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Smart Home Control for Disabled Using Brain Computer Interface

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Abstract: Electroencephalography (EEG) based smart home control system is one of the major applications of Brain Computer Interface (BCI) that allows disabled people to maximize their capabilities at home. A Brain Computer Interface (BCI) is a device that enables severely disabled people to communicate and interact with their environments using their brain waves. In this project, the scope includes Graphical User Interface (GUI) acts as a control and monitoring system for home appliances which using BCI as an input. Hence, NeuroSky MindWave headset is used to detect EEG signal from brain. Furthermore, a prototype model is developed using Raspberry Pi 3 Model B+, 4 channels 5V relay module, light bulb and fan. The raw data signal from brain wave is being extracted to operate the home appliances. Besides, the results agree well with the command signal used during the experiment. Lastly, the developed system can be easily implemented in smart homes and has high potential to be used in smart automation.

Keywords: Brain Computer Interface (BCI), Smart Home Control, Graphical User Interface (GUI)

1. Introduction

In this cutting edge of technology, smart home control relates to the use of computer and information technology to monitor home equipment and fan, lighting and so on. Systems can vary from easy remote lighting control to complicated computer or microcontroller-based networks with automation [1]. Home automation system has also been intended for certain situations in which someone requires unique attention such as elderly, the sick and the disabled [2]. Brain Computer Interface (BCI) is a communication pathway for device control between human brain and computer. It can be categorized into two types of BCI which includes non-invasive and invasive type. An invasive type BCI is implanted an IC in the brain through brain surgery. Hence, most of the people choose non-invasive BCI over

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invasive BCI since non-invasive type involves only wearing a dry electrode of a headset [3]. It may be very useful for people who lose the ability to use their muscles due to total or partial paralysis of their entire motor system due to stroke, traumatic brain injury or cerebral palsy [4].

Non-invasive BCI based smart home control has already been existed for a couple of years. A few related previous works related to this project are discussed. Ou et al. [5] and Lin et al. [6] suggested using user's mental state (drowsiness or alertness) to interact with the smart home environment around him. They propose a system called BCI-based Smart Living Environmental Auto-adjustment Control System (BSLEACS). Besides that, Carabalona et al. [7] suggested a non-invasive visual P300 based BCI system to regulate appliances in a smart home for disabled users. A 6x6 matrix of icons is created for users and each icon represents a daily home-use device. In thE previous works, Guruprakash et al. [8] suggested a non-invasive EEG based BCI for disabled people that takes an eyebrow raise or a smirk as an input to emulate mouse click. The user is provided with a GUI to interact with a virtual home environment. The proposed system uses NeuroSky BCI headband to acquire neural signals against an eye blink to turn on a desired he appliance. Guger et al. [9] suggested non-invasive Subject Dependent P300 stimulus based on BCI provides the subject with a stimulus and records his reaction as an input. P300 BCIs rely on selective attention to visual stimuli. Wherever user focuses on a specific stimulus, a brain wave called P300 may occur [10].

In face, "Home Automation" concept has existed for couple years. Smart Home Control includes the concept of centralization control of lighting, appliances and so on and is getting popular these days. Therefore, integration of BCI and smart home control is being proposed for the benefits of disabled people. Home automation can be an area for using BCI and our entire house can be controlled simply by our brain [5]. It would be a great boon for this technology for almost all people. Less energy would be wasted for menial tasks like switching on the lights and other electrical appliances. This system provides security and comfort for the people with disability. EEG signal will be extracted and transmit to computer to trigger the output for further action. Hence, a BCI controlled of smart home system leads to a new connection between natural interaction and control engineering. Nonetheless, this technology is decent and 3 has the potential to completely revolutionize and improve the quality of everyday lives [11].

Smart home system for the physically handicapped can indirectly improve quality of life of people who especially needs institutional care or caregivers. By not only regulating lighting system in a smart home control, this system has also been proposed so that nearly every electrical component in the house can be included in this automation recently. Smart home control will be very useful for disabled people which require assistance to carry out their daily routines.

This paper presents as follows. In Section 2, the aims and objectives are discussed. Towards the end, the SMC is briefly explained in the subsection. Section 3 tells about the model components. Next is the section 4 which briefly explained about the results and discussions. For the final section 5, conclusion is explained.

2. Aim and Objectives

The aim of this project is to develop a portable, cost-effective and real-time wireless EEG-based BCI smart home control system for disabled people. The objectives of this project to achieve the aim is shown as following:

i. To extract a non-invasive EEG signal with BCI in smart home control for disabled people who have lost the ability to move.
ii. To design a Graphical User Interface (GUI) using MATLAB for monitoring of smart home control system.
iii. To develop a smart home control prototype in order to enable users to perform operation of home appliances remotely without any physical movement using BCI.

3. Model Components

Nowadays, it is undeniable that BCI is an evolving system that acknowledges and responds to user's brain waves. The aim is to capture Electroencephalography (EEG) signal in order to detect when users think. To measure the electrical activity of the brain, a test which known as electroencephalogram is conducted. This test is used as a non-invasive technology that directly attaches the electrodes on human's scalp [11-13] There is multiple of recent studies that demonstrates brain computer interface can be used for individual with movement impairments [14]. Therefore, a simple yet effective technique for smart home control using Brain Computer Interface (BCI) is proposed in this study. The signals need to undergo a few signal enhancement processes since the neural signals acquired by invasive and non-invasive method are noisy and have trouble to record brain's internal functioning. However, non-invasive type is at lower cost and greater accessibility which in turn can combat these problems. The next phase of this BCI scheme is called pre-processor [15].

The block diagram shows the Brain Computer Interface Analysis Platform using MATLAB. The NeuroSky MindWave headset will be placed on human scalp and capture the brain signal produced by neurons. After acquired the signal, it will be continued to pre-processing process of signal and undergo feature extraction and classification of signal. The BCI algorithm filters the noise from the signals and extracts the raw EEG signal for use. MATLAB software is studied on how to connect between MATLAB with NeuroSky MindWave headset in order to design a GUI feedback. The GUI feedback design is to include the data for raw EEG signal and eye blinking feature. Data analysis through graph is being shown through MATLAB GUI.

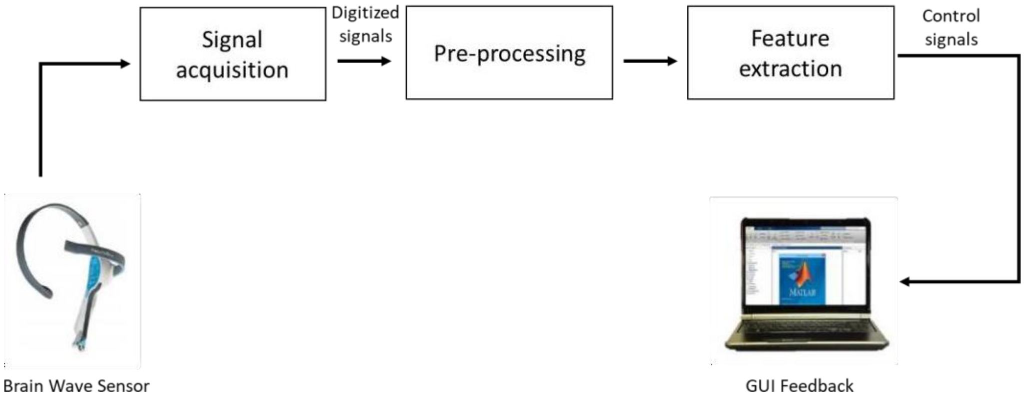


Fig. 1 - Block Diagram of BCI Analysis Platform using MATLAB

Figure 2 shows a simple block diagram in a BCI based Smart Home Control. The proposed block diagram aligns to recent research directions that aim to provide a more natural human-computer interaction. BCI has been mainly investigated in the context of disabled persons in order to control a smart home environment. The prototype is composed of head-mounted devices: NeuroSky MindWave EEG headset. EEG signals from the brain are measured by the signal acquisition unit and the BCI algorithm filters the noise from the signals and extracts the desired waves for use through MATLAB. ThinkGear technology is a chip inside Neurosky MindWave headset that enables a device to interface with the users' brain waves. It reads and extracts the brain signal for control in the MATLAB. Both the raw brain waves and the eSense Meters (Attention and Meditation) are calculated on the ThinkGear Chip. The serial data is then sent to the Raspberry Pi microcontroller so that users may perform ON and OFF operations on home appliances like doors, lights, fan and so on. All these commands can be shown via a GUI on the laptop screen.

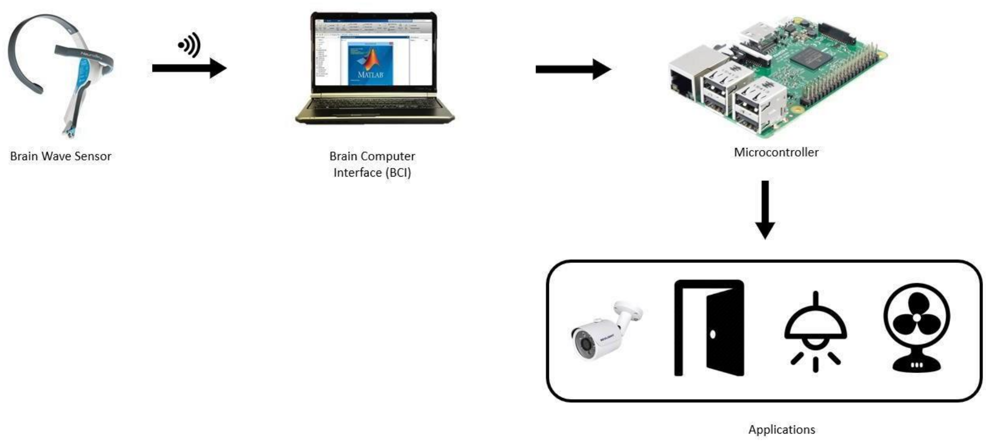


Fig. 2 - Block Diagram of Overall System for BCI based Smart Home Control

Figure 3 depicts the output control of Raspberry Pi as the microcontroller. In this system, Raspberry Pi is programmed and operated as the controller to operate home appliances like lights, fan, door and so on. This system integrates with relay module to perform all these operations at home in real time.

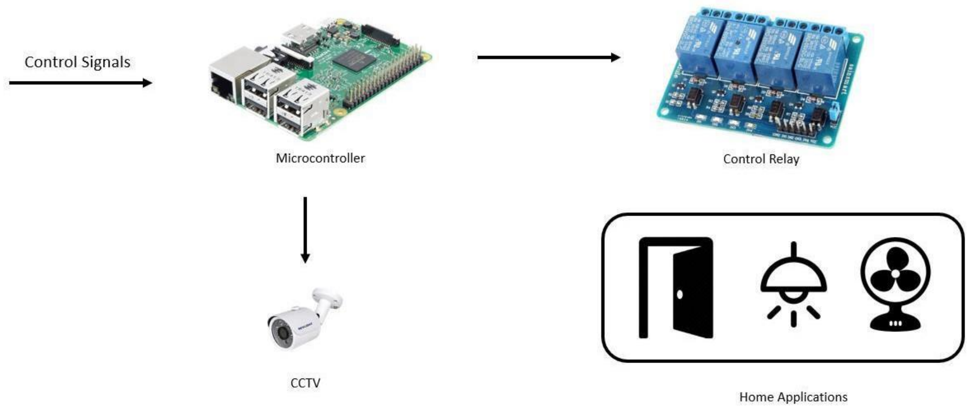


Fig. 3 - Output Control of Raspberry Pi as a Microcontroller

4. Results and Discussion

Eye blinking has been chosen to perform the tasks in this project since eye blinking will cause a significant pulse in the EEG signal. The personalized GUI developed in cooperation with the EEG device accesses the user's needs. Once the desired option is identified via the input control signal, the appropriate algorithm is called and executed. Therefore, it is easy to navigate through the GUI model. Additionally, the GUI is developed to facilitate the users so that they can interact with the smart home control system through the GUI.

Certain experiments on multiple users with different conditions has been carried out to test the reliability of the system. Experiment is carried out between normal people and disabled people. The data are collected from 7 individuals which consist of normal people to compare with 1 disable people for each trial to blink their eyes on purpose.

4.1 Testing on Normal Person

Two conditions, testing on normal person and disabled person were chosen to perform in order to obtain the result from GUI. The simulation results of GUI through MATLAB are shown as below.

If the user intended to open the door, user is required to blink his eyes at certain threshold within that time period. At the same time, the camera acts as a CCTV security camera for disabled people when the doorbell rings. Users may have a look on who rings the bell, and this ensures their safety when they are home alone. They can decide whether to open or not to open the door after checking on who is outside of the door. The door will then be opened and moved to the next appliance which is lights and by fan. Figure 5 shows the light is switched on by a normal person.

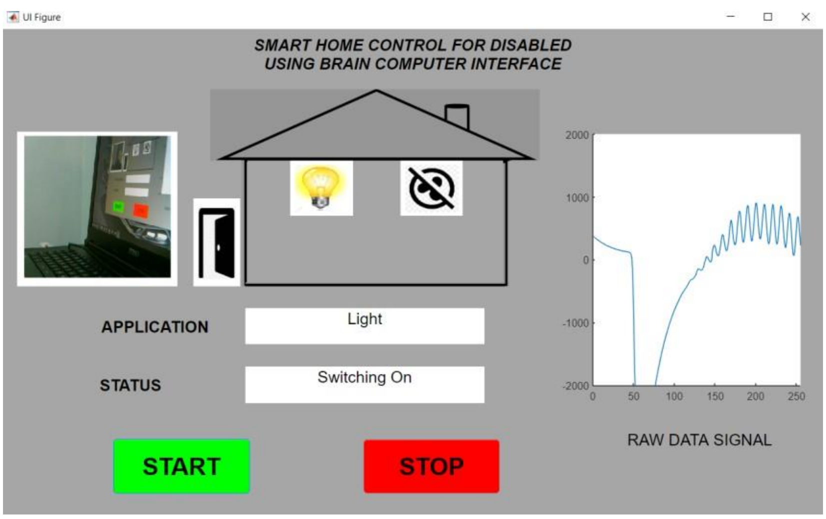


Fig. 4 - Light is switched on by normal person

Several tests regarding of the home appliances have been carried out randomly by the normal person. After testing, raw data signal is being recorded and compared with disabled people.

4.2 Testing on Disabled People

Figure 5 indicates the result obtained from GUI when testing on disabled person. It shows that the light is switched on after the eye blinking. This GUI is different between the one in figure 4 as this figure generates different raw data signal by the disable person. The raw data signal will be analysed in section 4.3.

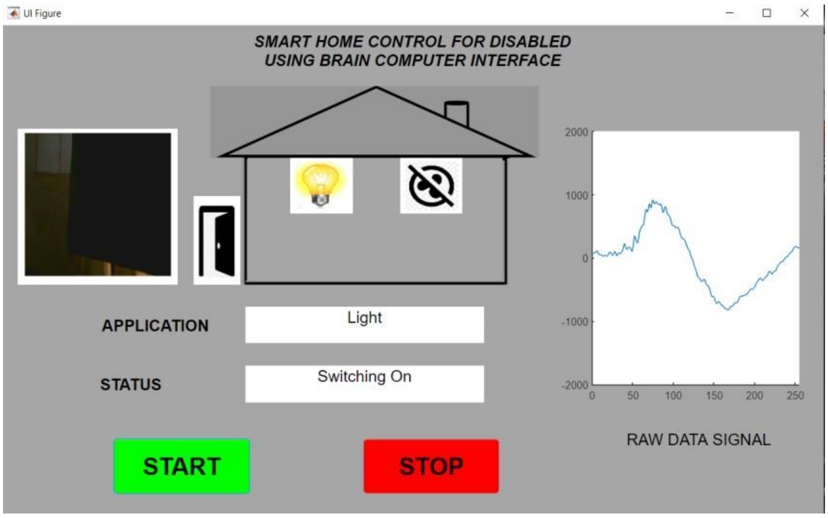


Fig. 5 - Light is closed by disabled person

4.3 Raw Data Signal Analysis

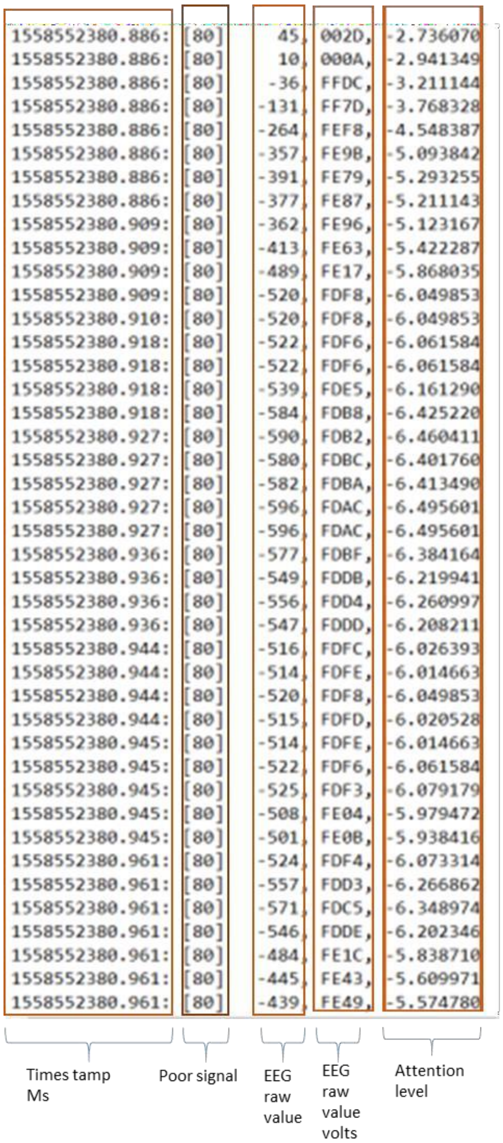
First and foremost, EEG signal is being captured and analysed using Brain Computer Interface (BCI). To acquire the EEG signal, ThinkGear in NeuroSky headset connector establishes a connection between the computer and the mobile mind wave. To extract the useful data from the redundant data, ThinkGear is connected to allow data collection. Thus, we can access the eye blink and meditation features where these parameters are used to operate and regulate the home appliances. Figure 6 shows all the parameters inside ThinkGear chip from the NeuroSky headset.

```
% Data type that can be requested from TG_GetValue().
TG_DATA_BATTERY =          0;
TG_DATA_POOR_SIGNAL =      1;
TG_DATA_ATTENTION =        2;
TG_DATA_MEDITATION =       3;
TG_DATA_RAW =              4;
TG_DATA_DELTA =            5;
TG_DATA_THETA =            6;
TG_DATA_ALPHA1 =           7;
TG_DATA_ALPHA2 =           8;
TG_DATA_BETA1 =            9;
TG_DATA_BETA2 =           10;
TG_DATA_GAMMA1 =          11;
TG_DATA_GAMMA2 =          12;
TG_DATA_BLINK_STRENGTH = 37;
```

Fig. 6 - Parameters inside ThinkGear Chip from NeuroSky Headset

Figure 6 shows the raw data signal collected from the NeuroSky BCI headset. This raw data signal is being extracted and processed by ThinkGear inside NeuroSky headset.

After NeuroSky BCI headset captured and extracted brain signal, ThinkGear translates the brain signal into a digital value. When the user blinks his eyes, it will have a drastic change at peak-to-peak values. Hence, there is also a drastic change of the values as shown in Figure 7. This drastic change of these values may occur when the eye movements are presented in the data. The eye blinks and lid closure may effect to this situation.



1558552380.886:	[80]	45,	002D,	-2.736070
1558552380.886:	[80]	10,	000A,	-2.941349
1558552380.886:	[80]	-36,	FFDC,	-3.211144
1558552380.886:	[80]	-131,	FF7D,	-3.768328
1558552380.886:	[80]	-264,	FEF8,	-4.548387
1558552380.886:	[80]	-357,	FE9B,	-5.093842
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1558552380.909:	[80]	-362,	FE96,	-5.123167
1558552380.909:	[80]	-413,	FE63,	-5.422287
1558552380.909:	[80]	-489,	FE17,	-5.868035
1558552380.909:	[80]	-520,	FDF8,	-6.049853
1558552380.910:	[80]	-520,	FDF8,	-6.049853
1558552380.918:	[80]	-522,	FDF6,	-6.061584
1558552380.918:	[80]	-522,	FDF6,	-6.061584
1558552380.918:	[80]	-539,	FDE5,	-6.161290
1558552380.918:	[80]	-584,	FDB8,	-6.425220
1558552380.927:	[80]	-590,	FDB2,	-6.460411
1558552380.927:	[80]	-580,	FDBC,	-6.401760
1558552380.927:	[80]	-582,	FDBA,	-6.413490
1558552380.927:	[80]	-596,	FDAC,	-6.495601
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1558552380.944:	[80]	-515,	FDFD,	-6.020528
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1558552380.945:	[80]	-522,	FDF6,	-6.061584
1558552380.945:	[80]	-525,	FDF3,	-6.079179
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1558552380.945:	[80]	-501,	FE0B,	-5.938416
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1558552380.961:	[80]	-546,	FDDE,	-6.202346
1558552380.961:	[80]	-484,	FE1C,	-5.838710
1558552380.961:	[80]	-445,	FE43,	-5.609971
1558552380.961:	[80]	-439,	FE49,	-5.574780
Times tamp Ms	Poor signal	EEG raw value	EEG raw value volts	Attention level

Fig. 7 - Raw Data Signal extracted from ThinkGear

4.3.1 Peak Values of Raw Data Signal for Normal People and Disabled People (Eye Blink Intentionally)

Figure 8 shows the peak values of an EEG raw data signal between different individuals that carried out the tests. The highest peak value is 1235 from 7th test while the lowest peak value falls at 5th test with value -1583. The values obtained is based on the individuals purposely blink their eyes to switch on or switch off home appliances.

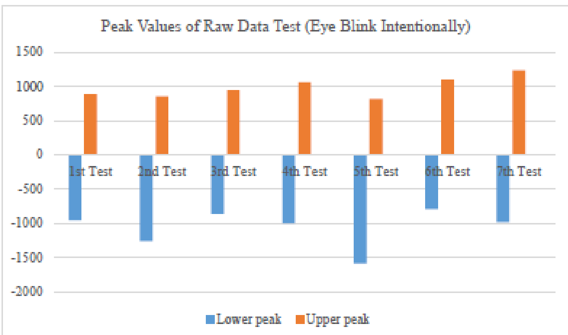

Fig. 8 - Histogram of Peak Values of Raw Data Test (Eye Blink Intentionally)

Table 1 shows the average peak values of a raw data signal between normal and disabled people. The average lower peak values of EEG raw data for normal and disabled people are -1060 and -896 respectively. Furthermore, for upper peak, the average peak values of a raw data signal are 985 and 812 for both normal person and disabled people. Hence, the average peak values of a raw data signal are considered to fall between -800 to 800. This data obtained when individuals purposely blink their eyes to operate the home appliances with BCI headset.

Table 1 - Comparison of Average Peak Values of Raw Data Signal (Eye Blink Intentionally)

Average Peak Values of Raw Data Signal (Eye Blink Intentionally)	Lower Peak Values	Upper Peak Values
Normal Person	-1060	985
Disabled People	-896	812

4.3.2 Peak Values of Raw Data Signal for Normal People and Disabled People (Eye Blink Involuntarily)

Figure 9 shows the peak values of an EEG raw data signal between different individuals that carried out the tests. The highest peak value is 850 from 3rd test while the lowest peak value falls at 6th test with value -788. The values obtained is based on the individuals involuntarily blink their eyes to switch on or switch off home appliances.

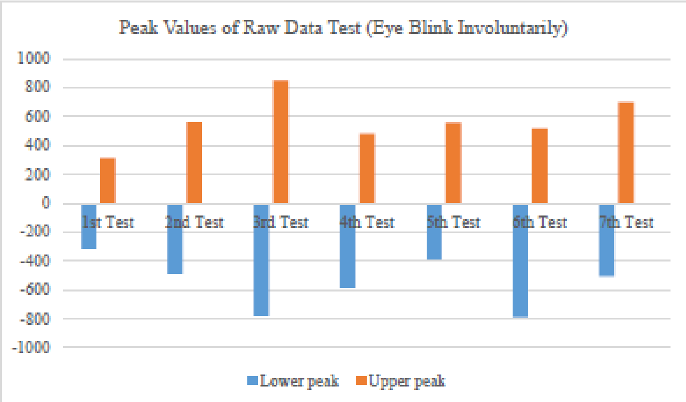

Fig. 9 - Histogram of Peak Values of Raw Data Test (Eye Blink Involuntarily)

Table 2 shows the average peak values of a raw data signal between normal and disabled people. The average lower peak values are -550 and -458 respectively. Furthermore, for upper peak, the average peak values of a raw data signal are 569 and 611 for both normal person and disabled people. Hence, the average peak values of a raw data signal are not over -800 and 800. This data obtained when individuals involuntarily blink their eyes to operate the home appliances with BCI headset. The threshold of eyes blinking strength is selected to be above normal blinking levels to prevent any commands caused by unintentional blinking.

Table 2 - Comparison of Average Peak Values of Raw Data Signal (Eye Blink Involuntarily)

Average Peak Values of Raw Data Signal (Eye Blink Involuntarily)	Lower Peak Values	Upper Peak Values
Normal Person	-550	569
Disabled People	-458	611

4.3.3 Prototype Setup

In Figure 10, it shows the overall system of smart home using BCI for disabled people. The brain computer interface (BCI) technology of NeuroSky works by monitoring these electrical impulses with a forehead sensor. The neural signals are then entered into ThinkGear chip and interpreted with patented algorithms. The measured electrical signals and the interpretations calculated are then delivered to the computer as digital messages. Hence, Raspberry Pi as the microcontroller will function as a small computer and is connected to 3 home appliances (door, light and fan) using relays and one camera as CCTV to perform the switching on and off processes, as illustrated in Figure 10.

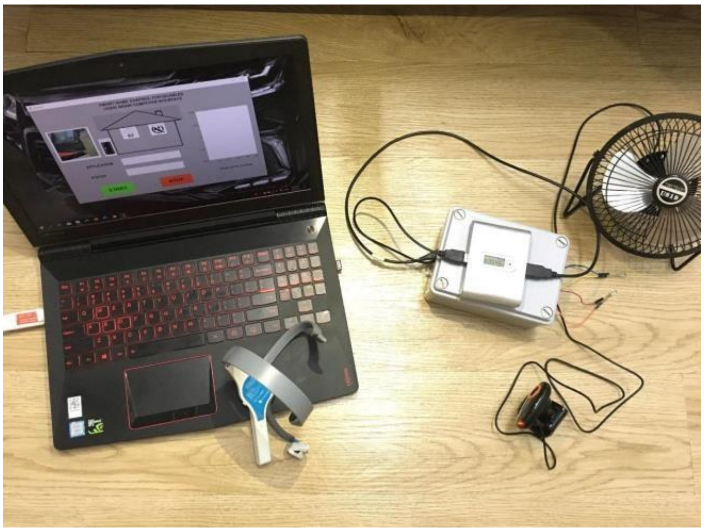

Fig. 10 - Overall Prototype of Smart Home Control using BCI

5. Conclusion

In conclusion, this paper aims to investigate the EEG signal acquired against the thoughts to interact with an everyday device such as lights. Our homes can be automated with the BCI using EEG brain signal. The NeuroSky MindWave headset is used by the system to acquire brain signals. Using the eye blinking function, the user can select and control the desired home appliances such as turn on the lights. The system has been trained and tested with four subjects which includes one camera acts as a CCTV security camera. Furthermore, a GUI based on the applications has been developed through MATLAB. We can implement a smart home control system using BCI technology since BCI based systems can facilitate physically disabled people and can change their lives drastically. This helps people with disabilities can independently carry out their daily activities. Besides, this BCI based smart home control system benefits the people and improve the quality of lives. A low cost and user-friendly design are presented in this study.

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