Brain Controlled Smart Home

Mid-project Report
Fall Semester 2015

- Full Report–

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Abstract

There are nearly 53 million people in the United States that have a limb impairment that would limit dexterity in a way that would diminish quality of life\textsuperscript{1}. For these individuals, completing tasks such as locking doors, enabling/disabling lights, or even changing the channel on television cannot be done by themselves. The problem faced today is how can their quality of life be improved? The current solutions for improving quality of life and completing tasks for people with limited dexterity involve assisted living. Assisted living requires an additional individual to take care of disabled individuals. This can be very expensive. The national median monthly rate for a one-bedroom unit in an assisted living facility is $3,500\textsuperscript{2}. This number is much larger than a typical monthly mortgage payment for a $300,000 home. Our project focuses on providing control to electronic devices using your mind. Brain control can provide disabled individuals with a solution for more independence and task completion.

Our project uses the science of electroencephalography (EEG) which is a method used to record electrical activity of the brain. For our project we used the Emotiv EPOC+ headset, which utilizes EEG technology to measure brain activity, to successfully interpret cognitive commands and generate an event. We were able to map different events to specific keyboard bindings that can be used as input to the computer. To keep cost at a minimum we opted to use Unity, which is a 2D and 3D game developing software, to create a virtual reality environment. This environment includes a modeled home which contains several smart devices. The smart devices found in the home are models of real devices that currently exist in smart homes today. The models can all be controlled by an individual's thoughts. To display the virtual reality to the user, we chose to use the Oculus Rift. This provides the user with the sensation of being in a real house.

We found that the headset was successful at interpreting our thoughts which were then able to become input for electronic devices, however it did consist of some drawbacks such as calibration, latency, and false event triggering. The code for the link between the headset and computer is still being optimized and may reduce this latency and take care of any false events triggered. This virtual reality consists of one room with several electronic smart home components including, lights, door locks, and a television. This room still lacks many textures, and is in an unfinished state, and we need to expand from a single room to a entire home.

\textsuperscript{1} "Accessibility Assistant," Georgia Tech Research Institute. Georgia Tech Institute of Technology

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Chapter 1 - Introduction

Today there are many people with disabilities that lack the dexterity to do basic tasks. They have trouble performing tasks that many take for granted. Right now, the options for individuals with these disabilities are either assisted living or nursing homes. Both of these options are inconvenient and expensive. Also, neither of these options provide the self-sufficiency that many desire. Our project goal is to look into possible inexpensive alternatives that can increase the self-sufficiency and quality of life of individuals with disabilities using brain controlled technology. The idea that springs from this would be a house, set up with smart devices that could open doors, turn on lights, control the television, etc. and have these devices be linked to another device that can interpret a user’s cognitive commands. This would allow someone to be able to use everything in his or her house without needing the dexterity normally required for such tasks.

Currently, what we are using to interpret these commands is the Emotiv EPOC headset. The Emotiv headset is a relatively cheap device that has 14 electrodes that read and amplify signals coming from the brain. These signals are sent as waveforms to the Emotiv Control Panel. The signals can be interpreted as many different cognitive commands chosen by the user. There are 13 commands (see Appendix A: Cognitive Commands) that the user can train the headset to recognize, four of which can be used at the same time. This is somewhat impressive, but it can be inaccurate, so in order to use the headset effectively, people have to “train” with the headset in order to use certain commands. This means that there is a learning curve to use it, which is one issue that we have encountered. The headset does come with a training program, but it does not give users any experience with using the Emotiv with smart home devices. Another issue is that we want to test this in a smart home environment, but we can not exactly build a house to do this.

In order to reduce the cost of building a real smart home, and to train the user to use the device we have created a virtual reality that can be manipulated through the Emotiv headset. This allows us to make the learning curve a bit easier by simulating a smart home for users as well as eliminates the immediate need of an actual house. Using the Unity 5 game engine and the 3D modeling software Maya, we have created a virtual house that suits our needs. We also had to

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use various tools for the Emotiv, like the Xavier SDK and the EmoKey, so that the Emotiv could be linked to the virtual reality. The house is not yet fully completed, but we have successfully controlled parts of the environment with the Emotiv headset. A critical review of this progress and the tools (Maya, Unity, Emotiv, etc.) we used for it is in section 2.

The virtual reality is to simulate a simple house with various devices and objects to control including lights, doors, a television, etc. We want this house to be as close to the real thing as possible. Using Maya we are able to make all of the 3D models that we needed for our house as well as add textures on the objects to make our house look more realistic. Maya is a powerful modeling tool, however, it can not make an environment interactive. That is why we needed the Unity 5 game engine. With Unity we can make it so users can move around and perform actions like turning on lights and opening doors in our environment. We have had some success with both of these tools, but they have had their drawbacks. Maya in particular is very time consuming and so it detracted from the productivity in other areas. Unity also had some problems, for instance, we had a script working once but after an update to Unity broke the script so we had to fix it. Another inconvenience is that to do anything useful with it you need to know the libraries it uses, which can take some time, but once you are used to it, Unity is actually pretty fun and extremely useful.

Even with these issues we were still able to make a working environment, and to display this environment we have the Oculus Rift. The Oculus Rift is a headset that straps around your head, displays a 3D environment and tracks your head movement so that if you look in one direction in real life you look that direction in the virtual environment. This technology is very important to our project, because it makes the user feel more immersed in the reality. It is very important that the user feel as comfortable as possible to best simulate a home environment. Recently we have also received the Samsung Gear VR, which is like the Oculus, but uses a Samsung Galaxy S6 as the display for the virtual reality. Since it uses a cell phone, it makes it hard to use what what are using right now for movement input so we have the Stratus controller to use with Gear VR. We have not used the Gear VR or Stratus much, but we have plans for them in the future. With these devices there were many issues and challenges that came with creating our virtual reality especially with getting the Emotiv headset to communicate with the virtual environment in Unity. To do this we had to create a headset “link” using the Xavier SDK. This “link” and its creation comes with many
challenges. The link program is not fully completed, but it is in a working condition, which enables us to interact with the virtual home. See section 2.2 for more information on the link and for more information on the hardware discussed in this paragraph see section 3.

Moving forward, we plan on expanding our testing as well as our research of creating a brain controlled smart home. We plan to finish our virtual reality have it tested by real patients so we can get some good feedback to improve our virtual house. In addition to this we are planning on making our own sort of network with multiple non-virtual smart devices that can be controlled with the Emotiv headset. We are also going to try other devices, like the Gear VR or even robots, to explore where brain control can go. This future progress will be covered in depth in section 3.

Also in section 3 will be the description of the ethical and marketing sides of the project. As far as ethical concerns, there are some things with the data that could come from the Emotiv that we might need to be careful about. Licensing for our software and whether we want our code to be open-source is also something we need to consider. On the marketing side, we have to consider not only our current target demographic, but the potential demographic of people that would want this technology in their homes.

Overall, we are tackling our challenge with a combination of hardware and software engineering. With the problems that individuals who lack dexterity face and the inconvenient, expensive options they have, the solution we are working toward can be a great alternative. We do not have the resources to make an actual smart home and the Emotiv EPOC headset is not perfect, so for now we have been making a virtual reality instead. By making a virtual reality instead of the a real house we can effectively test our concept. Using the Emotiv EPOC headset we are able to turn thoughts into commands that we can use in our virtual reality. To make this as feel real as possible, we have the Oculus Rift headset to display our environment. The Gear VR, much like the Oculus Rift, is another tool at our disposal to display the virtual reality in the future. We also made our virtual home realistic by using Maya to make 3D models and textures to make it look and feel as real as possible. We also used the Unity game engine to make the home functional so that the 3D models actually work i.e. lights can be turned on and doors can be opened. Both of these softwares have their drawbacks, but we have worked through them and have been able to use these softwares to our advantage. We also have to think about the ethical implications of our project and the demographics of people that our project applies to. All of this is what our project has been so far in a nutshell and it has been big for what we want to accomplish.
Chapter 2: Review of project progress

2.1 Review tools we used

Throughout this project, we have been using several powerful softwares that set valuable groundwork for us. These softwares include The Emotiv EPOC Control Panel, Emotiv Xavier SDK, EmoKey, and the Unity game engine. We also used some pre-existing code that was pulled from examples on the wiki for the Emotiv software. The software, and examples mentioned were invaluable for the progress we have made on the project this semester. They drastically sped up the process of creating a virtual reality and interpreting the brain’s signals. Without these, we would never have achieved what we have thus far.

The first, and most important software we used was the Emotiv EPOC Control Panel. This software is what connects to the Emotiv EPOC+ headset. The headset has 14 nodes that make contact with the user’s scalp. These nodes send the electrical impulses from the user’s brain to the control panel. The waveforms generated, are monitored by the control panel. The user will have to “train” the control panel to recognize patterns in the waveforms that the headset generates. Interpreting these waveforms by hand would be very challenging, and could be an entire year or two of senior design on it’s own. This software was the biggest factor that allowed this project to be viable.

The next software that we used in this project was the Emotiv Xavier SDK. The sdk uses the c++ language. This sdk allows us to use the waveform interpretations from the control panel and use them in another program that we create. These other things could include physical devices, or devices in the virtual environment that we created. This sdk is what we used to code the the “link” between the Emotiv EPOC headset, and the virtual reality.

The EmoKey application was used to emulate keystrokes on the computer from the headsets output. The emulated keystrokes are used to interact with the virtual reality. This software was very slow, and did not work particularly well, but it allowed us to continue work on other areas of the project while we were learning how to use the Emotiv SDK. The EmoKey application will not be used in the future, but was valuable for us in order to allow all of the team members to continue working on the project even when the headset interpreting program that we created began to fall behind.

The Unity engine is a powerful game development platform that has allowed us to create a working virtual reality environment. Unity provides the groundwork to develop complex games which allowed us to develop the virtual reality rather quickly. Creating a virtual reality was not the intention of our project, however we chose to use a virtual reality because it is a cost effect way to simulate the headset capabilities. Unity gave us the ability to import models created in modeling software relatively easily. This allowed us to focus our energy and time on the code that activates modeled smart devices in the virtual reality environment.
The Emotiv SDK was very hard to use without working in it before. We were able to follow several examples that were posted on a wiki page hosted by Emotiv. These examples are what we based our code off of. Without these examples, we would probably be several weeks, if not months behind where we are now. The code that was provided was the basis for all of the code we have written to establish a link between the headset and the virtual reality.

Using all of this software has set up our project very well and put us in a good position. The Emotiv Control Panel allows us to use the headset to read electrical impulses from a user’s brain and generate waveforms from those signals. The Emotiv SDK allows use to take these waveforms and use them in programs for virtual and physical devices. The EmoKey allowed use to assigns commands to keystrokes, which provided us a temporary way to test our environment and make progress in other areas until we obtain a better solution and Unity allowed us to pull everything together in a virtual environment. With all of this software combined, we were able to make significant progress with our project.

2.2 Work completed

This semester we have made very good progress on the project. We were able to create a single room virtual environment with several smart home nodes including lights, televisions, and door locks. This virtual reality can be explored by a user using the Oculus Rift, and is navigated by keyboard inputs. The devices in the home can be controlled using cognitive inputs that are interpreted from the Emotiv EPOC+ headset.

We created the models for the virtual reality using Autodesk Maya. Maya is a professional 2D and 3D modeling program that is an industry standard used by large companies such as Pixar, Disney, and several game developers. Maya provides a student free license that is great for creating state of the art 3D models. The models are able to be exported Unity. The drawbacks of this software is that it can be overwhelming at first. The provided tools take time and patience to learn, however with practice it becomes easier. The models are a large part of the virtual reality, without them we would have nothing to interact with. However, it was important to balance functionality and art with the models. The goal was to provide a visually appealing model that was recognizable. Creating models consumed a large part of time. We focused on creating basic models such as, light fixtures, doors, tables, TV's and small furniture, that are found in
households. The models can be improved over time, and we are trying to explore and find free open-source models.

To create the virtual reality, we used the Unity 5 game engine. Unity is a free, open-source game engine that is used by anybody ranging from amateurs to professionals. It is mostly used for video games, but can be used for other applications like creating a virtual reality. It can not make custom models like Maya can, but it can give functionality to models so that they are subject to action and reaction and not just static or a fixed animation. This is done by creating scripts in C# (what we use) or Javascript for objects in Unity. Unity can import models from many different modeling softwares including Maya. Although it is very useful, it does have some downsides. One of these is that the current free version that is available is still being worked on so it has frequent updates. This means that we have to stay on top of our code and make sure it works with every update. Another downside is that it has a learning curve because to do anything useful it needs its own C#/Javascript libraries. So even if you know those programming languages you still have to learn what all the functions and classes in those libraries made for Unity do and some of the information that can be found on these libraries is dated. Despite these issues, using Unity has been a great learning experience and has been great for our project.

The “link” between the Emotiv headset and the virtual reality was written in c++. It was created using the Xavier SDK which allowed us to receive commands that the control panel interprets, and re-distribute them to other programs of our choosing. If the waveform for the cognitive command is detected even for a very short period of time, the link program will be notified of this. It is important to never activate a node when the user did not intend to, so to activate a node, our program requires the user to sustain a cognitive command for a period of time. It is also important to not make the user sustain the command for too long, because it would cause discomfort to the user, and lower usability. Neither option is good for the end result. We will need to find the best settings for the required hold time(See section 3.2 for more information on how we will go about this). The link code is in a working state, but it is not as completed as we would like it to be. At this point, all of the functionality like key emulation, and the control of z-wave smart devices is in the same code. In the future we will need the code to be more modular. We are already hard at work getting this code to behave like we want it to. The modularity will be important to make the code more easily modifiable. This will allow us to very quickly add the ability to control real world smart devices later in the project. This code should be easy to modify so that it does not take extreme re-writes to change the outcomes of cognitive commands. We do this by defining what will happen for each command in the makefile. This is similar to the “suckless” style of coding. Our code was written in such a way that when we have completed it, we will likely not have to touch it again to add new functionality, we can simply re-compile the code and write our functionality into another program. This will give the added benefit that our code will not be broken by the added functionality, and if something breaks, we know that the error is in the new code. The link that we have been working on, when it is completed, will be easily modifiable by users who do not have to worry about how the headset
commands are interpreted. This abstraction will allow future developers to focus more on applying this technology to improving lives and the smart home side of this project, rather than on interpreting and distributing cognitive commands.
Chapter 3 Summary of work

3.1: Hardware

The Emotiv EPOC+ headset was inherited from the prior team. The reason this headset was chosen by the previous team is because it met specific requirements. The headset offers relatively accurate EEG output, and competitive performance compared to other EEG headsets, and a powerful SDK all at a relatively low cost of under $1000. The SDK includes a powerful control panel and access to raw EEG sensor waveform data that can be used if we decide to try and interpret these waveforms instead of using the control panel’s interpretation. Included in the price is access to all of the software that Emotiv provides, the wiki that has example code, and templates for functionality that the headset provides.

The Oculus Rift is a powerful device that has resparked the innovation of virtual reality. The Oculus Rift was chosen out of HTC Vive, Sony PlayStation VR, and Razer OSVR because it met all the requirements we were looking for in a virtual reality display device. The requirements are as follows, compatibility, performance, and cost. Unlike some of its competitors, The Oculus Rift is well supported in several popular game engines including Unity, Unreal Engine 4 and Cryengine, which allows for easy integration in our project. It has better performance than its competitors and is capable of accurately tracking the movement in a three dimensional world. The Oculus Rift DK2 is priced at around $379 which sits near the upper price range of most VR, however its compatibility and performance put it far above its competitors.

3.2 Ethical issues

Security is very important during this project. The waveform data from the Emotiv headset is very important to this project. With proper observation and training, this data could be used maliciously to monitor the user. The extent that this information could be used is not entirely clear, but is also not important. If this data could be a potential risk at all, no matter the consequences of failure, it is important that we do our best to protect this information. There will be several potential attack vectors that we will need to look into over the life of the project. At this point in the project it is more important to add functionality than it is to worry about security, but we also need to be sure that we accomplish this without making it difficult to secure later. If we are able to get the functionality we desire, we will begin to work on security, but it is doubtful that we will be able to secure everything. If we do not implement all of the security that we need, it will be up to the next year’s senior design team to work on this. It is important that we document everything we work on well enough that the next team will be able to add the necessary security.

The connection between the Emotiv headset and the computer is proprietary, so we will not be able to work with securing it at all. It may be important to switch to another EEG device if this headset compromises the security of the user’s information. This would be a huge setback.
for the project, because we would have to start from the ground up. This outcome is not likely as the developers for the headset should also be concerned about the security, but we do not know this for sure. We will have to research this connection and figure out if it is a problem. Similar to the other security vulnerabilities, this is not a priority at this time.

3.3 Marketing the product

The target market for this product is people who have dexterity or motor impairments that would prevent them from using devices mentioned previously in this paper. For these people, the product we are creating would be invaluable, and increase quality of life. We would ideally like to open source this product, which would require licensing. We will discuss licensing later in this section. If we open sourced the project, it would allow for further innovation from a wider community. The target demographic for this product is likely not the only people who would adopt this technology in their home, just some of the first to do so. Users without these impairments could also use this product. The widespread adoption of this technology would likely not be soon, but rather in half a decade or more.

Keeping this project open source in the future, including if other people were to branch from it is also important. This would require that we license it under the MIT License, the BSD License, or the GPL. We will need to decide if future developers are allowed to make money off of this project, with or without modification. If we decide that we do not want to sell this product, and that we do not want others making money off of our work, we would need to use the GPL license. As computer engineers, we do not learn a lot about licensing code, so we will need to discuss it further with someone who knows more about the legal side of things.

The code that we are creating so far is very modular. The purpose of this is to enable other developers to use the brain control with the smart home devices of their choosing. It will greatly widen the capabilities of the project, and ensure that the users can get the cheapest possible smart devices. A developer will need only to use the sdk for those devices, and will not have to worry about how the Emotiv headset works. This will provide for much greater competition, and pricing for the consumer, and will also make sure that decisions made by the smart device manufacturer will not have any undesired implications on the project. If we discover devices that are easier to work with, provide faster activation, or any other desired benefit, we can easily switch to that manufacturer. The decision to keep the code modular will become invaluable in the future of the project.
References


Appendix A - List of abbreviations, key terms

**API**: a software intermediary that will enable programs and applications to communicate and share data with each other. An API exposes specific software functionality while protecting the rest of the application.

**Cognitive command**: a specific signal from the Emotiv headset correlated to a user's trigger thought. These thoughts can be differentiated from passive everyday thoughts like speaking or walking. These commands include Push, Pull, Lift, Drop, Left, Right, Rotate clockwise, Rotate anticlockwise, Rotate forwards, Rotate backwards, Rotate left, Rotate right and Disappear

**Electroencephalogram (EEG)**: method for monitoring the electrical impulses and brain activity. These electrical impulses form waveforms that can be interpreted to distinguish between trained thoughts (See Cognitive Commands)

**EmoComposer**: This program emulates the cognitive commands in order to test if our software is working without having to use the headset. This allows multiple people to develop code at the same time

**EmoKey**: The initial program that we used to convert cognitive commands into keyboard keys

**Emotiv EPOC Headset**: A head wearable device with 14 contacts that will monitor electrical impulses and send these signals to a computer to be interpreted

**Emotiv Xavier SDK**: The software development kit that we will use to detect the cognitive commands and distribute these commands to other programs and devices

**Oculus Rift**: A Virtual Reality headset that has a built in screen for users to view a virtual environment. This device tracks head movement to allow the user to be immersed in the virtual reality and easily navigate the space.

**Samsung Galaxy S6**: A Samsung produced smartphone that will be the base for our voice control, as well as the device used in the Samsung Gear VR headset

**Samsung Gear VR**: Virtual Reality Headset that used the Samsung Galaxy S6 to display its environment

**Software development kit (SDK)**: A set of tools provided to enable programmers to develop for a platform. Includes one or more API’s.

**Unity**: The game engine that we will be developing the virtual reality in. This is the engine that we will test with, as well as create the user training environment in

**Virtual Reality (VR)**: A computer simulated environment that users are able to interact with. These environments can be very lifelike and immersive.
Appendix B - Budget

Purchases already made

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Purchases we are considering for future of project

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Analysis

Our team initially started with $600 at the beginning of August 2015, however our professor negotiated for us to be able to spend additional funds on the Galaxy S6, the Samsung Gear VR, and the SteelSeries Stratus Controller before receiving the required funding. This means that we
would like to spend $4,489.23 less the $600 that every team is given to start with. The team would like to achieve at least $3,889.23 of funding to get everything that we want at this point. This project is also only half over, so we may find other things that we need to purchase in the future. Next semester we will likely work much harder on the physical smart devices, rather than the virtual. Physical devices are more costly.
Appendix -C Project timeline evolution

Original project plan

**Phase 1  The Basics  9/16-10/4**
- Establish link between EPOC+ and Computer
- Begin setting up Unity
- Create basic untextured models in Maya
- Verify correctness of the link
- Wall collision detection
- Begin creating room in Maya for Virtual Reality

**Phase 2  Further Development 10/4-10/25**
- Begin testing 4 thought commands
- Implement the 4 commands to control devices
- Begin improving textures and models
- Create demonstration
- Continue improving room
- Finish single room design

**Phase 3  Finalize Virtual Reality  10/25-11/22**
- Begin modeling the house in Maya
- Incorporate advanced smart devices
- Continue modeling house
- Test with real patients
- Retest single room to verify correctness

**Phase 4  Demonstrate Virtual Reality  11/22-12/19**
- Finish modeling house and implementing it in Unity
- Implement necessary changes
- Begin testing full house
- Demonstrate full house

**Phase 5  Begin Planning Next Steps  1/19-1/31**
- Discuss which smart devices to implement
- Fundraise for purchasing smart devices

**Phase 6  Begin Room Construction  1/31-3/15**
- Discuss which smart devices to implement
- Fundraise for purchasing smart devices

**Phase 7  Testing  3/15-3/27**
- Discuss which smart devices to implement
- Fundraise for purchasing smart devices

**Phase 8  Demonstration E-Days**
Updated project plan

Green - Finished on time
Blue - Finished late
Red - Not yet finished, behind schedule

Phase 1   The Basics    9/16-10/4
- Establish link between EPOC+ and Computer
- Begin setting up Unity
- Create basic untextured models in Maya
- Verify correctness of the link
- Wall collision detection
- Begin creating room in Maya for Virtual Reality

Phase 2   Further Development 10/4-11/22
- Begin testing 4 thought commands
- Implement the 4 commands to control devices
- Fix problems with Emotiv Control Panel
- Incorporate advanced smart devices

Phase 4   Demonstrate Virtual Reality    11/22-12/19
- Finish modeling single room, implement it in unity
- Begin work on full house design
- Demonstrate single room design

Phase 5   Begin Planning Next Steps 1/19-1/31
- Discuss which smart devices to implement in real world
- Begin work with Occupational Therapy department to test with real patients
- Fundraise for purchasing smart devices

Phase 6   Begin Room Construction 1/31-3/15
- Work on command distribution to smart devices
- Testing with real patients
- Begin implementing changes discussed with patients
- Fundraise for purchasing smart devices

Phase 7   Testing    3/15-3/27
- Continue testing with real patients
- Continue changing the virtual reality to address changes requested by patients
- Fundraise for purchasing smart devices

Phase 8   Demonstration E-Days