A Novel Brain Computer Interface Design

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Abstract

A brain computer interface (BCI) is a system which connects neural signals to a computer system. They have been used for controlling systems including robotics, on-screen computer control such as mouse movement, typing, and synthesizing audio signals. Invasive, or implanted, systems are often long-term medical solutions, or used for research where very clear signal is required. Non-invasive systems usually rely on exterior signals gathered through a headset using one or more electrode sensors. These signals are composed of sums of neuron activation potentials from brain activity and can be used to determine particular aspects of brain function. All BCIs rely on neural feedback of some form; the most effective systems combine multiple forms of feedback. The proposed BCI design will control audio playback through a connection to a non-invasive EEG sensor headset worn by the user. This design will take a conclusive step toward better integration of this technology for more effective control of systems in the future. It would be helpful to any consumer who wants to control media play back hands free, as well as patients unable to use hands for control. Its advantages include a low price point and simple implementation compared to medical and research grade equipment. In summary, the proposed BCI audio playback control system is a simple yet vital step toward a truly robust implementation of such a system on a larger scale.

Keywords: brain computer interface (BCI), electroencephalogram (EEG), non-invasive, feedback, signal analysis, audio system, audio control, remote control, audio playback, C#

A Novel Brain Computer Interface System

This thesis will propose a design framework for a novel system. This non-invasive design will control an audio playback program on a supporting remote device, using a single-channel wearable electroencephalogram sensor. In order to better understand the operation of the system and its relationship to the biological functions involved, the thesis will also explore in some depth the growing research field of the brain-computer interface, or BCI.

A BCI is an interface between the brain of a user and an external computing system. This connection can be two-way or one-way in either direction. BCIs are often used in medical applications but are applicable to many topics (Mridha et al., 2021). This thesis will primarily deal with the sensing and control applications of a BCI. Topics covered will include delineation within the field, advantages and disadvantages of invasive and non-invasive systems, the neurological background of signals used, the biology of learning and feedback, and prior work in similar topics.

The thesis will also describe the system proposed in more depth. Aspects covered will include specific function of the design, biological analysis of its operation, its overall purpose, prior work on this topic, and the unique contribution that this design brings to the field.
It will also describe and analyze a system constructed to demonstrate the design. This will include design options, the design process of the system, reasoning for the choice of design, and an explanation of the purpose and function of the specific components of the design. These components, including software and hardware components, will be documented. The system analysis will include the in-practice operation of the design and its performance, strengths and weaknesses of the general design and its specific implementation, the possible market and industry applications of the design, and possibilities for future work based on this thesis.

Theoretical Background

In order to better understand the function of a BCI and of the system being described, it is beneficial to elaborate on the theoretical knowledge used in the synthesis and operation of these systems. A BCI is most often described as either “invasive” or “non-invasive” (Leuthardt et al., 2021, para. 1). Invasive BCI systems employ electrodes which require some sort of surgical involvement to function within the body. Clearly, then, non-invasive BCI systems require no surgical procedures because they do not penetrate the body, functioning entirely on sensing from the exterior (Leuthardt et al., 2021).

In the interest of clarifying the risk involved with various BCI systems, it has been proposed that an additional distinction be implemented within invasive BCIs. Leuthardt et al. (2021) suggest that they be divided into “embedded” and “intracranial” systems (para. 3). Embedded systems involve any invasive BCI system that does not penetrate deeper than the skull, while intracranial systems penetrate the skull. Although all surgical procedures involve risk, the embedded system carries lower risk for complication compared to the intracranial, since the procedure does not require penetration of the cranium (Leuthardt et al., 2021).

One more possibility for a BCI system does not fit any of these categories. This is a DARPA-funded system that would use neural nanotransmitters to reach the brain directly without using a surgical procedure. While there are no surgical risks involved, this is a very new development and requires some exploration to be useful in the field. Additionally, it will most likely not be useful in small-scale commercial products, because of its expense and sensitivity (DARPA, 2019).

Every type of BCI has various advantages and disadvantages. In general, the trend is that clarity and directness of signal is inversely related to the complexity and intrusion of the receiver or transmitter involved in the biosensing. Invasive BCIs have the advantage of extremely clear and accurate signal, since they can usually probe by physically contacting nervous tissue directly. The signal noise ratio (SNR) is much higher for these systems. They are also able to isolate a signal very accurately and receive it from deeper or more inaccessible brain regions. This enables them to target specific areas, which is very helpful for research involving higher brain function (Zhao et al., 2023). In addition to heightened risk of procedure, however, they also tend to degrade quickly over time, since scar tissue accumulates around the sensor and harms its receptivity to signals. This is a complex biological response that does not only harm the electrode also neighboring neural cells (Mian et al., 2021). In response to this issue, research is being pursued on the possibility of biocompatible electrodes that do not evoke a foreign body response in the nervous system. Such electrodes would be chronically viable and would also not create issues for the neural tissue surrounding the implant (Norton et al., 2015).

Non-invasive BCIs rely on exterior signal sensing to interface with the brain. They could include scanning methods like magnetoencephalography, functional magnetic resonance imaging (fMRI), or functional near-infrared spectroscopy (fNIRS) (Zhao et al., 2023). fNIRS methods are less popular but have still been implemented. Since they measure activity throughout the brain, fNIRS methods have been used with go/stop and on/off type controls. Usually, the area of the brain used is something clearly under conscious control, like the prefrontal or motor cortices of the brain (Naseer & Hong, 2015).

The most popular approach is electroencephalography (EEG), which uses scalp electrodes to interpret voltage potentials generated by synchronous neuron activity. The reason for the popularity of this method is related to its simplicity compared to other options. MRIs are complex, large, and expensive. EEGs, on the other hand, can be low-profile, relatively cheap, and provide signals directly derived from brain activity. Applications of EEG BCIs are the most frequently observed in many fields. Some of these applications include systems to analyze alertness, assist in communication, control exterior prosthetic systems, and control other robotics. Possible future applications include smart home systems, car controls, and other consumer applications (Värbu et al., 2022).

The EEG signal, which will be used in this project, is a measure of voltage potential signal over scalp electrodes. This voltage potential is caused by electric fields from group neuron activity. This method of receiving signal means that it cannot detect individual neuron potentials only waveforms from many different locations. These can be used directly for signal analysis or split into frequency bands, which are often useful for general analysis of brain activity (Abo-Zahhad et al., 2015).

EEG signals are generally below 200 µV in amplitude and lower than 40Hz in frequency. They are generally divided into five frequency bands: alpha, beta, delta, theta, and gamma. The delta band waves are very slow, from 0.5 to 4 Hz, and are associated with deep sleep. The theta band waves can range from 4 to 8 Hz and are associated with some sleep phases and some waking quiet focus states. The alpha band waves are from 8 to 14 Hz and are associated with relaxation when awake. The gamma wave band is faster than 30 Hz and is usually associated with visual stimulation and other quick response stimuli. The beta wave band ranges from 14-30 Hz and is associated with normal conscious states and concentration on tasks (Abo-Zahhad et al., 2015).

Other waveforms that can affect the EEG signal include eye blinking, among other eye movements. A signal is also generated by general eye movements; this is because the eye is polarized, with a positive charge at the cornea and negative at the retina, and movements of these charges create large field changes. The signal from a blink is not caused by the position of the eye but is the result of the muscle potential change (Abo-Zahhad et al., 2015).

As an example of how complex the study of the EEG signal is, there are significant differences between the EEG signals observed in right-handed and left-handed people. This is due to the functional differences in their brains. The EEG signals indicate neither an identical nor a mirrored expression of functionality instead seem to have asymmetrical and fundamentally different signal response to various stimuli. The way in which this asymmetry behaves seems to indicate that left-handed people's brain hemispheres and separate parts work more in concordance, one of the hemispheres supporting the other, than in concurrence, with both hemispheres simultaneously supporting each other. If this is true, it may turn out to be helpful in understanding why left-handed people are more vulnerable to harm from radiation, and yet seem to recover more quickly from some injuries not related to radiation. Similarly, research indicates that left-handed people may have a less complex system of brain state shifts (Trofimova, 2000) (Zhavoronkova, 2007).

This research seeks to demonstrate that waveforms have an undeniably complicated relationship with consciousness. Thoughts and brain signals are decidedly non-linear and therefore not easily correlated with desired system states (Mridha et al., 2021). However, in order to control a BCI, the brain must learn to generate signals of the desired description on command. Certain frequency bands are undoubtedly more suited for conscious control (Abo-Zahhad et al., 2015). Some commercial products like the MindFlex™ toy use calculated values to approximate various values like focus and relaxation. The MindFlex uses Attention and Meditation values (NeuroSky, n. d.).

One study performed in a real-life situation found that increased left frontal alpha and parietal theta power as well as decreased central delta power corresponded to attention. In this study, the researchers were able to achieve a binary accuracy of over 95% through the use of machine learning analysis (Kaushik et al., 2022). Powerful computing is necessary to quickly achieve an effective analysis of many individuals. Kralikova et al. (2022) demonstrated that an EEG signature is unique from person to person; they achieved an accuracy of 98% on recognition of a person's EEG signature on escalating cognitive load.

BCIs depend on feedback to the user to train the brain for the learning of control tasks (Hinterberger et al., 2004). The effect of the feedback is dependent on the way in which it is provided to the user; different types of feedback can affect its impact. Visual feedback has been shown to be significantly more effective than auditory feedback, when compared by time required for mastery. However, both types of feedback together outperform either by themselves (Hinterberger et al., 2004).

Haptic feedback is another less frequently explored option. A sensory feedback related to spatial awareness, haptic feedback is defined as sensory feedback of touch (tactile) or of proprioception, the ability to know the body's position (kinesthetic). Tactile feedback can be represented by techniques like temperature or vibrotactile feedback, where tactile sensations are provided to the skin. Kinesthetic feedback includes techniques like control restriction, for instance when the muscles of the body are pushed or otherwise interacted with by the system under control (Fleury et al., 2020).

Feedback does not have to be obviously and clearly sensory; in theory, any kind of signal to the brain can be used as feedback. This is demonstrated by a project performed by researchers at University of Florida. In this project, 25,000 rat neurons and a microarray of electrodes were employed, establishing an electrical signal connection between a flight simulator and the resulting neuronal network. The neurons created pathways based on the received electrical feedback that allowed them to send signals to simulated F22 jet plane controls to effectively level the pitch and yaw of the simulated flight (DeMarse, 2005).

Non-invasive BCI systems are more limited. They are usually required to provide accessory sensory feedback to enable the brain to create controlling signals effectively. A good example of the implementation of these types of feedback is a project which uses an EEG to control physical robots and VR agents. In this project, the researcher used all three forms of feedback: visual, audio, and tactile, and then compared them. The BCIs powered by auditory feedback suffered severely from a lack of accuracy, as did the tactile ones to a lesser extent. The visual feedback was the strongest method of feedback (Rutkowski, 2016).

Purpose and Originality

The purpose of this thesis is to describe a design for media playback control using a BCI. This design would be applicable as a commercial product for any consumer who listens to music on a regular basis. It would operate in conjunction with a mobile device or other audio playback device and would allow for hands free and rapid control of the audio by the consumer, in normal life scenarios such as the gym, the office, the home, and anywhere else hands-free control of audio playback could be convenient. Additionally, for handicapped consumers who have challenges doing tasks with their hands, this product would provide a quick and easy way for them to control media playback.

This thesis presents a general structural design. The design is portable, somewhat low-profile, simple in implementation, and capable of controlling an audio playback system through a

BCI. The idea of audio control using a BCI has been approached before: an anonymous student posted a design for an audio volume control using an EEG detector (jingw, 2011). The system detects eye blinks and can modulate the volume of the audio based on their frequency. This was the only work uncovered in the process of research that addressed the concept of a BCI audio playback control. However, this is a rudimentary system that controls the volume of audio only and not its play/pause state. It is also not implemented in a way that enables connection to an outside playback device. It represents a step in the direction of an audio playback control BCI does not suggest the commercial BCI structure described in this thesis. Besides this system, some examples of other BCIs related to auditory playback include a system that can compose music using BCI (Pinegger et al., 2015) and a system that uses musical notes as auditory feedback (Huang et al., 2016). This thesis proposes a BCI that directly controls media playback, which is not proposed in any of the researched sources. In order to assess the feasibility of the proposed BCI, this thesis will also describe a system constructed to demonstrate the principles of the BCI design. It will be a proof of concept system that will use a headband and Bluetooth connection to control media playback on a separate target device.

Design Approaches and Selected Design Approach

Quite a few possibilities should be considered for how this project could have been approached. These possibilities include the sensing paradigm, the hardware used for sensing, the connection between the hardware and software, the target platform, the language of software implementation, and especially the signal analysis.

The choice of sensing hardware is definitive for the scope of the design. Sensing options include any of the broad categories of BCI described above. These include embedded, intracranial, or non-invasive system. Invasive systems, including embedded and intracranial systems, involve more health risks due to surgery (Kawala-Sterniuk et al., 2021). Insurance might cover some of the costs for patients, and it would require approval from a review board in order to proceed with research. For a project of this scope, the financial and time investment required to conduct this research are impractical. Considerations would have to be made for the risk involved for subjects of the research. However, these systems would provide the advantages of much clearer and quicker connection. The target market of this design is a commercial application, which requires that it be implementable in a way that is convenient, effective, price appropriate, and almost certainly disposable. In this respect, an invasive system would be heavily disadvantaged in the market, since a costly surgical procedure and a commitment to the state of a constantly present system would conflict with public interest.

A non-invasive system would not suffer from the disadvantages inherent in invasive systems. It would be easily removable and also affordable and accessible for the normal consumer or patient. With equipment similar to that used in the demonstrative system explained later in this thesis, such a product could likely be marketed for $40-$50, or even less. Research for a non-invasive system would also be significantly simpler. If the system required documentation of human testing, approval from an IRB would still be necessary. However, design and implementation could be performed without this approval.

Another option within the design range is the hardware used to record signals. This will be heavily limited by the scope of the study. An invasive system would be implementable either as a sensor outside the skull or an intracranial sensor. An extracranial sensor could be located on the head or on some other nervous or muscular tissue that could transmit signal. An intracranial sensor would be the most dangerous yet direct way to obtain signal.

A non-invasive sensing system would be implemented in one of several forms. Many of these are too large and expensive to be used for a low-profile audio controller design. MRIs would fall into this category. fNIRS, or infrared scanning, could also be used. This would provide the relative brain activity of different areas based on blood oxidation level and would be capable of easy switch-style commands based on activation or deactivation of different areas (Naseer & Hong, 2015).

EEG signal could be used in order to simplify signal reception. Its advantages include quantitative, real-time signal, and ease of implementation. It is small compared to the other methods of signal gathering and provides many options for command translation. However, the signals received are very complicated. They are also unique to everyone, and unlike the data from the other methods, cannot be simply and directly mapped to brain regions.

Within the EEG implementation, several approaches are viable. A medical-grade wet-sensor EEG could be used. This would provide clear signal from many channels, giving superior resolution. However, these systems can be prohibitively expensive. For instance, a Grass Comet EEG system is over $1200 (MFI Medical, 2023). Commercial EEG headsets are another option. They are often cheaper and are becoming better in their signal reception ability. Additionally, they tend to have dry electrodes, which while the resulting signal is less clear, are much more attractive to a customer. For instance, the Muse headband is an EEG sensing array designed to use sensed brain states to direct meditation (InteraXon Inc., 2023). It costs $249.99 on Amazon as of this year (Amazon & Muse, 2023).

System Implementation Design Space

The target platform is another design decision that greatly affects the course of this project. Depending on the objective of the development, mobile platforms, macOS, or PC apps could be viable options for the target platform. A mobile platform like iOS or Android would be an excellent choice for a commercial product. These are extensively supported and would be immediately applicable to most consumers on the market. The disadvantage of these platforms would be the challenge of developing for them and the restrictiveness of the platforms. macOS has the advantage and disadvantage of being a distinct class of technology that is used by a certain fraction of the population. It would be an excellent stepping stone, but an app for Apple Mac computers would not be accessible for PC users. Of course, this could be remediated later in the life of the design if it is successful to that point. A Windows PC implementation would have the disadvantage of being only accessible from a laptop, and not a mobile device. This would greatly restrict its commercial applicability. However, this implementation would be very flexible in terms of development. It would simplify the research stage greatly, and ease separation of challenges into manageable parts.

Software language options would be highly dependent on the platform chosen. For iOS, Swift or Objective C would be the obvious choice, though other options are of course available. For Android, either C, C++, or Java would be an optimal choice. For Windows, there are many more options: C# or Python would be a good choice. Additionally, for research purposes, MATLAB could probably be used to simplify signal analysis and ease calculation.

One of the most important options in the design is the signal analysis method. This will take very different forms based on the sensing method chosen. For the fNIRS method, the resulting signal is a map of brain activity. In order to control a BCI with this information, a functional region of the brain must be chosen to selectively activate or deactivate at will. This would most likely be a motor area or the prefrontal cortex area. An action that is performed or visualized would be selected and used to activate the specific area selected. One pitfall to consider is the ongoing brain activity in all sorts of other cortices of the brain; for instance, the prefrontal cortex is constantly receiving inputs not related to the target action from other cortices of the brain. Since fNIRS control would be based on general areas of the brain, using one as a switch would necessitate not using that part of the brain for other activities during operation. While this is a concern for all sensing methods, it is particularly relevant for an fNIRS scan (Naseer & Hong, 2015).

fMRI scanning could also have been used and would have the necessary resolution to use brain areas for control easily. A potential obstacle for this approach would be the cost. A single fMRI session, operated by a technician and not a physician, costs $122 as a national average in the United States. For a patient who requires a BCI as treatment or analysis for health purposes, insurance will cover much of that cost; under Medicare, the average cost to the patient for a technician-operated fMRI session is $24. However, health insurance would not cover researchers wanting to use the procedure for development (Medicare, 2023).

EEG signal would be a convenient and effective choice. While it would not have as much resolution as an MRI, it could still achieve some locational awareness of brain signal, and since it is a direct measure of signal, it would not have to depend on general brain activity information. Its disadvantages would include a lack of spatial specificity and a great increase in the complication of signal analysis. There are several different possible approaches to EEG signal analysis.

Controls like volume and potentially playback speed could be assigned either discrete or continuous control. Discrete control would involve a set number of outcomes from which the control decides. Continuous control would involve a continuous space from which the control decides. Of course, with a digital system, a continuous control must be implemented as discrete. The key variable then becomes the number of outcomes. For fewer outcomes, the resolution is lower, but the ease of accuracy in control is higher.

Signals for signal analysis could be used in several ways, depending on the specificity of the data. First, the signals could be analyzed through frequency power bands. This is a method used by many different headsets and systems available and would be easy to implement with respect to hardware. This approach would have several disadvantages. Probably the most significant is the difficulty of a consistent control mechanism. The waves are directly correlated to brain states, and attempting to reproduce brain states on command is difficult, while not impossible. Additionally, the different power bands are stronger and weaker in various places for different states, meaning for some sensor arrays, certain bands will be feeble or unusable (Abo-Zahhad et al., 2015).

Second, the signals could be analyzed through raw waveform artifacts. These could include actions like eye movement waves or eye blinks especially. These are identifiable and discrete signals that could easily be mapped to outcomes. These artifacts do run slightly counter to the objective of such a system; they are not strictly brain-generated signals but are created by actions of the user. This may not affect the function or applicability of the device. In BCI applications for most research involving locked-in patients, this type of control would be impossible, since they can’t blink on command. Another disadvantage of this control method is its limitation to very few system states to be mapped to outcomes. It lends itself only to binary response controls.

A third approach to EEG signal analysis would be the direct spectrum analysis of the waveform signal. This would involve aspects of the signal like certain frequencies from different bands peaking at resonant points, which occurs in response to some brain states. This method of control would be effective if understood well. However, it is inherently a challenging control method.

Design Process and Selection of Design Approach

This overall design was influenced by factors including price point, convenience for a consumer, and simplicity. Selection of a sensing type was based primarily on cost and ease of implementation. Larger systems like MRI were not considered because of expense and impracticability for normal uses.

Instead, EEG signal was selected because of its feasibility at a very small scale. It is capable of functioning on small headsets, like the Muse 2 mentioned earlier in this thesis, priced at $249.99 (InteraXon Inc., 2023). Commercially available headband sensors like this one usually have a few channels of EEG signal data. Future versions of the design may involve multiple channels in order to integrate more advanced features requiring higher resolution and more range of options for control. However, since the design is implementable with one channel, a single channel headset is selected for simplicity. This would also reduce the cost of the product.

For the connection to a computer, the considerations were again based on convenience and cost. Wireless connection is very beneficial for a consumer design intended for extensive daily use. Hence, a Bluetooth framework was selected, so that the design will fit easily into the network of already existing devices and be simply configurable within this network.

The platform selection was motivated by applicability to the market. In order to be applicable to most people, the design should have a presence on mobile platforms. This design would therefore be implemented on either iOS or Android for its first generation, and probably expand support to the other platform. During development, however, ease of implementation is key for platform selection. With this in mind, the developmental stage of this design uses a Windows system with C#.

EEG signal analysis is complex and sensitive to individualities. Taking this into consideration, signal analysis was simplified as much as possible. One of the things that can be said to be universal between users is the effect of artifacts on the EEG signal. This motivated the selection of artifacts for control of discrete properties of audio playback, such as play and pause functions.

Continuous controls such as volume level are more difficult to make symmetric across users. Using an EEG power band-calculated value like attention or meditation would be capable of achieving this but would require some training to use effectively. With more robust software, this type of control could eventually be implemented. However, for this preliminary design, such controls are reduced to discrete controls in the interest of simplicity and applicability to the market. They can then be operated using artifacts and waveform detection, which are universal immediately. Also, with further research and design, EEG signal analysis control design could be greatly extended, especially with the help of learning models and adaptive software that could quickly characterize a user and customize the design to their mental organization.

Design and System Elaboration

This design's components involve sensing, transmission, translation, and execution. For sensing, the design involves a single channel forehead EEG sensor in a headband. For transmission, the design involves Bluetooth capability in the sensing headband, as well as enabled connection on a mobile device application, or a PC application for development. For translation, the design involves translation of the single channel EEG data on the receiving device, identification of target artifacts, and translation of artifact sequence into audio playback command types. For execution, the design involves playback capability on the receiving device application that is controlled by the translated commands. These commands include play/pause, song skip, and volume control.

The design was tested with an exemplary system. The system implements the components of the design in a development setting. The system sensing involves a customized Mattel Mind Flex headband, enabled by the TGAM1 chip, which interprets a single channel EEG sensor.

The system transmission involves a Bluetooth HC-06 chip interfaced with the TGAM1 chip and corresponding receiving software in C#. The system translation involves an application for Windows in C#, which receives Bluetooth data from the TGAM1 chip and processes it for targeted artifacts. It translates artifact sequence into a desired command. The system executes these commands into the receiving device's audio playback operation.

System Purpose

The system described in this thesis is a proof of concept system that illustrates the function of the design. It utilizes a Mattel product to gather EEG signals, a Bluetooth chip to transmit them, a developmental PC application in C# to translate them, and executes the commands on the PC.

This system demonstrates the feasibility of the design proposed by this thesis. This design entails a headband with EEG sensing capability, a Bluetooth transmission system, a receiving application on a device capable of audio playback, and translation of EEG signals to audio playback commands. The system exhibits all of those features and is a functioning example of the design.

System Documentation

Sensing and Transmission

Figure 1 is an image of the container for the device used for sensing. The Mattel MindFlex uses the TGAM1 chip and an electrode on a headband to sense and process EEG signal. The device uses the proprietary Attention and Meditation values to control a ball with fans. However, this design uses the TGAM1 solely for its raw value reading ability.

Figure 1

The Mattel MindFlex product

Note. Vogan, S., n. d.

Sensing and Transmission (continued)

Figure 2 shows the headband component of the device, used for sensing. The electrode can be observed in the bottom right, meant to be placed on the forehead. The headset is worn with the clips on the earlobes for grounding.

Figure 2

The MindFlex headband

Note. Vogan, S., n. d.

Transmission (continued)

Figure 3 shows the interior of the headset. The TGAM1 board can be observed in the bottom left of the entire chip. The Bluetooth module (not included in the original device) used for communication with the external application is the blue rectangular device connected to the TGAM1 board and protruding from the top of the headset.

Figure 3

The customized MindFlex headband

Note. Vogan, S., n. d.

Translation

Figure 4 shows the Windows Forms C# app used for development. It contains classes that allow it to connect to the Bluetooth chip used above, interpret the raw waveforms sent over Bluetooth, scan them for blinking artifacts, and control the media that the Windows PC is playing at the time. It also includes many tools for development, such as a sound generator and player, graphical representations of the attention and meditation values, graphical representations of the different EEG power bands, a window that plots the raw EEG waveforms in real time, and commands to send over Bluetooth for configuration of the sensing device.

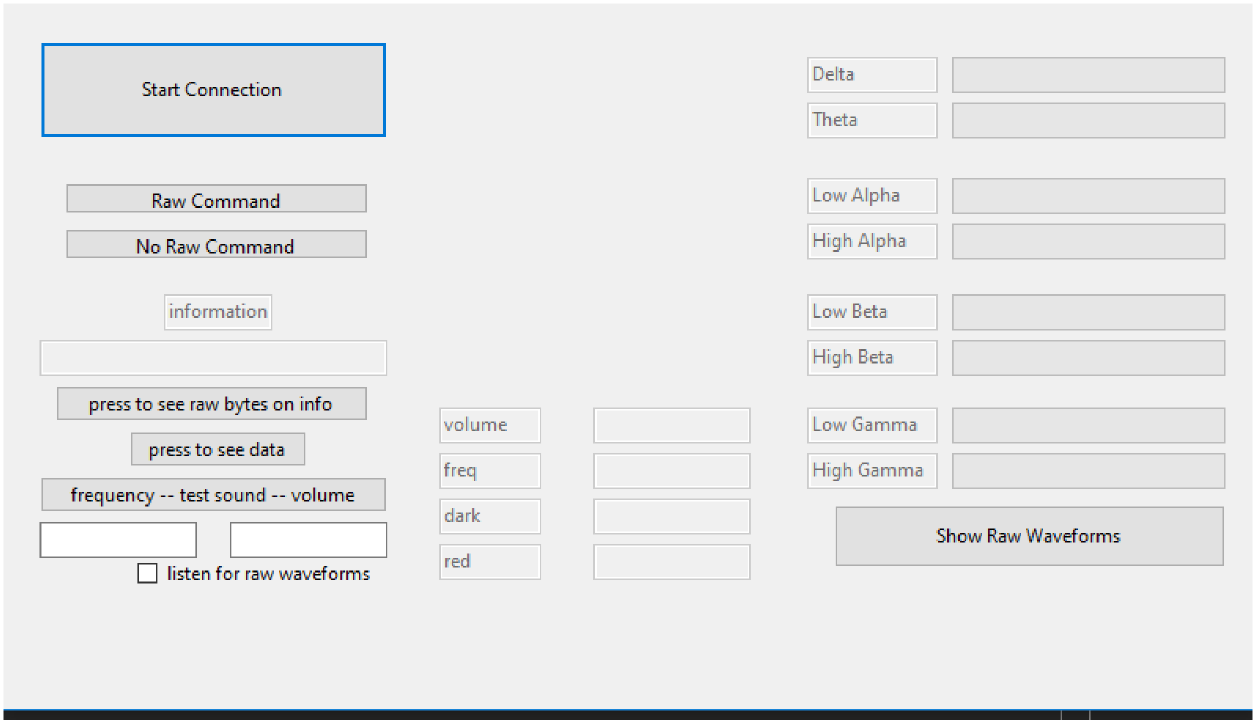
The application tracks for blinks close to each other by analyzing the waveform for steep drops in voltage. It plays or pauses the audio on sensing two proximal blinks, skips ahead a track for three blinks, and rewinds a track for four blinks.

System Verification

The system was tested for functionality and recorded in operation. A demonstration of the results can be found in this link, which is also included in the Appendix.

Figure 4

The PC interface



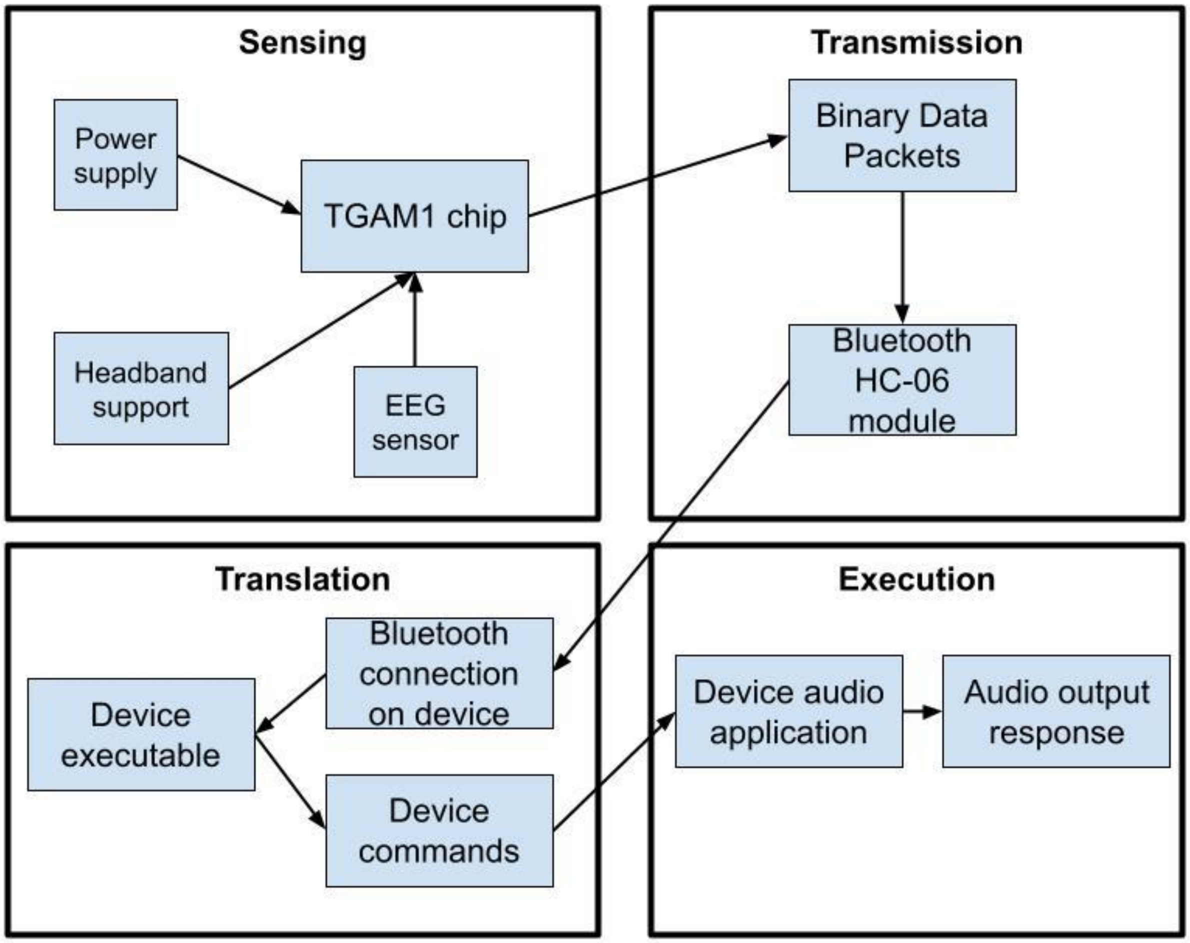
Note. Vogan, S., n. d.

System Summary

Figure 5 shows the block diagram of the implemented system. It represents a general structure of the Sensing, Transmission, Translation, and Execution stages of the system.

Figure 4

The implemented BCI system



Note. Vogan, S., n. d.

Design and System Post Analysis

The disadvantages of this system are mostly involved with the complication of the design implementation. A headband directly intended for audio control at a low price point will initially have some performance issues, and the same applies for the application responsible for controlling it. Over time, this will improve, if the product is accepted on the market or taken over by a mobile technology company. Additionally, the control method selected is vulnerable to interference from normal activities. Eye blink patterns can be selected that are difficult to perform accidentally but will occasionally be unintentionally replicated, possibly with some disturbance to the user.

The system possesses similar advantages and disadvantages to the design, while suffering from some additional setbacks that make it not marketable. First, it is built around an existing headband. It is not feasible to market such a customized secondhand product; the example system is only valuable for validation purposes. Additionally, the product was intended purely for amusement, and would require a visual redesign to be viable on the market. Second, it is designed for low cost, accessibility, and simplicity, and so sacrifices some aspects of performance. It can be sensitive to interference. Third, the supporting software is not optimized for the design intention. It is a workaround for existing systems that could be drastically simplified in a new design.

Among the strengths of this design is its robust yet simple control logic. By avoiding the more variable and complex EEG frequency data, it maintains simplicity of design, yet is capable of being immediately operated by almost any user. While future iterations of the design could implement this frequency data for additional features, the robustness of the artifact analysis method is an advantage during this stage of development.

Another strength is its low-profile implementation. Many potential consumers are accustomed to the use of a normal headband. If the design can be produced in a way that appears familiar, it will be received well. It requires no obvious medical equipment or wet electrodes, is small and portable, and is generally convenient for use. Most importantly, it successfully demonstrates the function and feasibility of the design.

Summary

This thesis proposes a new general design for a commercial BCI audio playback control system. The design set forward in this thesis involves a headset sensor which detects EEG signals in real time from the operator. The sensor relays information to a receiving remote application, which translates the EEG signal received into intended audio playback commands. These commands are then executed by the application.

The design function was demonstrated by a system which implemented the core principles of the design. A marketable version of this design would be applicable to a normal consumer during everyday life, with the receiving application installed on a mobile device, or to a handicapped consumer with impaired ability to operate devices with their hands. It would be a convenient way to control audio hands-free. The design set forward could be improved by elaboration of key details, such as the physical design of a headset, optimized command codes, application design for mobile devices, and other necessary considerations for a market product.

Based on the research set forward in this thesis, as well as the system designed to demonstrate its function, the design is a step toward a viable schema for a market product in the future.

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Appendix: System Verification

This is the network location of a video recording of the system in operation. In the video, the play/pause and song selection functionality of the system as well as its raw waveform viewer are demonstrated.

https://libertyuniv-my.sharepoint.com/personal/sjvogan_liberty_edu/_layouts/15/stream.aspx?id=%2Fpersonal%2Fsjvogan%5Fliberty%5Fedu%2FDocuments%2FRecordings%2FMeeting%20with%20Vogan%2C%20Steven%20James%2D20230719%5F202403%2DMeeting%20Recording%2Emp4