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EEG-Based Smart Control System for Managing Multiple Living Room Devices via Eye Blinking

Yasir M.Abdal[1]
[1]Technical Engineering College for Computer and AI /Mosul, Northern Technical University, Iraq
yasir.m.abdal@ntu.edu.iq.

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Corresponding author:
Name: Yasir M.Abdal
Affiliation : NTU
Email: yasir.m.abdal@ntu.edu.iq

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Brain Link Headset,
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ABSTRACT

In recent years, technology utilizing electroencephalography (EEG) for the control of electrical devices has advanced significantly. Today, anyone may monitor their own brain patterns and waves outside of clinics and medical laboratories. Moreover, in addition to evaluating brain signals, these signals may be utilized to operate daily electronic devices, also referred to as the brain-computer interface (BCI). The suggested system can effectively aid older persons and others with disabilities who experience speech and mobility suffering, enabling them to remain at home safely and comfortably. Ten participants between the ages of 25 and 45 participated in the study. The EEG headset used has a sensor that senses human attention, meditation, and eye-blinking. This paper presents an EEG-based home automation system that uses eye-blink detection to control multiple living room devices, achieving an accuracy between 86.21% and 92.86%. These findings enhance the brain-computer interface and also highlight the potential for improving its immobility.

1. Introduction

Home care is a form of long-term assistance that is provided to assist disabled individuals in their daily activities. Living with a disability is a challenging experience for an individual. Families should prioritize the care of disabled individuals. But in order to maintain a standard of living in our society, it is impossible for anyone to remain in constant contact with these individuals who are disabled. It is difficult to comprehend the process of providing special attention to a disabled individual [1]. A huge number of individuals have seen an improvement in their quality of life as a result of home automation systems. These systems have made it possible for users to control various household equipment, such as fans, light bulbs, TVs, and thermostats. Unfortunately, there are some people who are unable to benefit from the numerous technical improvements that have been made. There are certain people who are affected by speech and motion-related ailments, such as aphasia, aphonia, arthritis, hemiplegia, palsy, and paraplegia, in addition to illnesses that are associated with motor neurons [2]. Individuals who suffer from speech and motion-related problems may now be able to take advantage of advancements in home automation technology and improve their overall quality of life by utilizing (BCI). The (BCI) is a technique that allows for communication with a computer through the use of electroencephalogram (EEG) signals [3]. EEG is considered a compelling focal point in the debate on noninvasive methods for assessing the cognitive state of the human brain [4]. Micro voltage variations throughout the scalp are estimated by EEG due to currents caused by ionic concentration inside brain neurons [5]. Through electrical signals, nerve cells communicate and transmit information about the action potential. The impressions of the continuous dynamics of the brain are represented by these vacillation signals, which also portray the behavior of the mind. These electrical signals, which carry brain information, have a clear pattern of size and shape that shows how smart, emotional, or thinking the person is [6]. Control and communication between the human brain and physical equipment are made easier via brain-computer interfaces. Delta, theta, alpha, beta, and gamma waves are the most common types of waves that are used to classify brain signals [7]. To capture electrical signals produced by the human brain, eight to sixteen pairs of electrodes were placed on the scalp. The electrical impulses pass a particular channel of the EEG recording through a pair of cables attached to the electrodes [8]. Numerous (BCI) systems have been sophisticated in order to offer solutions to the aforementioned problems. These systems create a direct neural link between the brain and other physical devices. This lets people talk to and control these devices using different brain activity patterns. The noninvasive technique is more economical than the invasive approach, causes minimum annoyance, and is extremely conclusive. An EEG, for example, uses electrodes applied to the scalp to measure and record brain wave patterns. After the wave patterns are obtained, the signals are sent to a computer. Some noninvasive commercial EEG equipment is shown in Figure 1 [9].

The suggested system enables users to manage their home appliances using an Arduino Mega Board. One tool for extracting brain data is the Brainlink Lite EEG Headset. To turn the appliances on and off, the Eyeblink level is utilized, which provides a solution that is ideal for persons who are impaired or old. During the experiment, the user's brain activity and the system's responses are described, as well as the system's performance and the recorded EEG data. In a variety of biomedical and home automation applications, the designed technology is affordable and simple to use.

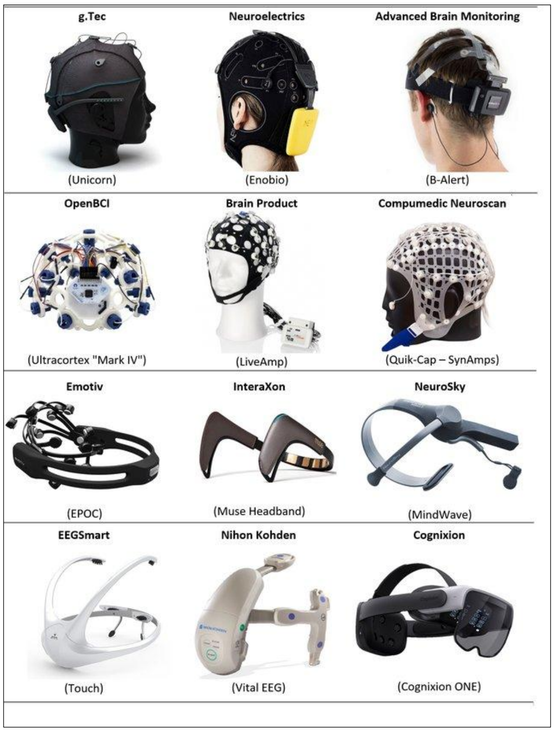


Fig. 1. Illustrations of Commercially Available Noninvasive EEG Devices Utilizing BCI Technology [9].

2. Related Works

It is discussed in this section how (BCI) technology that is based on electroencephalograms (EEG) might be utilized in home automation systems to make it possible for those with impairments to operate them. The authors in [10] presented a home security system utilizing an EEG-based BCI to control a door and lighting. The individual with a disability can controls the door and the LED using brain waves recognized by the EMOTIV Insight™ headset. The system in [11] proposed efficiently controls multi-device performance by classifying attention signals and demonstrates the performance of EEG-based control systems. The process begins with an EEG recording obtained from (FP1) for experience testing. Data are processed using MATLAB software. The attention level computed is a measure for controlling smart electronic devices in the house. The SSVEP method [12] offers Wi-Fi-based smart home automation, which controls the fan speed and light intensity depending on a person's physiological state without needing an outside stimulus. The technology aims to allow people with physical constraints to control electronics merely by will. To turn neural activity into testable instructions is a remarkable advance in itself in this field. EEG signals have been selected extract some features and those have been used to control devices such as electric lights. The system has successfully proven to activate and deactivate devices upon the user’s discretion [13]. As shown in the system described by [14], other experiments show a prototype that can be used to handle home appliances like an LED light and a fan. A brain headset, a laptop, an ESP32 microprocessor, an LED, and a fan were what they used. They used Bluetooth to connect the headset to the computer, which in turn was linked to the microcontroller. The fan and LED were attached to the microprocessor. In this way, they came up with a way for a healthy, handicapped, or paralyzed user's electric mind wave to control a fan and an LED. The researchers in [15] suggested using an EEG-based HMI system to help people who are tetraplegic or quadriplegic handle a motorized wheelchair with their minds, allowing them to move around easily and independently. This work [16] seeks to establish an emotion dataset derived from computer games, utilizing an innovative approach for gathering brain signals. Furthermore, it aims to assess the effectiveness of the portable EEG equipment and contrast its results with those of traditional EEG devices. The 14-channel EMOTIV EPOC+ is a wearable and portable EEG device that was used to gather EEG data from 28 distinct people. There are many applications that use brain link headsets to help people with disabilities meet their needs. In [17], the authors developed a brain-controlled electric wheelchair designed for quadriplegic patients. On the other hand, researchers introduced BRIEDGE as a comprehensive multi-brain, multi-robot interaction system that utilizes an EEG-adaptive neural network and an encoding-decoding communication architecture [18]. Additionally, this study [19] investigates the viability of controlling robotic arms built into autonomous wheelchairs with inexpensive commercial EEG headsets like Neurosky and Brainlink. In order to guarantee accurate and flexible control, a neural network was integrated, which analyzes these variables in real time and ensures the robotic arm reacts as the user intended. While the existing BCI systems enable device control, few focus exclusively on eye blink detection for multi-device management. Table 1 compares prior EEG-based systems with proposed work.

Table 1. compares prior EEG-based systems with proposed work.

Ref.	Year	EEG Headset	Number of Channels	Wire/ wireless	Price/ Ebay web	Device Automation	Subjects	Eye blink used?	accuracy
[10]	2024	EMOTIV Insight	5	wireless	350$	Door, Led	20	no	70.16%
[11]	2023	-	1	wire	-	Fan, Light, TV, air conditioner	-	no	-
[15]	2022	NeuroSky	1	wireless	130$	wheelchair	5	yes	-
[16]	2020	EMOTIV EPOC+	14	wireless	2000$	-	28	no	-
[17]	2023	Brainlink	1	wireless	220$	wheelchair	-	yes	91%
[19]	2024	Neurosky, Brainlink	1, 1	wireless	130$, 220$	Robotic Arms, Wheelchairs	-	no	-
[23]	2023	Brainlink	1	wireless	220$	lights, fans, alarm, TVs.	-	yes	-
proposed work	-	Brainlink	1	wireless	220$	lights, fans, music, TVs.	10	yes	89.53%

3. Methodology

3.1 Hardware Architecture

Figure 2 shows the design of the proposed brain-computer interface (BCI) system. This system was designed to control the functionality of indoor devices by utilizing EEG signals.

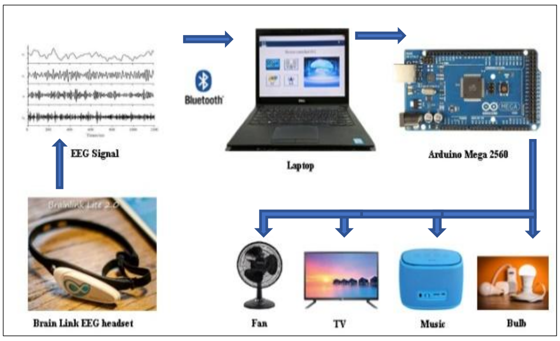


Fig. 2. The Proposed Brain-Computer Interface System

3.1.1 EEG Data Acquisition

To record brain signals, the device uses a wireless headgear called the Brain Link EEG headset (shown in Figure 3). This headband provides a useful and non-invasive way to record brain waves, unlike conventional EEG equipment. However, because they only gather signals from a certain region of the user's brain, they have some limits with regard to resolution and spatial precision. But these headbands' simplicity of usage eliminates the need for cumbersome equipment or caps with several electrodes, favoring the user's comfort and mobility [20].

Fig. 3. Brain Link Headset [20].

Recent research has examined the use of Brainlink Lite, including emotional state recognition, cognitive load analysis, and attention tracking this research establishes the suitability of the head cover to capture and process EEG data for various applications emphasis. Additionally, the Bluetooth connectivity of the headset assures seamless transfer of data to the user interface, which is a key feature for real-time consumption systems the function [21].

3.1.2 Integration into The Proposed System

The Brainlink Lite EEG Headset is an integral part of the proposed appliance control system, allowing users to control devices with mental signals. The integration process is described as follows:

- Connection: First, establish a Bluetooth connection between the Brainlink Lite headphones and the PC. The laptop serves as a bridge for communication between the headset and the Arduino microcontroller that manages the connected devices.
- Calibration: The Brainlink Lite requires calibration software (ThinkGear AM (TGAM) for optimal performance. Users find this gadget more convenient because its 0.3 mm dry electrode design does not require the application of conductive gel. Additionally, baseline measurements of attention and eye blink strength are taken as reference points for future data analysis.
- Data acquisition: The Brainlink Lite headset with the ThinkGear chip facts electric impulses generated through the brain through its electrodes. The brain signals were processed by this device using a ThinkGear AM (TGAM) module (NeuroSky, Inc., Silicon Valley, United States). This module employed its eSense biometric algorithms to measure the brain's attention and relaxation in order to determine whether it was focused or relaxed [22]. Brainlink was used to record the subject's current level of attention, Raw data, and eye blinking strength. Raw EEG data, detected by low tiers of rhythmic pastime, are amplified and digitized before being transmitted through Bluetooth to a related computer for similar processing
- Signal Processing: After receiving the raw EEG data, the computer uses the ThinkGear module to interpret the signal and extract relevant information This processing phase involves several necessary steps:

1. Preprocessing: The raw signals are filtered to remove noise and artifacts, thus assuring data clarity and reliability for further analysis.

2. Feature Extraction: ThinkGear technology uses to process and quantitatively segment EEG input. EEG processing methods are closed-source and not accessible to the public. Output data consist of the raw EEG signal, eSense Attention, and Meditation value, expressed as integers from 0 to 100. Blink Strength is represented as integers from 0 to 255. In this study, the eye blink strength

obtained from the raw EEG signal is used as a control signal for device control.

3.1.3 Computer System

A computer system is essential for the proposed brain-computer interface (BCI) because it uses expert software to interpret simple EEG signals transmitted via Bluetooth. In data acquisition, the activity requires EEG. The symbols contain and identify the necessary elements that can be converted into execution commands. These commands are configured to interact with multiple interconnected devices, allowing users to control their immediate environment with mental input.

Graphical User Interfaces (GUIs) are designed to improve the user experience and enable intuitive interactions. These interfaces allow users to effortlessly select and manage certain devices within their residence, thus optimizing device management. The GUI design emphasizes user-friendliness, allowing anyone to control the system with minimal training or technical knowledge (instructible). Using visual elements and interactive features in the GUI provides greater accessibility and a more immersive user experience.

3.1.4 Arduino Controller

The Arduino controller acts as an essential microcontroller in the proposed system, which acts as a bridge between the computer environment and the real hardware receiving control commands from the computer through serial connections, and it enables communication with multiple devices through wired connections [18, 19]. The Arduino platform was chosen because of its customizability, user-friendly programming, and wide range of libraries and modules available to facilitate hardware interfaces.

3.1.5 Devices Interfacing

The control devices are connected to a PC using an Arduino microcontroller. The Arduino is connected to the PC using a Universal Asynchronous Receiver-Transmitter (UART) cable, which provides a reliable communication link between the microcontroller and the computer. The system is designed to detect eye blinks and control connected devices. This innovative technology allows users to control their surroundings with simple eye movements, thus providing hands-free interaction.

3.2 The Software Component

The main component of the proposed brain-computer interface (BCI) system is the graphical user interface (GUI), which aims to improve the interaction between humans and connected devices.

Figure 4 shows the main features of the GUI in the proposed framework.

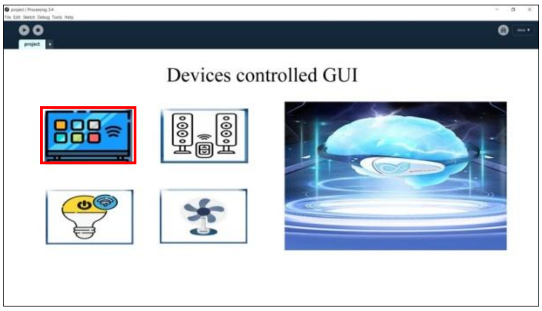


Fig. 4. GUI Design for Device Selection using Eye Blink Detection.

The operation of the system is illustrated in the next step:

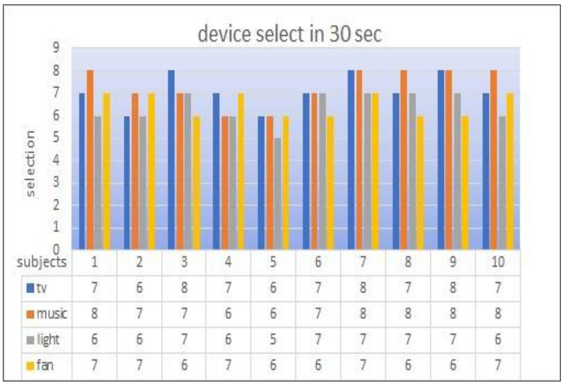
1. Bluetooth Pairing: The Brain Link Lite headset first uses Bluetooth to connect to a personal computer (PC). This wireless connection allows EEG data to be transmitted from the skull to the computer for processing.
2. Program Operation: After recording raw EEG data, the program generates a visual representation in a graphical user interface (GUI). The red rectangle, indicated as a pointer, rotates above the buttons on the interface in sequence (TV, music players, lights and fan), completing a full cycle in about four seconds. This movement acts as a visual sign for the user, indicating the currently selected device.
3. The blink strength value is based on a certain threshold (90 - integer value) in the developed algorithm. This is higher than a normal human blink to distinguish between the user-selected commands and ordinary eye blinks.

4. Results and Analysis

The proposed Brain-Computer Interface (BCI) system was extensively tested to evaluate its performance using the Brainlink Lite EEG Headset. The study included 10 participants between the ages of 25 and 45 to provide diverse consumer samples. Two separate experiments were conducted to evaluate the system's effectiveness: the first focused on the accuracy of button selection, and the second examined the time spent activating the devices and using them in the work.

4.1 First Experiment

In the first experiment, participants were instructed to select an identified button associated with a device such as a television (TV). Four trials (30 seconds each) were conducted to evaluate the system scanning speed and its capability to offer selections in a specific time. The main objective was to determine the ability of each subject to select a specific device in each trial to observe how the system responded to different activities.



subjects	1	2	3	4	5	6	7	8	9	10
■ tv	7	6	8	7	6	7	8	7	8	7
■ music	8	7	7	6	6	7	8	8	8	8
■ light	6	6	7	6	5	7	7	7	7	6
■ fan	7	7	6	7	6	6	7	6	6	7

Fig. 5. Number of Correct Selection Per Trial

The experiment was set up in the following way.

1. Task assignment: Each participant was given an interactive graphic with buttons to control the devices. They were instructed to choose the television button as the first task.
2. Data Collection: Multiple accurate choices were made within 30 seconds. The process was repeated for other devices (music, lights, and fans), enabling the system's performance to be carefully analyzed on all devices.

Figure 5 clearly shows the results of the first test and the capability of each subject to select a specific device in each trial.

4.2 Second Experiment:

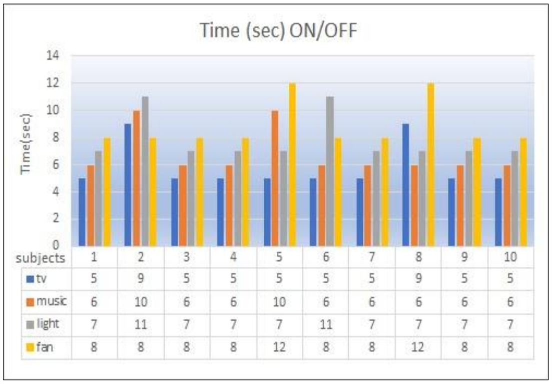
In the second experiment, participants were instructed to switch the devices on and off, starting with the television (TV). The main goal was to count the time used for each trial. Four trials were conducted to evaluate the system. The main objective was to determine the ability of each subject to turn on/off a specific device in each trial to observe how the system responded to different activities.

The experimental procedure was as follows:

1. Task Assignment: Each participant was instructed to turn on and off the television set, and the total time spent on each activity was measured.
2. Data Collection: Subsequent to the original activity, individuals replicated the procedure for the other devices, including the music player, lighting, and fan.

The duration of each on/off action was carefully recorded to provide a thorough review of the system's performance across various devices.

Figure 6 shows the time each subject spent turning ON/OFF devices in each trial. These data are essential to understanding how BCI systems work and perform well in real-world applications.



subjects	1	2	3	4	5	6	7	8	9	10
■ tv	5	9	5	5	5	5	5	9	5	5
■ music	6	10	6	6	10	6	6	6	6	6
■ light	7	11	7	7	7	11	7	7	7	7
■ fan	8	8	8	8	12	8	8	12	8	8

Fig. 6. ON/OFF Execution Time of Device Per Trial

At the end of the two experiments, the selection accuracy varied from 88.75% to 92.86% of the participants in the first experiment, where television and fan devices showed the highest accuracy. In experiment 2, individual contrast appeared when devices were switched on and off, with an accuracy rate of 86.21% up to 90.91%. Figure 7 summarizes the findings and provides a visual representation of accuracy metrics for both tests. Both participants attended both sessions.

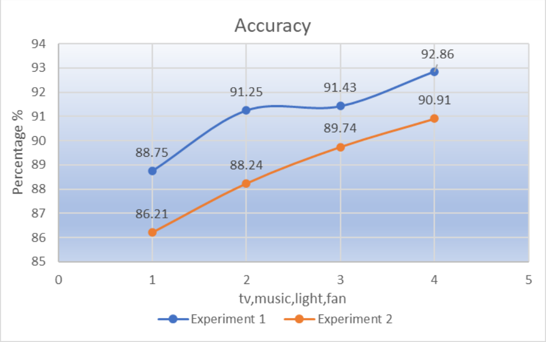


Fig. 7. The Accuracy of Experiments for Ten Participate.

5. Conclusion

The proposed Brain-Computer Interface (BCI) system using the Brainlink Lite EEG Headset shows that it can improve user-device interactions through cognitive education. The proposed BCI system has an easy setup based on blink detection, device control, and high accuracy at a low cost.

Two separate experiments were conducted to evaluate the system's effectiveness, each subject completed four trials. The experiments provided important insights into system performance and improved levels of accuracy in device selection and ON/OFF operation instruction for participants, this achieved an accuracy between 86.21% and 92.86%. The results show that the BCI is a simple and practical alternative for mechanical applications. Future research will focus on upgrading the system design, expanding its functionality to include additional devices, and exploring its use of EEG-based BCIs in real-world applications, e.g. (in healthcare and industrial environments). Future improvements in BCI systems may include the integration of machine learning technology for more accurate results.

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