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A Wireless Lighting System Harnessing MindFlex and Electroencephalographic Signals for a Potential Tool for Individuals with Motor Disabilities

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Abstract*– his article presents a comprehensive study aimed at developing a wireless lighting control system based on Arduino UNO, utilizing the acquisition of brain waves through a NeuroSky chip module. The primary objective of this research is to explore the potential application of this system as a future tool for individuals with motor disabilities. By integrating the Arduino UNO platform with the NeuroSky chip module, the system enables the detection and interpretation of brain signals, facilitating the control of lighting devices. The study incorporates a quantitative and experimental approach, encompassing the design, implementation, and evaluation of the wireless control system. Tests were conducted with fifteen students from UNITEC, San Pedro Sula for analysis purposes to ensure the efficiency, reliability, and compatibility of the lighting system. The findings of this research have the potential to pave the way for future advancements in the field of assistive technology, benefiting individuals with motor disabilities and opening new avenues for inclusive and accessible living environments. Similarly, it aimed to create cutting-edge technology within the country.

***Keywords*-- EEG, Mobility Aids, Neurosky Technology, Mindflex, BCI.**

I. Introduction

Brain activity is primarily characterized by the manifestation of frequencies per second in distinct patterns, referred to as brain oscillations [1]. These oscillations are detected using Electroencephalogram (EEG) technology, a non-invasive method involving electrode placement on the scalp to record cerebral electrical activity. Currently, brain waves are categorized into five types: Alpha, Beta, Delta, Theta, and Gamma [2]. The domain of Brain-Computer Interaction (BCI) has witnessed significant technological advancements. This interface allows direct communication between the brain and electronic devices, such as computers or prosthetics, fostering their integration in recent decades [3].

Motor disabilities include conditions marked by the restriction or absence of motor skills, often resulting from brain trauma, neuromuscular disorders or disorders of the nervous system [4]. These limitations significantly affect an individual's mobility and ability to perform routine activities. Brain-computer interfaces (BCIs) have emerged as a fundamental solution, as they enable people affected by these conditions to regulate external devices by interpreting brain signals, thus overcoming their physical limitations [5]. Previous projects have investigated the application of BCIs in various fields, such as assisted mobility, communication and device manipulation.

Rus¸anu et al. undertook a research endeavor titled "Experimental Model of a Neurosky Mindwave Mobile-Controlled Robotic Hand," with the objective of devising a robotic hand controlled by the second-generation Neurosky Mindwave Mobile headset [6]. This study entailed the capture of EEG signals during deliberate blinking and the development of a LabVIEW application to capture, process, and designate commands for orchestrating movements in the four designated fingers of the robotic hand. The principal aim was to augment the safety and reliability of employing this system for individuals affected by neuromuscular disabilities.

In the market, a myriad of devices serve as Brain-Computer Interfaces (BCIs) in similar projects. Mindflex represents a tabletop gaming and cerebral entertainment apparatus founded upon ThinkGear technology engineered by NeuroSky [7]. Its pioneering brain-computer interaction features have generated interest across diverse age demographics [8]. Mindflex enables direct manipulation of physical entities through cognitive abilities. The signal processing module, an offshoot of NeuroSky's ThinkGear technology, possesses the capability to assess levels of concentration or attention. Auxiliary tools like Mindflex have elevated the realm of BCI interaction, empowering users to command objects, conduct experiments, and engage cognitive faculties [9].

A study conducted in 2022 assessed the preparedness levels of different countries in embracing and advancing sophisticated technologies. These cutting-edge technologies encompassed Ar- tificial Intelligence, Internet of Things, Blockchain technology, nanotechnology, genetic editing, among others. In this context, Brazil led with the highest readiness score of 0.71%, followed by Chile at 0.65%, and Costa Rica at 0.61%. Conversely, Honduras presented a lower readiness score of 0.3%, positioning it among the least equipped nations for adopting these advanced technologies, alongside Haiti, which ranked among the lowest at 0.15% [10].

This inadequacy creates a scenario where individuals afflicted with motor disabilities in Honduras are deprived of the chance to regain a certain level of autonomy by controlling electronic devices within their domestic environment.

Acknowledging this necessity, this study endeavors to enhance the standard of living for Honduran individuals grappling with motor disabilities through the implementation of Brain-Computer Interface technology for household lighting control. This innovative technology holds the promise of offering fresh opportunities and resolutions for those encountering substantial hurdles in their daily lives due to this condition.

II. State of Art

The Brain-Computer Interface (BCI) centers on deciphering neural signals to facilitate the control of external apparatuses, including but not limited to prosthetic devices or mobility aids like wheelchairs. The continuous progression of technology in the realm of cerebral function and Brain-Computer Interface has been a subject of worldwide investigation throughout the years. This investigation delves into an examination of these technological strides aimed at implementing BCI technology into a wireless illumination system.

Table 1 shows that out of the 31 studies conducted, the predominant BCI devices were NeuroSky technology devices, Emotiv Epoc Headset, and another type of devices that accounted for 29.03% that could be employed for BCI technology purposes.

TABLE I
BCI Projects Overview

BCI Device	Projects	Percentage
Neurosky’s BCI Technology	10	32.26%
Emotiv EPOC Headset	5	16.13%
StarstimR32	1	3.23%
Mental Imagery	2	6.45%
Brain Sense Headset	1	3.32%
Muse Headset	1	3.32%
OpenBCI	2	6.45%
Other	9	29.03%
Total	31	100%

Studies such as ’Playing with Robots Using Your Brain’ provide a retrospective view that this brain-computer interface technology is not only used for managing devices such as wheelchairs or home assistance but also for maneuvering other types of devices such as robots [11]. Similarly, in the study conducted by [12], the focus was on controlling a drone. The development of technology for controlling drones through brain waves is an area that is being further explored, offering the opportunity to open new possibilities in drone control with reduced skill requirements.”

III. Methodology

The methodological framework was designed with a quanti- tative approach, aiming to measure and analyze data numerically (Table II). This study was categorized as experimental and cross- sectional, primarily because the researcher directly intervened in the independent variables. While classified as an experimental study, it doesn’t anticipate analyzing each variable at a corre- lational or causal-explanatory level.The sample chosen was non- probabilistic, chosen for its functional suitability for the research objectives, considering constraints related to acquiring available participants within the allocated study timeframe.

For the execution of the research project, both dependent and independent variables were defined. In this case, the indepen- dent variable of this research will be influenced by the selected dependent variables. (Fig. 1)

A. *Techniques and Instruments Applied*

The techniques and instruments applied in the development process of the wireless lighting system for its design, proper per- formance, and statistical analysis included a variety of supporting software and techniques. Among them are:

1) Software Processing: Subjecting the signals to an analysis process to extract relevant information for the research, such as pattern identification, elimination of artifacts present in the signals, and determination of brain activity.

TABLE II
Research Methodology

Approach	Quantitative
Types of Study Types of Design Scope	Cross-sectional Experimental Prospective
Type of Samples	Descriptive Non-probabilistic (Discretionary
Techniques and Instru- ments	Sampling) Hardware / Signal Processing Techniques with Software / Non-parametric Statistical Analysis

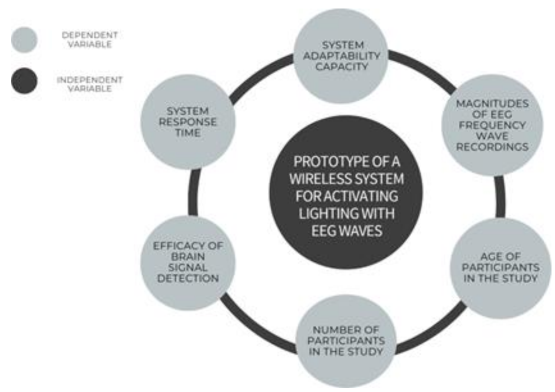

Fig. 1 Dependent Variables and Independent

- Neurosky Chip: Acquiring brain signals represents a funda- mental step in the research, aiming to obtain these signals to be subsequently translated and converted into a command.
- Arduino IDE Paper Margins: Establishing a connection with Arduino to work as the central component to receive, process, and execute the commands obtained from brain signals after being processed.
- Minitab Software: Conducting statistical analysis to vali- date the operational functionality of the Mindflex device compared to the OpenBCI device.
- OpenBCI GUI: Is a graphical interface used to visualize and process data from OpenBCI devices for brain analysis

B. *Materials*

- Mindflex

- Arduino Uno
- Bluetooth Module HC-05
- Bluetooth Module HC-06Mindflex
- Relay Module 5V/10A/1 ChannelMindflex
- Lightbulb

C. Methodology of Study

The research project adopted the V-model methodology (fig. 2) as its study framework. This methodological approach is notable for offering a well-defined and systematic structure for project progression. The guidance articulated in VDI 2206 - A novel directive for the design of mechatronic systems [13] served as the foundation. It recommended executing the process across three distinct stages, each undergoing a validation process, with the ultimate goal of realizing the development of a residential lighting system.

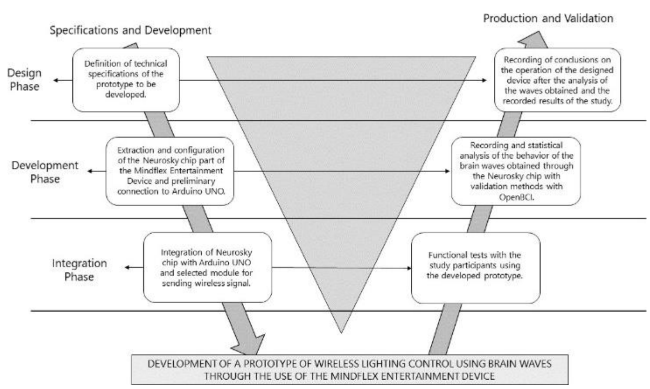

Fig. 2 V-Model Methodology

IV. RESULTS

A. Schematic Design

A schematic design was conducted, emphasizing a meticulous approach to guarantee the holistic functionality of the system (fig. 3). This entailed intricately simulating the interaction and communication among diverse components, specifically concen- trating on their interrelationships and data transmission meth- ods. Through this design process, a precise assessment of the components' communication within the system was achieved. It offered a visual depiction that intricately showcased the detailed interactions among the system elements in a schematic manner.

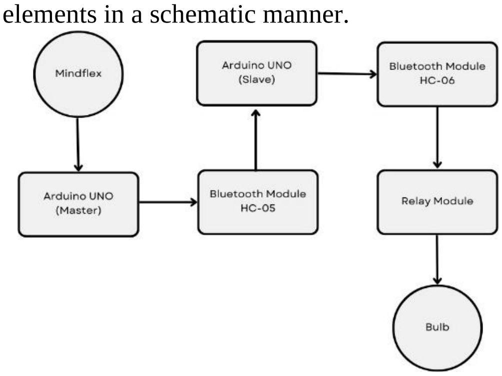

Fig. 3 Schematic Design

B. Integration of Neurosky Chip with Arduino UNO and Incorporation of Bluetooth Module

The integration of Bluetooth modules with Arduino encom- passed both physical and programming integration. Physically, the modules were interconnected with the communication ports of the respective Arduinos, establishing a direct and reliable linkage. This interconnection adhered to technical specifications and appropriate connection protocols to guarantee an efficient data exchange between the devices. The Arduino Integrated Development Environment (IDE) served as the platform for programming the devices. A dedicated code was formulated to manage the information received from the NeuroSky chip via the Bluetooth modules. This facilitated the transmission of signals from the primary device to the secondary device.

C. Description of participants

The investigation involved the participation of fifteen (15) students from UNITEC, San Pedro Sula. A non-probabilistic convenience sampling method was employed for student selection. To determine the amount of participants for this investigation a series of analysis where taken from previous studies, such as "An empirical evaluation of a hands-free computer interaction for users with motor disabilities" [5], which involved 10 participants, and the project "Distinguishing mental attention states of humans via an EEG-based passive BCI using machine learning methods" [14], which had 5 participants. Hence, this study aimed to include a larger participant pool to effectively assess the functionality of the lighting system (Table III).

TABLE III
PARTICIPANT INFORMATION

Subject	Gender	Age	University Major
1	Female	21	Biomedical Engineering
2	Female	20	Biomedical Engineering
3	Female	21	Biomedical Engineering
4	Female	21	Biomedical Engineering
5	Female	20	Biomedical Engineering
6	Male	22	Mechatronics Engineering
7	Female	20	Law
8	Male	21	Biomedical Engineering
9	Male	19	Industrial and Operations Management
10	Male	23	Mechatronics Engineering
11	Male	20	Systems Engineering
12	Male	18	Systems Engineering
13	Female	18	Systems Engineering
14	Male	20	Systems Engineering
15	Female	19	Industrial Engineering and Entrepreneurship

Throughout the data collection phase of the investigation, the students' brain signals were captured within a one-minute timeframe. The Mindflex device served as the primary tool configured for acquiring the participants' brain waves. Proper placement of the Mindflex device necessitated direct contact with the user's skin to ensure precise readings of brain activity. Hence, it was advised to appropriately adjust the headband, ensuring the device's sensors maintained consistent contact with the forehead for optimal acquisition of brain signals (see fig. 4).

D. Brainwave Analysis in Processing

The utilization of programming environments like Processing for studying brain signals stands as a valuable asset within neuroscience research. These signals, derived from devices such as electroencephalograms (EEG), serve as representations of the brain's electrical activity, offering a unique avenue to compre- hend cognitive and emotional processes. In the Processing analy- sis, the filtered signals were graphically depicted, represented by bar graphs corresponding to ten specific channels. These channels conveyed data associated with attention and meditation. The analysis revealed the prevalence of Delta, Low Beta, and High Beta waves during the examined session.

Fig. 4 Correct Placement of Mindflex.

Post-analysis unveiled that the waves indicated a state of concentration, focus, and heightened attention by the subject under examination (fig. 5). Moreover, an alternating sequence of these waves indicated fluctuations in the subject's concen- tration levels throughout the session. This dynamic pattern of brain waves reflected changes in the subject's cognitive state, highlighting the capability of brain signals to mirror alterations in attention and focus during the assessment period. Details of the signals for other subjects can be found in the appendix section.

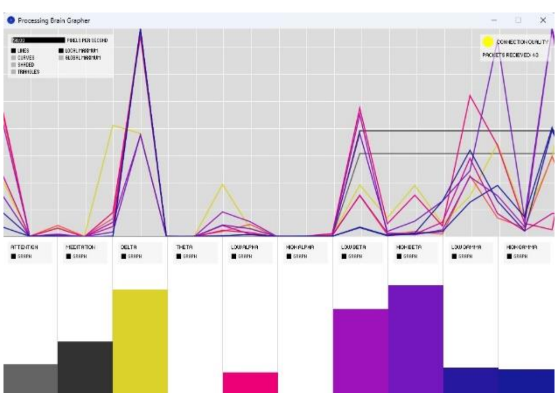

Fig. 5 Correct Placement of Mindflex

E. Comparison with OpenBCI

The OpenBCI represents an electroencephalography (EEG) device comprising a helmet utilized for the measure- ment of cerebral electrical activity. This specialized headgear incorporates an array of electrodes positioned on the scalp's surface to capture and gather brain signals. Its intended appli- cations encompass scientific research, medical utilization, and the facilitation of brain-computer interface (BCI) development projects [15]. Researchers Aldridge et al. conducted a study [16] to assess the OpenBCI Ultracortex Mark IV in terms of affordability, accessibility, and accuracy in comparison to alternative commercial and medical EEG systems.

1) Comparative Analysis: During this phase of the study, a comparative analysis was conducted on the data obtained from both the OpenBCI and Mindflex devices. The objective centered on contrasting and scrutinizing the characteristics and outcomes derived from each brain-computer interface (BCI) device. To fulfill this aim, a series of methodologies were implemented, encompassing the application of the Fourier Transform and the segmentation of brain signals. These pro- cesses were executed utilizing Matlab software, enabling the thorough analysis and manipulation of the data amassed during the experimental phases.

Following the acquisition of frequency ranges from both the Mindflex and OpenBCI devices, a statistical validation of the Mindflex ranges was conducted by comparing them with data from a higher capacity EEG device. This phase of analysis was performed using Minitab software, facilitating the generation of statistical tables and graphs for an effective comparison between the two devices.

Upon analyzing statistics for subject 7 (Table IV). It was observed that the mean of the Mindflex data was 15.55, while the mean of the OpenBCI data was 26.6, resulting in a difference of -11.06 units. The estimated mean difference of -11.06 suggested that, on average, the Mindflex exhibited lower levels by -11.06 units in comparison to the OpenBCI. To assess these findings further, a 95% confidence interval was calculated, yielding a range between -19.44 and -2.69.

TABLE IV
DIFERENCE ESTIMATION – SUBJECT 7

Difference	95% CI for the Difference
-11.06	(-19.44; -2.69)

Table V presented the results of a test of difference of means between two groups, where the null hypothesis (H0) posed equality of means and the alternative hypothesis (H1) suggested a disparity between them. With a t-value of -2.71 and 27 degrees of freedom, the p-value turned out to be 0.012. Since this p-value was less than the conventional significance level (0.05), sufficient evidence was obtained to reject the null hypothesis, indicating a statistically significant difference between the means of both groups.

TABLE V
RESULTS OF 2-SAMPLE T-TEST APPLICATION -SUBJECT7

Null Hypothesis (H_0)	$\mu_1 - \mu_2 = 0$	
Alternative Hypothesis (H_1)	$\mu_1 - \mu_2 \neq 0$	
T-value	Degrees of Freedom (DF)	p-value
-2.71	27	0.012

The statistical analysis of data from 15 subjects revealed notable variability in mean differences between the two compared devices. Across subjects, OpenBCI means consistently exceeded Mindflex means, supported by 95% confidence intervals, highlighting a distinct disparity. Most p-values (below 0.05) in the mean comparison test signified significant differences between devices across subjects. Graphical analysis further illustrated a prevalent trend of higher values recorded for OpenBCI compared to Mindflex.

F. Performance Analysis Comparison

A detailed analysis of the performance of the residen- tial lighting system, which was controlled by the Mindflex entertainment device, is presented. The analysis focused on evaluating the performance of the lighting system in relation to the signals and commands transmitted by Mindflex. The brain wave that was being evaluated during the whole process was low beta because after investigation, it was found that this wave is where the mental state of concentration is found.

1) Response Time: The response time of the system refers to the time elapsed from the emission of the brain signals to the execution of the command to control the lighting of the system. This variable was analyzed in order to understand how efficient the system was considering its response time, it allowed to evaluate and understand the efficiency of the system in terms of its capacity to minimize this time lapse.

A statistic was made for each subject of the response time obtained during the test minute. In this case for subject 7, a statistical analysis of the ”Low Beta” brain wave was performed to verify the values obtained for this specific wave (Table VI). The mean value indicated that the brain activity of subject 7 in the frequency band was relatively high. The standard deviation indicated that there was variability in the Beta Low values. The lowest concentration value the subject was at was at a level of 13 (μV) and when he was most concentrated his level was 111841 13 (μV).

TABLE VI
DESCRIPTIVE STATISTICS OF LOW BETA -SUBJECT7

Variable	Low Beta
N	12
Mean	18888
Standard Deviation	38187
Median	383
Minimum	13
Maximum	111841

1) System Performance: The lighting system's operational performance denotes its efficacy and functional ability in delivering illumination as per predetermined parameters. To assess the residential lighting system's performance, each participating subject underwent a total of four one-minute tests.

Following the test sessions, an evaluation of the lighting system's performance was conducted concerning each subject among the 15 participants. The analysis captured the average instances of successful system responses and failures. Among the initial five subjects, the system exhibited an average response rate of 45%, with a failure rate of 55% in the conducted tests. The subsequent group demonstrated a balanced outcome, showcasing a 50% success rate and an equal 50% failure rate. As for the last five participants, the system showed a 50% success rate alongside an equal 50% failure rate. Cumulatively across all 15 subjects, the overall average performance of the system reflected a success rate of 48.33%, while the average failure rate stood at 51.67%.

Upon completion of tests using the wireless module, it was observed that the system attained a 100% effectiveness in at least one of the four tests for each subject. Considering all 15 subjects, an aggregate assessment revealed a system success rate of 48.33% and an average failure rate of 51.67% (Table VII). The system was generally effective but exhibited

TABLE VII
SUCCES RATE

Subject	Worked	Did not Work
1-5	45%	55%
6-10	50%	50%
11-15	50%	50%
Total	48.33%	51.67%

flaws during testing. Irregularities in Low Beta brainwave measurements indicated difficulty in sustaining concentration among most subjects. Communication issues between the Bluetooth module and the lighting control system, stemming from data transmission interference from the Mindflex device, led to system failures.

Following the utilization of the Bluetooth module, subsequent tests were exclusively conducted using the wiring of the Relay module to assess the lighting system’s performance in comparison to the Bluetooth module. These tests revealed a more efficient behavior of the lighting system (Table VIII). It

TABLE VIII
SYSTEM PERFORMANCE WITH RELAY MODULE

Subject	Tests Conducted	System Activation
1	1	Yes
2	1	Yes
3	1	Yes
4	1	Yes
5	1	Yes
6	1	Yes
8	1	Yes
9	1	Yes
10	1	Yes
11	1	Yes

12	1	Yes
13	1	Yes
14	1	Yes
15	1	Yes

was evidenced that the system could be activated 100% in each of the tests performed when the Relay module was used in the subjects. This implies that there was a difference between the efficiency of both uses, but there was always 100% activation and operation of the system.

V. CONCLUSIONS

- The wireless control system developed using Arduino UNO and Mindflex brainwave technology achieved a 100% activation rate in at least one of the four tests when utilizing the Bluetooth module. Across the fifteen subjects, the overall effectiveness was 48.33% in the four tests, with a corresponding 51.67% failure margin. Subsequently, tests conducted solely with the relay module demonstrated a 100% activation rate. Despite being in an initial developmental phase, this technology shows promise for assisting individuals with motor limitations, offering potential enhancements through the use of wired connections or alternative materials.
- The assessment of current Brain-Computer Interface (BCI) systems provided comprehensive insights into this burgeoning field of assistive technology. Among 31 projects utilizing BCI technology, 32.26% employed NeuroSky technology. This understanding elucidated the applicability of these devices for specific user groups, offering insights into future advancements and enhancements.
- A detailed methodology was devised for the seamless integration of the wireless system with the lighting system using the NeuroSky chip. Employing a V-model approach facilitated the proper execution of development and validation phases, proving pivotal for implementing the proposed system effectively.
- Practical testing of the system involved fifteen (15) UNITEC, San Pedro Sula campus students, unveiling communication issues between the Bluetooth module and Arduino, potentially due to interference. This underscored the necessity of considering alternative wireless devices such as the Wi-Fi module for better connectivity or exploring devices like a Raspberry Pi for improved functionality.

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