Draft Proposal

VR Learning Environment with Real Time Brain Signal Monitoring

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Executive Summary

With the rise of the Covid 19 pandemic, the world has been forced to quickly adapt to unfamiliar circumstances. Public safety guidelines have spurred a mass transition from face-to-face meetings into online workspaces.This migration to online workspaces has had a huge impact on the normal workday, but it also caused many changes to the traditional learning environment. Although there have been incredible efforts from schools and teachers, some students are struggling to adapt to new teaching techniques.

Distance learning introduces many new challenges and distractions to the average school day. The usage of collaborative environments aids teachers with relaying information, but there are many subjects that are taught more effectively through hands-on learning. Some ways of simulating this hands on experience is through virtual labs and videos. This method can be lacking, however, and it doesn't give the immersive feeling of being in a lab. One way to improve this method is to implement virtual reality to aid with learning. Virtual reality can give a fully immersive experience that makes you feel like you're actually there. It also allows you to experience things that would never be possible otherwise, such as walking through an old civil war museum or look at the individual parts of a cell.

While virtual reality by itself is a powerful tool, we can take it one step further to make it even more useful for schools. By implementing a brainwave headband reader, such as the EMOTIV's EPOC+, we can monitor students' attentiveness and understanding of a certain topic. In doing so, teachers can take an active role in the students' learning. This allows teachers to challenge a student who is thriving, or help along one who is falling behind. Brain waves can be rather complex, though, so we will implement an easy to read centralized interface for the teacher to monitor a large group of students at once. To do so, we will use information gathered from the EPOC+ and compare them to generalized brainwave patterns for concentration, understanding, and more.

A customized game incorporating both VR and brain wave pattern analysis will allow for a deeply immersive experience tailored to a course's needs. Almost every course could benefit from this, but hands-on intensive courses in the STEM and medical fields could have incredible potential. The specially fit headset we will design alongside the EPOC+ will be a perfect tool for implementing these kinds of games. Technology in virtual learning environments could be a huge market in the future.

Problem Statement

Introduction/Motivation

During the COVID -19 pandemic, learning can be extremely difficult due to the situation it puts students and teachers in. With most schools and universities transitioning to virtual learning, it can be especially tough for those students who benefit the most from in-person teachings. As this has been a pressing issue over the past seven months, the issue needs a solution to help both students and teachers in this situation. Most students learn in different ways and most can't focus in these virtual learning environments as external factors can take over that would otherwise not be there in a classroom environment. This creates major limitations in virtual learning environments. Shown in figure 1, is a study which teachers and students identified the limitations of virtual learning as a whole.

		Limitations
Inefficiency	Unable to teach skills	"In anatomy, the study through models was good. But hands on training is not possible, the student will not be able to understand properly. Skills needs actual hands on training".
	Lack of student feedback	"I find it annoying that during lectures you don't have students feedback whether they are getting the point or not".
	Limited attention span	"There is no continuity of lecture. We lose our concentration and the syllabus is so lengthy."
	Lack of attentiveness	"As the students know that they will get the recordings, they don't listen the lecture properly".
	Resource intensive	"Lots of people might not be having these gadgets. Buying these gadgets comes an extra burden on them in such stressful situation".
Maintaining academic integrity	Lack of discipline	"There is some problem coming with discipline, some students use to misbehave during lectures".
	Plagiarism	As this system is new to everyone, it is difficult to have individual assessment. During assignment, they easily copy paste stuff from web."

Figure 1: Limitations with online learning environments.

Source: Adapted from [1]

This has been an obvious issue since march 2020 to present (September 2020) and there haven't been many major ways this issue has attempted to be mitigated. Our virtual reality learning environment could help not only students but teachers as well. Creating an affordable learning environment through monitoring different aspects of brain signals can help identify what help is really needed for every individual. Overall, many studies such as the one shown in figure 1, identify a multitude of issues with online learning and this project is a great opportunity to help identify and solve these issues.

Identification of need

In this project, our VR environment would need to help monitor the different aspects of learning in an educational environment such as attention span, stress, and other variables through an EEG. Through this data our VR environment would need to provide feedback to the user in order to help each individual with specific issues. This would need to be a low cost solution so it can be accessed by multiple students/teachers.

Market/Application

This product can directly be used by learning institutions specifically for students and teachers who need it. A prevalent problem in the education system amidst a pandemic is the lack of a personalized digital educational experience. A tool to assist learning retention in online education environments via an extended reality platform that is low-cost and accessible for those underrepresented in educational environments and for educators to monitor the effectiveness of their lessons as the goal of the project is to monitor brain signals.

Approach

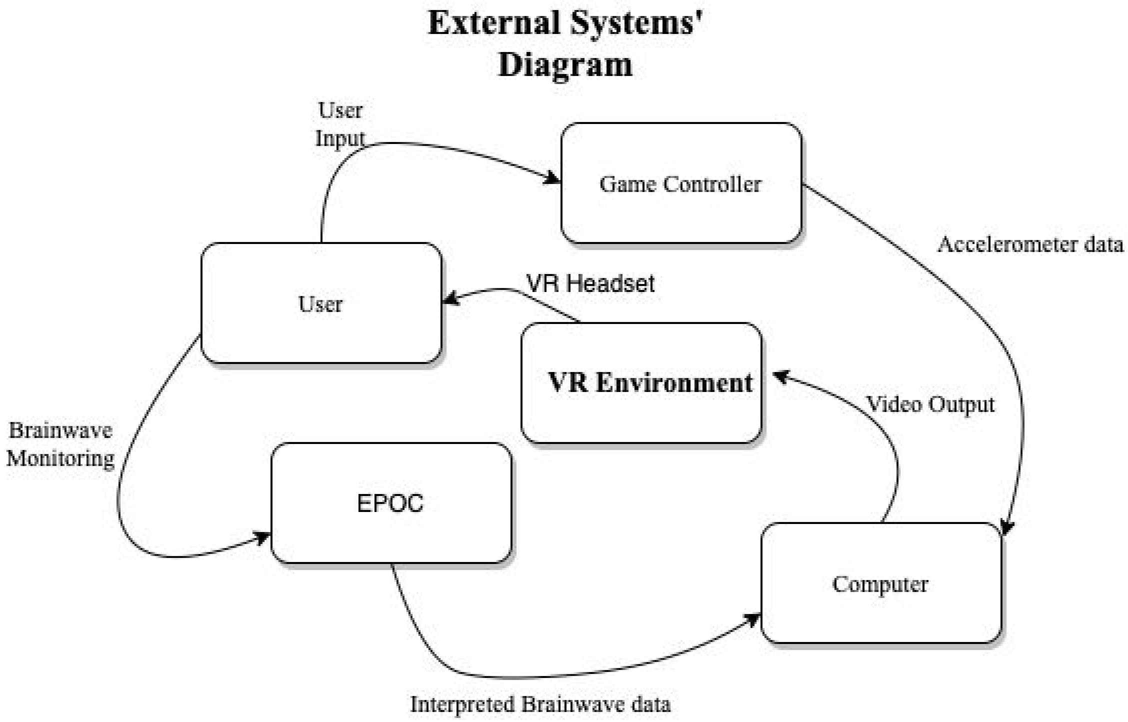
Problem analysis:

The main problems that this project intends to address are issues associated with learning outside of the classroom during the COVID-19 pandemic. Evaluating this solution revolves around several aspects. The first aspect is the safety of students from the pandemic. One of the main purposes of this project is to make distance learning more efficient in order to maintain safety. Assuming that students will obtain access to this hardware through the school, similarly to borrowing a laptop, there are a few safety precautions that need to be considered. Proper precautions such as social distancing, the wearing of masks, and consistent sanitation of areas should be taken when obtaining the hardware. Doing this should preserve the safety of the students and faculty and provide a very safe way to enhance their distance learning experience.

The second issue that needs to be addressed in this project is the implementation of the virtual environment. This environment needs to be intellectually stimulating and provide accurate information that the student can learn from. Many classes such as STEM and medical courses will be ideal subjects for implementation of this project. In order to properly implement a functioning module in a particular subject, the information from the module must be properly researched. These modules can also be made to go along with specific lessons, allowing them to be a supplemental teaching aid to what is discussed in the class meeting.

The third issue that needs to be addressed is the comfortability of the student. This is extremely important if the student will be using the virtual environment for an extended period of time. The proposed solution revolves around modeling a VR headset that fits well with the EMOTIV EPOC+, the brainwave monitoring headset we will be using. 3D modeling a custom headset allows the design to have maximum comfortability. The first issue that is addressed is the orientation of the headset of the student. The headset will be designed to work similarly to other popular VR headsets. The implementation of proper padding and adjustable head straps will allow the user to have the most comfortable experience. The VR headset also needs to allow the EPOC+ to sit in the proper place on the students head. This is the reason for the creation of the custom headset. Modeling the VR headset with the EPOC+ in mind allows for both to fit properly.

The last issue that needs to be addressed in this project is ensuring the usability of the data obtained from the EPOC+. The brain signals obtained would be difficult to interpret for someone who does not fully understand each of the readings. However, this project will have a central hub for the teachers to monitor students to see their concentration and understanding of the information currently being presented. In order to do this properly, we must find a way to extrapolate the data and make it easily readable for people who don't fully understand brain waves.



Approach:

When approaching the solution for building a virtual reality learning environment monitored by brain signals, there are many things that need to be considered. The first thing that needs to be considered is the environment itself. The learning environment needs to be able to hold the attention of the student. A big advantage to using virtual reality is that it cuts out distractions. When wearing a VR headset, the student will be submerged in the virtual environment. This helps mitigate distractions not normally present in a normal classroom. Another important factor to consider in this design is the creation of interesting and relevant modules. These modules can be tailored to fit the needs of specific subjects. Some potential applications could be its use in STEM classes, science labs, and medical applications. A major benefit to using virtual reality for teaching is that it can provide a hands-on experience. Knowing that all students learn in different ways, this can address the problem that many students face when learning outside of the classroom. The creation of a stimulating virtual environment with relevant course material will provide a deeper learning experience to students who are forced to learn in an at home setting.

The second problem that our solution addressed is the methods used to obtain brain signals from students. For this project design, the EMOTIV EPOC+ will be used. While using this headset to monitor brainwaves, different factors in a student's physiological state can be obtained. Among the many things that can be monitored, a student's concentration and relaxation levels can serve as an indication for their real-time experience while doing a module. This can show which students are most interested in a topic, as well as the students who are struggling. The second issue that our solution addresses is the use of this information. Unless experienced with brain waves, most teachers will not be able to determine brain state from the signals alone. Using the EPOC+, the brain signals can be exported from each student. The monitored patterns will be displayed in an easily readable format through a central location provided for the teachers. This will allow for the teacher to monitor how engaged a student is in real time. Lastly, the modules are designed to give the students lessons of many durations. This means that the hardware for this design must be comfortable for a student to wear for extended periods of time. The creation of a VR headset that works in accordance with the EPOC+ will be important for addressing this. A custom design will allow for maximum comfort when using both the EPOC+ and the VR headset in conjunction. This custom headset will also allow for every contact point of the EPOC+ to sit in the correct location on the students head for proper brain wave monitoring. Implementing all of these factors will allow for the student to get the most from their learning experience in an at-home learning environment.

Alternative Approach:

Due to the nature of this project, there are several possible issues that may arise when attempting to implement this solution. The first potential issue revolves around the creation of the virtual reality headset. Our senior design team has limited experience with 3D modeling. To fully utilize the created virtual environment, a functioning headset is necessary. The consumer market is filled with many virtual reality headsets that are optimized to create the best virtual experience. If the group cannot create a functioning model, we plan to use the Oculus headset. Switching to the approach would cause a significant increase in price, but would provide an ideal experience for using the created modules.

Another major issue that surfaces when implementing our solution is the placements of the VR headset and EMOTIV EPOC+. When using the EPOC+, it is crucial that the placements of the sensors fall in the correct location. As shown in Figure 2 below, the location of the sensors fall in the same space that the VR headset is positioned on the head. If both pieces cannot be positioned correctly, this would compromise either comfort of the VR headset or accuracy of the EPOC+. Also, the EPOC+ covers a large area of the head, potentially leading to difficulties surrounding its use. As a backup, we have intentions on using the MUSE headset to brain wave monitoring. This headset is positioned exclusively on the forehead, allowing for easier use of the two items conjointly. Modeling a VR headset around a headband is also an easier task than modeling one around a whole head covering. The MUSE is our alternative approach because it contains less sensors than the EPOC+, meaning that less data about physiological state can be obtained from it.

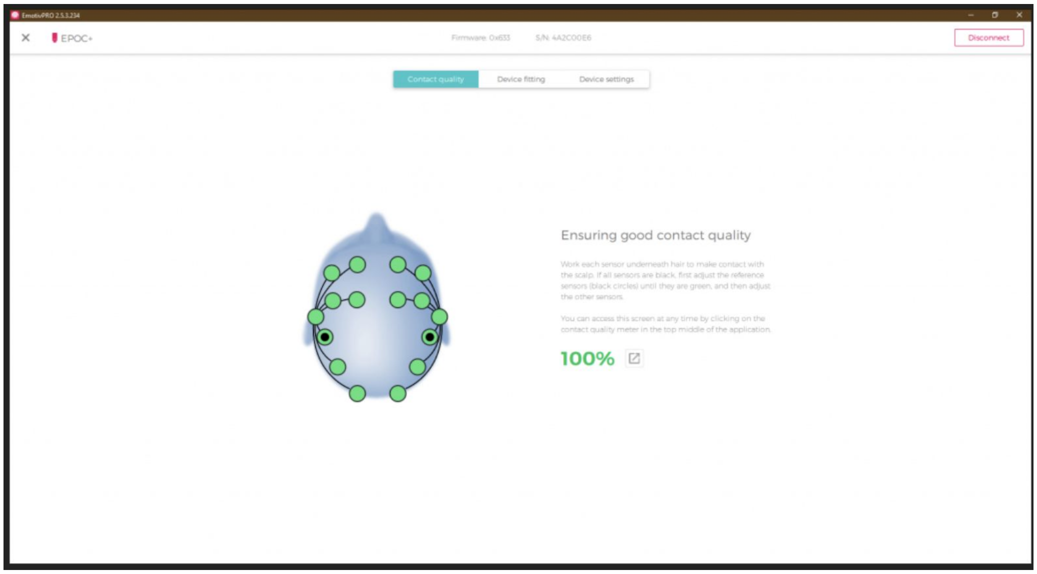


Figure 2: Placement of EPOC+
Adapted from [3]

The last potential issue doesn't pose as big of a problem but it still needs to be considered. For this project we intend to use an LCD screen to display the virtual environment. Implementing a screen into a VR headset would require a design for a larger housing. This would also require an HDMI cord to run into the headset. This was our primary idea for the headset because it allows the code to be written as a computer application instead of a mobile app. If using the LCD is not practical, using a phone for the display in the headset is our alternative plan. This would require mobile app development for the modules. This could be problematic because our team has limited experience in this area. Switching to this alternative approach would require more time to produce a finalized product, but the functionality should remain the same

Intro to Background Knowledge:

When attempting to understand readings from EEG, it is essential to understand the different types of brainwaves that readings are obtained from. Distinctions between different categories of brain waves lie in their variation in frequency. Different brain wave categories are responsible for different brain functions. When using EEG, the primary wave types that are measured consist of Beta, Alpha, Theta and Delta [5]. Beta waves, typically ranging from 12 to 38 hertz, “dominate our normal waking state of consciousness when attention is directed towards cognitive tasks and the outside world” [4]. These types of waves are ideal for studying brain function, making them an ideal method to determine brain state during our designed modules. Alpha waves generally signal thoughts, aiding in, “ mental coordination, calmness, alertness, mind/body integration and learning” [4]. Alpha waves will also be very important when monitoring the physiological state of a student. Tracking these waves provides a good indication of active thought process and potentially attention span. Theta waves act as a gateway to cognition, demonstrating when the user is in the process of falling asleep or waking up [4]. Delta waves are generally only present when in a state of deep sleep. These two types of waves probably will not be as useful for application in this lab. Figure 3 below provides differences in frequency and potential uses for each of the brainwave categories. It should be noted that this chart includes Gamma waves. The EPOC+ has the potential to read gamma waves, but being the highest frequency waves, it may be harder to interpret them. Understanding the distinction between brave wave types and frequencies will allow for a better understanding of the information gathered from the EPOC+.

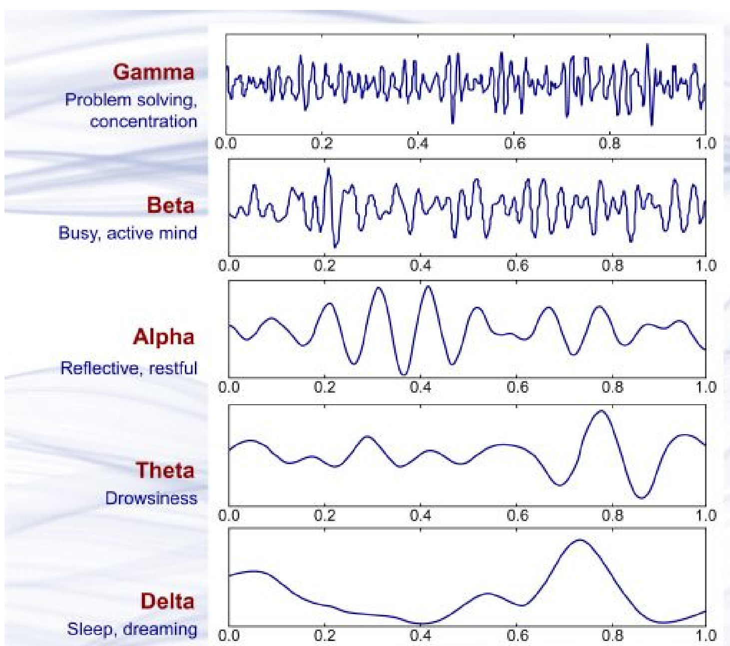


Figure 3: Brain Wave Samples Usable to Determine Concentration
Adapted from [2]

Project Requirements Specification:

Mission Requirements

- We will use the Emotiv headband to collect brain signal data as inputs for an educational virtual reality environment.

Input/Output Requirements

- The Emotiv shall output brain signal data packets.
- The computer shall accept an input from a user through brain signal data via data exported.
- The computer shall provide power to the VR headset and its components.
- The computer will use the data and output the results into the VR environment.
- The computer shall accept an input from the user through the VR controllers.
- VR controllers will receive power from 2-4 1.5V AA batteries.

Functional Requirements

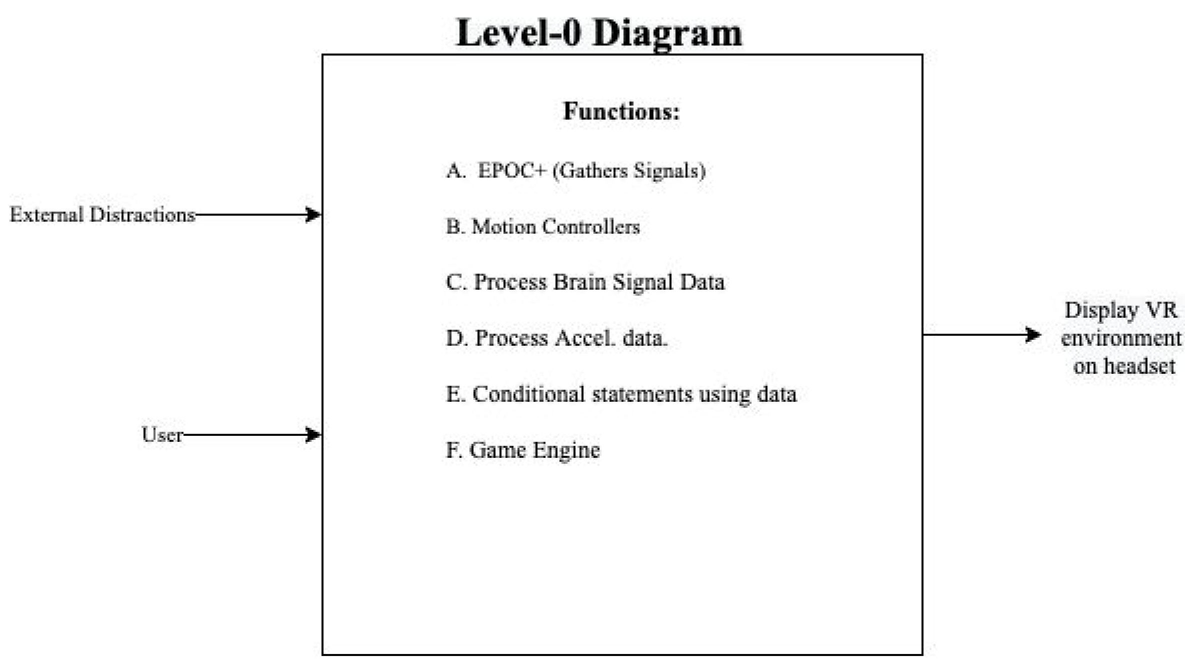
- The Emotiv will record brain signals at a rate of 128 samples per second.
- The Emotiv shall send data over to the computer with no packet loss.
- The software will detect variations in brain signals while interacting with a virtual reality environment.
- The program will be written efficiently to prevent data loss and reduce latency.

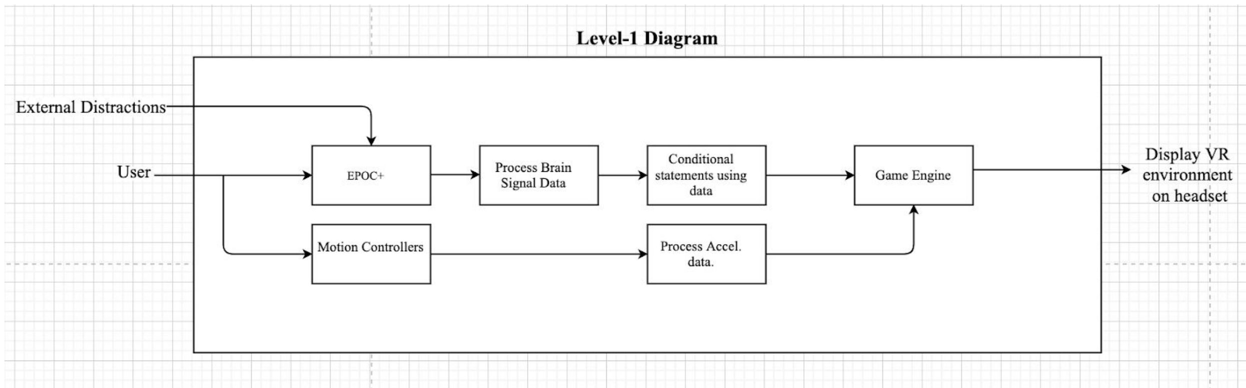
Technology and System-Wide Requirements

- A dedicated series graphics card with HDMI output ports.
- two USB 2.0 ports (at least one them is powered)
- Bluetooth will be required for use of Emotiv and controllers.
- Windows 7 or higher operating system
- Our VR headset will be cost efficient as possible to fit the needs of affordability for students.
- Controllers will use an accelerometer with I2C interface to help locate placement of the user in game.
- Hardware will be simplified and straightforward for easy integration with software.

Preliminary Design

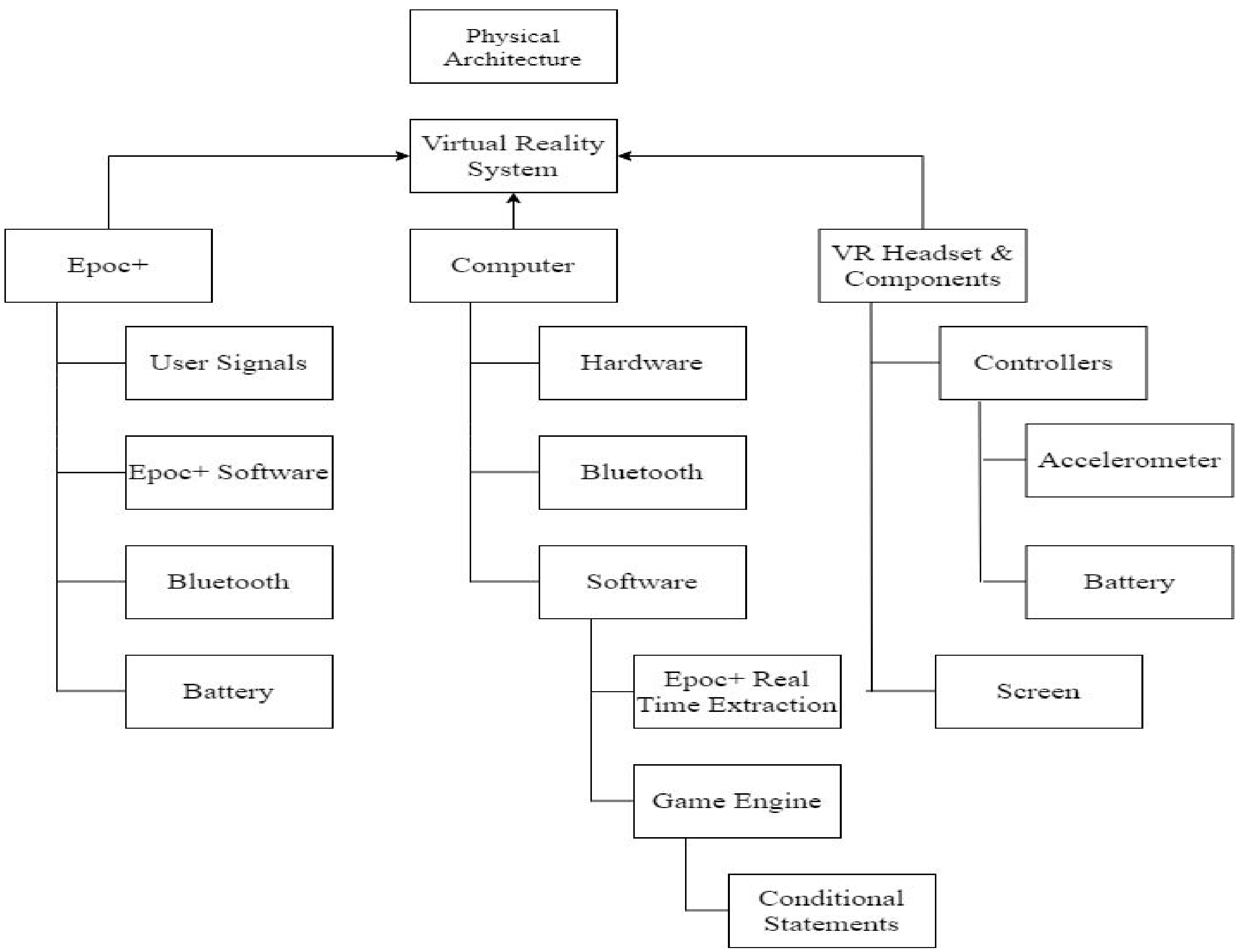
Functional decomposition





System Architecture

- **Physical Architecture:**



Component selection

- Component 1 - Epoc +

    - The Epoc + is a mobile EEG testing headset that will allow us to track brain signals that we will use as inputs to our design.
    - Provided to us by Nathalia Peixoto. The Epoc + has been discontinued and replaced with a newer version, the Epoc X, which is $849. This version will be compatible with our design as well.
    - Allows for 12 hours of battery life tracking 14 different channels of brain signals.
    - Link - https://www.emotiv.com/epoc/
- Component 2 - VR Controller
    - We will make our own controllers for arm movement tracking and button selection. This will serve as inputs to our design.
    - The controllers will have accelerometers, buttons, pcb design, batteries, and a cover to hold everything. In total, it will cost around $15 to make each controller.
    - Alternatively, if it becomes too inefficient to create our own, we will use controllers that come with a commercial VR headset.
- Component 3 - Epoc Software
    - Emotiv created commercial software to bundle with their EEG testing headset. We will be buying their student version of the software.
    - The software will include real time playback, import/ export, converting to recordings, and the raw EEG API software. We chose the student version for the raw EEG API software, as it allows for us to connect our data and our virtual environment design together.
    - The software is billed monthly at the cost of $29.
    - Link - https://www.emotiv.com/emotivpro/
    - Alternatively, we will be using the lite version and grab the data ourselves through our own software incorporated into the lite version.
- Component 4 - Computer
    - A computer is required to run the software for the game and for the Epoc software. This will be, at first, through the use of personal computers from our group members.
    - Alternatively, we will be going to one of the school's lab computers to work on our design.
- Component 5 - VR Headset
    - We will be buying the commercial Oculus Virtual Reality headset. This will allow for us to view our design.
    - Alternatively, we will create our own headset through a combination of LCD screens and accelerometers to track head movement.

<u>System Architecture diagram</u>

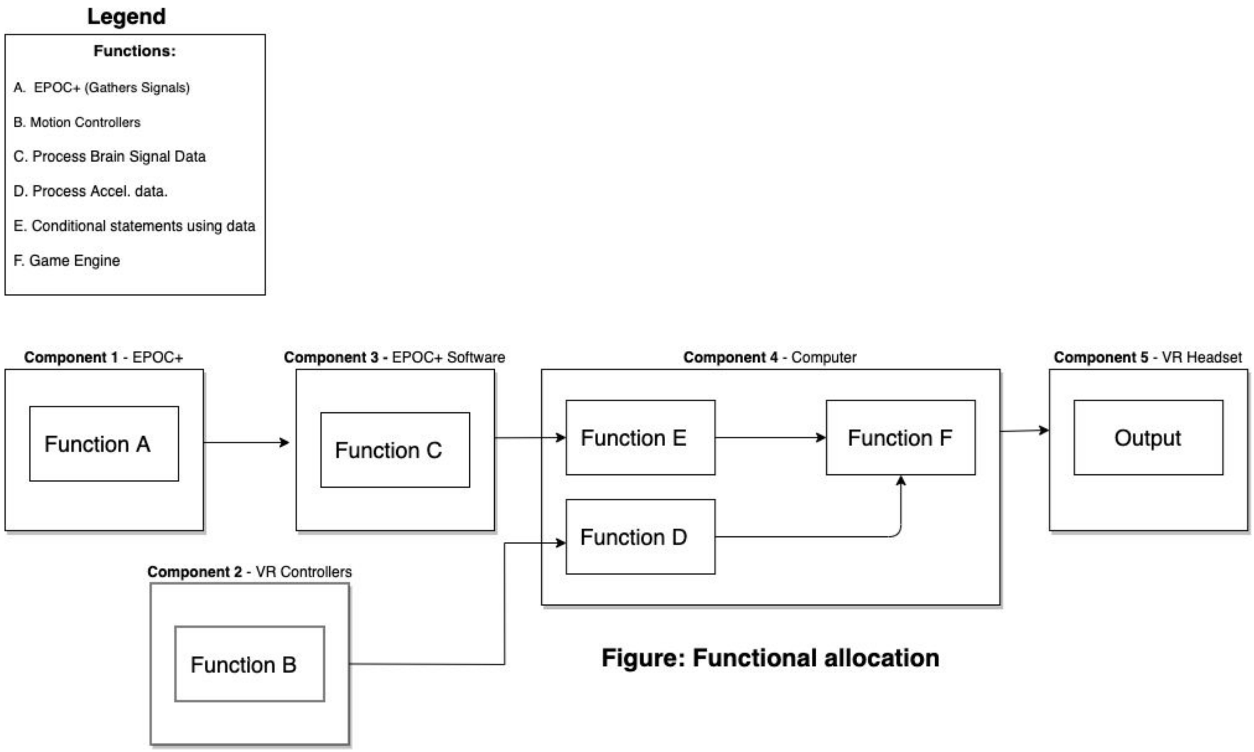


Figure: Functional allocation

Preliminary Experimentation Plan

Selection of requirements for experimental validation:

1. Requires use of EPOC+ sampling at a rate of 128 samples per second.
2. Software has a success rate in processing data *at least* 95 percent of the time.
3. Accelerometers are always calibrated correctly with a recalibration method.
4. Hardware has no shorts and is functioning correctly.
5. EPOC+ signals are able to be read and exchanged with the software with minimal amount of latency.
6. Brain signals are able to interact with the game and are reflected through a heads up display or action within the gameplay.

Experiment 1 - *Collecting Brain Signal Data and Data Transfer, along with getting the virtual environment set up.*

In this experiment, we plan to collect electroencephalogram (EEG) brain waves from our Emotiv device and transfer the data to our software. While conducting these experiments we will test what brain waves are associated with playing certain kinds of educational games and being in different scenarios and see and document changes in brain waves associated with those changes. After documenting different changes associated with different brain signals, we will introduce real time extraction of the data into the transfer of signals. This will allow us to incorporate conditional statements within our code to help the signals interact with the virtual reality environment. We will also be testing to see if our basic configuration of a virtual environment simulates correctly. This environment will have little to no inputs connected and has a main purpose of checking if it displays.

Experiment 2 - *Testing how VR software interacts with brain signal data*

Experiment 2 has a goal of transferring the brain signal data at real time to the virtual reality environment. This will be a test of if the signals are strong enough to be detected and if the conditional statements are being enacted. We will go about this by setting up a simple environment with 14 different conditional statements, one for each of the EEG nodes, and have the user try to interact with any of those statements. The goal will be to utilize all 14 conditional statements in one way or another. This will aslo test if our game is structured and running properly.

<u>Experiment 3</u> - *Hardware/Structural Verification/Testing*

Within experiment 3, this is where we would test our hardwares performance to make sure the system works properly in conjunction with our software. Part one would be our hardware verification tests. In which, we would be testing hardware under conditions simulating expected real-life conditions, including storage, transportation, operation and maintenance environments. Secondly for this experiment we would test the hardware. We would begin by developing a set of test criteria while applying functional tests to determine whether the test criteria have been met, then applying qualitative assessments to determine whether the test criteria have been met. Lastly, we would find any weaknesses with our hardware and create a way to fix/contain the problems post experiment.

Preliminary Project Plan

List of Tasks for 493

1. 3D designing and printing our VR headset housing.
2. Begin fabrication and assembly of hardware.
3. Begin writing software for our VR game.
4. Start experimenting with collection of brain signals and draw conclusions from those tests.
5. Request access and get familiar with Emotivpro software (student version).
    - ➔ **These tasks will be completed in parallel.**
6. Begin testing Hardware
7. Begin testing Software.
8. Test hardware/software compatibility.

Allocation of Responsibility

Tasks:

3D designing printing our VR headset housing - Ethan

Begin fabrication and assembly of hardware - Yumna

Begin writing software for our VR game - Jacob

Start experimenting with collection of brain signals and draw conclusions from those tests - Brendan

Request access and get familiar with Emotivpro software (student version) - Zayne

Begin testing Hardware - Brendan / Yumna / Ethan

Begin testing Software - Jacob / Zayne / Ethan

Test hardware/software compatibility - Whole Team

Potential Problems -

Risk Analysis & Knowledge

Project Objective	Risk Description	Effect	Risk Severity	Risk Likelihood	Risk Response Strategy
Financial Cost	Underestimation of budget - insufficient to carry out designing tasks	Deterioration of project quality	Medium	0-4%	Limit scope of design to a necessary, manageable, minimum
Skills & Information	Unavailability of core skills affecting designing & building processes. Unavailability of information & lack of understanding of new software required, including access to open source software & expertise	Delays & errors in design & implementation - verification increases cost & time due to developments of revisions	Low	50-90%	Team strengthens skills by consulting with experts & transparency about skills needed to be learnt. Information required is obtained in advance of requirement
Durability & Compatibility	Problems due to the lack of foresight in the durability of 3D constructed products as well as the compatibility with other materials and software	Deterioration of quality. Delays & errors. Increases in costs if materials aren't durable or compatible.	High	30-60%	Various phases of testing & troubleshooting for compatibility of hardware & software in a timely manner as a project priority. Important tools & components are stored securely.
Opinions & Permission	Delays in obtaining opinions & permissions from faculty advisors regarding scope of the project, completion of tasks and access to resources	Disturbed project process & suspension of work	Medium	30-60%	Ordering & reserving resources. Alternatives are considered ahead of time. Earlier diagnosis of the situations is handled in meetings preceding communication with advisors.

Internal Conflicts	Conflicts amongst members due to insufficient information & communication.	Delays & disruption in completion	High	0-4%	Response of all team members to communicate & mediate conflicts in the team
Completion	Unrealistic goals & deadlines	Deterioration of design quality & failure to meet deadlines	High	0-4%	Response of all team members to prioritize completing goals ahead of deadlines. Meetings preceding deadlines to review progress.

Bibliography

[1] K. Mukhtar *et al*, "Advantages, Limitations and Recommendations for online learning during COVID-19 pandemic era," *Pakistan Journal of Medical Sciences Quarterly,* vol. 36, 2020.

[2] Priyanka A.Abhang, Bharti W.Gawali, Suresh C.Mehrotra, “Technological Basics of EEG Recording and Operation of Apparatus,” Dr. Babasaheb Ambedkar, Aurangabad, India, 2016, ch. 2, pp. 19-50. https://doi.org/10.1016/B978-0-12-804490-2.00002-6

[3] Z. Scavotto, N. Peixoto, “Video Games and Brain Wave Frequencies,” 2020. [Online]. Available: http://gamingwaves.onmason.com/

[4] Brainworks, “What Are Brain Waves?,” 2020. [Online] Available: https://brainworksneurotherapy.com/what-are-brainwaves

[5] Emotiv, “How Does an EEG Work?,” 2020. [Online] https://www.emotiv.com/eeg-guide/