[Lunia and Bagdai* *et al.*, 5(8): August, 2016] ISSN: 2277-9655
IC™ Value: 3.00 Impact Factor: 4.116

IJESRT
INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

BRAIN MACHINE INTERFACING WITH IoT FUNTIONALITY

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DOI: 10.5281/zenodo.59673

ABSTRACT

Brain dead people and people having any disability related to brain cannot normally communicate with others and for their betterment some electronic need to be developed and Brain Machine Interfacing (BMI) is one such solution. BMI includes extracting brain signals directly from the skull of the subject and interfacing it with a machine to determine the state of thinking and act accordingly. The brainwaves are collected by non-invasive electrodes and the output is fed to an amplifier and filter circuit which is then fed into an ADC to process and recognize which act the subject wish to perform. Also for additional functionality Internet of Things (IoT) feature is added so that subject can control devices and perform any act even from remote locations. The complete module is developed with the help of Tiva C series TM4C1294 board for ADC and as processing unit, CC3100 for providing IoT feature and Beaglebone Black (BBB) to work as a processor at the receiver end.

KEYWORDS: Non Invasive methods, BeagleBone Black, TM4C1294, CC3100, EEG, IoT, Home Automation

INTRODUCTION

Brain Machine Interfacing module is a device developed to help disable people communicate easily with others and need not to depend on caretakers for performing daily operations. Brain produces specific signals when one uses any of the sensory organs, move any part of the body or think cautiously. These signals differ in frequency range and by extracting these signals, one can perform corresponding task. These signals have very low amplitude in range of microvolts and need to be amplified before further processing so that further task becomes less complicated.

Researchers over the world have worked on BMI and have developed various modules using the principle of EEG. Initially when not much was known about EEG and also its instruments were expensive its application was limited only upto medical field but with time people have developed the principle and with instruments and processing becoming less complicated various apllications I different fields have been developed. For example Mufti Mahmud, David Hawellek and Aleksander Valjamae have in their paper 'A Brain- Machine Interface based on EEG: Extracted Alpha waves applied to Mobile Robot' have discussed about how the extracted brain signals can be used to control robot and navigate it through different paths [1]. N.R.Raajan and G.N. Jayabhavani in their paper 'A smart way to play using Brain Machine Interfacing (BMI)' have applied the concept to develop devices which can be used for virtual gaming experience and have opened a whole new dimension of application for BMI [2]. Moreover apart from EEG principle many other methods have also been developed and discussed for BMI like Jae-Ho Han, Ji-hyun Kim and Jichai Jeong in their paper 'Non Invasive Optical Methods for Brain- Machine Interfacing and Imaging' have discussed about optical methods for same application and has these methods are considered very effective in case of guided treatment and small area detection [3]. Also Ehsan Kamrani, S.K. Hahn and S.H. Andy Yun have also discussed about optical EEG techniques like Functional-magnetic-resonance imaging (fMRI) and Functional-near-infrared spectroscopy (fNIRS) for detection of fast neuronal and slow-hemodynamic signals in their paper titled 'Optical EEG: A Novel Technique Toward Plug-and-Play Non-Invasive Brain Imaging and Human Machine Interfacing [4]. In this paper the principle of EEG is applied to develop a module for BMI and also to take the same module to other level of application it is combined with IoT functionality so that one can control any device from remote or far away location, thus enhancing its application domain to industrial as well as in home automation also. Cloud is used to store the information about the state of mind and is retrieved at receiver side to control appliances or bring automation to devices.

The following topics in this paper discuss about the hardware and the software environment in which this module has been developed. Hardware environment talks about the how the signals are extracted, filter and amplifier used to process the signals and the further interfacing with Tiva C series board for ADC and booster pack. Further to it the software environment topic discusses various software used to develop the complete system and at what stage which software is used and in what way. After that results chapter follow discussing the output obtained after testing the system on human subject and its success ratio as used in different scenarios.

HARDWARE ENVIRONMENT

BMI module hardware consist of sensors need to extract the signals from the brain skull, a processing circuit for filtering and amplifying the brain signals, an analog to digital converter (ADC) to convert the signals to digital domain, a processor to work on the digital data obtained from ADC to take decisions on which task to be performed or what brainwaves signify, a booster pack for uploading the data from processor to cloud to add the functionality of IoT, a computer processor at the receiver side to retrieve the data from cloud and operate the corresponding device or perform intended application. Block diagram depicting the flow is shown in figure 1.

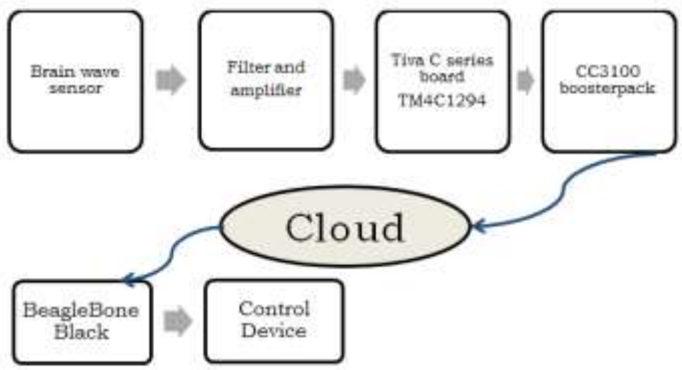

Figure 1: Block diagram of BMI module

Brain wave sensor

For extracting the signal from the brain sensors are placed on the skull called as electrodes. These electrodes help collect the signals and transfer them to the input circuit of the filter and amplifier circuit. The electrode are attach to the skull with the help of a conductive paste which acts as a dielectric between the skull and metal plate of electrode and help conduct signals with minimum interference. Also the electrodes are attached with the brain using skin adhesive tapes. For the development of this module, surface electrodes with cup surface are used for comfort of testing, relative freedom from injection and lower electrode impedance. These electrodes look like as shown in figure 2.

Figure 2: Metal Disc electrodes [5]

Along with the discussion of electrodes the placement of electrodes also plays an important role in the success and proper functioning of the system. The brain waves are obtained by placing electrodes on the skull but the exact point from where signals can be extracted with utmost accuracy is a matter of question. The medical people researched and came out with a 10-20 system of electrode placement and now this system has been standardized for any applications of EEG.

ISSN: 2277-9655
Impact Factor: 4.116

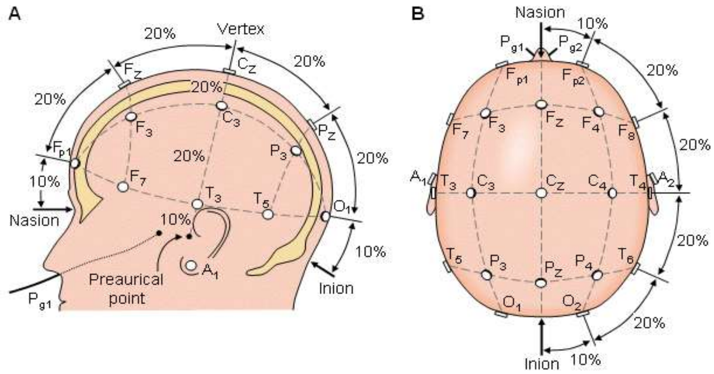

Figure 3: 10-20 system of electrode placement

Figure 3 shows the placement position for the electrodes. The name 10-20 stands for the distance between any two electrodes. The maximum distance on the skull is identified and then the complete skull area is divided in points with distance between them been 10% or 20% of the maximum distance. As shown above the points are indicated by letters and numbers. The letters F, T, C, P, and O stand for Frontal, Temporal, Central, Parietal and Occipital. Even numbers (2,4,6,8) refer to the right hemisphere and odd numbers (1,3,5,7) refer to the left hemisphere. The z refers to an electrode placed on the midline. Also note that the smaller the number, the closer the position is to the midline. [6]

Filter and amplifier circuit

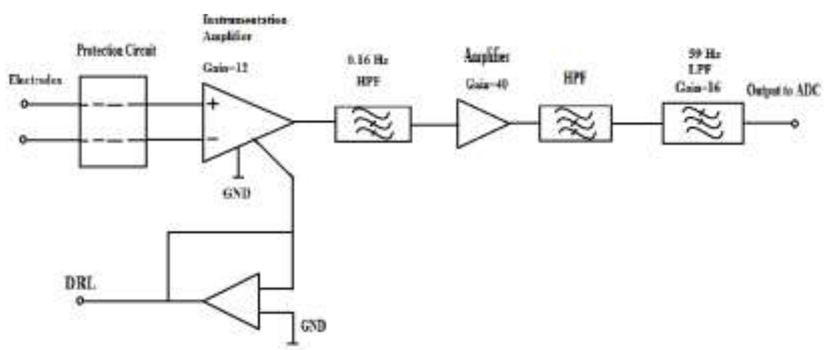

Figure 4: Block diagram of Filter and amplifier circuit

The main circuit to develop in the hardware environment is the filter and amplifier circuit as it need to be designed keeping in mind the low frequency as well as very low amplitude of the brain signal received. The importance of this stage also increases as the further stages consist of developed modules and does not require any designing. The aim of analog circuit is to remove noise signal, provide very high gain and filter out unwanted frequencies. The signal from brain has very low amplitude in order of microvolts and therefore needed to be amplify. Because the signal is faint, it may carry noise especially from 50 Hz AC mains hum. The output from here is given to the TIVA C board ADC for further processing, therefore last three stages of this circuit serves goal of anti-alias filtering.

Different stages of the design are illustrated below.

Protection circuit

The signals picked up from various electrodes must pass through protection circuit first. This stage serves two purposes. It provides ElectroStatic Discharge (ESD) protection to following circuit and protects user from failing circuitry. The design is made up from

Instrumentation Amplifier

This amplifier is made up from INA114P IC which is general purpose and very accurate amplifier. Here it is put to obtain gain of 12.

DRL (Driven Right Leg)

The ground electrode is connected on DRL terminal. The DRL name has its own history. The driver circuit is and was used in ECG meters for measuring heart activities. During process, the DRL terminal is attached to right leg of subject, as far away from heart as possible. The common mode signal is trapped from above amplifier stage and fed to DRL circuit in order to remove 50/60 Hz AC mains hums from DC power supply.

High Pass Filter

Due to the material of electrode e.g. polarizable gold or steel, the charge can get accumulated on the surface of electrode generating several DC mV. If this DC voltage gets amplified, the later stage output will be saturated to +ve or –ve Vcc voltage, which is completely undesirable. Therefore single pole high pass filter having cut-off frequency 0.16 Hz is put after instrumentation amplifier.

Amplifier

After HPF, amplifier made up from TLC277 is put to obtain gain of 40. TLC277 is precise dual OP AMP IC.

HPF stages

The DC offset introduced by previous stages is to be removed before it may cause clipping of signals in later stages. Here, 2 simple high pass filter stages just remove DC part from the signal.

Low Pass Filter

It is 'Besselworth' 3rd order low pass filter having cut-off frequency of 59 Hz. The name 'Besselworth' is not a standard name but it is as to show the blend of Bessel and Butterworth filter. This filter follows group delay of Bessel as it gives constant propagation delay across the input frequency spectrum. Therefore unlike other filter, Bessel doesn't give overshoot in time domain if given square wave as input. The LPF adopts amplitude response of Butterworth as it ensures maximally flat response and then sharper cut-off response than Bessel.

The antialiasing process allows sampling rate for ADC of 256 Hz or 512 Hz for most purposes. For higher accuracy, high sampling rate is preferable.

The overall gain of the analog circuit is 12x40x16=7680. Thus, a 512 uV Vpp signal from brain will give measurable output of 3.9 V Vpp.

As per above mentioned explanation and specification of the filter and amplifier circuit, the complete circuit is designed of 3 stage amplifier and design of those stages are as follows

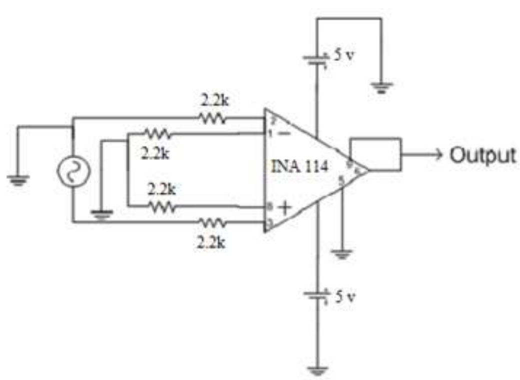

Figure 5: Stage 1 filter and amplifier design

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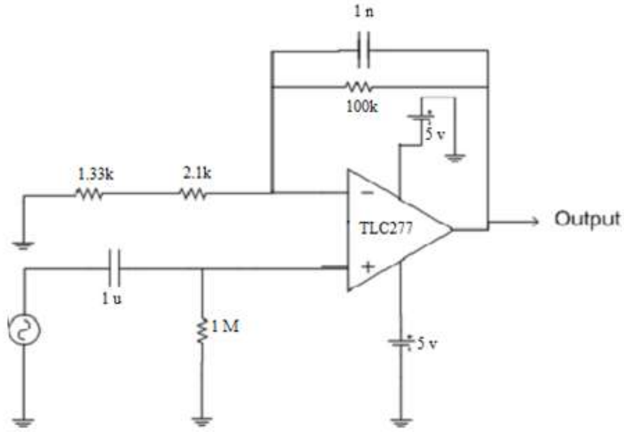

Figure 6: Stage 2 filter and amplifier design

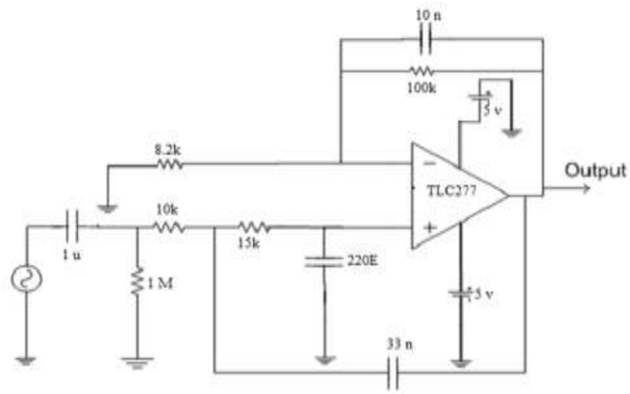

Figure 7: Stage 3 filter and amplifier design

Other Hardware Modules

After the signals have been filtered in the range of 12-59 Hz and obtained amplification of near 60 dB to bring the signals to volts level, the next task in processing is to convert the analog signal to digital domain and for that the signal is given as an input to Tiva C series board TM4C1294 because it has an inbuilt ADC of 12 bit precision and also provide functions of a microcontroller with TM4C1294NCPDTI which is a 32 bit ARM- cortex M4 microcontroller with 120 MHz operation frequency. Apart from this Tiva board also has a 40 pin interfaces which help interfacing booster pack so that functionality of IoT can be added.

The signal after been processed and been able to know what functions need to be performed this information need to be uploaded on the cloud so that one can control devices and perform desired task from far away location. For this CC3100 booster pack is used. Also because CC3100 provides easy connection, security, cloud support and compatibility with Texas Instruments microcontroller, it becomes a good option for providing internet solutions.

The information uploaded on the cloud need to be retrieved at the receiver end so that desired work can be done. For this a CPU based microcontroller is required which not only fetches the information from cloud but also controls the device. BeagleBone Black, which is a low cost, single chip computer, can be best suitable for this application. Beaglebone Black consists of Sitara AM3358 ARM cortex-A8 processor with inbuilt Debian GNU/Linux system. BBB is compatible with software like Ubuntu, Android, Debian, Cloud9 IDE. Also with 46 pin expansion header, other functionality such as VGA, LCD, motor control, battery power can also be added.

This completes the discussion on the hardware requirements of developing a BMI module with added functionality of IoT. Controlling hardware requires the use of software and which software are required here are discussed in next section.

SOFTWARE ENVIRONMENT

Hardware modules discussed in the previous sections consists of a circuit board for filtering and amplifying purpose, Tiva C series board for ADC and microcontroller purpose, CC3100 booster pack for providing internet solutions and BeagleBone Black at receiver side for controlling device. Among all this except filtering amplifying circuit requires to be controlled by software. In this section some software are discussed which are utilized in controlling the above mentioned hardware modules and developing the complete system of BMI. Software used are:

- TINA
- EAGLE
- Energia
- Temboo
- Matlab supported EEG-Lab

TINA

TINA stands for Toolkit for Interactive Network analysis developed by Texas Instruments and DesignSoft Inc. for providing engineers and designers a tool to easily design and implements any circuit. It is a powerful circuit simulator as well as PCB design software package used for designing, testing and verifying analog, mixed circuit simulations and digital and switched mode power supply circuits.

EAGLE

Eagle is a short-form for Easily Applicable Graphical Layout Editor developed by CadSoft Computer Company providing features like electronic design automation with schematic capture editor, auto-router and computer aided manufacturing, PCB layout and bill of materials tool. After designing and testing a circuit, the next step is to prepare its PCB and for that its layout need to be prepared. EAGLE provides this application to designers and engineers and has established itself as an important tool in PCB manufacturing.

ENERGIA

The TIVA C series board used need to be operated by some software platform. Texas Instruments have developed a platform based on Wiring and Arduino framework called Energia.

Energia is an open source and community driven Integrated Development Environment (IDE) and software framework. Energia is an intuitive IDE that is based on popular and easy to use processing IDE. Along with this Energia is simple and also supports robust framework of intuitive APIs and many libraries for programming any microcontroller. Languages that are supported by Energia are in line C, assembly and driver library based code.

Energia have a very wide family of MCU in which it is used. It has the advantage of all in-one software for editing, compiling and flashing code providing seamless compatibility between MSP, TM4C, CC3100 and other devices. Apart from this Energia has an integrated serial monitor to communicate with the Launchpad serially. It has built-in serial monitor which enable bi-directional communication with the Launchpad at various Baud rates. Energia also provide functionality of multi-tasking as we can open multiple sketches at the same time. Also if some additional functionality is required Energia project can be easily migrated to other IDEs such as Code Composer Studio v6 thus allowing developers to take advantage of the Launchpad kit's on board debugger.

TEMBOO

Temboo is cloud based code virtualization platform that automatically generates production ready code in various programming languages for software and hardware developers. Temboo is not new framework or language but just a library of programing processes that helps to enhance the code and reduce code development time. Temboo has structured code that can be generated on Temboo's official website which let us copy and paste it on Integrated Development Environment (IDE). Using Temboo, we can write a small code which calls a choreo, triggering whole complicated process of interconnecting and managing communication protocols. Choreo stands for choreography which are smart code snippets that can call APIs, perform authentication process, stream data, send email or messages, perform encryption and update database. Temboo contains various choreos that manage API interactions, work with databases, perform code utility functions, and much more.

MATLAB supported EEG-Lab

EEGLAB is an interactive toolbox provided by MATLAB for processing data which is continuous in nature or event related EEG, MEG or any other electrophysiological data. It has features like independent component analysis (ICA), time and frequency analysis (TFA), artifact rejection, statistics related to the event and many other useful modes of visualization of average and single trial data. This tool provides with lot many methods for visualizing and modelling brain dynamics at individual level EEGLAB 'datasets' as well as across collection of datasets brought at one place in an EEGLAB 'studyset'. EEGLAB also offers wide range of structured programming for storing, manipulating, visualizing and measuring event related EEG data.

RESULTS AND DISCUSSION

In above sections, a system is proposed for BMI and in this section the results obtained by testing the system is discussed. The system is developed to detect the eye blink of the subject and controlling a LED on/off depending on the eye blink. The circuit for filtering and amplifying as discussed in section 'Hardware Environment' is tested and simulated in TINA software and following are its results:

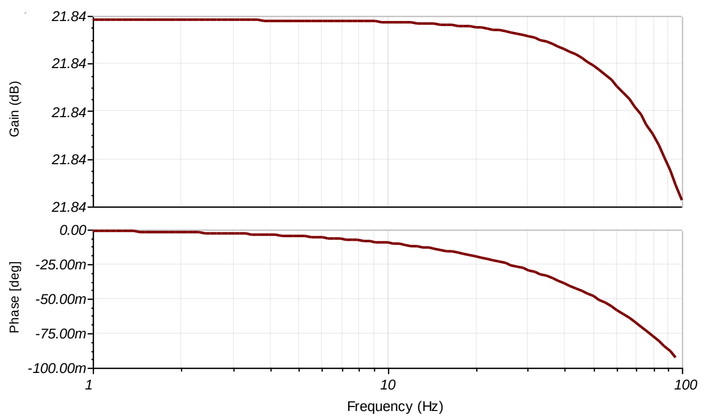

Figure 8: AC analysis of stage 1 of filter and amplifier circuit

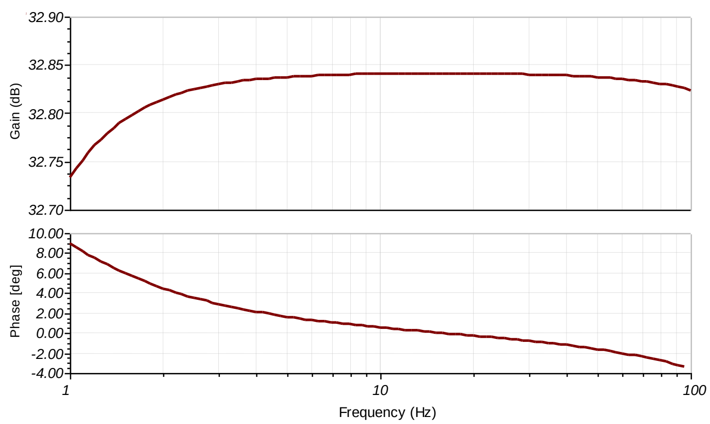

Figure 9: AC analysis of stage 2 of filter and amplifier circuit

ISSN: 2277-9655
Impact Factor: 4.116

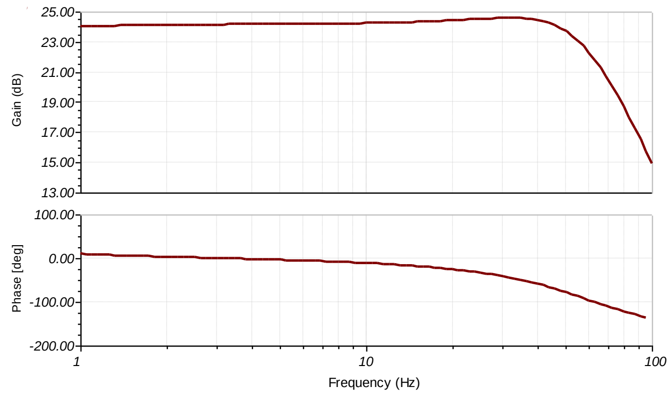

Figure 10: AC analysis of stage 3 of filter and amplifier circuit

Figure 8,9,10 shows the simulation results of the 3 stages of filter and amplifier circuit and all stages provides a gain of 21.84 dB, 32.85 dB and 24 dB respectively thus converting a signal with as low amplitude as microvolts to the level of volts and also the unwanted frequency after 59 Hz is removed.

Figure 11 shows the output when the system is tested on a subject. To make sure that the board is working, on-board square wave generator of amplitude in range of microvolts is designed and its output is fed as an input to filter and amplifier circuit and as a result we obtain square wave as an output. The small spikes seen in between the square wave is the indication that the eye blink is detected.

Figure 11: Testing of BMI system

The waveform as observed on CRO depicts that whenever subject blinks his eyes a peak is detected between the square wave signals. This change is then processed by the ADC of Tiva C series board TM4C1294 and corresponding digital value is generated which is then analysed to perform any application. So once a proper and detectable signal is obtained next step is to feed the output to ADC and perform processing as per desired function. Figure 12 shows the other half of the setup indicating interfacing with ADC and controlling the on-board LED of Tiva board.

Figure 12: Interfacing with ADC and on-board LED control of Tiva board

The developed system was not only tested on just 1 subject but was tested on 15 subjects with 5 in each age groups of 1) 15-20 years 2) 20-30 years and 3) 30-45 years, to test is there any change in the signal level from skull of different age groups and the result depicts that there is no significant change with the accuracy ranging in 94%-96%. X axis depicts the different age groups on which the system is tested and Y axis depicts the number of times eye blinked and number of times eye blink detected.

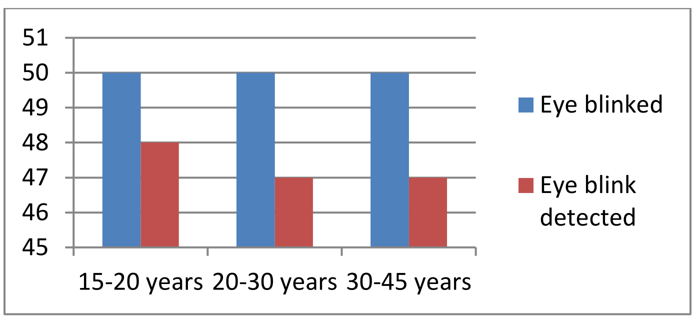

Chart 1: Comparisons of eye blink detection of different age groups

Further the system was also tested on subjects with bald skull and with hairy skull and the results show that the system shows a better response in case of bald skull as compared to hairy skull as the electrodes can be easily and properly fitted to skull without any interference with hair but the response with hairy skull is also not that demeaning. In this case the accuracy ranges from 98% in case of bald skull to 80% in case of hairy skull

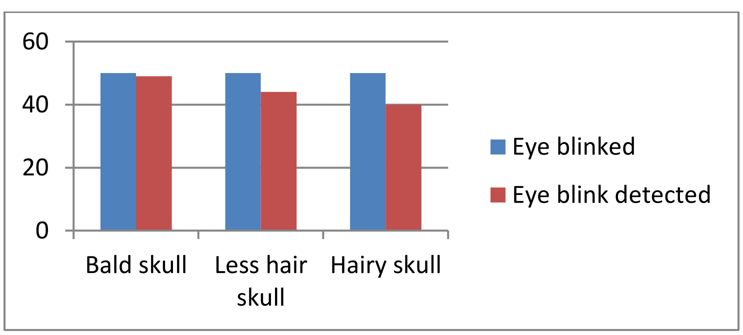

Chart 2: Comparison of system on different types of skull

CONCLUSION

BMI is a system which has been in use in medical industry since ages to cater to the needs of brain dead people but now due to the lower components cost and other technologies developed, BMI is been developed in such a way that it can be used in other fields as in for gaming purpose or for making life of disable people a little easier. Here an attempt is made to develop such a system at low cost with the high accuracy along with added functionality of IoT. Further developing the same system can be used to control devices of whole house and can take home automation to other level of success.

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