EEG-based Brain Computer Interface (BCI) for Smart Home Control using Raspberry Pi

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ABSTRACT

Electroencephalogram (EEG) is brain electrical activities recorded through electrodes when placed on human scalp with an EEG bio amplifier. BCI is a system that detects the brain electrical activities and translate those specific features of those signals that represents the intents of the users into computer readable commands. The basic idea of BCI is to connect human brain with machines to accomplish certain tasks. Currently, some low cost EEG systems were developed to provide a new way to explore human mind with affordable price in the market. Hence in this project, a smart home control using brain wave with the use of real time information is developed from a low-cost EEG system, Emotiv EPOC to build a smart home using Raspberry Pi and MATLAB software. Graphic user interface (GUI) is developed to visualize the brain signals and these signals are vital to control and monitor simple home appliances. Basically, the EEG system amplifies the real time brain signals and then send it wirelessly to the computer/laptop using Bluetooth. The signals are then being processed and filtered using MATLAB software and later the processed signals are sent to the Raspberry Pi via Ethernet cable to execute the simple functions such as switch on or off of lamps, CCTV and to play music using BCI. This application is very useful especially for people with special needs. It is vital to escalate living quality of citizens and it is going to be a trend in future technologies.

ABSTRAK

Electroencephalogram (EEG) merupakan isyarat otak yang dirakam melalui elektrod-elektrod pada penguat-bio EEG yang unik apabila diletakkan di atas kulit kepala. Brain Computer Interface (BCI) merupakan satu sistem yang boleh mengesan isyarat-isyarat otak dan mentafsirkannya niat pengguna tersebut dalam bentuk yang boleh difahami oleh komputer. Idea asas BCI adalah untuk menggabungkan otak manusia dengan mesin bagi menyempurnakan tugas-tugas yang ditetapkan. Baru-baru ini, sistem EEG yang lebih murah telah dicipta dan ciptaan ini merupakan satu kaedah baru yang membolehkan penerokaan otak manusia dengan harga yang berpatutan. Maka dalam projek ini, sebuah rumah pintar yang menggunakan isyarat otak berserta dengan informasi masa sebenar telah direkacipta dengan sistem EEG yang kos rendah, Emotiv EOPC dengan menggunakan Raspberry Pi dan program MATLAB. Graphic user interface (GUI) telah disertai untuk menggambarkan isyarat otak kerana meraka memainkan peranan yang penting dalam pengawalan peralatan rumah. Dengan kata lain, sistem EEG menguatkan isyarat otak dengan informasi masa sebenar dan hantarkan isyarat tersebut kepada komputer / komputer peribadi tanpa wayar dengan menggunakan teknologi Bluetooth. Isyarat tersebut diproses dan ditapis dengan menggunakan MATLAB. Akhirnya, isyarat tersebut akan dihantarkan kepada pemproses Raspberry Pi dengan menggunakan kabel Ethernet untuk membuka / menutup lampu, CCTV dan menyiarkan lagu music dengan menggunakan BCI. Aplikasi ini amat berguna terutama bagi orang yang kurang berupaya. Projek ini juga penting untuk meningkatkan kualiti hidup semua lapisan masyarakat dan ia akan menjadi trend yang penting pada masa yang akan datang.

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EEG	-	Electroencephalogram
GUI	-	Graphical User Interface
BCI	-	Brain Computer Interface
RISC	-	Reduced Instruction Set Computer
ARM	-	Advanced RISC Machine
CCTV	-	Close-circuit television
GIF	-	Graphics Interchange Format

CHAPTER I

INTRODUCTION

An electroencephalogram (EEG) is an electrical signal recorded from the scalp surface after it is being picked up by metal electrodes and conductive media known as EEG bio amplifier. The electrodes detect the weak electrical signals and then amplify them before represent them in the form of graph or data in a computer or laptop. This allows users to see how the brain functions over time and it is being implemented in medical industry to evaluate brain disorders. Also, it enables the detection of abnormalities in the brain by investigation on the frequency and waveform of the brain. This can be applied directly to all mankind including patients, adults, adolescents or even children without any risk. This system is totally non-invasive because the EEG signal is directly measured from the cortical surface of the brain.

Currently, some low-cost EEG systems are developed to provide a new way to explore human mind with affordable price in the market. Emotiv EPOC is one of the selections as it offers lower price (499 USD) with 14 electrodes mounted on a wireless headset which can connect to laptop and computer wirelessly using Bluetooth at bandwidth of 2.4 GHz. Users can do a lots of analysis from the data collected via Emotiv EPOC headset as it enables the access of raw data with its SDK research version. Apart from that, EEG bio amplifier is used as a brain computer interface (BCI)

to translate the intent of the users which originally in the form of EEG signals into computer readable commands to execute the task designed.

Recently, many researchers have developed products that can be commercialize to bring convenience to every people in the daily life. This scenario has prompt smart home to become one of the mainstream in research and commercialize areas. Various types of environmental control systems thus are available in market. However, most of the existing BCI control system requires user's active mental command to control the appliances or devices. For example, it requires the user to raise their arms or turn their head in order to control the devices. This is really inconvenience especially to those people with mobility impairment. Consumers are lack of confidence with this system as it is less ubiquitous to control devices automatically. Hence, BCI with the use of cognitive state only is must in the future and should be implemented as fast as possible to enhance the living quality of every human being.

In this project, two attractive graphical user interfaces (GUI) are developed. The first GUI is used to show users' real time brain signal activities while the second GUI is used to control the whole smart home with the aid of Raspberry Pi and knowledge in MATLAB. Raspberry Pi is a low cost single board mobile computer equipped with ARM Linux box in credit-card size that enable the users to interact with outside world no matter it is analog or digital. The brain signals are filtered and processed before send to the Raspberry Pi to removes noise and artifacts that will interrupt the execution of designed tasks. Hence, EEG-based brain computer interface (BCI) for smart home control using Raspberry Pi is developed within two semesters.

1.1 Problem Statement

Human wishes to get better and more convenience life with the advance of technologies nowadays. Creations nowadays are so smart until things and stuffs can be control wirelessly and digitally by sensors, smartphones, robots, tablets, laptops and so on. Smart Home is one of the example that loves by mankind and it is still being developed. Current trend for smart home nowadays is by using sensors and thumbprint which is troublesome sometimes. It is not ubiquitous with the use of sensors and thumbprint as the task designed can be executed only if the user is within the range of execution of the sensors. Also, the cost for a complete smart home system is very high and thus most of the people is not affordable to own this technology. Apart from that, there are a lot of people in this world suffering malfunction in the motor activities that cause them facing inconvenience in their daily life. They have difficulties in performing their daily activities. Hence, this project is to develop a brand new and attractive GUI with an affordable EEG system to control and monitor home appliances wirelessly using Raspberry Pi with the knowledge in MATLAB software.

1.2 Objectives

The main objectives of this project are:

- To develop a prototype of smart home using low-cost EEG system and Raspberry Pi.
- To analyze brain signals using MATLAB software.
- To develop a user friendly Graphic User Interface (GUI) to display real-time information.

1.3 Scope of Work

A reliable Graphical User Interface (GUI) that allows users to process high density EEG data is designed. Emotiv EPOC is chosen as the low-cost EEG system. Bluetooth technology will be used to transmit the amplified EEG signals to the laptop/computer at a frequency of 2.4GHz. These signals are filtered and processed in the MATLAB to reduce noise and artifacts. Raspberry Pi is connected to the laptop/computer via Ethernet cable to receive the processed signals from MATLAB to switch on or off of lamps, CCTV and to play music using BCI. GUIs are created to ease the control of whole system.

CHAPTER II

LITERATURE REVIEW

This chapter gives reviews on the terms and information that is essential for the project, this includes Electroencephalogram (EEG), brain wave classification, 10/20 Electrode Placement System, Brain Computer Interface (BCI), Smart Home and Raspberry Pi 2. These are all written based on the published works from related researches.

2.1 Electroencephalography

2.1.1 History of Electroencephalography

Electroencephalography is a medical technique that can read the brain signal in the form of electrical activity from human scalp. The recorded signal is known as Electroenchephalogram. Basically, there are three neuroimaging methods, they are invasive, partially invasive or non-invasive method. Non-invasive method is more popular as it can be directly applied to human scalp without any danger and risk [1]. Every adult has an average of 10^{10} neurons. With large population of active neurons,

they can generate electrical voltage in microvolts inside brain cortex. This differences in electrical potential is due to the potential difference between neuron and dendrites [2]. When it comes to the scalp, its voltage will drop to microvolts. These type of signals are massively amplified and then send to the laptop to further process or display. Brain signals can be acquired by attaching metal electrodes onto the scalp surface. This method is known as electroencephalography (EEG) and the use of this technology has expended within these few years as it is very user friendly and the price is affordable.

The discovery of electroencephalography (EEG) by the German psychiatrist Hans Berger in 1929 was a historical breakthrough providing a new neurologic and psychiatric diagnostic tool at the time. Electroencephalography has undergone tremendous changes for more than 100 years and it is still counting. At the very beginning, Richard Caton, an English physician observed the EEG signals of monkeys and rabbits from their exposed brains. Han Berger who was impressed by his great work tend to continue his research and he tried to amplify the brain signal measured on human scalp. Finally, he successfully recorded and reveal the brain signals graphically on paper without opening the skull by using amplifier with ordinary radio equipment. From his experiment, he noticed that the brain waves change accordingly depends on the activities being carried out. For instances, stages like concentrate, sleep and epilepsy will have different waveforms. He was right with his observations and he suggested that general status of a subject changes will cause the brain activities change in a consistent and recognizable way [2]. This great finding had become a great fundamental for many applications of electroencephalography. Also, he was the first person to use the word electroencephalogram to describe brain electric potentials generate by human brain. Later in 1934, a paper verified the concept of "human brain waves' was published by Adrian and Matthews. They named "alpha rhythm" for brain wave that oscillates around 10 to 12 Hz.

At first, EEG monitoring was carried out as an inpatient with video recording and long cables to an amplifier, it was not portable and convenient. Then, it was being improved to portable yet is was bulky. Hence, wearable EEG had taken over the older

technologies. Current EEG unit has rechargeable battery, lightweight with wireless connectivity has stand a place in the market with affordable price. Users can record the EEG signals for days, weeks, or months at once easily [3]. Several of activities can be performed with this advanced of technologies as well.

2.1.2 Brain Waves Classification

EEG signals can be classified into 4 main groups, named Delta, Theta, Alpha and Beta according to the frequencies. The dominant brain signal is Alpha wave. It is mostly can be obtained in relax state where its amplitude ranges 30-50 μV in 8-12Hz. The second dominant wave is Beta wave. In human brain, different frequencies can be acquired and observed easily as via the brain waves. It depends highly on the activities carried out by each mankind [4]. Table 1 below show the frequency components of brain waves:

Brain Wave	Frequency (Hz)	Amplitude (μV)	Cognitive States
Delta	0.1 – 4.0	100 - 200	• Deep sleep • Unconscious state
Theta	4.0 – 8.0	<30	• Dreaming • Sleep
Alpha	8.0 – 13.0	30 – 50	• Relax • Non-sleepy state
Beta	> 13	<20	• Excited • Awake • Conscious State

Table 2.1: Frequency Components of Brain Waves [4].

Figure 2.1 below shows the graphical EEG waves at different frequencies.