends the motor signal to the foot is located above the one that controls the lip. Large area of motor cortex is attached to lips and hands [3].

Betz cells, neurons in motor cortex, have direct and indirect communication with motor neuron [4]. The direct output is sent from from layer 5 via internal capsule. The indirect output is sent through thalamus [5]. The information sent by those cells is probably the direction of force and particular joint position.

As index finger flexes forcefully, images from Magnetic Resonance Imaging (MRI) told us that a part of the motor cortex was active. However, when complex sequence of finger movements were performed, more parts of the brain were active. This means that the sequencing of the movement is calculated at the other parts.

By only thinking about performing a complex movement of right hand index finger, specific part of the brain of the brain are also activated. Those active parts are not motor cortex. From this, it might be possible that by probing the area using EEG. The computer can recognize particular thought before the test subject really move the finger.

3.2 Brain Waves

A human brain operates by electrical, magnetic and chemical activity. The activity gives us order in our lives. Since the early 1900's, doctors and scientists have been able to look into the brain and view its activity. While the doctors and scientists were probing the regions of the brain, they found out that for the most part the activity detected, there were many different frequencies of rhythmic and non-rhythmic waves ranging from 0.2 to several hundred hertz. These brain waves were further broken down into individual categories for easier study and for there particular properties [6].

3.2.1 Beta wave

This wave is in the range of approximately 10-30 hertz or pulses per second, sometimes Beta waves are also referred to those frequencies up into the hundreds of hertz. The mental activity normally associated with Beta waves is the active awareness state that we experience from day to day at work and play. There are many external chemicals that can be induced into the brain to produce this state and they are known generally as stimulants. Some of those stimulants are small amounts of alcohol, the nicotine in cigarettes, caffeine in coffee and tea.

3.2.2 Alpha wave

Most people can generate this wave with meditation, and all sorts of strange ideas. Alpha ranges between 7-12 hertz and is prominent during relaxation mostly with eyes closed and day dreaming. The 1960's made this activity famous when it was found out that marijuana, which grew naturally, induced this state in people. Scientist have found out that the chemical substance in marijuana caused this euphoric feeling

3.2.3 Theta wave

This wave is in the range of 5-8 hertz and is characterized mainly with light sleep, Rapid Eye Movement (REM) dreams, and hallucinations. The brain uses this state to exercise itself, somewhat like working out your muscles to make them stronger and to release overall tension. The drugs that promote this activity are, on the whole, illegal.

3.2.4 Delta wave

The Delta's frequency is in between 0.2 and 6 hertz. The appearance of this area is the sleep, no dreaming, and coma occur during this state. Excessive amount of alcohol induces the brain into the Delta state as so the body can repair and filter out toxins and poisons within itself. The body uses this state to put full effort to repair itself from the days activities. Its significant to know that two third of our sleep time is taken up by this state to complete these repairs and to give the brain time to rest. Other chemicals that induce this Delta state are known as downers, things like sleeping pills, aspirin, muscle relaxants, and barbiturates. All these chemicals can be very dangerous if taken in excessive amount which causes the brain and body to totally relax into death itself.

4. Electroencephalogram (EEG)

In our experiment, we will use electroencephalogram (EEG) to measure brain wave and notice its waveform. EEG is the result of technical development in the field of electrical measurement and recording in the last quarter of the 19th century. It made possible one of the greatest triumphs of modern neuroscience; the discovery, made by a German psychiatrist named Hans Berger, that the human brain has a continuous electrical activity and those activities can be recorded.

EEG is normally used to record the brain wave in medical treatment. The recording is usually taken by electrodes (small metallic discs) pasted by an electricity conducting gel to the surface of the scalp. The patients should wash their hair before measurement in order to get more accurate result. We decide to use EEG facility at The Faculty of Medicine, Chulalongkorn University. Dr. Tayat and his team developed the signal receiving part and graphical display software in Thailand. It worked well when compared with the imported one but it is less expense.

In EEG recording, a powerful electronic amplifier increases several hundreds or thousands of times the amplitude of the weak signal (less than a few micro volts) which is generated in this place. In the past, a device called galvanometer, which has a pen attached to its pointer, writes on the paper strip, which moves continuously at a fixed speed past it. In the present time, with the advent of powerful electronic computer and very high storage, we can use A/D device to transform signal between electrode and computer. A lot of data can be recorded and easily analyzed and printed. One pair of electrodes usually makes up a channel. EEG recording, depending on its use, can have from 8 to 40 channels recorded in parallel. This is call multi-channel EEG recording.

Since the times of Berger, it is known that the characteristics of EEG activity change in many different situations, particularly with the level of vigilance: alertness, rest, sleep and dreaming. The frequency of wave change can be labeled with names such as alpha, beta, theta and delta. Particular mental tasks also alter the pattern of the waves in different parts of the brain.

4.1 The History of EEG

In 1929, a German psychiatrist named Hans Berger, who worked in the city of Jena, announced to the world as follows:

- It was possible to record the feeble electric currents generated on the brain, without opening the skull, and to depict them graphically onto a strip of paper. Berger named this new form of recording as the Electroencephalogram (EEG, for short);
- That this activity changed according to the functional status of the brain, such as in sleep, anesthesia, hypoxia (lack of oxygen) and in certain nervous diseases, such as in epilepsy.

These were revolutionary discoveries, and, in fact, Berger founded an entirely new and very important branch of medical science, named clinical neurophysiology. Berger electrodes were too large to made detailed topographical studies of the EEG (in other words, to use electrical activity recorded from the brain to pinpoint areas of sensory projection, the localization of tumors or of epileptic foci, etc.).

W. Gray Walter, a remarkable British scientist, who, in 1936, proved that, by using a larger number of electrodes pasted to the scalp, each one having a small size, it was possible to identify abnormal electrical activity in the brain areas around a tumor, and diminished activity inside it. Impressed with the possibilities of building bidimensional maps of the EEG activity over the brain surface, W. Gray Walter invented the toposcope in 1957. This was a remarkably complex device and showed Grey Walter's inventiveness (besides being a physician, he was also an engineer). It had 22 cathode ray tubes (similar to a TV tube); each of them connected to a pair of electrodes attached to the skull. The electrodes (and their corresponding tubes) were arranged in a bidimensional geometrical array, such that each tube was able to depict the intensity of the several rhythms which compose the EEG in a particular area of the brain.

4.2 A 32-channel EEG using a modern recorder.

Each horizontal tracing corresponds to an electrode pair placed on a particular area of the patient's scalp, forming a regular grid-like pattern. By noting the set of channels where abnormal waves occur, the neurologist is able to infer the parts of the brain where the abnormality is located. This is very difficult to scan and to interpret, and subject to many errors. However, when the number of abnormal channels is large, or the nature of changes is complex, a precise bidimensional location of a focus or tumor is impossible to achieve.

Today, there are many commercial EEG brain topography systems in use. They are generally installed in PC-based or Macintosh-based microcomputer platforms, and can be easily operated by technicians or physicians, due to the Windows-based software, which comes with the package. This software is highly flexible, permitting the programming of many recording configurations and parameters, as well as to build a reference database of images, composed of typical patient cases in several pathologies. Usually, the multi channel records can be shown side by side with the reconstructed topographical brain map.

4.3 The Future of EEG

The recent development is the use of powerful graphical processing software to render three-dimensional reconstruction of the head and of the brain, where the electrical activity parameters recorded in the EEG brain topography are depicted as 3D color maps. Dynamic video animations can be produced, showing the alterations of electrical activity as a function of time. The future of quantitative EEG for clinical applications lies, undoubtedly, in the coupling of digital methods of signal analysis and of image processing. The increased sophistication and number of resources available on computerized EEG systems and of medical imaging processing will continue to evolve. Quantitative, high resolution EEG has a bright future as a tool in the medical diagnostic work.

5. Related Work

After we gathered many information from several sources, we found that although Dr. Tayat said the BCI is difficult and may be impossible, but there are a lot of researches achieve cursor control in 1-dimension or 2-dimension. For example, the Department of Electrical Engineering, Imperial College, London, can run this experiment successfully. The experiments are inspired by a program of research in Albany by Wolpaw *et al.* in 1991.

The current approaches fall into 2 categories.

(1) Those using evoked responses (ER) -- EEG signals collected by specific evoking stimuli.
(2) Those using spontaneous EEG components, that is, spontaneous in the sense that they occur in the course of normal brain function are not strongly linked to evoking stimuli.

The ER approaches have the advantage that simple processing methods can readily detect the signals. However, this method has the disadvantage of requiring the relevant sensory modality to be wholly or in part devoted to EEG-based communication e.g. in some ER systems attention is paid (or not) to a visual stimulus occupying a major part of the visual field. The `spontaneous' approaches, however, do not demand the constant commitment of a sensory modality and therefore may prove more convenient to use, more compatible with simultaneous performance of other activities and more practical for individuals with impaired modalities.

The inspiring experiment of Wolpaw *et al.* have shown that people can learn to use spontaneous EEG activity to control the movements of a cursor on a computer screen. Their system is based on the mu-rhythm which is known to desynchronize (reduce in power) during movement planning, imagination or execution. Unlink occipital alpha, the mu rhythm can be modulated over a period of seconds. In the experiment, subjects were trained to perform one-dimensional movement (i.e., up or down). Five subjects were chosen from a pool of 60 on the basis of having a strong mu-rhythm. The subjects' task was to move a cursor in order to hit targets that appeared at the top or bottom of the screen. This type o cursor control is called ballistic cursor control. After several weeks of training, four out of the five subjects achieved significant control (typically 90% of targets were hit at a rate of about 20 per minute). The system used two electrodes placed just in front of and behind C3 and upward cursor movement was proportional to the signal power in the 8-12Hz band as measured by a Fourier transform method. After that work, Wolpaw run the another experiment, subjects were asked to perform a more difficult task to move the cursor to a specific location and to keep it there in order to intercept a target (i.e., graded cursor control). In a 1994 experiment, subjects attempted 2D-cursor control (i.e. up, down, left and right). After 6 to 8 weeks of training, 4 out of 5 subjects achieved significant control (typically 65% of targets were hit at a rate of 20 moves per minute).

The training process of Wolpaw's experiment in 1991 took several weeks, for example, each subject undertook 15-20 half hour training session over a period of at least 3 weeks. Each session consisted of 6 or 7 runs where each run lasted about 3 minutes and approximately 100 trails were made in each session.

Despite the considerable achievements of the Wolpaw research program a number of open problems and areas for improvement remain:

(1) Accuracy. Currently, the accuracy of 1 dimension ballistic cursor control is about 90% and of 2D control is about 65%.
(2) Speed. Currently, both 1D and 2D systems operate at about 10 to 15 bits per minute. This corresponds to approximately 2 to 3 characters per minute.
(3) Training time. To achieve the above bit-rates, it takes between 3 and 8 weeks of biofeedback training.
(4) Subject variability. EEG-based interfaces seem to work well for some people and not at all for others. One out of the five of Wolpaw's subjects, for example, failed to achieve cursor control whilst another did so with 95% accuracy. Furthermore, these 5 subjects were selected from a pool of 60 subjects.
(5) Artifact elimination. Muscle artifacts appearing in the EEG trace affects accuracy, speed, subject variability and learning time. It would be very nice if those artifacts can be detected and removed automatically.
(6) Graded control. A mouse-driven cursor offers the user-graded control. Not only ballistic control (i.e., control of the direction of movement) but also the amount. Research in this area is at an early stage.
(7) On-off switch. Because the EEG components occur in the course of normal brain function some extra signal is needed to flag when EEG communication is intended and when it is not. For example, though a subject may be physically connected to a BCI, he may wish to be involved in other activities (e.g., resting) and not want to be communicating via the EEG all the time. Therefore, the interface needs an `on/off switch'.
(8) Application as an assistive technology. Work in this area is at an early stage. Miner et al. reported on an individual with Amyotrophic Lateral Sclerosis (ALS) who achieved cursor control via mu-rhythm training. Birbaumer et al. reported on two individuals with ALS who were trained to use a spelling device via operant conditioning of slow cortical potentials. Recently, the Graz group did the same research with other patient groups.

Of all these problems, the experiments at Imperial College try to solve the training time problem. They used the following approaches to reduce the training time.

(1) Trying an additional cognitive task (i.e. not just imagined hand movement)
(2) Using a variety of EEG features (i.e. not just the mu rhythm)
(3) Using more sophisticated signal processing and pattern recognition methods.

They collect the EEG data from 4 male and 3 female volunteers healthy and aged between 24 and 34. Each subject participated in a recording session lasting between 1 hour and 1 hour 30 minutes. The EEG was recorded from electrodes positioned over the left and right sensorimotor cortex in positions C3' and C4' (3cm posterior to the C3 and C4 positions in the 10/20 system). The signals were recorded with respect to a reference electrode placed over the right mastoid and the impedance between each electrode and the reference was less than 5K\Omega\Gamma. The surface electromyogram (EMG) was recorded from the left or right forearm extensor (depending on the handedness of the subject). The EEG and EMG signals were amplified using two ISODAM amplifiers. Two analog filters on board the ISODAMs were used to remove activity below 0.1Hz and above 100Hz. The signals were then digitized to 11-bit accuracy at a sampling rate of 384 Hz (by recording segments of 128 samples every 1/3 second). All data was stored on computer disk and, during the biofeedback tasks, was also analysed on-line in order to drive the cursor movements.

The subjects were asked to do many activities. For example, moving their eyes from left edge to right edge of computer screen, moving their eyes from top to bottom of computer screen, frowning, blinking. Or, looking at the cursor and imagine opening and closing their hands, look at the cursor and serially subtract 7 from X. The experiment attempt to classify the EEG wave of these. These EEG waves are then fed into the recognition tasks (Signal Processing, Bayesian Logistic Classifier, Temporal smoothing and Generation of cursor movement). This experiment had 75% of accuracy.

We designed the first experiment inspired by the research of the department of Electrical Engineering, the Imperial College, London. The researchers at Imperial College tried to classify the EEG waveform in alpha range (8-12 Hz). The subjects in that experiment were asked to close their eye. It was found that after the eyes closed, the alpha wave commonly occurred. So the EEG wave can be easily classify into 2 classes: normal and alpha wave. They used the result of the experiment as a switch to turn on and turn off circuit of the toy car. However, the purpose of our project is to classify EEG wave into 3 classes: no moves, a left move and a right move. The normal wave will be used for freezing the cursor. The left and the right move wave pattern will be use to move the cursor to left and right, respectively.

There was another experiment at the Imperial College using the another waveform. This experiment employed the mu-rhythm as the input. The EEG wave happens when we move any part of body. The position of the surface of the brain that mu-rhythm occurs depends on the moving organ. It happens in alpha range and reduction in power. They use two arrays of the golden probes. Each array contains eleven probes and measures at the position near the point C3 of the brain.

After we decided to use the mu-rhythm like the latter experiment, we consulted Dr. Tayat Desudchit several times. He advised us to run first experiment by testing with the person who have the mu-rhythm EEG waveform. This kind of person who has the mu-rhythm is strange from the normal people. They must have the alpha waveform whenever they close or open their eyes. So we must try to find the people that has the mu-rhythm now. One type of the people who has such a property is a Zen monk who practices zazen or Zen meditate.

6. Experiment

6.1 First Experiment

We went to see Dr. Tayat Desudchit and run a sample experiment with one male subject. We put only one probe at the left C3 and put ground and the reference point behind the ear. The expectation of this first experiment was testing whether the subject had the mu-rhythm whenever he opened or closed his eyes.

The diagram shown in figure 1, 2, and 3 are the EEG wave after transformed by the Fast Fourier Transform (FFT). These EEG waves were recorded at C3 position of each subject. The diagram shows that The EEG wave consists of various frequency waves. We assort the wave in range 0-2 Hz as noise. Figure 1 is the diagram when the first subject open his eyes. The EEG wave of opening eyes has various frequencies between 2-25 Hz, and we can found that the wave in range 8-14 Hz seems more than the wave in other range.

Figure 2 shows the diagram of EEG wave when the first subject closed his eyes. The alpha wave (8-12 Hz) occurs obviously. In the experiment at the department of Electrical Engineer, Imperial College, London, showed that this alpha wave occur normally when the human close their eyes. The amount of the alpha wave depends on each person. As shown in figure 3, the alpha wave of the second subject occurred more than the wave generated when he opened his eyes, but the amount of alpha wave in the second subject is not equal to the first subject.

The result showed that he has an alpha wave when he close his eye but do not have alpha wave while he open his eyes. Therefore, the first subject cannot be tested for the mu-rhythm experiment. Even though he does not have the mu-rhythm, but the first experiment at the Imperial College was found very easy to repeat because the alpha wave is produced when the subject close his eyes. If we use Fast Fourier Transform (FFT), we can discriminate the alpha wave from the normal wave easily. Thus, we can classify the EEG wave into two groups. This classification can be used as the same purpose as the experiment at the Imperial College, as a switch.

Our next step will be trying to find a person who has the alpha wave no matter his eyes are open or close. If he has the mu-rhythm waveform, we are able to detect which side of the body he is moving. If he moves the right side organ, the left side brain will produce the mu-rhythm. In contrast, if he move the left side organ, the right side brain will produce the mu-rhythm. The next experiment will be run for classify this type of EEG into three classes to find out the method that can be used for controlling the cursor.

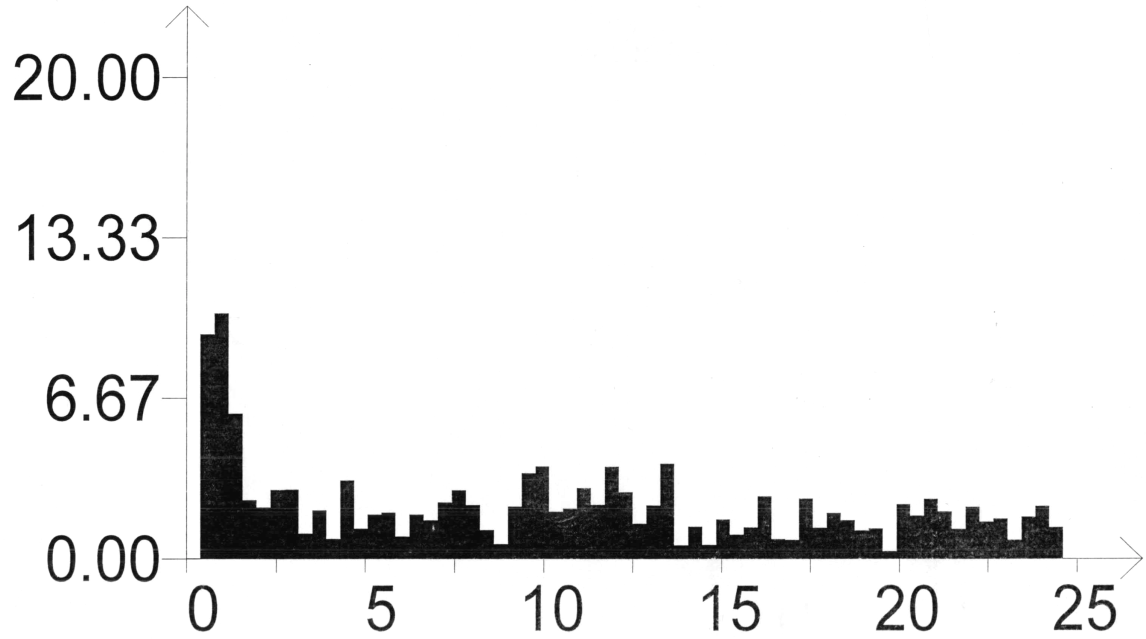

Figure 1. The EEG wave transformed by Fast Fourier Transform when the first subject opened his eyes.

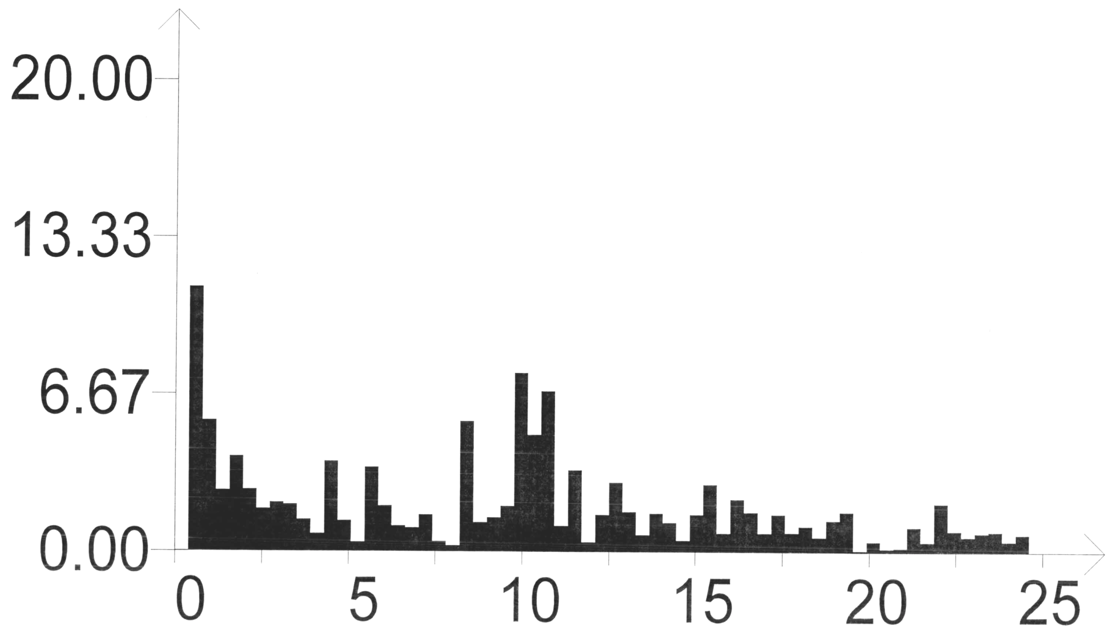

Figure 2. The EEG wave when the first subject closed his eyes.

6.2 Second Experiment

Our group went the EEG room about 5 PM. Dr. Tayat was in the room. We talked about the experiment plan. We concluded that only able to detect the difference in alpha waves when eyes are open and close would be good enough. Dr. Tayat talked about the position on the scalp which he will put the electrode on. In fact, he would like to teach us how to put the electrode and how to operate the EEG. However, since we think that this will be the last time we used his facility, we decided to let him do it without explaining.

He put the probe with the gel that helps bringing the electricity from the scalp. The probes are made of pure gold. It is used to listen for electric signal from scalp. Therefore, there is no danger for the subject. The doctor put five probes: on the top, topback, back, side, and in the middle of them. The middle one was used as a reference point. This style of probing is not the for the full test but it suit our purpose.

There was some problem at first. There were so much noise probably because the subject did not shampoo his hair before the examination. Dr. Tayat turned the filter on. It works better but not full satisfying. He used a bandage to wrap the subject's head so that the electrodes are fix and getting closer to the scalp. After doing this and waiting for the gel to do its job, the wave form was readable.

After everything seems to be on track, Dr. Tayat told the subject to close his eyes. He told the rest of the team that there were increase in alpha wave. This is normal for normal people. The alpha wave occurs when the subject close his eyes. However, when the subject opened his eyes, the alpha wave was disappeared. Thus, this subject cannot be used in this type of experiment.

Figure 4 shows the EEG wave when the second subject released and pressed his fist. We performed this experiment to check the desynchronization of the mu-rhythm when the human move or plan to move his organs. Because the mu-rhythm does not occur in every people and it is very hard to find. So the wave shown in figure 4 looks like the wave when the subject release his fist and press his fist are not different. However, only the expert can read the difference between releasing and pressing his fist.

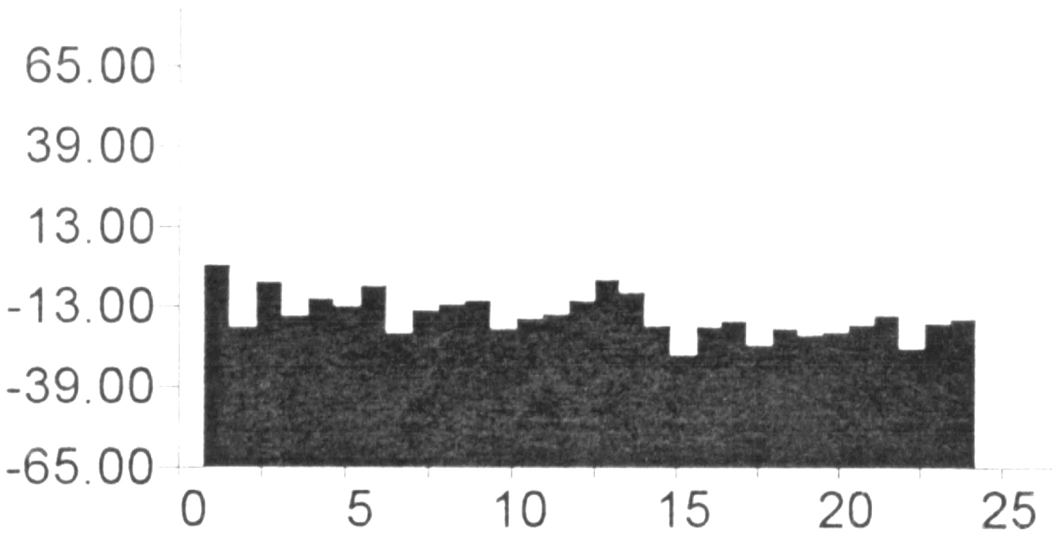

Figure 3. The EEG wave when the second subject closed his eyes.

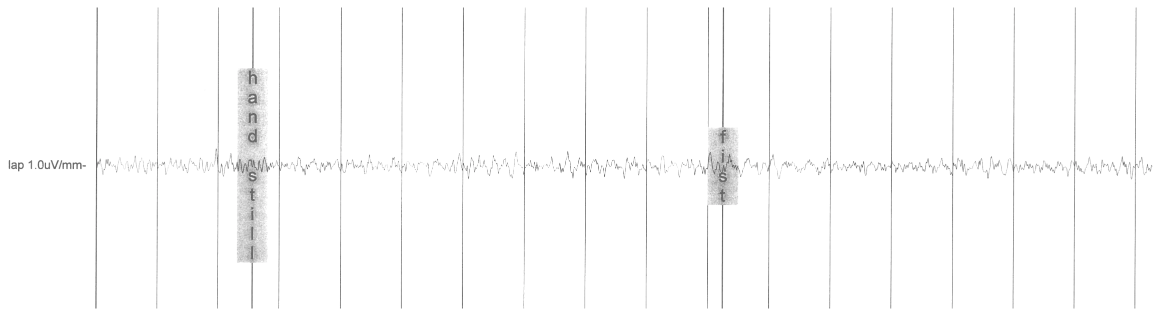

Figure 4. The EEG wave when the second subject release and press his right fist.

7. Conclusion

Can we use our mind to control anything?

It is not easy to answer this question. With the help of neuroscience and its associated instruments, we are likely to have the confidence that brain wave patterns are able to response the activity we perform in daily life. Activity such as walking, running, doing housework or anything that bring about body movement will produce brain wave called beta wave. Beta wave is the wave in the range between 10-30 Hz. However, when we get rest or do the concentration, we have got different wave called alpha wave that is in the range 7-12 Hz.

With the advent of computer age, we can use Electroencephalogram (EEG) to digitized brain wave pattern and analyze it. Usually, a doctor or an experienced operator will use probes (as many as 32 probes) with electrical conducting gel to stick on the patient's scalp. The received wave pattern can tell us disorder or some disease in the brain.

However, we can use this instrument in our experiment. We would like to know that we, as normal people, could use to recorded EEG data classify wave pattern. Dr. Tayat at the Department of Medicine, Chulalongkorn University, help us by introducing the instruction for the measurement. We would like to classify brain wave by thinking or with the movement with thinking is in our interest. However, Dr. Tayat told us that we should find someone with mu-rhythm because it is one of the important factors in the experiment.

Finding anyone with mu-rhythm is rather difficult with the time constraint. We chose two of the members in the team for mu-rhythm measurement. Telling that anyone have mu-rhythm is not difficult. One of the methods is to check his alpha wave while eyes are opened and closed. If his brain wave patterns are different, he has no mu-rhythm.

Although we have not got the persons who have mu-rhythm, we are surely in some levels that at least we can use wave pattern while opening and closing eyes in one dimension for applicable to the control for further experiment.

Acknowledgement

We would like to thank to Dr. Tayat Desudchit. Not only providing us the equipment, he also guided us about the subject we know very little about. Our project cannot be done without his help.

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