BIOCYBERNETIC ADAPTATION OF AN UNCREWED VEHICLE FLEET

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Abstract:

"Systems are now being developed that use brain and body sensors to automatically discover aspects of the user's cognitive state and use this information as passive or implicit input to a system, augmenting any explicit input from other devices and increasing the bandwidth from humans to computers." E. T. Solovey, D. Afergan, E. M. Peck, S. W. Hincks, and R.J. K. Jacob, 2015. Designing implicit interfaces for physiological computing: Guidelines and lessons learned using fNIRS. ACM Trans. Comput.-Hum. Interact. 21, 6, Article 35 (January 2015)

The project will design and develop a system that implements a version of the "Dynamic Difficulty and Task Allocation" simulation outlined in section 5.3 of Solovey, et al., 2015 (attached), with actual robots or UAVs. The system will allocate control between a human operator and an autopilot in each of several robots or quadcopters based upon the cognitive state of the operator as inferred from EEG and EKG signals. These signals can be processed through various integral transforms and filtered, providing frequently data that correlates to one's state of mind. Due to the complexity of constructing such a device that can operate accurately and reliably, a method of retrieving only the desired frequencies and implementing these frequencies was needed. To do this, the frequencies related to the user's attention were processed though the OpenBCI platform and run through programs for processing and filtering the data, as well as both weighting and relaying it to a centralized control program. Control was then divided up among the robots between autonomous and manual control, providing an "implicit" EEG control style.

The EEG system was designed and built, the robot fleet constructed, and the communication protocols established, all to facilitate the gathering of collision data (and potentially additional data). Data derived from empirical testing and projected results show that the attention of the user can be quantified and relayed to a computer and/or robotic vehicles, and this could, in turn, lead to a reliable method of controlling groups of robotic vehicles more efficiently.

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1 Introduction

The prospect of controlling robots using only the mind has been a fantasy of many since the conception of robotic vehicles. Full control, however, remains beyond the reach of any system currently available, due to limitations in resolution and processing capabilities. The hybrid system we developed allows for a balance between automated control and direct user control.

This technique, known as implicit brain computer interfacing, or implicit BCI, allows bypassing the requirements needed for direct interfacing with computer systems. Instead, implicit BCI allows the user to control the systems as they would normally, with the added bonus of offering autonomous control when the system wears down the user's attentiveness or focus. A balance begins to form as the user is able to find a dynamic medium between unfocused control of all robotic units, and completely focused control of a single robotic unit. This balance allows the user to maximize the efficiency of the system, with little to no additional (conscious) user input.

The subset of electroencephalography, or EEG, that is implicit BCI control requires the retrieval and analysis of electrical signals obtained through the scalp. While not the most accurate or high-resolution option, EEG offers many benefits over methods such as invasive brain signal acquisition, and functional MRI acquisition. These benefits include wide availability of code libraries and hardware, simplicity of design, and minimal intrusiveness. To mitigate the disadvantages of EEG, we will set up a system that is able to gather, process, and distribute the data to the robotic units in the most efficient manner possible, given our constraints.

The system we use to acquire and process the EEG signals is an open source electronic platform designed to provide the user with viable data from the measurements. The OpenBCI platform collects the data gathered from the EEG electrodes and relays it to the PC terminal. The PC terminal completes the EEG data processing using a combination of Fourier analysis and other simpler forms of analysis, such as time-averaging, in conjunction with the OpenBCI device itself. The data is then assessed and given a discrete, quantitative distribution on a scale of one to six. That number will be delivered to the Kobuki robots, utilizing the control system that the user will operate directly. The Kobuki robots operate as semi-autonomous robotic vehicles. The control system consists of a controller designed to give basic control of the Kobuki robots to the user, pending attentiveness.

Using this set up, developed a basic obstacle course to assess the efficiency of the implicit BCI control system. Objects were placed throughout the course, while the objective will be for all robots to maneuver the course with minimal collisions. While operating autonomously under reduced attention levels, the robots follow basic object avoidance protocols, though they lack capabilities comparable to human control. While under direct user control, the robots continue their current trajectories until selected by the user and given new commands. Time averaged values correlating to attentiveness are gathered and sent to the Kobuki robots every 10 seconds.

This control system and obstacle course will allow us to determine whether or not implicit EEG control of unscrewed vehicle systems will be a viable alternative to either purely autonomous control or explicit user control.

2 Design and Specification

2.1 Summary of Design

Our system will be designed to retrieve data from the user's brainwave patterns via the scalp, process the information, and relay it to the Kobuki robots to control them. When not being controlled by the user, the Kobukis will operate in an autonomous mode.

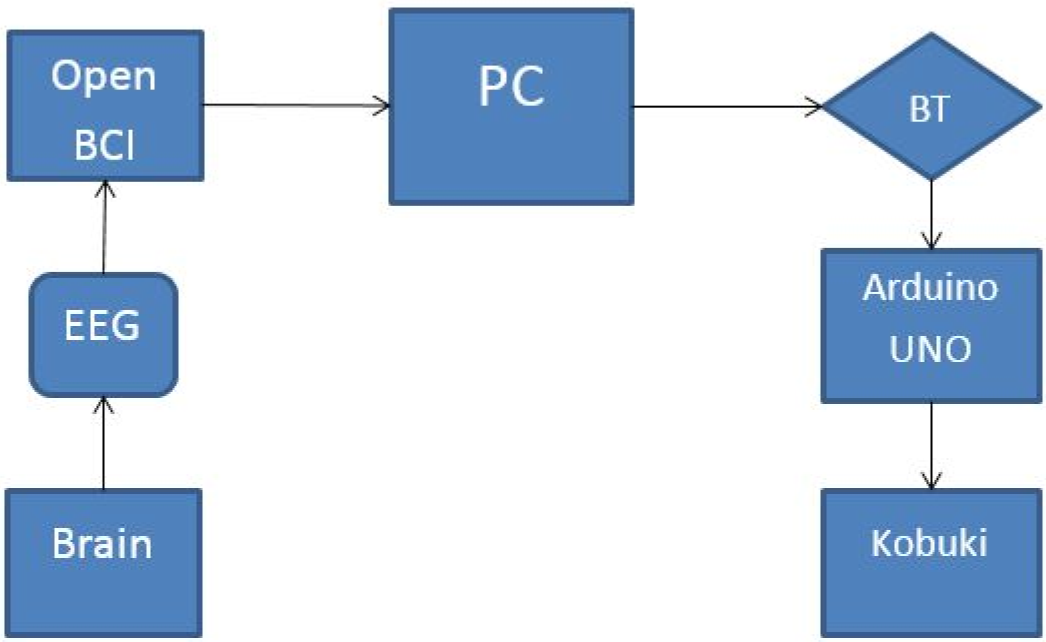


Figure 1: Process Flow Diagram

The system consists of the OpenBCI platform, the EEG electrode headwear, a PC terminal, a Bluetooth-connection agent, and the Kobuki robots with their associated microcontrollers.
The EEG device uses eight channels of passive electrodes to monitor brainwaves with relatively high resolution. Electrodes may be altered from passive to active, meaning amplification may be utilized, depending on the how well the device is operating. The channels feed into the OpenBCI board for preliminary processing, and the signals are sent to the PC terminal via an integrated RF connection to a dedicated USB receiver. Processing is completed using the PC, and the user has basic controls of the Kobuki robots through the keyboard. The data will be sent to a Bluetooth terminal within the PC system, and relayed to the Kobuki robots for control.

The Kobuki robots receive the signal via a Bluetooth receiver which then sends it to a microcontroller as a serial signal. The microcontroller also receives inputs from the Kobiki's physical sensors through a 25 pin parallel port. All of these inputs are processed by the microcontroller, which then controls the Kobuki's motor controls through the same 25 pin parallel port.

The Kobuki's motor controls interpret an analog signal from zero to five volts as forward or backward for each motor, with 2.5 V being stop. The microcontroller uses a pulse wave signal sent through a full bridge rectifier to achieve this analog signal.

The software consists of the provided OpenBCI software, which allows for partially-automated collection and manipulation, via Fourier and/or wavelet transformations and analysis, of the incoming brainwave signals. These signals are passed on to the PC, where additional software accepts the signals, averages them over a given period of time, and reduces the signals to a numerical value between one and six, along with the controls being inputfrom the user. The function deciding the values will be open to configuration, after analysis of the most efficient function is determined.

This value of one through six is considered the focus level of the user and is used to determine the number of robots under the user's control. The PC software determines which robots to send the control signal to, and sends the signals for switching between control and autonomy. The onboard microcontrollers are programmed with autonomous behavior, switching between it and manual control with the received signal.

Overall, the desired specifications met by our system include, but are not limited to, the following key points:

- EEG headwear must continuously and reliably maintain contact with the user's scalp on all electrodes. This will be performed by using the UltraCortex frame along with fitted spiked electrodes and electrode gel.

- BCI hardware and software should be able to process accurately and in real-time, and confer data to the Kobuki control software. This will be established by processing and transforming the "attentiveness" data into numerical form, and saving the data to a file or relaying it to the Kobukis through means of TCP/IP serial communication.

- Control software and communication protocols must be consistent, and maintain signal to Kobuki robots at all times. This will be done by using the same PC terminal mentioned above and the PC's integrated Bluetooth protocols, along with data from the saved file (if necessary).

- Kobuki robots should be able to navigate their course appropriately. They were configured and tested thoroughly after all other portions of the project were completed.

2.2 Detailed Description

2.2.1 OpenBCI

OpenBCI is an open-source EEG device capable of reading up to 16 channels. An electrode cap was built to support the electrodes. The system recognizes various frequencies acquired through the user's scalp, which are noted in the following table.

Table 1. Brain Waves by Frequency

Wave Type	Frequency	Primary State
Gamma Waves	31 – 120 Hz	High Concentration; Sudden insight

Beta Waves	13 – 30 Hz	Focus on activities, conversation
Alpha Waves	8 – 12 Hz	Relaxation, meditation
Theta Waves	4 – 7 Hz	Drowsiness, drifting to sleep
Delta Waves	.5 – 3 Hz	Deep sleep

Visually, the brain wave patterns are depicted as follows:

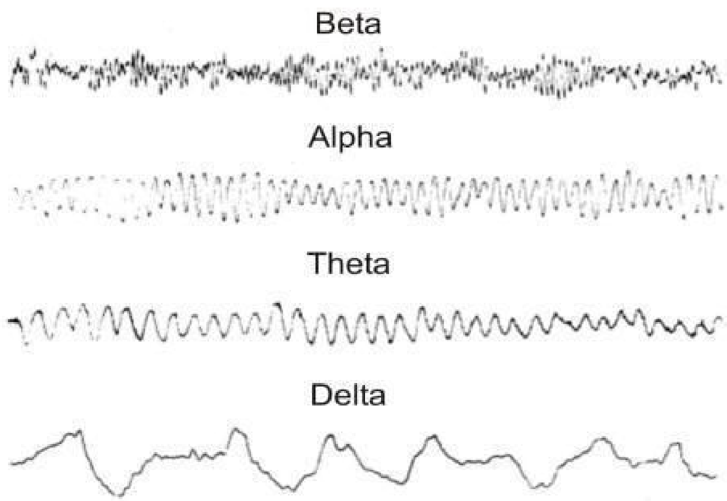


Figure 2. EEG Brainwave Patterns

To facilitate the acquisition of these signals, the Ultracortex Mark 3 headwear will be used, in part. Due to limitations of the 3D printing technology, only the main portion of the headwear was able to be constructed. The positioning of the frame of the headwear allows electrode placement in a "10-20" pattern, which allows for a standard for placing electrodes, and gives the readings that are taken meaning in a larger, less individualized context, though they may still have their data gathered individually as well. This can then be used to facilitate the technology to be of a more universal use, and therefore, be used in systems independent of the user's personal physicalities.

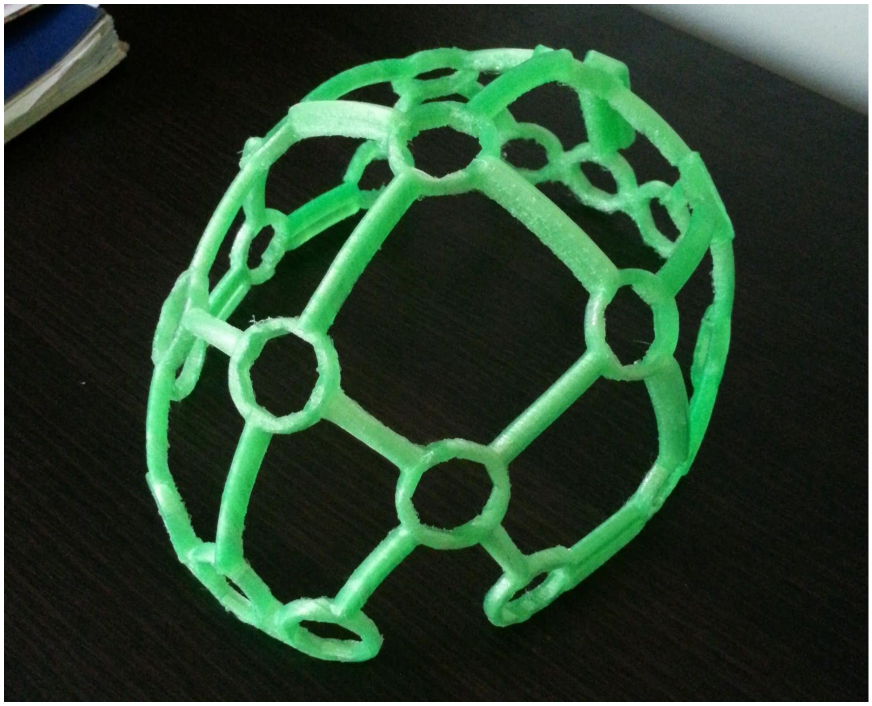


Figure 3. Ultracortex, Mark 3 (partial)

Only part of the Ultracortex model is depicted. Given time and technology constraints, some components (primarily those used for electrode contact to scalp) will have to be designed and built by hand.

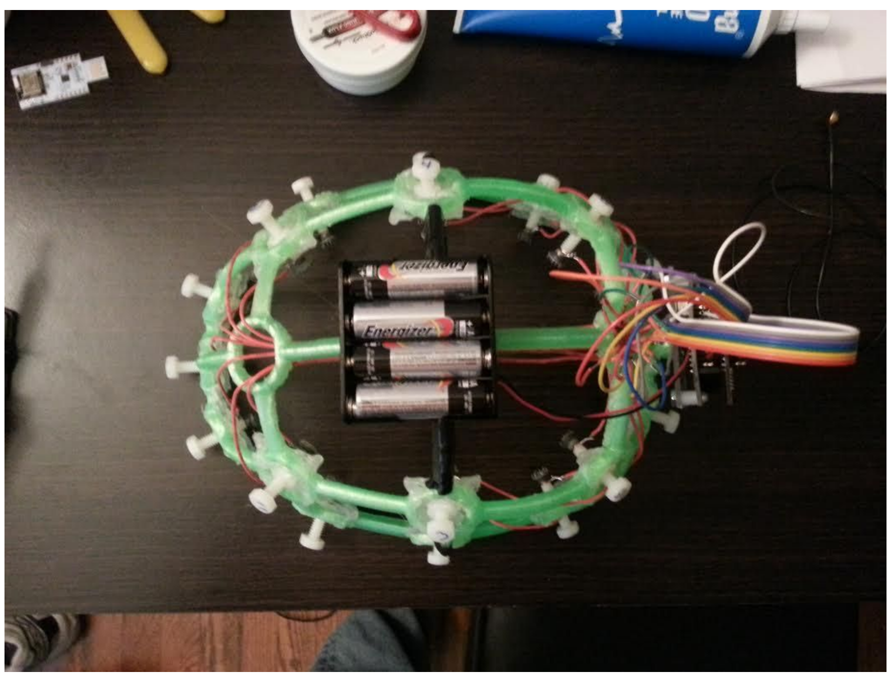


Figure 4. EEG System (complete)

Since initial development, the hardware has been completed for the EEG system, incorporating spiked electrodes for scalp contact. While this substantially increases discomfort to the user, it ensures the most accurate reading possible from the OpenBCI platform. The electrodes are connected via nylon bolts and a fitted wire loop to maintain contact while allowing the electrodes to be screwed into place, and each electrode is numbered to correspond to the placement on the 10-20 configuration diagram (Figure 10).

2.2.2 PC Terminal

The PC terminal will be a personal laptop setup to run the required software for the BCI integration, the main program or script, and the integration of data via the control keys. The terminal will also include Bluetooth connections, minimizing additional hardware required.

The main C++ console application that will control the Kobukis will operate by making regular checks to the processed BCI data. The program will send a signal to the kobukis converting those that need to from autonomous to controlled, or vice versa. To get the control keys, a getch function will be used to read the arrow keys the moment they are pressed

The program may use serial communication functions to send the control signals to the Kobukis via Bluetooth. Alternatively, until the above is determined to be necessary, testing will incorporate both group members' participation. The person not actively using the EEG system can simply record the values from the OpenVIBE platform (calculated and outputted at regular intervals) directly, and manually send the numbers to the Kobuki robots, negating the need for a serial communication as part of the PC program.

The PC terminal programs initial startup and main phase operation programs are finished. Additional modification may be needed to further reduce input latency (which will be evaluated prior to testing). Areas that remain unfinished are end phase data collection, where the stored information on the Kobukis is collected, and the communication protocols between the PC Terminal and the OpenBCI program.

2.2.3 Microcontroller

Each robot will have a microcontroller to control the motor functions as the Kobukis do not have that functionality built in. The microcontrollers will be Arduino UNOs paired with a Bluetooth serial shield. They will process the inputs received by the PC to their respective Kobuki control function.

The shield itself will convert all serial communications of the Arduino into a Bluetooth signal, as well as make the process of syncing to the pc easier. The shield we will be using is the Adafruit Bluefruit EZ link.

2.2.4 Kobuki

Fig. 5 Kobuki Robot

The robot platform used will be Kobuki from Yujin Robot. The kobuki robots contain 3 bump sensors, 3 cliff sensors, 2 wheel sensors, and an IR sensor. They are powered by a built in battery, and use 2 servo motor powered wheels to move. The Kobuki platform does not have built a built in controller, but is instead controlled externally via either USB or 25 pin parallel.

Fig. 6 Kobuki Robot (with Additional Hardware)

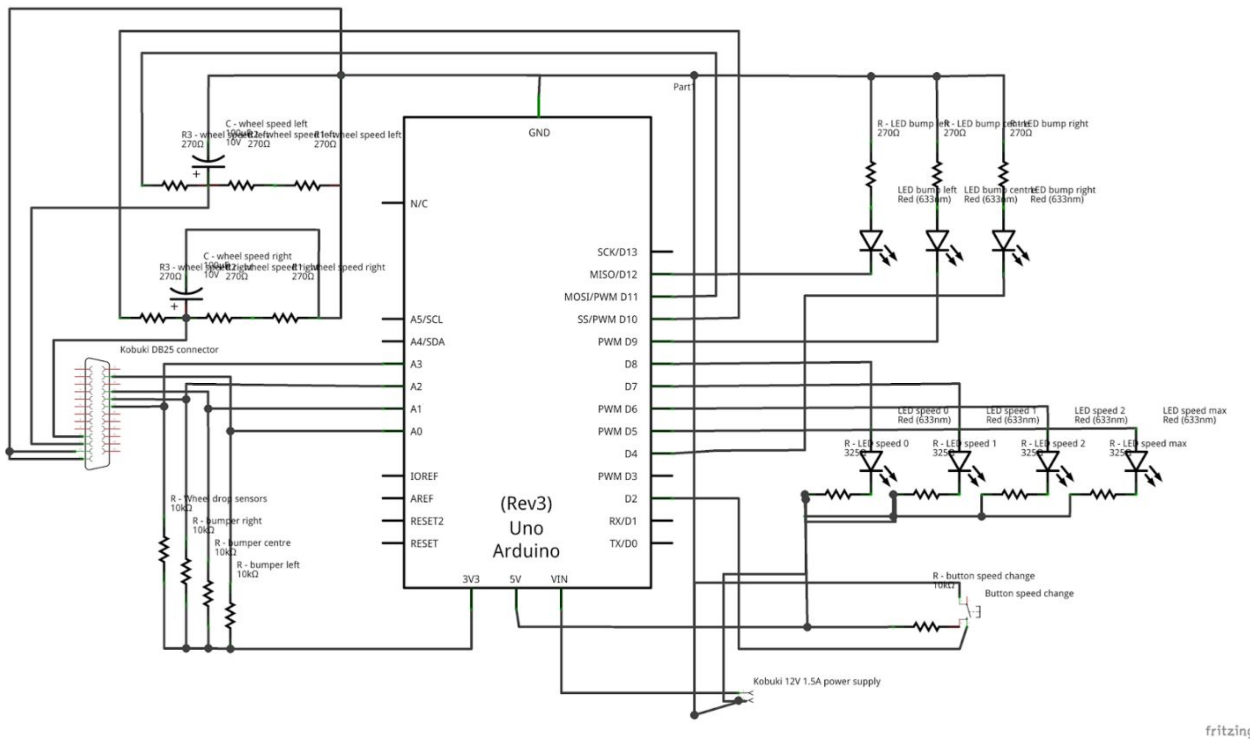


Figure 7. Kobuki Control Schematic

Figures 6 and 7 show the Kobuki hardware, fully built (unofficially, as not all functions have been tested), and the schematics of the additional hardware, respectively. Essentially, the schematic above shows the connections to the Kobuki's natural hardware (bump sensors, motors, etc.), and how the Arduino is able to maintain communications.

2.2.5 BCI Software

The OpenBCI platform uses an IDE similar to many Arduino platforms to write object-based code for the system. In addition to this IDE, there is also a program available that is designed to visually convey the information currently being provided via the electrodes of the EEG system.

In addition to the OpenBCI platform, OpenVIBE will be used to interpret the incoming EEG data from the OpenBCI device and filter the signals. The EEG signals for alpha and beta wave frequencies (which will be used to monitor the user's attention to their current task) will be filtered out and quantified, from which the absolute values and the ratios of the readings provided may be written into a separate file periodically, and read by the Kobuki robots as a sensor input (if the serial link is used). However, if the link is found to not be necessary, the link will instead be effectively provided by the second (without EEG) group member. By using time-based epoching (e.g., the past 10 seconds of evaluated data, updated every 5 seconds) the EEG signal within OpenVIBE, evaluation of frequencies can be performed at regular intervals that are easy to relay manually to the Kobuki robots.

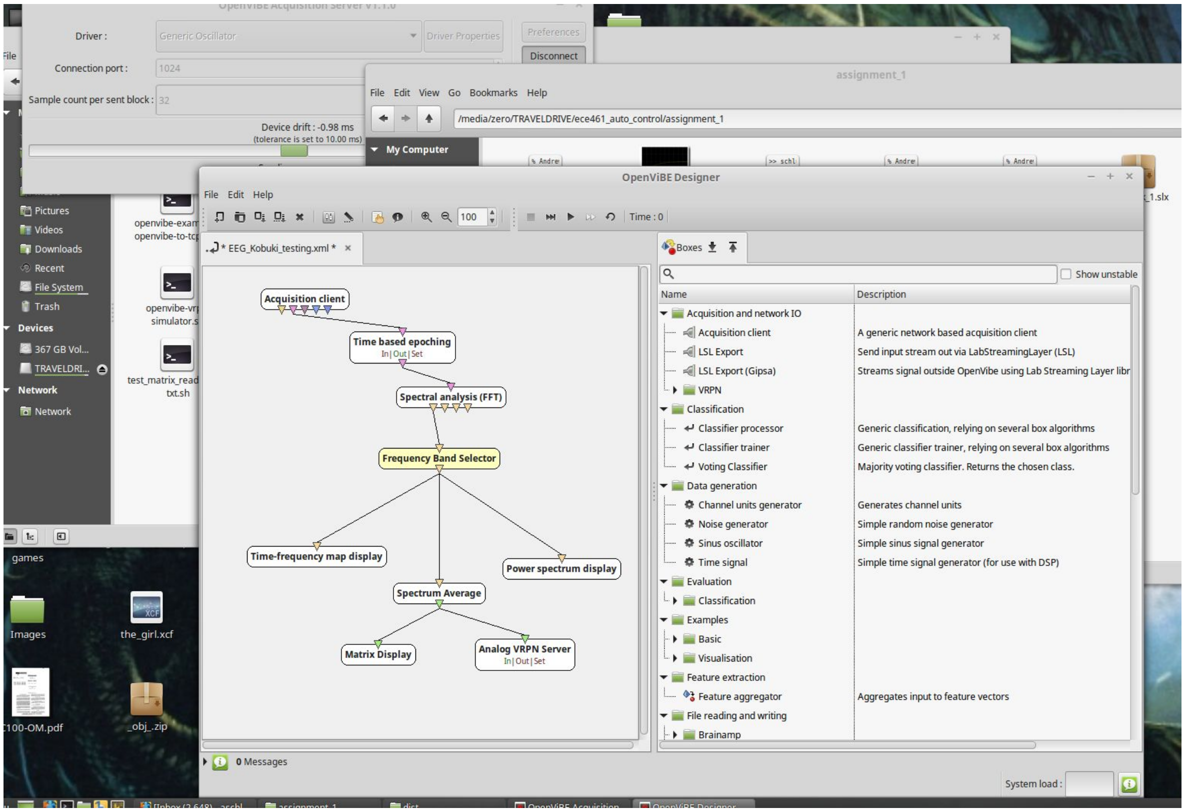


Figure 8. OpenVIBE Test Scenario Example

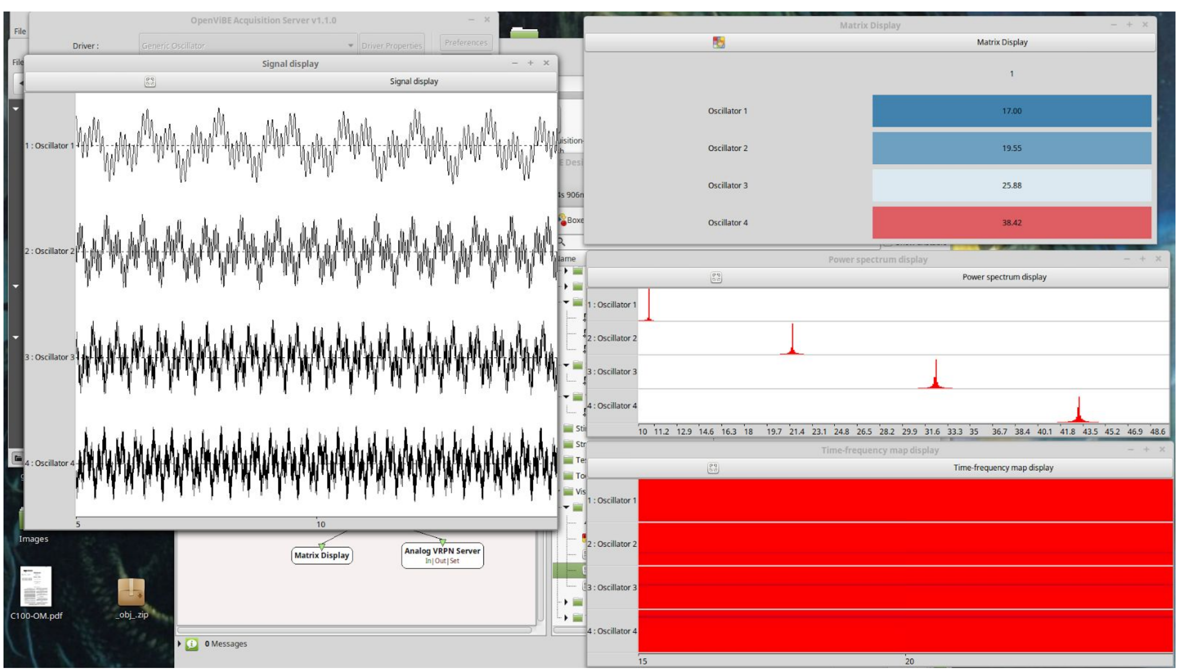


Figure 9. OpenVIBE Test Output

2.2.6 Kobuki Control Software

The Kobuki's have no onboard processing. As such a microcontroller will be used to process the received signals. The controller will cycle through checking for Bluetooth signals and checking for Kobuki sensor signals. When either is found it will determine the proper action based on whether it is currently in autonomous or controlled mode.

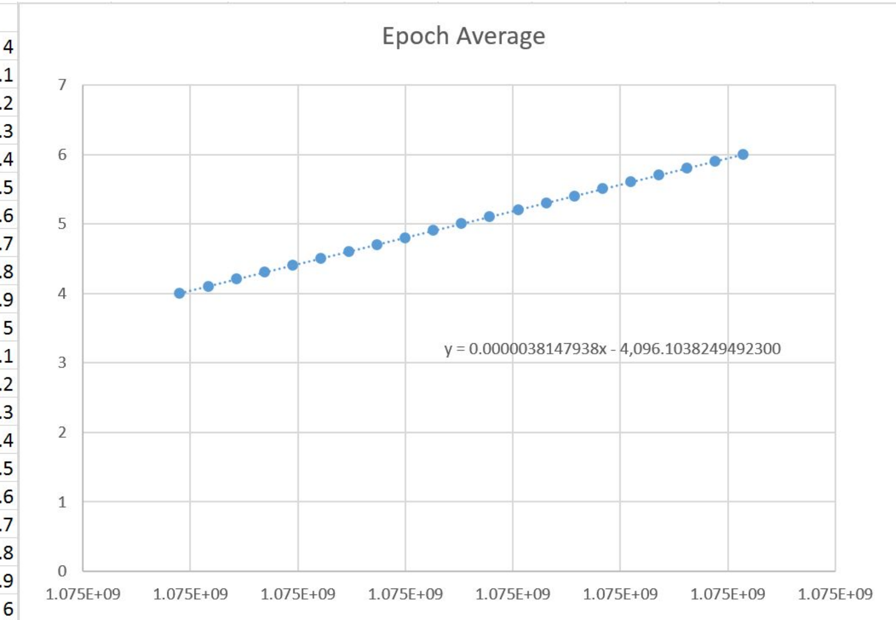
2.2.7 Serial Program

OpenVIBE stores the eight epoch average values based on the data passed from the eight channels of the EEG into a matrix. This matrix is then sent to OpenVIBE's TCP Writer, which opens a server that sends a data stream to a TCP socket to be picked up by the Kobuki control software. The Kobuki control program establishes a client connection to the server and collects the data. The data is then collected and decrypted into meaningful values to be used in determining the user's focus value. On the OpenVIBE side, this process simply requires instantiating a new TCP Writer object, assigning a port to establish the server on, and connecting the arrow from the matrix of epoch averages to the new TCP Writer object. Building a program capable of collecting and decrypting this data is much more difficult however.

It is important to note that opening a TCP socket is platform dependent. We chose to design our software to run on Windows, an ANSI platform. The first step is to open the Windows Socket API (WSA) through a WSAStartup function call. This allows the application to use sockets on a windows based system and returns the system specific version number. Then getaddrinfo is called to store the system's address information including IP, port number, IP family, socket type, and data transfer protocol. Next a socket is created and connected to the local OpenVIBE server with the port number specified in the TCP Writer object. We then shutdown the client's' ability to send data to the server, since we only want it to collect data. Then, inside of a while loop, the data is received by the client and stored into a buffer to be decrypted and extrapolated.

The raw data conversion is a personal hack developed specifically for this project to decrypt and truncate the data to a zero to six range. We first cast the individual unsigned integer data bits sent from the TCP Writer to a floating point value. The resulting value represents the actual numerical value, but on a different scale. We sent epoch values from four to six in increments of 0.1 and recorded the corresponding results. We then plotted the data to a graph and found the resulting trendline that will convert our values into the actual value. Since the epoch average is on a four to six range and we want it to represent a value from zero to six, we subtracted four from it and multiplied it by three to map it to the new range. The values of each of the eight channels are added up and divided by eight to return us the user's focus value.

Raw Float	Epoch Average
1074790400	4
1074816640	4.1
1074842880	4.2
1074868992	4.3
1074895232	4.4
1074921472	4.5
1074947712	4.6
1074973952	4.7
1075000064	4.8
1075026304	4.9
1075052544	5
1075078784	5.1
1075105024	5.2
1075131136	5.3
1075157376	5.4
1075183616	5.5
1075209856	5.6
1075236096	5.7
1075262208	5.8
1075288448	5.9
1075314688	6



2.3 Parts List and Cost Analysis

All costs and items are estimated. Components include major and some minor components. All parts and equipment needed are present. No other equipment should be necessary.

Table 2: Component List and Prices

Item	#	Unit Cost	Cost $ (est)
Kobuki	6	N/A	N/A
Open BCI	1	N/A	N/A
Arduino UNO Microcontroller	6	25	150
Adafruit Bluefruit EZ-Link	6	25	150
25 pin parallel adapter	6	~	10
Bread board	6	5	30
Stacking Headers (set)	6	2	12
Breadboard wires	N/A		10
Miscellaneous Circuit Components	N/A		30
Total			~400

3 Summary of Approach

3.1 Course Layout

The obstacle course is currently still being designed, however it be set up in such a way that the efficiency of using implicit EEG technology can be. The course will need to take into account the size and movement capabilities of the Kobuki robots, and allow clear description of which robots are available for assuming control of and which are not (pending attention state). We are also focused on factors such as lighting, should the final design require the use of LEDs for input (eg, infrared sensors, etc.) or even for status display to the user, and space required for accurate monitoring and meaningful results.

Currently, the on-campus gymnasium appears suitable for a smaller course, while maintaining the necessary walls needed to minimize complexity of the navigation AI and an appropriate lighting. A room will be scheduled once the BCI and Kobuki systems are operational and testing is ready to be initiated.

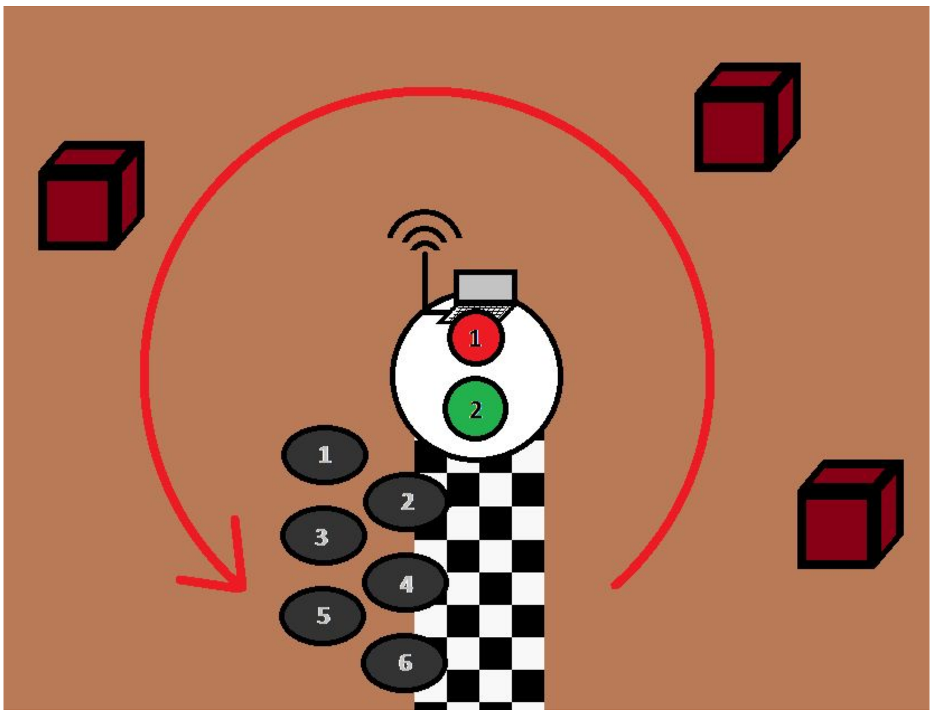


Figure 10. Original Course Layout

Figure 10 shows the original course intended to be used for evaluation. The terminal was to be set up in a small walled-off area (or raised platform) in the center course, along with both team members. The robots would have been lined up at the starting point, and the obstacles laid out. Due to constraints with the testing location, a track was unable to be built to allow for any form of lapping system. Difficulties due to the testing location availability lead to the simplified course layout that follows:

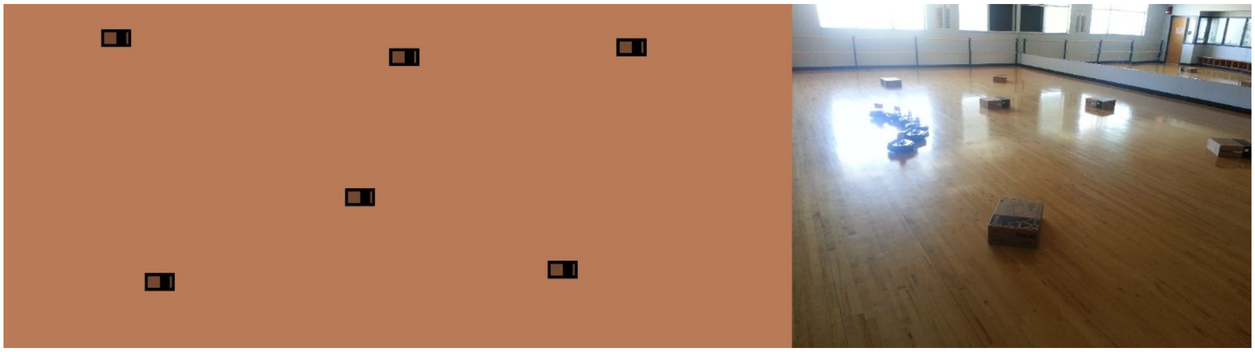


Figure 11. Current Course Layout

Figure 11 shows the course layout used for collecting data. Dance Studio C in the Old Dominion University gymnasium was selected, with dimensions of 47’x29’ (sufficiently satisfying the range of the Bluetooth connections with the laptop placed in the center or center-side of the room), however availability of other rooms was extremely limited. The current course layout provided only for the evaluation of collisions and collision rates, which was determined to be sufficient for testing purposes, provided that the data was weighted to reflect the number and types of collisions effectively. Problems arose while setting up Kobuki testing, due to the particularly smooth floor and large space needed by the Kobukis and the previously reserved rooms being removed from our continuous use, leading to the conclusion that a reserved testing area (on which a semi-permanent track could be built and the Kobuki robots tested without artificial restraints from management) would be vital for continued testing.

To allow for testing, over a time window of about 5 minutes, the Kobuki robots were maneuvered using all three modes of operation (however, technical problems prevented the collection of data from the EEG-based mode). In each case, control was given to the Kobuki robots only autonomously, only via manual control, and a combined version for testing basal attention levels and control capabilities from the operator. One group member acted as the operator for the cases of both full manual and EEG-based control while another monitored program operation and function, and another ensured data collection and proper operation of the testing procedure.

Figure 12. Kobuki Fleet, Awaiting Testing

3.2 Analyses of Alternative Design Concepts

There are a number of possible control system alternatives available for the Kobuki robots, and even a few for the BCI system itself. The decisions we have made as a group have been in an effort to minimize overall cost and complexity, while still keeping the intentions and spirit of the overall assessment and available data expected at the end of the course.

The original design had expected the OpenBCI wireless, serial USB connection to the PC terminal to have the potential to transmit serial data along with receiving serial data. This potential would have allowed us to forego an additional transmitter in favor of using the receiver has a transceiver instead. Unfortunately, this design would have encountered problems with timing, as timing is already a critical factor in delivering control data to the Kobuki robots from the terminal. A dedicated wireless transmitter would have to be used instead. Thankfully, the PC terminals we would be using already have built-in Bluetooth connections, and if necessary, a separate USB transmitter could still be used.

The original microcontroller that was researched was the RFduino. Given its built-in wireless capabilities, with minimal cost, the RFduino would have had limited functionality, and it was determined that it was incapable of processing the basic functions of the Kobuki robots in real time.

For the obstacle course, a room was initially envisioned that would allow the traversal by 6 individual Kobuki robots, with obstacles placed intermittently, blocking the Kobukis from their goals. The length of the course would be the main difficulty then, particularly given the limited range of the wireless Bluetooth control system. Ultimately, a course would need to be designed to allow movement of all Kobukis together, while staying within range of the PC terminal.

Although there were many advantages to the alternative designs, including reduced price, there were too many limitations to using the bare minimum of components. Instead, more capable systems, particularly the microcontrollers, were found and decided upon in place of the initial design microcontrollers. This enabled far more effective control of the Kobuki robots, and still maintained minimal costs by continuing the use of simple, economic choices in components and minimizing the addition of unnecessary extraneous systems. By using Bluetooth connections, the systems are already able to be connected via the PC terminal, minimizing additional cost. This also has the advantage of having its own protocol structure, negating the need to create one.

3.3 Realistic Constraints

The primary constraint we encountered was monetary. During the entire design process, we kept the overall cost in mind. Knowing that the Kobuki robots each needed a control system, the price was going to be a noticeable sum already. From here, we simply made the most cost-effective choice, given our available options, and noted the early estimates in the parts table shown earlier in the proposal.

Constraints were also found in the technologies available to us. While it would be ideal to have more channels, or higher processing capabilities, the efforts required to design and utilize such a system would be beyond those likely expected, and would again result in an increased cost. More elaborate robotics would also be ideal, but unnecessary to reach the goals required of the assignment.

Lastly, a major and unexpected constraint was the limitation of testing areas. An enclosed room with a smooth floor and dimensions of approximately 40’x40’ was determined to be ideal, given the 30’ range minimum of the Bluetooth connections. Unfortunately, upon preparing for testing, access was denied for the testing of the robots on the grounds of potentially damaging the equipment or room. An agreement was reached to allow for one full day of testing, however, in the future, a different testing room will need to be made available.

4 Evaluation

Data was collected from both the autonomous and manual control modes. Due to technical issues (terminal-side), data was not able to be obtained from the EEG-based control mode, however the system is sufficiently prepared to acquire, so long as a proper course is provided or able to be maintained.

4.1 Evaluation Plan

While awaiting parts, each subsystem was be properly built, written in software, and calibrated. Once all parts were obtained, the physical construction of all robotic systems was completed and the software was uploaded to each robot and tested for proper individual robot function and control program command.

The course was be designed following the earliest implementation of the system, allowing for the injection of substituted EEG data for testing purposes as needed. As progress developed, the substituted data was dropped to allow for the serial program to bridge the programs and allow control from the terminal as well as transmit the 1 to 6 value to the Kobuki robots to indicate attention levels.

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As the project develops, so will the system and course complexity, until the stage is reached in which full evaluation may be conducted. The current plan is to evaluate the EEG signals using alpha and beta wave data pulled using OpenVibe, processed, and saved into a text file that may be read by the Kobuki software (simplified to a single value, from 0 to 6, for 0, an error code). As stated earlier, unless determined to be ineffective, the second team member will be reading the data manually and relaying it to the Kobuki robots directly.

Analysis of the data will consider both the number of completed laps and number of contacts made with other objects. These can be compared with control runs (including both fully automated and fully manual tests). The working theory is that there should be fewer collisions and potentially greater speed of completing the task (more completed laps per Kobuki) than either control run. This will be expounded in the final report once the data is available.

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4.1.1 EEG Evaluation

The

4.1.2 Kobuki Control Evaluation

The

4.1.3 System Evaluation

The

4.1.4 Issues and Resolutions

Apparent Potential Issues and Resolutions:

- Unable to acquire adequate EEG signal strength: Adjust filtering, epoching, and electrode placement/configuration.
- Inadequate differentiation between channels: Increase number of channels

- Unclear results from analysis: Re-perform test. Adjust test itself if necessary

4.2 Team Organization and Performance

4.2.1 Contribution of Each Member

Each team member worked hard for this project's development, and specific tasks were distributed based on individual skillset to ensure we maximize the efficacy of our workflow. Note this does not mean we were limited to only working on our portions; however, below listrs the responsibilities of each group member.

- Joshua Collins – Robot control implementation, PC control program, and Bluetooth communications.
- Andrew Schluchter – EEG system development, BCI hardware and software implementation, and biological concerns.
- Jonathan Blincoe – TCP/IP communications and overall software support.

4.2.2 Integration of Contribution

The BCI systems will be developed separately from the Kobuki control systems so as to efficiently divide the efforts of both team members. Black box operations will be used for early-stage designs, meaning the simple output numerical values from the BCI system, and the use of given values to assist in controlling the Kobuki systems. Integration will follow the development of working stages of each side of the project.

4.2.3 Next Steps

Further testing is needed to come to any conclusions on the viability of implicit EEG as an effective option of partitioning control of robotic vehicles based on the mental capabilities of the user. Testing should include the selection of a new testing room or course, and subsequently, the formation of a testing plan that fits the location. Data will need to be obtained for a number of runs in fully autonomous, fully manual, and the EEG-based control methods. All methods have been tested and determined to work fully, such that data collection should be easy and straightforward in later tests.

4.2.4 Engineering Standards

We incorporated Bluetooth into our project for communication between the PC and Microcontrollers, and the "10-20" configuration for the EEG electrode placement setup.

IEEE 802.15.1 - Bluetooth is a wireless technology standard for communicating data over short distances. The Bluetooth specification was established in 1994 and is based on frequency-hopping spread spectrum technology. Bluetooth was established as an IEEE 802.15.1 standard. This standard is no longer maintained by IEEE. Bluetooth is now managed by the Bluetooth Special Interest Group.

IEEE standards for robotics and automation also apply, however these standards are still in development. Currently, focus remains on ensuring common forms of measure and evaluation, standards for comparison across systems, and subjects such as integrity, longevity, and ease of transport. This can be found in accordance with the Standing Committee for Standards Activities (SCSA) under the Industrial Activities Board (IAB) of the IEEE Robotics and Automation Society.

Standards are also met for the FCC, inherent to the design of the RF and Bluetooth modules purchased. No additional wireless activity was present.

The 10-20 configuration is an unofficial standard of the industry for EEG-based systems. Manuals can be found online, such as the 10/20 System Positioning Manual by Trans Cranial Technologies. Essentially, the electrodes are placed in such a way as, from a top-down view, the user's hemispheres are divided into sectioned angles from the user's forehead to the back of their head. The proportions of these angles are as follows: 10%, 20%, 20%, 20%, 20%, and 10% of the hemisphere. Thus, the 10-20" standard. The remaining electrodes are placed evenly along the vertical and transverse portions of the user's scalp to the addition of 9 electrodes. Therefore, there are a total of 21 possible locations at which to place electrodes and extract EEG data. With OpenBCI allowing up to 16 channels, only 16 electrode locations will be used. Readings will be taken to find the ideal electrode locations when the system becomes operational and, once determined, the locations will be recorded and used consistently.

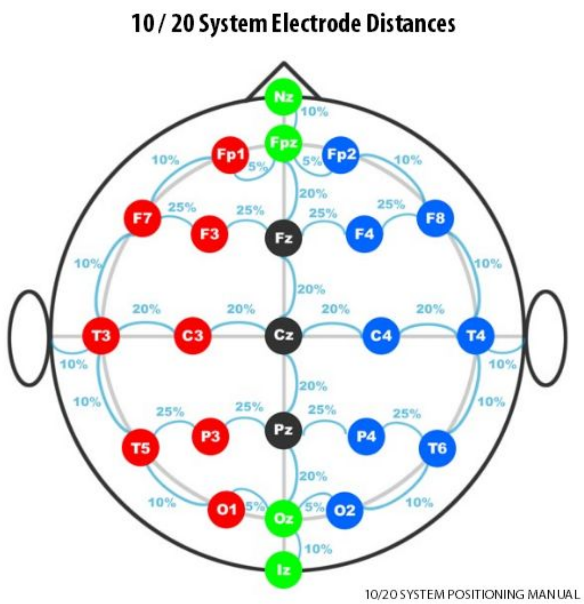

Figure X. 10-20 Configuration Overview

5 Discussion

5.1 Ethical Implications of Issues of the Project

Biomedical engineering poses an ethical concern by its own existence. If engineers are able to manipulate biological systems, tissues, etc., than the question arises as to whether or not people are machines. Yet from a biological perspective, all life consists of machinery, and this is what biomedical engineering is actually manipulating. While life maintains its sacred nature, conflicts that arise from individual systems still must be dealt with, and the creation of biomedical devices allows this. Using systems like those designed to utilize EEG technology allows for the betterment of individuals, and allows a greater depth of interaction with technology and the world around us.

Robotics are also a major ethical concern, particularly in the modern age. Given that the machinery we built must act, to some degree, of its own accord, one must ask at which point the machinery must be considered sentient. Fortunately, the level of intelligence needed by, and in fact, capable from, this assignment are not at any level which raises ethical concerns from the robotics themselves.

The primary ethical concern in our project is the novel concept of using a person's brainwaves, without their conscious consent, and evaluating their ability to perform a task. This poses an ethical issue similar to consent in life-threatening situations, such as hospital care. However, although it is a legitimate concern, the accuracy of evaluation at this level is minimal, and in essence, of no large concern at this point.

5.1.1 Privacy

In the age of information, privacy is a prime concern. Because most members of society are integrated into a digital world, to varying degrees, and because information must be given to grant access to even simply checking restaurant hours, or purchasing movie tickets, information tends to be almost a currency of the online world. To mitigate the damage this could cause in the wrong hands, privacy concerns were voiced and have been dealt with on many occasions. The issue is not one that will lessen in the near future, but we can each do our part to ensure that privacy is not violated.

One of the main concerns over systems which can effectively read the brainwaves, and therefore states of consciousness, lies in the idea that the thoughts that the system is designed to read could instead be controlled. While this could easily be seen as privacy violation, the systems we are using have no ability to alter brainwave patterns, nor retrieve information beyond simple states of mind. The project currently being undertaken has no use for a more intimate reading of the brain or brainwave patterns.

5.1.2 Accuracy and Reliability

Accuracy and reliability are the two most critical points of EEG technology, and of automated systems in general. Without consistent, meaningful results, there is no purpose in using the systems we are designing. Without the ability to reliably obtain accurate results from the BCI system, there is no real point in using the system at all. Likewise, the Kobuki robots must be able to receive commands and execute them in a manner that the system intends. With no relative guarantee of reliable function, the entire goal of automation ceases, and the system cannot function. To resolve this, we are designing the system both on the BCI and on the robotics fronts. So long as we are able to obtain the results we expect, consistently, from the BCI system, we will reliably be able to use the signals generated. From there, the Kobuki robots will be designed to function in accordance with their written programs, and testing throughout all phases of the project will help to ensure that this goal is met.

5.1.3 Safety

Safety is a serious concern in all forms of engineering, but especially within the fields of medical engineering and robotics. Any devices built to interface with human users must be safe for the user and others. Some devices cannot be removed easily after being installed in certain environments, such as within the body, or can otherwise not be presumed to be safe without careful guidance and a solid understanding of the equipment. This clearly presents the issue within the robotics as well.

In order for many systems within the biomedical fields, and in fact, many engineering fields, to function properly, a complex autonomous system must play a crucial part. Machines such as surgical robots, automobiles, and even simple transport equipment, like elevators and escalators, all require safe designs to be maintained, meaning that faults in these designs should be taken seriously, and redundancies and other safety measures need to be designed into any system that may endanger the user.

In our case, none of our equipment actively applies electrical energy to the user, and so the user is under no risk of injury. There is also potential risk of uncontrolled errors when operating in autonomous mode, however the robots will be monitored over the entire course of the experiment, negating the issue in our case.

5.1.4 Drone Ethics

Lastly, it is important to emphasize that the use of robotic drones to evaluate the efficacy of implicit BCI control is singular. Similar to testing using a computer game, the implementations of EEG systems for drones are not to be treated as real-world examples of what the technology should be used for, but instead, testing platforms only. Although drone control could incorporate EEG technology, the use of drones themselves is ethically ambiguous at best, and downright malicious at worst. Given the recent records of drone operators both targeting civilians and subsequently quitting in large numbers, extreme care should be taken in drone control, and our data is therefore not intended to further facilitate real-world drone operations at this time.

5.2 Lifelong Learning

5.2.1 Andrew Schluchter

My responsibility for this project is to focus on the BCI portion of the device and system. The EEG headgear is complete, and the next step is to establish connection of the system via USB to the PC terminal or to verify that OpenVIBE is capable of relaying information through the method which allows for the most useful data to be retrieved. I am also responsible, alongside my team mates Joshua Collins and Jonathan Blincoe, for the obstacle course design and layout to test the implicit BCI system.

I will be continuing my education into graduate studies in biomedical engineering, and I will need the knowledge of many applications of medical devices, including EEG technology, and the concerns of implementing such a system. Many bionic devices may require the implementation of EEG, or the highly similar electromyography (for reading signals from the muscle tissue), and the techniques regarding wavelet and Fourier analysis may prove indispensable.

5.2.2 Joshua Collins

My responsibility for this project is the second half of the PC implementation, Bluetooth communication, and microcontroller implementation. The part of the PC program I will be developing will use the 1 – 6 number calculated by the first half of the program and the input commands to calculate the signal to be sent to the robots. I will be working with Andrew Schluchter on the actual robot construction.

The program will be written in C++, a language I am very familiar with from my classes taken for my degree. I have much experience with microcontrollers, primarily the Arduino which is the most likely one to be used. I will have to learn about Bluetooth communications from online resources. I expect to gain a great deal of knowledge and experience in control systems and serial/Bluetooth communication as this project progresses.

5.2.3 Jonathan Blincoe

I joined this group late, so much of the work was already completed. My responsibility for this project was to build a TCP/IP data collector to accept the epoch average and truncate it to a value from a range of one to six. I also worked with Andrew Schluchter and Joshua Collins to smooth out any software issues encountered throughout the development of the project. As a computer engineering major, I am familiar with interfacing devices with software, and I was able to practically apply what I learned throughout my undergraduate career to this project. I learned to program TCP/IP connections on a POSIX system in an operating systems course, but the software was run on a Windows system. As a result, I gained valuable knowledge on the inner workings of the Windows operating system.

I plan to pursue higher education in Nanoscience and Nanotechnology Engineering. This project is a great opportunity to apply my understanding to a field related to my undergraduate studies and to expand my knowledge base into other fields of science.

5.3 Impact of Engineering

The impact of creating an implicit EEG-based system that promises meaningful results could mean the advent of a new type of technology. Given the prevalence of systems such as optical equipment for tracking eye movement in pilots, and monitoring brainwaves and mental states for further analyses, many new devices may be able to positively integrate this type of technology to allow better interfacing with other devices.

This also posits the idea that EEG, and all BCI technology, may have a much larger role to play in the near future.

5.3.1 Economic, Environmental, and Societal Issues Related to Project

There are many practical devices that could be designed using the technology being studied. Some of these may include military applications, and our course is designed to partially reflect this. Other applications include equipment for more allowing deeper connections to computer technology through a new type of interfacing, and critical research equipment for use in learning more about the human brain. Unfortunately, the issue arises as to the potential consequences of research into brain control interfacing. Some may see this as leading to invasions of privacy, or otherwise seeming somewhat unsafe. In reality, EEG only draws readings from the scalp, without introducing any additional electrical signals to the user's body, meaning that there is minimal chance of electrical injury. And to dissuade any privacy concerns, the resolution of data that can be retrieved via EEG is extremely small. Simple assessments can be made regarding the user's state of mind and, with certain systems, a small number of trainable thought "commands." The complexity of this type of system, however, will likely exceed the capabilities of our own.

5.3.2 Expected Overall Educational Benefits from Project

If these systems are able to be built as expected, and the course allows for a clear interpretation of whether or not to continue on with research in the field of implicit EEG technology, then this may well impact the future of biomedical devices. And with such a large emphasis on engineering and robotics within the field of biomedical engineering, understanding EEG and BCI systems will likely provide a solid groundwork for many devices to come in the near future.

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Appendix A

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