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Brain Controlled LED System using EEG Signals

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***Abstract*—Brain Computer Interface (BCI) systems allow a human brain to interact directly with external devices. This paper presents a brain-controlled device system based on the processing of Electroencephalography (EEG) signals through the use of an embedded microcontroller platform. The EEG signals in the proposed system are obtained with scalp electrodes and amplified with a bio-amplifier module. Filtering is then used to eliminate noise and power line interference on the acquired signals, with an analysis of the Fast Fourier Transform (FFT) to obtain frequency domain information of significant EEG bands of Delta, Theta, Alpha, Beta, and Gamma. The level of attention of the user is estimated by the analysis of the relative power of Beta frequency band that is usually related to focused mental activity. In the event that the level of attention detected surpasses a predefined threshold, the system switches on an external device via a relay interface, and a reduced attention level switches the device off. I2C-based real-time monitoring of the system is also shown with an LCD interface. The given prototype is a good example of a successful application of the EEG-based human-machine interaction with the assistance of the low-cost hardware and embedded signal processing. These systems can find their future in assistive technologies of physically challenged persons, automation of smart home systems and systems of monitoring cerebral states.**

***Index Terms*—Brain–Computer Interface, EEG Signal Processing, Fast Fourier Transform, Embedded Microcontroller, Human–Machine Interaction.**

I. Introduction

The technology of Brain-Computer Interface (BCI) [4] allows communicating directly with the human brain and with external devices [2]. Electroencephalography (EEG) is one of the common methods of acquiring brain signals because it is non-invasive and can be used to monitor in real-time [5]. EEG signals are electrical movements of the brain and they have a great amount of information concerning cognitive functions like attention, relaxation and workload of the brain [1]. With the help of the analysis of these signals, one can create the systems according to which the user can regulate external devices with the help of his/her brain activity.

The recent developments in embedded systems and signal processing have enabled one to develop compact and low-cost BCI-based control systems [3]. These systems are capable of considerable potential in the assistive technologies, especially among the people who are physically challenged and who might experience difficulties in communicating with external electrical devices. Moreover, brain-controlled systems could also be used in the application of smart environments, human-machines interactions, and cognitive state monitors [6].

This paper will provide a system of brain-controlled devices, which will be built on the principle of an embedded microcontroller platform accompanied with an EEG signal processing system. The scalp electrodes record the EEG signals in the proposed system and amplify them to the bio-amplifier module. Filtering techniques are then done to process the amplified signals to eliminate noise and interference. FFT algorithm is used to get frequency domain components of the EEG signal which enables the system to analyze various brainwave bands including Delta, Theta, Alpha, Beta and Gamma [5]. The level of attention is given by examining the power of the Beta frequency band which is usually related to an attentive mental activity of the user.

Depending on the level of identified attention, a system makes an external electrical device respond in a relay interface. When the attention level is more than a certain set point, the device is turned on, and as the attention level goes low, the device is switched off. The system also has an LCD display that gives real-time feedback of the current state of attention.

The presented prototype shows a cheaper and feasible application of EEG based human-machine interaction with embedded hardware and digital signal processing methods. These systems may play a base in the future advancement of assistive control systems, smart automation of the home, and interactive systems that are controlled by the brain.

II. Methodology

A. Problem Formulation

The objective of this work is to develop a brain-controlled device which will be able to monitor the level of attention of the user as a result of EEG signals and use it to operate an

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external electrical device. The stated system is based on the examination of the frequency range of Beta (13-30 Hz) that is usually linked to concentration and active mental activity [1]. The system then determines the relative power of the Beta frequency band to determine the level of attention of the user. Once the level of attention is higher than a predefined threshold, then the system triggers an output device, and a low level of attention causes the device to be switched off.

B. System Architecture

This system consists of four main stages: EEG signal acquisition, signal preprocessing, feature extraction, and device control.

1) EEG Signal Acquisition: Electrodes placed on scalp records the brain signals which are amplified by a bio-amplifier module [4]. The resulting increased analog signal is fed on the analog input pin of the microcontroller - Arduino UNO R4 Minima to be processed.

2) Signal Preprocessing: EEG is vulnerable to power line interference and noise [5]. Hence a notch filter is used to eliminate 50 Hz noise of the power line and then a bandpass filter to save useful EEG frequency bands.

3) Feature Extraction: The Fast Fourier Transform (FFT) algorithm is used to transform the signal, which has been filtered, to the frequency domain. This allows the extraction of power values that are of various frequencies of EEG such as Delta, Theta, Alpha, Beta and Gamma.

4) Device Control: To realize the level of attention, the relative power of the Beta band is employed. On exceeding a predetermined threshold, the attention computed value is compared to a pre-programmed threshold which activates a relay module to switch an external LED bulb.

C. EEG Frequency Bands

EEG signals are grouped into the various frequency bands which depict different mental states. These bands are defined as follows:

- Delta (0.5-4 Hz): This is related to deep sleep.
- Theta (4-8 Hz): Theta is associated with drowsiness and relaxation.
- Alpha (8-13Hz): Reflects states of calmness and relaxation.
- Beta (13-30 Hz): Level is related to concentration and alertness.
- Gamma (30-45 Hz): This kind of frequency is associated with high-order cognitive processing.

The Beta band is mainly applied to detect the level of attention in this work [1].

D. Attention Level Calculation

The relative power of the Beta band to the total signal power of the EEGs is estimated to determine the level of attention [1].The Beta percentage is calculated as:

$$\text{Beta Percentage} = \frac{P_\beta}{P_{total}} \times 100 \quad (1)$$

P_β = Power of the Beta frequency band

P_{total} = Total power of all EEG frequency bands

When the percentage of the Beta calculated is higher than a pre-defined threshold, the system will recognise the state to be high attention and when it is lower, it will recognise the state to be low attention.

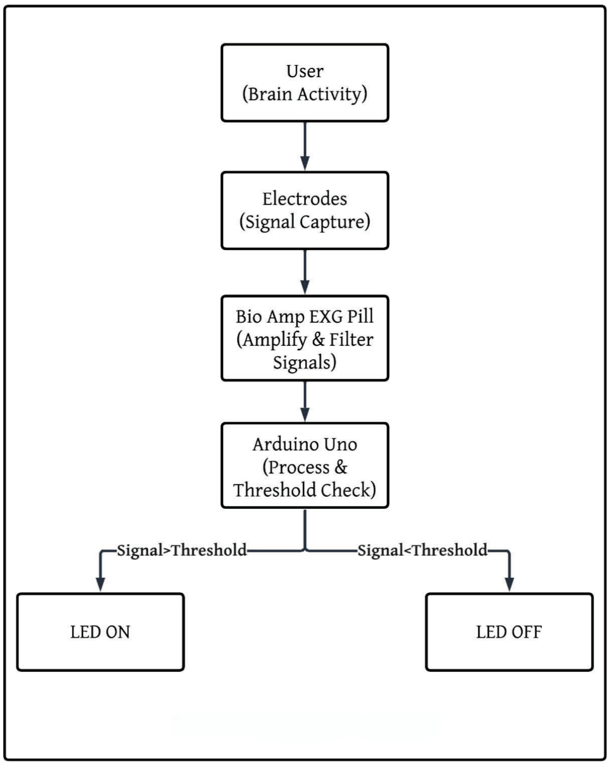

Fig. 1. Block Diagram

III. Implementation

The proposed system was implemented using a combination of EEG signal acquisition hardware and an embedded processing platform. This system integrates signal acquisition, signal processing, attention detection, and device control modules to achieve real-time brain-based device operation.

A. Hardware Setup

The hardware implementation will involve EEG electrodes, a bio-amplifier module, a Arduino Uno R4 Minima microcontroller, I2C based LCD display , and a relay module to control the device. EEG electrodes are attached to the head to record brain signals produced by the neural activity [9]. EEG signals are measured in microvolt range, so the captured signals are amplified with a bio-amplifier and the signal is sent to the microcontroller. Amplified analog EEG signal is fed to the analog input pin on the Arduino board which continually reads the signal at a specified rate. A 16×2 LCD display is connected through the I2C interface to provide real-time feedback on the system status and detected attention level. A relay module is then attached to a digital output pin of the microcontroller

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permiting the system to regulate an external LED bulb in a safe manner.

B. Software Implementation

The system software was developed using the Arduino programming environment. The program is responsible for signal acquisition, preprocessing, frequency analysis, attention detection and output control. The signal samples of the EEG are recorded and stored on a buffer to be processed. The use of digital filtering methods helps to decrease the noise as well as the interference by power lines whereby only the frequencies related to brain signals are preserved. Once preprocessed, Fast Fourier Transform (FFT) algorithm is used to transform the signal of the time domain to the frequency domain [5]. The energy distribution of various frequency bands of the EEG is analyzed with the help of the power spectrum acquired by the FFT. According to the system, these values allow identifying the level of attention of the user based on the activity of Beta bands.

C. Device Control Integration

After the determination of the level of attention, the microcontroller sends a control signal to the relay module. When the level of attention measured is greater than the predetermined threshold, the relay is triggered and the current is passed through the device connected to it and it switches on. If the attention level falls below the threshold, the relay is deactivated, turning the device off. The system also keeps the LCD screen up to date to show the current state of attention so that the user can also see the effect of the system in action. This application shows how the EEG signal processing can be functionally integrated with the embedded hardware to get brain controlled operation of devices.

IV. Results and Discussion

The brain-controlled device system was successfully implemented and tested to analyze whether the system can identify user attention based on the EEG signals and activate an external device. The real-time EEG signals obtained using scalp electrodes attached to the bio-amplifier module were used to test the system. The embedded microcontroller in the instrumentation obtained the frequency band information by processing the amplified signals and then it was used to determine the attention state of the user.

During experimentation, the system kept track of the EEG signal and estimated the relative power of the Beta band with the help of Fast Fourier Transform (FFT). As Beta waves typically correlate with intense mental activity [1], the system used the relative power of the Beta band as a measure of the level of attention. When the computed Beta was greater than the predefined threshold, the high attention state was recognized by the system and the relay module was switched on, which caused the LED bulb to turn on. Conversely, a low concentration state was detected by the system when the Beta power was less than the threshold and this resulted in deactivation of the relay that would switch off the device. The outcomes showed that the system could react to the changes in the level of attention of the user in real time [8]. LCD display gave a continuous feedback and displayed a detected attention status as “Attention HIGH” or “Attention LOW” and this gave the users the opportunity to examine how the system was responding to the brain activity. The implemented control mechanism was effective as the relay module was able to control the external object according to the attention state.

However, some variations in the EEG signal where observed due to external noise, electrode position and slight body motion. Despite these challenges, the interference was minimized and the stability of the signals enhanced through the filtering methods used in the system. These findings show that the suggested system will be capable of converting EEG-based signals of attention into control instructions used by external devices. This proves that low-cost embedded systems can be used to make useful Brain-Computer Interface (BCI) applications in assistive technologies and smart environments [4].

V. Conclusion and Future Work

The paper has introduced the design and implementation of a brain-controlled device system on the basis of EEG signal processing with an embedded microcontroller platform. The system records signals of the brain using scalp electrodes, boosts them with the help of a bio-amplifier module and then processes the signals to extract frequency-domain features using Fast Fourier Transform (FFT). The system measures the relative power of the Beta frequency band and uses this to determine the level of attention of the user and this is used to operate an external device via a relay interface.

The prototype built was able to identify changes in user attention and convert them into control signals to an LED bulb connected to the prototype. A real-time feedback based on the LCD display was also a part of the system, and the users could keep track of their attention status. The findings suggest that it is possible to successfully utilize low-cost embedded platforms to deploy simple Brain-Computer Interface (BCI) systems to device control systems.

Although the system demonstrated reliable functionality, further development of the work can involve the use of wireless communication to control devices remotely, improving signal acquisition with advanced EEG sensors, and the use of machine learning to develop a more precise set of cognitive states. It can also be extended to manage several devices and other assistive technologies such as brain-controlled wheelchairs, smart home systems, and computer interfaces, thereby increasing its potential use in both assistive and human-machine interaction technologies [2].

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