2015-04-30

Design and Validation of Control Interfaces for Anna

Daniel Charles Fox
Worcester Polytechnic Institute

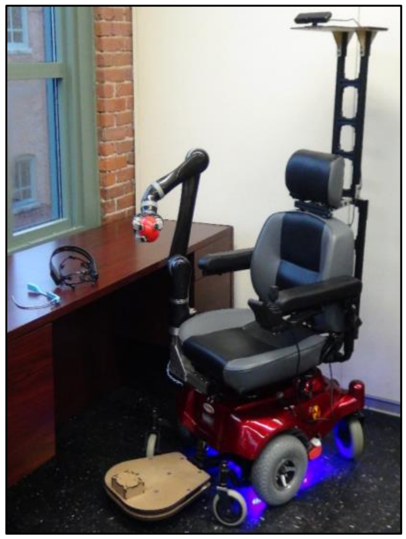
Marisa Nicole Warner
Worcester Polytechnic Institute

Rashida Tamiza Nayeem
Worcester Polytechnic Institute

Tanishq Bhalla
Worcester Polytechnic Institute

Tenell Glen Rhodes
Worcester Polytechnic Institute

Design and Validation of Control Interfaces for Anna



A Major Qualifying Project Report Submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the
Degree of Bachelor of Science by

Tanishq Bhalla (ECE)
Daniel Fox (RBE)
Rashida Nayeem (ECE)
Tenell Rhodes (ECE/RBE)
Marisa Warner (ECE)

Date: April 20, 2015
Report Submitted to:
Taskin Padir, Advisor

Abstract

This project improves the control mechanisms for a semi-autonomous wheelchair with an assistive robotic arm system, also known as Anna. Anna was designed by the Robotics and Intelligent Vehicles Research Laboratory (RIVeR Lab) at Worcester Polytechnic Institute (WPI). The system is aimed at increasing the self-sufficiency of individuals with Locked-In Syndrome (LIS). Throughout the development of Anna, the following control interfaces have been introduced: a joystick, a wireless brain-computer headset, and voice control device. These interfaces were integrated with the aim to increase a user's interaction with their environment. The objectives of this project include the validation of the existing control interfaces, as well as the integration and design of new systems. The wireless brain-computer headset, used to implement the control system for wheelchair navigation, is validated through several user studies. An Electromyography (EMG) sensor system serves as an alternative control module for wheelchair navigation. To increase physical interaction with the environment through object manipulation, a 6 degree-of-freedom robotic arm system is integrated with Anna. The arm system includes a RGB-D camera for object detection and localization, enabling autonomous object retrieval to enable self-feeding. The project outcomes include a demonstration of Anna in various conditions performing navigation and manipulation tasks.

Acknowledgements

We would like to thank our project advisors, Professor Taskin Padir and Professor Looft as well as Professor Chernova, a previous advisor for this project. We would also like to thank our graduate student advisors, Dmitry Sinyukov and Velin Dimitrov for all their support. In addition this project would not be possible without the following organizations.

National Science Foundation

Without the generous financial support of NSF, this project would not have been possible.

Worcester Polytechnic Institute

Without the use of WPI's laboratories and manufacturing facilities this team would not have had the proper resources to complete this project. Also we would like to thank all members of the Robotics Engineering Department as well as the Electrical and Computer Engineering Department. This includes but is not exclusive to Tracey Coetzee, the students working in the RIVeR and RAIL laboratories, and all other students and faculty who supported our project through their efforts and advice.

Authorship

Section		Author
1	Introduction	All
2	Background	All
2.1	Target Users	Rashida
2.1.1	Muscular Dystrophy	Rashida
2.1.2	Multiple Sclerosis	Rashida
2.1.3	Cerebral Palsy	Rashida
2.1.4	Traumatic Injury	Rashida
2.1.5	Amyotrophic Lateral Sclerosis (ALS)	Rashida
2.2	Environment	Rashida
2.3	Other Wheelchairs	Tanishq
2.4	User Requirements	Daniel/Rashida
3	Navigation Enhancements	Daniel/Tenell
3.1	Previous Work & Requirements	Daniel/Tenell
3.1.1	Assistive Navigation with LiDAR	Daniel/Tenell
3.1.2	Relocation of LiDAR System	Tenell
3.2	Methodology	Tenell
3.3	Results	Tenell
3.4	Discussion	Tenell
4	Manipulation System	Daniel/Tenell
4.1	Previous Work & Requirements	Daniel
4.1.1	Self-Feeding	Daniel
4.2	Methodology	Daniel/Tenell
4.2.1	Mounting the Arm-System	Tenell
4.2.2	Arm Trajectory Planning	Daniel
4.2.3	Vision System	Tenell
4.3	Results	Daniel/Tenell
4.3.1	Mounting the Arm-System	Tenell
4.3.2	Arm Trajectory Planning	Daniel
4.3.3	Vision System	Tenell
4.4	Discussion	Daniel/Tenell
4.4.1	Mounting the Arm-System	Tenell
4.4.2	Arm Trajectory Planning	Daniel
4.4.3	Vision System	Tenell
5	User Interface Design and Analysis	Daniel/Marisa/Rashida/Tanishq
5.1	Previous Work & Requirements	Daniel/Tanishq

5.1.1	Previous Work	Tanishq
5.1.2	Project Goals	Daniel/Rashida
5.2	Methodology	Marisa/Rashida/Tanishq
5.2.1	Emotiv Testing Procedure	Marisa/Rashida/Tanishq
5.2.2	Testing the Emotiv ROS Driver Code	Tanishq
5.2.3	EMG Testing Procedure	Marisa
5.3	Results	Marisa/Rashida/Tanishq
5.3.1	Emotiv	Rashida/Tanishq
5.3.2	EMG Control	Marisa
5.4	Discussion	Marisa/Rashida/Tanishq
5.4.1	Emotiv	Rashida/Tanishq
5.4.2	EMG Control	Marisa
6	Social Implications	Daniel
7	Conclusions	All
8	Citations	All
9	Appendix A: LiDAR Relocation	Daniel/Tenell
10	Appendix B: Emotiv Control System	Marisa/Rashida/Tanishq
11	Appendix C: EMG Control System	Marisa
12	Appendix D: Terminology	Rashida

Table of Contents

Table of Figures

Table of Tables

Table of Equations

1. Introduction

Modern day rehabilitative research has provided a multitude of assistive technologies for those affected by disability [1]. This has created great opportunities that were not previously available for this population. However, there remains a gap in the assistive devices available to those who have limited to no mobility in their upper body. Commercially available power wheelchairs are some of the most common assistive devices for persons with limited mobility. A rising issue with these devices is that most implement a control interface that takes motion based commands from joysticks. This leaves those with little to no control of their hands few options.

Fortunately, technologies have been developed that place an emphasis upon voice control, Electrocenphalogram signals (EEG) and Electromyogram signals (EMG). The EEG and EMG signals are a measure of brain activity and muscle activity, respectively. Furthermore, there are a number of commercially available products that measure and process conscious thoughts, facial expressions, emotions, minor neck movements and minor hand gestures. Products such as EPOC Emotiv Headset, Google Glass and Mindwave have made it feasible to integrate facial, vocal, and thought controls into existing products.

Additionally, commercially available powered wheelchairs have limited environmental awareness to allow the user to avoid obstacles. Unfortunately, this awareness is not always enough to ensure the safety of a person with limited reactionary skills. Existing technology such as LiDAR and various cameras are capable or reading environmental input and processing said data. These systems can and have been integrated into a powered wheelchair system and provide additional safety for the user. In addition, a number of robotic arms have been made available on the market and allow for the user to integrate their own control interfaces. Kinova Robotics' Jaco arm can be configured to different control schemes and then integrated into existing products as well.

In order to facilitate ease of movement for persons with disabilities, there are a range of individual requirements that this project will need integrate various control interfaces on a powered wheelchair system. By utilizing systems such as Emotiv and EMG sensors, the wheelchair system can assist a wide range of individuals with different levels of impairment. Additionally, to allow for increase in user independence, the Anna platform has integrated a robotic arm. It was the purpose of this project to allow a user a range of movement and mobility to assist their life.

2. Background

2.1 Target Users

This project aims to assist individuals that have little to no movement of arms and some movement of facial muscles. There are a number of conditions and diseases that limit the user's movement. Since Anna is a multimodal system, it will be useful to individuals with various conditions. This project is generally targeted toward those that have Locked-in Syndrome. Locked-in Syndrome (LIS) is a condition in which a person is conscious and alert but unable to communicate or interact with the world due to muscle function loss. This can be caused by injury to the spinal cord, hemorrhage or trauma. The symptoms of this condition are quadriplegia and anarthria with preservation of consciousness [1]. LIS can be classified into three categories: classic, which is quadriplegia and anarthria with preserved consciousness and vertical eye movement; incomplete, which is the same as classic but with remnants of voluntary movement other than vertical eye movement; total, total immobility and inability to communicate, with full consciousness. Patients can learn with training to communicate with eye movements [1]. Computers may also facilitate communication for those with LIS when augmentative communication devices are available [1]. Several conditions can cause LIS including, but not exclusive to the following: muscular dystrophy, multiple sclerosis, cerebral palsy, traumatic injury, and amyotrophic lateral sclerosis (ALS). These diseases will be described in the following sections.

2.1.1 Muscular Dystrophy

Muscular dystrophy (MD) is the term used to refer to a class of approximately 30 genetic diseases that manifest themselves by progressive weakness and degeneration of muscles that control movement [2]. The prognoses for individuals with MD vary depending on the person and the type of disease that they have. The most severe cases of MD will result in muscle weakness, functional disability and loss of the ability to walk [3]. An individual with advanced MD may still have some arm control and facial control [2].

2.1.2 Multiple Sclerosis

Multiple sclerosis (MS) is an autoimmune disease that affects the central nervous system of an individual. These effects include: loss of balance, muscle spasms, weakness in limbs, an inability to walk, issues with coordination, numbness, facial pain and other nerve symptoms. These symptoms can arise as attacks that last for days, weeks or months [4]. After these attacks, there can be periods of little to no symptoms. Currently, there is no cure for MS other than attempting to minimize symptoms by maintaining a healthy lifestyle.

2.1.3 Cerebral Palsy

Cerebral Palsy permanently affects movement and muscle coordination [5]. It is a neurological disorder that arises in infancy or early childhood. The Center for Disease Control (CDC) estimates that about an average of 1 in 323 children in the U.S. are diagnosed with cerebral palsy [6]. The causes of cerebral palsy are from abnormalities in parts of the brain that control muscle movement. Certain cases can be caused by head injury, bacterial meningitis or viral encephalitis. Symptoms of cerebral palsy vary on a case by case basis, however, symptoms can include the following: variations in muscle tone, stiff muscles, exaggerated reflexes, lack of muscle coordination, tremors, involuntary movements, difficulty with precise movements, difficulty eating, difficulty speaking, trouble walking and or inability to walk [6]. The team interviewed a family whose 20 year old son was diagnosed with cerebral palsy and the family articulated that their son could not walk, was nonverbal and had trouble with sustained movement. His current wheelchair functioned by him holding a pad when he wants move forward however, his spasticity would not allow him to hold the pad for a sustained period. He has no facial control but he can blink on command to communicate. Furthermore, he can communicate through his computer system, DynaVox Vmax, to give auditory feedback by choosing a set number of symbols.

2.1.4 Traumatic Injury

Individuals can also lose control of their limbs due to traumatic injury. This can occur if the spinal cord is injured. Other major causes are stroke, trauma with nerve injury, poliomyelitis, cerebral palsy, peripheral neuropathy, botulism, spina bifida, multiple sclerosis, and Guillain-Barré syndrome. Quadriplegia is a term that indicates that part of the spinal cord inside ones neck has been injured and can result in a loss in feeling and movement of arms, legs and the center of one's body [7] .

2.1.5 Amyotrophic Lateral Sclerosis (ALS)

Amyotrophic Lateral Sclerosis (ALS) is a condition in which affected individuals suffer from muscle atrophy and weakness. ALS often begins with muscle twitching and weakness in an arm or leg, or sometimes with slurring of speech. Eventually, ALS can affect your ability to control the muscles needed to move, speak, eat and breathe. The effects of the disease worsen as the disease progresses and over time, individuals will not be able to stand, walk, and use their hands or arms [8]. These individuals also have trouble speaking (dysarthria) and swallowing (dysphagia) [8]. Other symptoms include exaggerated reflexes [7]. The onset of the disease is most common in people between the ages of 40 and 60. After initial diagnosis more than half of all patients live up to three more years. Furthermore, about twenty percent of people with ALS live five years or more and up to ten percent will survive more than ten years and five percent will live 20 years [9]. It is important to consider information such as this when designing the future plans for the wheelchair.

Figure 1: Person with Amyotrophic Lateral Sclerosis

2.2 Environment

Ideally Anna will be used in homes, hospitals and nursing homes. These places are currently the most feasible because they are the most wheelchair friendly environments. For future research, there will be emphasis on using the wheelchair in all public areas including workplaces. There are other wheelchair systems in development and academia that aim to provide the same assistive control that the wheelchair in discussion hopes to address.

2.3 Other Wheelchairs

Figure 2: Sip and Puff System for Wheelchair Control

One type of wheelchair currently on the market utilizes the sip-and-puff system (SNP) [9]. With this system, a user either draws in air or exhales into a wand or a tube. This method requires individual calibration and will only recognize the commands from that specific user once implemented. SNP recognized four different commands, hard sip, soft sip, hard puff and soft puff. These act as directional commands with directions such as forwards, backwards, left, and right [9].

Another type of assistive control is the Eye and Gaze system. This system utilizes a camera that is placed in front of the user. By tracking the eyes for blinks and estimating gaze direction users are able to navigate the wheelchair as desired. This system can be adapted to any wheelchair by placing a camera in the front to capture an image of the user. The gaze direction is expressed by the horizontal angle of the gaze and this is derived from the triangle formed by the centers of the eyes and the nose. The gaze direction and eye blinking are implemented to for direction and timing commands respectively. The direction command correlates to the navigation of the movement of Anna and the timing command directs the wheelchair when to move. This creates ready, backward and stop inputs for Anna [9]. For some users of this system sustained movement of gaze may be an issue.

A new system is being developed by a team at Georgia Institute of Technology called the Tongue Drive System (TDS). This system uses a magnetic tongue piercing and magnetic sensors placed on each side of the users head. The user can control the direction of the wheelchair by placing their tongue in different positions. The principal investigator of this project, Professor Maysam Ghovanloo, has stated that this invention is more useful for quadriplegics than voice commands because their voices may be weak [1]. This concept could also be applied to other devices and existing technologies as well.

Figure 3: The EPOC Emotiv Neural Headset

Interactive Dynamics is a startup in Argentina that utilizes the EPOC Emotiv Neural Headset to control an existing commercially available wheelchair [9]. This Emotiv headset recognizes facial expressions, conscious thoughts, and emotions of the user by reading the electrical signals generated by the brain and muscles. These are used as inputs to control said wheelchair [9]. Interactive dynamics has partnered the Fundación Rosarina de Neuro-Rehabilitación (the Neuro-Rehabilitation Foundation of Rosario) to further develop their product. The company and the foundation first trained the patients to use a combination of thoughts, words, and facial tics on the EPOC Emotive neural headset to control video game-style software. After the patients were trained on this system they were transferred to the electric chairs. The founders of the startup have stated that their device is meant for use within a person's home rather than public use [9].

The Massachusetts Institute of Technology is developing a voice controlled wheelchair with navigation [10]. Their wheelchair would allow a user to tell the wheelchair to go to a specific location. This system wheelchair can interpret conversational language that is picked up through a standard headset and microphone. Furthermore, the robotic wheelchair learns the layout of its native environment (hospital, rehabilitation center, home, etc.) through a narrated, guided tour given by the user or the user's caregivers. Thus, the wheelchair can move to any previously-named location under the same command. This technology is appropriate for people who have lost mobility due to brain injury or the loss of limbs, but who retain speech. The wheelchair has since been made available to patients at the Boston Home in Dorchester. The limitations of this wheelchair are that as certain degenerative disease progress, individuals voices may have weaker voices or lose their voice entirely [10]. Subsequently, many of those with LIS may only be able to use it for a short amount of time.

2.4 User Requirements

The United States currently has 1.7 million wheelchairs and powered scooters being used by its citizens. Of these users, at least 155,000 are in electric wheelchairs [12]. While powered wheelchairs have been a great help to those who cannot push themselves, over 60% of users report they cannot perform standard daily activities [11].

As stated above, there are a variety of illnesses that restrict mobility to the extent that traditional wheelchairs are no longer sufficient. Movement is important for any person trying to accomplish daily tasks independently. In addition to mobility, many users also require a robotic arm to facilitate interaction with the world around them. This system merits several distinct requirements, both explicit and implied.

This project would have to allow people to navigate in an alternative manner that is tailored to their need while seated in a wheelchair. Various control methods would be integrated to allow a wider range of useful control. Since some users have lost the ability to use a joystick, it is not unexpected that he or she would lose the ability to fully extend their arm. This is the reason that this project included a robotic arm. Since the user may be unable to control this arm with a joystick, an alternative control method is required.

The goal is to produce a product that is safe for the user and surrounding people. Previous work has suggested the current battery can successfully power the wheelchair and control system. The additional power requirement of the robotic arm is negligible [12].

3. Navigation Enhancements

3.1 Previous Work & Requirements

Anna already had some assistive navigation for each control system. The current system would attempt to locate obstacles when moving forward. Anna would automatically move around these objects; if Anna detects it is heading for a wall, the system will move to a side and move along the wall. Unfortunately, this system had shortcomings.

3.1.1 Assistive Navigation with LiDAR

Figure 4: UTM-30LX Hokuyo LiDAR Sensor

LiDAR (Light Detection and Ranging) is a type of remote sensory technology used to measure distances between objects and the base sensor. The sensor reads the surrounding environment by bouncing a laser off of a mirror into the surrounding environment and recording the delay the light takes to return to its source. This delay is then used to calculate how far away objects are. A Hokuyo LiDAR sensor, shown in Figure 4, was mounted on the right arm rest of the wheelchair to generate a map of Anna's surroundings [13]. Previous project groups chose to use a LiDAR over other similar sensors due to its high degree of accuracy despite its high cost. The sensors enable Anna to detect and avoid obstacles as well as follow walls within indoor environments. Unfortunately, the viewing area of the LiDAR sensor is limited by its current location. The 270 degree possible viewing range is always obstructed by both the user and Anna. In addition to this limitation, the sensor can only view objects within the same plane of the sensor (which is parallel to the floor), leaving obstacles located above and below the height of the sensor invisible.

3.1.2 Relocation of LiDAR System

Previous project work included creating assistive navigation for Anna. Using a LiDAR, the wheelchair would locate and avoid obstacles while following a wall. Unfortunately, this navigation was hampered by the location of the LiDAR. Since the LiDAR was located on the arm rest of the wheelchair, much of its viewing range was blocked by the person sitting in the wheelchair. The arm rest was also subjected to additional movement compared to the wheelchair, decreasing the accuracy of the LiDAR's readings. There were also no sensors in the back of the wheelchair, meaning there is a large blind spot, decreasing the accuracy of navigation. Anna also failed to detect any obstacle below waist level, meaning it would hit low objects. To improve the navigation of the wheelchair, sensors were moved to where they can maximize viewing range and obstacle sensing capabilities while still being free from harm. The ideal result was to increase the viewing range from 270 degree viewing range to around 360 degrees.

3.2 Methodology

As suggested by previous project groups, the semi-autonomous navigation could be improved by increasing the view range of the Hokuyo LiDAR sensor. The new location for the LiDAR had to meet several project requirements and needs. The new mounting location had to ensure the sensor:

- Had a minimum 180 degree viewing angle in front of the wheelchair
- Could detect objects within 1cm of the wheelchair foot plate
- Did not impede wheelchair motion in any way
- Could detect objects within 0.15m of the ground
- Cannot change the wheelchair's current ground clearance (mount closer to the ground than foot plate height)
- Is protected from direct impact on all sides

The team developed two different design configurations for mounting the LiDAR sensor. However, to meet the design requirements, the UTM-30LX Hokuyo LiDAR was replaced by a different model (URG-04LX-UG01) because of its smaller profile. Changing LiDAR sensors automatically reduced the view range from 30m to 6m but, this trade-off was acceptable due to the fact that Anna is primarily used indoors and smaller environments. The specifics of the design process can be viewed in Appendix A. Both configurations realized the best location for mounting the LiDAR was on the wheelchair's footplate since it could see objects close to the ground without the wheelchair base blocking its view. It being anywhere on the footplate met almost every requirement. The requirement that required the most effort was ensuring the sensor would be protected from impact on all sides. The final design for mounting the LiDAR sensor on the footplate is shown in Figure 5.

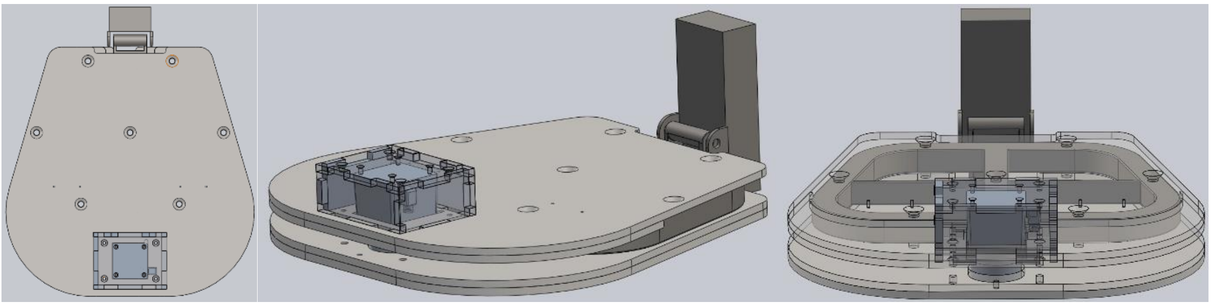


Figure 5: Final Footplate Design

The final design consisted of embedding the LiDAR into the front of the footplate. This enlarged the footplate surface area from the previous footplate design. This was to accommodate the protective box that shielded the sensor on all sides. The preferred material for manufacturing was Delrin plastic due to its durability and weather-resistant surface. However, the final design was not completed in Delrin. WPI's laser manufacturing policies forbid cutting Delrin plastics due to the harmful gases dissipated when the plastic is burned. Instead, the footplate was laser cut out of Medium Density Fiberboard (MDF) due to its durability and low cost. The only tradeoff with using MDF is its extreme susceptibility to liquids. After fabrication, the new design was tested to ensure it met the relocation requirements.

3.3 Results

The manufactured product for the LiDAR sensor integration in the wheelchair footplate is shown in Figure 6. After installation, a requirement verification test was performed to validate that the design requirements were met. This test simply tested that the LiDAR viewing angle, minimum distance reading, and accuracy were consistent with its specification document. By visual inspection, when measuring the sensor output in Rviz, a visualization tool, the sensor was able to maintain its full 240 degree viewing range with ±0.03m accuracy. This outcome was well within the URG-04LX-UG01 Hokuyo specification sheet.

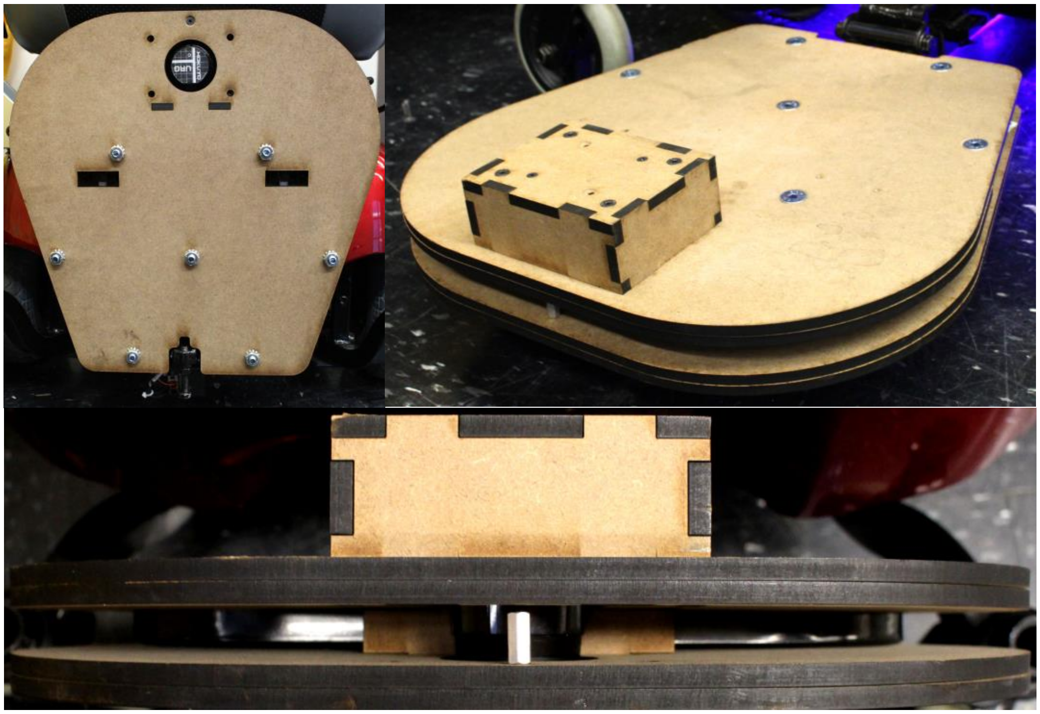


Figure 6: Completed Footplate with LiDAR

Figure 7 shows the ROS Rviz output of the laser scan performed by the LiDARs together with a cost map. A cost map is a rendering of the environment in which sections, or cells, are given values based on the cost of reaching that location. The yellow lines are obstacles and green shows the foot print of the wheelchair. This image shows the wheelchair heading toward a corner surrounded on three sides.

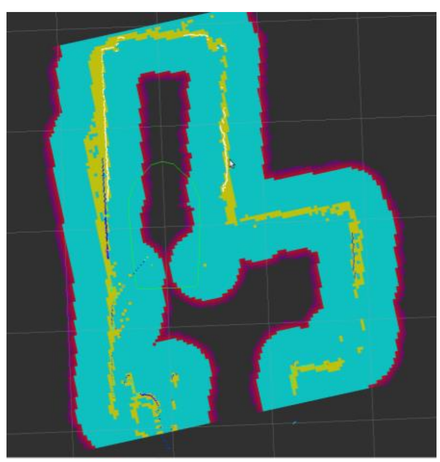


Figure 7: Anna Cost Map Laser Scan

3.4 Discussion

The new LiDAR location successfully improved Anna's existing semi-autonomous navigation. By placing a LiDAR sensor (URG-04LX-UG01) closer to the ground and at the front-center of the wheelchair, Anna was able to sense objects within close proximity of the ground over the complete viewing range of the sensor. However, being at the front of the wheelchair, Anna was unable to sense obstacles at the sides or rear of the wheelchair. To account for this, the original UTM-30LX sensor was mounted underneath the seat at the center point of the wheelchair. This is shown in Figure 8. Now, Anna uses two LiDAR sensors for a nearly 360 degree viewing perimeter. A small portion of the environment is hidden by the arm mount, but no navigation faults have been observed.

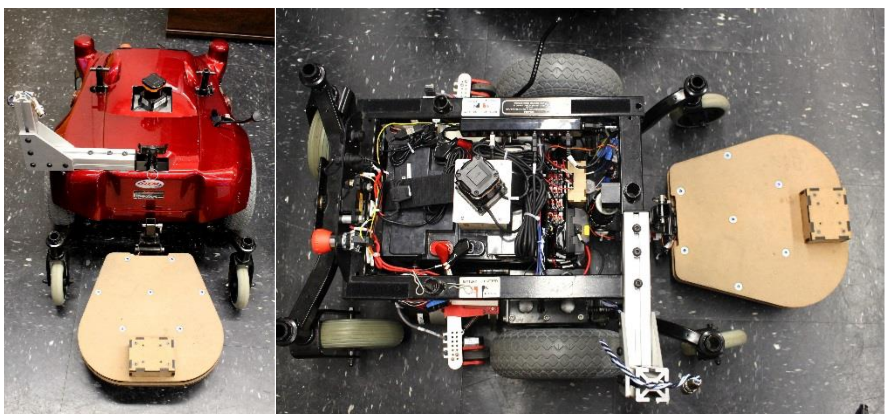


Figure 8: Final LiDAR Relocation

The new design also improved the existing footplate design. Anna's previous footplate required many washers that made the assembly process challenging. Any time the footplate was disassembled, it was difficult to reassemble, taking around 15 minutes. The new design eliminated all washers from footplate assembly, regardless of the material.

Although all requirements were met, the LiDAR/footplate assembly had two main improvements that should be included to further improve the design. Firstly, the footplate should be laser cut out of Delrin plastic instead of MDF. The plastic is more durable and protects against liquids unlike the MDF material. Secondly, a tilting mechanism should be added to the LiDAR mount. This mechanism would allow the sensor to tilt independently from the footplate. This enables the LiDAR laser scan angle to be adjusted easily without adding spacers under its mounting point.

4. Manipulation System

4.1 Previous Work & Requirements

There has been no previous project work to allow the user to manipulate their environment. That being said, stakeholders wanted an additional system to allow the user to interact with their environment. This would be measured by the ability to allow the user to feed themselves, a basic function needed to allow independence.

4.1.1 Self-Feeding

Many of the individuals that will use Anna will not have full control of their arms, vastly limiting the ways in which they can interact with the world around them. With these controller interfaces enabling these patients to navigate, they also need to be able to interact with their environment.

Robotic Arm

Being able to control a robotic arm is quite helpful for those that have little to no control of their arms since it would allow them to interact with their environment and become more self-sufficient. Ideally, users would be able to perform tasks such as self-feeding. The method that the robotic arm is controlled should accommodate to suit the range of movement of the target user. For example, some patients may be able to control the arm using a joystick, while others have no control of their limbs and need to use either voice commands or even facial expressions to move the arm.

An ideal robotic arm that would be installed on this wheelchair would have the following requirements:

1) Can lift everyday lightweight objects, such as an apple
2) Does not significantly increase the width of the wheelchair so it may still go through doorways

3) Same weatherproof qualities as the wheelchair
4) Lightweight and energy efficient

With these requirements, the user would successfully be able to better interact with the environment and perform tasks such as self-feeding.

The JACO Robotic Arm designed by Kinova Robotics, as shown in Figure 2, has been selected as the arm for this project. This arm was selected because it was readily available and met the project requirements. The arm still needed to be integrated into the existing wheelchair system.

Figure 9: Kinova Robotics Jaco Robot Arm [14]

This arm has many critical features that make it an ideal choice for this project, as shown in Table 1.

Table 1: Jaco Robotic Arm features [14]

Feature	Description
Lightweight	Low weight of 5.7 kg
3 flexible fingers	
Payload of 1.5 kg	
Weatherproof	Resistant to the same condition as the power wheelchair
Low energy consumption	Consumes about the same energy as a light bulb
Reach of 90 cm	Long enough reach to pick up objects on a table

JACO can be integrated into almost all the models and power configurations for wheelchair control. It is compatible with Windows and Ubuntu, and easily programmable in

C++, C#, or using their ROS driver. For this project, the ROS driver was used in conjunction with the existing system architecture. Figure 10 shows the Jaco arm on a standard wheelchair.

Figure 10: Jaco Robot Arm on Wheelchair [12]

The arm for this project was integrated in a location similar to the one shown in Figure 10. This arm's base location will be determined by attempting maximize the arm's workspace while making sure the wheelchair is still capable of moving through doors. At first, the arm will be controlled by the remote control provided, in order for testing to be done. Once this installation is complete and it is functioning properly other methods of control (i.e. voice and emotive) will be explored.

Object Detection with the Kinect or a Similar Camera

In order for the robotic arm to be able to detect and pick up objects autonomously, a 3D sensor is needed. Several options were weighed. Stereo cameras are light and can map in 3D, but require a relatively high amount of computing power. Another option is the Kinect for Windows v2 Sensor. This is a device with depth sensing technology, built-in color camera, an infrared (IR) emitter, and a microphone array. It can sense the location and movement of individual humans as well as their voices; it can track up to 6 people and 25 limbs per person. The overall price of the sensor is $200. This is significantly less that the price of the LiDAR sensors on the wheelchair, which range from $1,000 - $5,000. In addition to the release of the sensor, Microsoft released a software development kit (SDK) that provides developers with drivers, tools, APIs, device interfaces, and code samples to facilitate the development of Kinect-enabled applications for commercial deployment. Developers can build applications with C++, C#, VB.Net, Cx, or JavaScript [15].

There have been various projects completed that utilize the Kinect as a 3D sensor to recognize objects and detect the distance between the sensor and the object. At Cornell University, a team completed a project titled "3D Object Detection with Kinect" [16]. The main goal of their project was to have a robot be able to take the name of the object as an input, scan its surroundings, and move to the most likely matching object that it finds. There were five major components to their project: gather RGB-D images of the environment and stitch them together into a 3D map; implement a 3D image segmentation algorithm building on well-known 2D image segmentation algorithms: create a program to label and extract feature values from the segmented objects; choose a set of features, baselines, and a machine learning model to use; and, implement the automated planning and control for the robot.

Another project that used the Kinect for 3D object detection was "A Category-Level 3-D Object Data Set: Putting the Kinect to Work" [17]. In this project, they compiled a large-scale dataset of images taken in domestic and office settings with the Kinect sensor. This dataset is intended for evaluating approaches to category-level object recognition and localization. There are over 50 different object classes that are represented with large variability in the appearance of object class instances.

4.2 Methodology

To achieve the project goal of to enable a user to engage their environment through object manipulation, a robotic arm-system was integrated with Anna. The arm-system consisted of the Kinova Robotics 6 Degree-Of-Freedom (DOF) Jaco robotic arm and an ASUS XTION PRO Live RGB-D camera. Together, the system allows the user to manually or autonomously retrieve objects within reach of the arm. Integrating the arm-system with Anna created new requirements for the existing wheelchair framework. The primary requirement being the new system could not interference with the current footprint or performance capabilities of the wheelchair.

4.2.1 Mounting the Arm-System

The two devices, the actual arm and its control joystick, needed to be mounted directly to the frame of the wheelchair. However, the width of the mount needed to be consider since the wheelchair must to be able to pass through standard doorways. The camera was the simplest to mount because Anna already had a custom "Back-Rack" designed to support the addition of sensory equipment, such as this camera. New holes were drilled to accommodate this specific camera on the "Back-Rack" platforms. This gave multiple locations for mounting the camera while searching for the optimal mount point. Integrating the Jaco arm was much more involved, as there was no pre-existing wheelchair mount. Also, the wheelchair had to be reconfigured to provide a stable 24V power source for arm.

Figure 11: Final Arm Mount

Figure 11 shows the arm mount that was designed for the wheelchair. This mount would be fixed to the wheelchair by bolting it to the frame. A 24V DC-DC power converter was added to the wheelchair power unit to supply power the arm. In addition to adding the converter, the power unit was retrofitted to accommodate additional power ports for 5V and 12V in addition to the 24V port. The wheelchair frame was also retrofitted to make the power unit immovable after being installed in Anna, as the existing location did not restrict the unit from moving while the wheelchair was in motion.

4.2.2 Arm Trajectory Planning

The goal of adding the arm was to allow the user with autonomous self-feeding capabilities. This required a working model of the environment to ensure that the arm would not collide with another object, a camera capable of locating objects and relaying that information to the arm as well as a program that allows these components to interact. The model created for this project can be seen in Figure 12. The model, shown in Rviz, is intractable using the panels on the left. A start state and goal state can be specified as well as the planning parameters (planning time, attempts and allowances for re-planning) can be specified. The path between the start and goal can be calculated and executed in simulation.

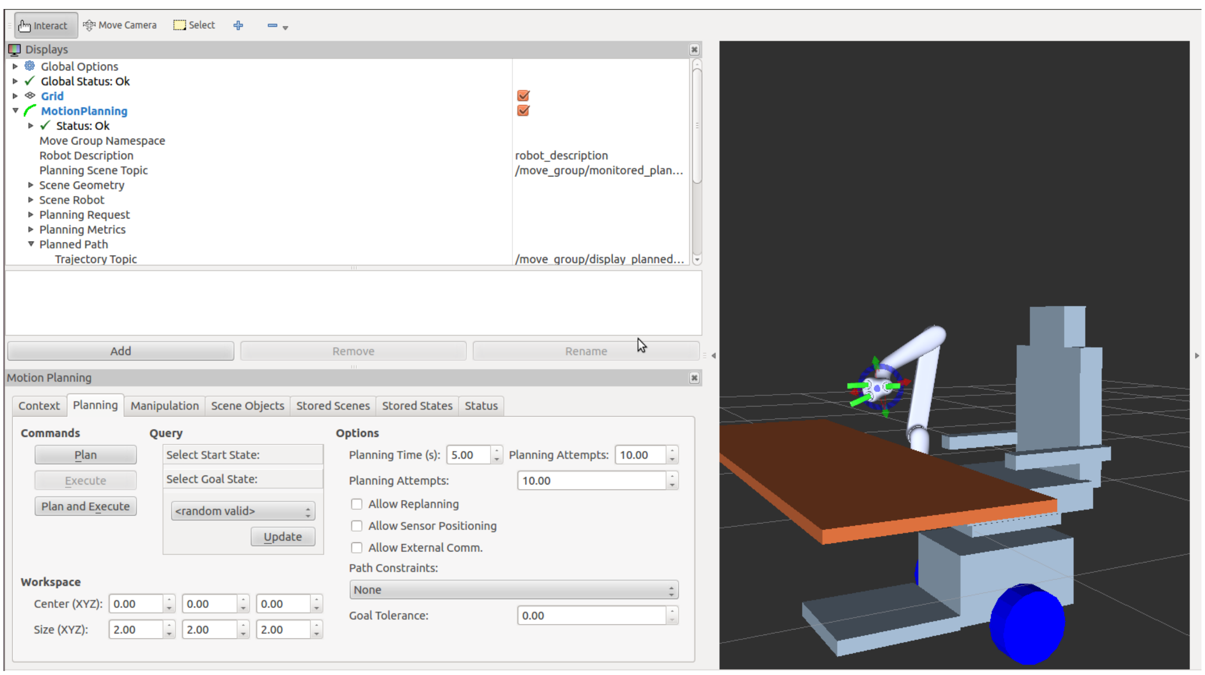


Figure 12: Path Planning in ROS Rviz

To allow the program to safely avoid hitting the human sitting in the chair, a human will need to modelled and added to the environment. This can be accomplished through changing the scene in which the planning is taking place.

The current algorithm for path planning begins with a known arm configuration based on the joint positions reported by the arm's sensors. In most cases, this was the arm's standard ‘home position’ shown in Figure 12. Once the program is activated, the camera would return a point at which the object rested. A position above the object was then set as the goal point for the arm’s end effector with a set orientation. This orientation was chosen as a reliable approach for picking up objects.

4.2.3 Vision System

The ASUS XTION PRO Live RGB-D (Figure 13) was chosen as the camera for the arm-system. This camera was chosen over the competitors such as the Kinect or CREATIVE SENZ3D camera because it has the optimal distance range (0.8m to 3.5m compared with 0.15 – 1m) as well as a better degree of accuracy. Additionally, the Robot Autonomy and Interactive Learning Laboratory (RAIL Lab) at WPI had created an extensive image segmentation library for a similar arm-system using the same arm and camera. Using the pre-existing library available on GitHub, it was possible to calculate the centroid of objects placed on a flat surface and determine the object’s location centroid with respect to the base of the Jaco arm. The camera is shown in Figure 13.

Figure 13: ASUS XTION PRO Live

4.3 Results

Overall, the manipulation system was a success. The camera was capable of recognizing the location of several objects on a table. The arm could navigate to this position while avoiding obstacles and bring the object to the user’s mouth.

4.3.1 Mounting the Arm-System

As shown in Figure 14, the camera was mounted high enough to see the table without the user blocking its view. The height of the mount is adjustable and the camera can change its angle.

Figure 14: Vision System Mounted on Back-Rack

The camera was secured on the highest platform on the wheelchair “Back-Rack”. The final arm mount was constructed using 1.5” Aluminum T-Slot and 3” 8M screws. The mount configuration is shown in Figure 14. The final power unit (Figure 15) supports 16 power ports (nine 5V, six 12V, one 24V).

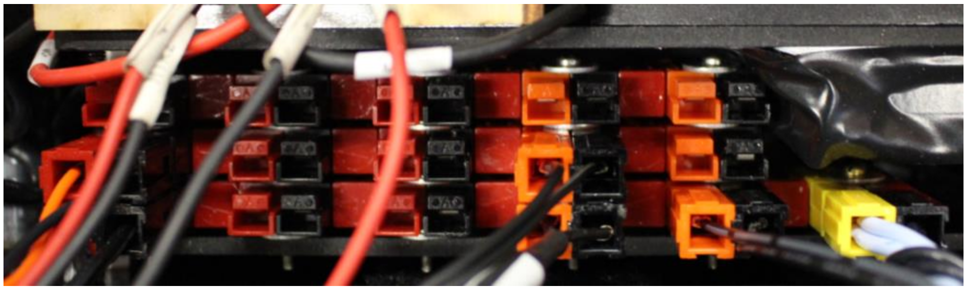


Figure 15: Final Power Unit Ports

4.3.2 Arm Trajectory Planning

The program was able to repeatedly path plan to a known point in Cartesian space. The program would ensure that the arm would avoid known obstacles, such as the table and wheelchair. The orientation of the end-effector (hand) was not always exact, but the difference was negligible. The program had issues calculating joint positions for the arm given end-effector position and orientation. It would take over 20 seconds a majority of the time to calculate this goal unless the orientation tolerances were set to 1 radian (~60 degrees). This was addressed by using a separate program to approximate joint values before path planning. This program was much more successful and would usually take less than half a second to calculate the joint positions. Once the joint values were calculated, the various poses needed to reach the goal could be found.

In Figure 16, the arm is navigating from the 'home position' to a position pointing straight up. A trajectory is then simplified, published, and executed by the physical arm. All of the path locations along the trajectory are shown in Figure 16.

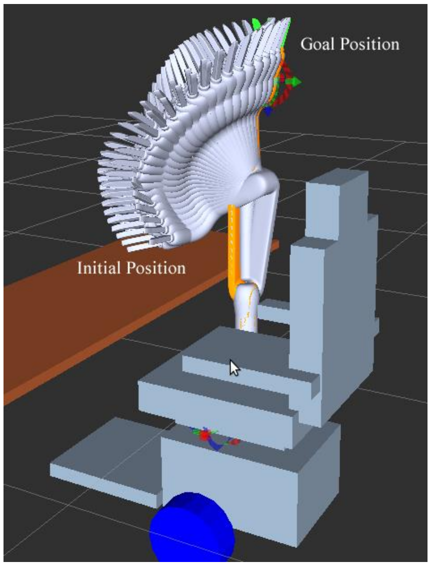


Figure 16: Joint Trajectory Locations in ROS Rviz

Various issues with Kinova's API had to be worked around. For example, when the finger joints would move, the arm would 'sag', moving downward several centimeters. Finger control was also lost at certain locations, regardless of environmental factors.

4.3.3 Vision System

The camera was mounted on a platform that extended 12" forward from the "Back-Rack". This distance kept the Anna user's head below the view of the camera.

Figure 17 shows the Point Cloud output of the camera facing a table top with objects on the surface. This Rviz output screenshot shows the regions of the image that could not be processed. The camera cannot sense glass or reflective surfaces. By comparing the camera view and the Point Cloud, the windows, Jaco arm, and part of the table surface do not appear in the output. Figure 18 shows how the output improves by changing the surface of the table. With the table cloth, more of the objects are present as well as the entire table surface. The Jaco arm surface is still not visible as the surface is reflective.

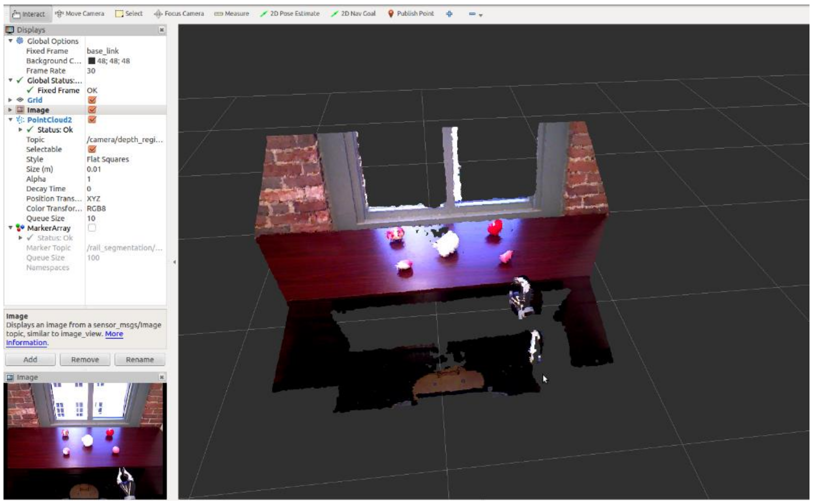


Figure 17: Point Cloud Output on Reflective Surface

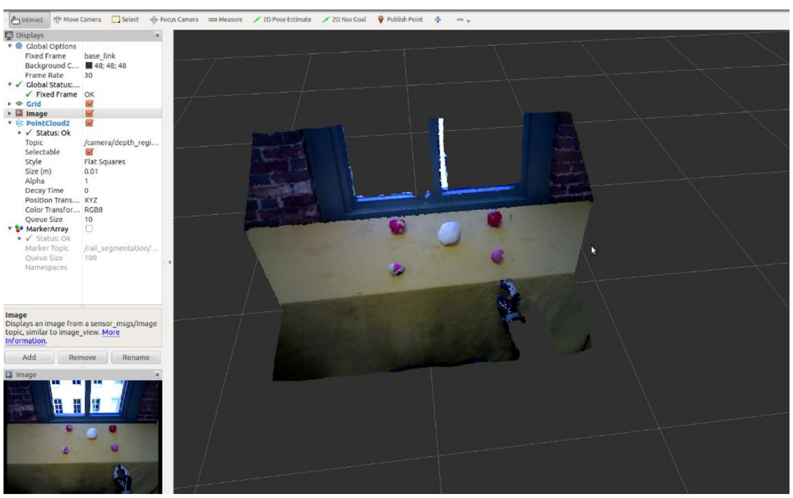


Figure 18: Point Cloud Output on Non Reflective Surface

Figure 19 shows the segmented output data from the camera. Using the RAIL image segmentation software package, the point clouds for all five objects are published as well as the 3D Cartesian coordinates of the centroid of each object.

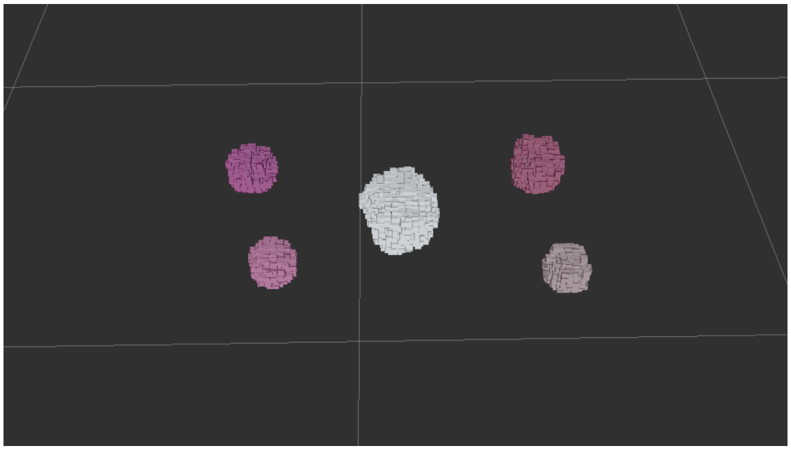


Figure 19: Segmented Objects on Horizontal Surface

4.4 Discussion

The system worked as specified and was able to repeatedly pick up objects without failure. The camera was accurate and reliable enough to send useful information to the arm and the arm was able to repeatedly navigate to poses in its workspace.

4.4.1 Mounting the Arm-System

The arm-camera system was successfully mounted and capable of supporting both the arm and the camera. The arm mount securely held the Jaco arm and its location enabled the arm to rest on the arm rest when not in use. The "Back-Rack" structure fully supported the camera allowing it to maintain its pose with respect to the wheelchair base. However, because of the wheelchair's suspension system, when a user sits in the chair, it caused the seat moved downward from the rest position. Since the camera is on the "Back-Rack", mounted directly to the seat, the camera position changes. This position varied depending upon where the user is sitting in the chair, thus making the static transformation between the camera and wheelchair base variable.

The power unit effectively serves as a custom power strip for powering devices on Anna. Any future work on this unit should involve a complete redesign. Currently, there is very limited space where the unit is mounted. To make any adjustments the entire unit must be uninstalled from the wheelchair base. This could be improved by increasing the size of the plates that hold the unit together.

4.4.2 Arm Trajectory Planning

The Jaco arm worked successfully in multiple trials and enabled self-feeding capabilities. The arm is able to pick up round solid foods such as apples or oranges. Further work could be done to allow more versatile self-feeding capability. The Jaco controller includes a mode that allows the user to pick up and object such as an open cup and maneuver it so it does not spill. Future work should include utilizing this mode for autonomous movement. The program does not currently re-plan its path if multiple objects are detected. This issue will need to be addressed in the future.

Figure 20 shows the arm moving to a location to the right of the chair. The orange square sitting in the chair is there to represent the dimensions of a human being including error. The environment was changed to include a table and a wall to the right.

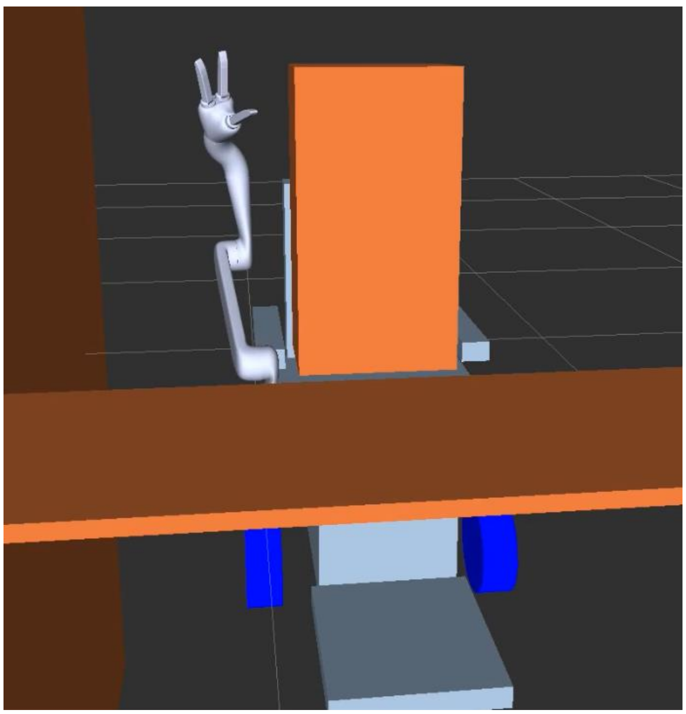


Figure 20: Robot Model during movement

4.4.3 Vision System

After integrating the RAIL laboratory's image segmentation software with Anna, the camera performed as described. The ASUS camera successfully segmented objects from horizontal surfaces. However, the camera IR depth technology was not capable of obtaining data on reflective materials/surfaces. Image segmentation processes were improved by adding a table cloth to the surface. Additionally, it was challenging to compute and accurately approximate the position of objects due to the varying position of the camera. The measured static transformation between the camera and wheelchair base could unpredictably vary because the seat moved due to the suspension. However, for grasping spherical objects, a static transformation between the camera and the wheelchair base was assumed. This proved to be accurate enough for the objects used during testing (various sized balls).

Future work for the vision system would include object recognition and environment mapping. Object recognition would enable the arm to grasp more than just spherical objects. If the camera was able to recognize the target, it could store the desired grasping pose for retrieving the object. As well as selecting a specific object amongst many objects.

5. User Interface Design and Analysis

5.1 Previous Work & Requirements

The semi-autonomous wheelchair has four different user interfaces for controlling navigation: standard Xbox controller/keyboard, EPOC Emotiv control, Voice control, and joystick interface.

5.1.1 Previous Work

The Xbox controller and standard computer keyboard are used during development as the "control" interface for directing the wheelchair. The EPOC Emotiv control is a commercialized product that uses electromyography (EMG) to capture movement in the face and brain activity. Three control methods (Expressiv, Cognitiv, and Affectiv) were tested using the Emotiv to evaluate the user navigation ability. Unfortunately, none of these control schemes were implemented well with Expressiv reporting less than 50% accuracy during control, cognitive with around 35% accuracy following commands, and affective was not implemented at all due to poor readings. The four most successfully recognized expressions were in descending order: left smirk, right smirk, raise brow, and furrow brow. Voice control was implemented using about fifty different preprogrammed voice commands for controlling the wheelchair through a microphone. The joystick interface was designed to control the original wheelchair joystick without altering the original construction. The prototyped joystick model suffered many complications and was not fully integrated into the present wheelchair design.

5.1.2 Project Goals

There are a various number of control interfaces to be implemented in this project. This is a critical aspect of designing Anna considering that it is specifically being targeted to those with a lack of upper mobility. Since this wheelchair system will be meant for a range of people with different levels of mobility it will need to be multi-modal. The team has decided upon implementing two distinct control schemes. The first will be utilizing inputs from the Emotiv headset. The previous project also utilized the Emotiv system; however, insufficient testing was conducted. Further investigation must be done upon the Expressiv and Affectiv suites. The second system will be creating an EMG sensor to be placed on the arm.

Emotiv Headset

The Emotiv headset will be used to monitor facial expression and conscious thoughts. These will serve as inputs to the wheelchair navigation. A current issue is that the previous project did not collect sufficient data to evaluate the full capabilities the Emotiv headset has. There were a very limited number of trials conducted and there is no background data concerning each subject. In addition the previous team did not investigate the full capability of the Emotiv in terms of using it in the Expressiv and Cognitiv mode.

The stakeholders for the Emotiv control interface are the wheelchair operators that are incapacitated from the neck down. These users would be able to control Anna using minor facial movements and conscious thoughts.

One goal of this project is to improve the accuracy and robustness of the Emotiv control system in the assistive wheelchair. Currently, the accuracy for inputs from the Expressiv suite is 50 percentile and the accuracy for the inputs from the Cognitiv suite is 35 percentile. At the culmination of this project it is hoped that both the accuracies for these systems will be at 75 percentile. This will be completed by investigating previous trials done with the Emotiv and conducting trials that study each available command on the device.

An additional goal is to conduct experimental trials of the Emotiv's Expressiv and Cognitiv modes with at least 25 subjects in order to create a probabilistic model of the system. These trials will include documentation of extensive information about each subject. This information will include but not be exclusive to hair length and gender. These subjects will perform controlled tasks and the results will be recorded. Then cross comparison will be utilized in order to determine if there are any correlations between a subjects bio-information to the results of the experiment. Furthermore, trials will be performed such that a probabilistic model for each input command can be produced.

The purpose of integrating the Emotiv Headset into Anna's system is to allow for a navigation controller that requires no movement of the arms. This aligns with the goals of the project which are to create an assistive wheelchair for individuals who have limited upper body mobility. For the Emotiv Headset to be successfully integrated into the wheelchair, there are a number of requirements and needs the system must fulfill. The most important need is that the user can actually control wheelchair navigation via commands from the Emotiv headset. Based on prior research, it has been deemed a requirement that the inputs from the Emotiv headset produce the desired output at least 75% of the time for the system to be considered successful.

The Emotiv headset was used to monitor facial expression and conscious thoughts. These served as inputs to the wheelchair navigation. An issue that arose was that the previous project did not collect sufficient data to evaluate the full capabilities the Emotiv headset has. There were a very limited number of trials conducted and there is no background data concerning each subject. In addition the previous team did not investigate the full capability of the Emotiv in terms of using it in the Expressiv and Cognitiv mode.

Table 2: Needs and Requirements of Emotiv Control

ID	Need	Description	Cost	Source	Priority
&emot	Emotive Control	The user will be able to navigate the wheelchair using the EPOC Emotiv Interface	High	$user, $nsf, $home, $care, $pw, $comp	5
&cog	Cognitiv Control	The inputs from the cognitiv system will produce the desired cognitiv commands	High	$user, $nsf, $home, $care, $pw, $comp	5
&exp	Expressiv Control	The inputs from expressiv system will produce the desired expressiv commands	High	$user, $nsf, $home, $care, $pw, $comp	5
&modul	Modularity	It will be possible to provide inputs from the various individual components of the wheelchair interface while using the Emotiv.	High	$user, $nsf, $comp	4
&rel	Reliability	The inputs from each interface will provide the desired output	High	$user, $nsf,	4
%safeemo	Safety	Emotiv input shall be safe for the user to use	High	$user, $home, $care, $comp	4
%emoacc	Accuracy	The emotiv controller system will produce the accurate output at least 75% of the time	Low	$user, $home, $care, $comp	2
%indep	Modularity	The inputs from Emotiv will only produce the desired navigation command and will not affect other aspects of the wheelchair	High	$user, $nsf, $comp ,$home, $care	4

The performance of this system is dependent upon how accurate the input commands are. There are a multitude of command options from the Affective, Cognitiv and Expressiv Suites. However, Anna's pilot will use a limited number of set input commands that are set. In order for the principal investigators of this project to implement the most successful commands extensive testing must be completed to determine which commands have the highest success rate. Subsequently, performance tests were designed with the intention of testing approximately 25 human subjects. The subjects were recruited via word of mouth by the principal investigators and advertising within the Electrical and Computer Engineering Department. Figure 21 shows the decision process used when determining whether to integrate these systems with Anna.

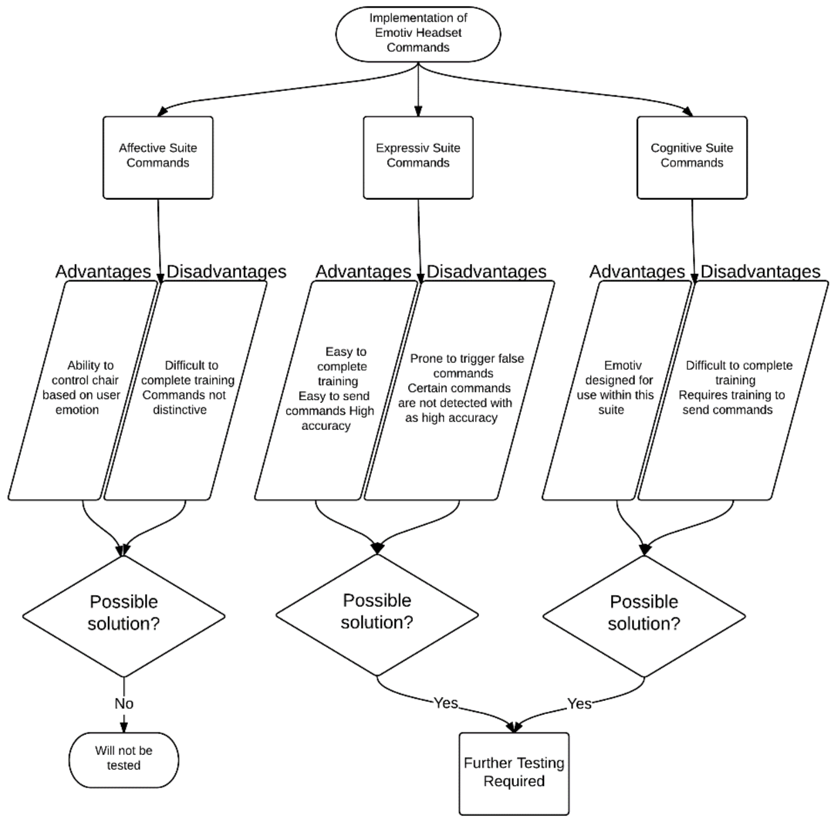


Figure 21: Decision Diagram for Emotiv System

EMG Sensor

Another goal for this project is to be able create a device that incorporates a muscle signals to drive the wheelchair. There is currently project within the RIVeR lab that involves creating a modular EMG board that will be able to detect muscle signals and transfer the signals into a command. The proposed idea is to integrate EMG with wheelchair drive control is through detecting the muscle signals when the user makes a fist or moves certain fingers. The wheelchair base will be calibrated to the user that will determine what voltage threshold will determine that the user did flex a particular muscle.

To be able to accomplish this goal, the modular EMG board would have to be transferred into a prototype circuit board (PCB). From there, the EMG PCB with be tested to determine the different voltage thresholds for different muscle contractions and then continue more testing once the board is integrate with Anna. The goal to be able to have the user flex an arm muscle and have the wheelchair react by either moving forward, backward, right, or left.

The purpose of the EMG board was to be able to detect muscle tissue signals on a limb and amplify the signal to determine whether or not the muscle was flexed. The final goal for this component of the project is to control wheelchair navigation and Jaco arm movement via small hand movements. Currently board can measure up to two muscles and outputs 2 voltage signals. The EMG input system is comprised of the EMG board and three electrodes for each muscle including pads. The voltage signals are measured using an oscilloscope. In order for the system to be successful different inputs must different inputs must amplify the distinct signals which can be measured using the oscilloscope. The design for this EMG board must meet the following requirements: must be the size of a Tiva Board and each testing point must be placed before each stage of the amplifier circuit.

The most important need is that the user can actually control wheelchair navigation via commands from the EMG Board. Another need is that the system must be modular. This means that each system of the board can be changed or expanded to suit the user's needs. This also means that the board will allow multiple connects and shield expandability for multiple electrode connections. Furthermore, this board must be able to connect with other shield boards and it must not be bigger than the size of the Tiva board in length and width. Other basic requirements include designing the board with a voltage input of 3.3V, have inputs for the electrodes and output a voltage signal.

Table 3: Needs of the EMG control system

IID	Requirement	Description	Cost	Source	Priority
%tes	Testing	The board should allow in board testing between each stage	High	$user	5
%mod	Modularity	The board shall be configured to allow multiple shield boards to be added	High	$user	4
%rel	reliability	The board should be able to continuously recognize muscle signals	Low	$user	5
%acc	Accuracy	The board shall be able to detect muscle signals from just moving a finger	High	$user	5
%saf	Safety	The board shall not break down or cause the user electric shock	Low	$user	4

5.2 Methodology

The Emotiv system was tested and optimized for Anna's users. The code was validated and trails were conducted. The EMG board was tested and improved through several generations.

5.2.1 Emotiv Testing Procedure

The purpose of this study was to determine which facial and cognitive commands for the Emotiv headset have the highest rates of success in terms of controlling Anna's motion. These trials aim to assess the success of a various inputs on various users. Then the data was analyzed utilizing cross-correlation. This was accomplished by gathering information about a subject's pigmentation and fatigue. Then the subjects was given a training session on how to use the EPOC Emotiv headset. Then the subjects will attempt to control Anna using given commands.

Each subject's success with accomplishing each command was recorded. Then the data was analyzed.

There is a specific procedure for conducting the Emotiv trials. First the Emotiv headset must be fully charged. Furthermore, to ensure good contact and a controlled experiment each electrode node will receive three drops of saline before being placed in the headset. The headset will then be turned on. The USB will then be placed into the computer with the Emotiv SDK application such that the headset can connect to the SDK. Upon the first screen the investigator can check the quality of the connection.

The subject will then arrive and they will complete the required preliminary information sheet. The subject will then be debriefed on the entire procedure and asked if they have any questions or concerns. The subject was given instructions on how to use the Emotiv headset and then they will place the headset on their head. The principal investigators will check the Emotiv headset placement and the apparent connection of the Emotiv nodes to the SDK and adjust the headset accordingly. Once the connection is optimal the connection state of each node was recorded.

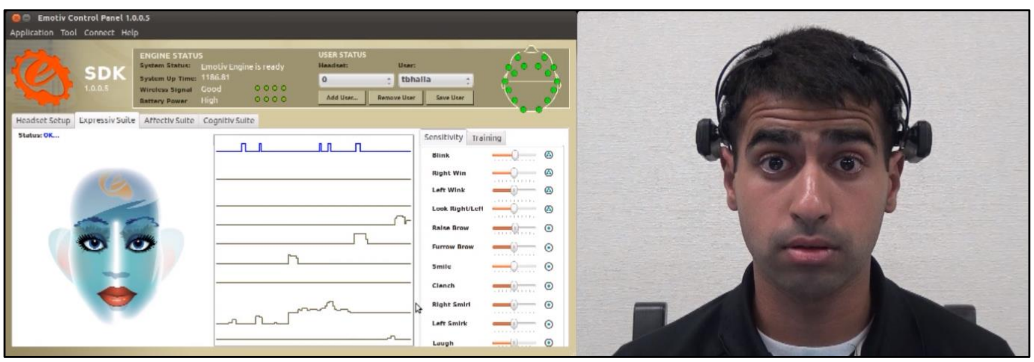


Figure 22: Emotiv Facial Expression Trial

The subjects will then be explained to that there are two testing suites: Cognitiv and Expressiv. The subject will then complete training on each suite within the SDK. For the Cognitiv suite training consists of virtually moving an object through conscious thoughts. The Expressiv suite consists of a blue avatar mimicking the detected facial movements that the headset picks up from the user. Figure 22 shows an individual, a project member, doing the

Expressiv training. Once the subject has completed all trainings then the subject will use a Qualtrics survey to fill out their initial conditions.

The subject will then begin the testing program that was created by the principal investigators. The testing program consists of a series of prompts asking for the name of the subject, length of each trial, and length of buffer time between each trial. The user will then begin the Expressiv trial. The Expressiv trial consists of the program giving prompts to complete each of the 12 Expressiv commands in randomized order. The subject will have a 3 second window to complete the command and then a three second buffer time between each command. There was no notification if the subject has done the command correctly to ensure a blind study. Furthermore, once all 12 commands have been exhausted the subject will repeat this 9 more times to create 10 total trials for Expressiv. Then the subject was given 2 minutes of rest.

The subject will then complete the Cognitiv Suite. There are 12 total Cognitiv commands. However, since the Emotiv system can only retain user profiles for 4 active Cognitiv commands at a given time the trials for Cognitiv was presented in 3 groups of 4 commands. This means that the subject is given prompts for the first 4 specific commands in randomized order and repeats this 9 more times. The subject will then move to the next group of Cognitiv commands and complete the prompts until there are 10 trials for each of the 3 Cognitiv groups. The student investigators will thank the subject for participating in the study and cautiously remove the Emotiv Headset. The subject will receive a follow up email within 24 hours of the test to ask if there are any concerns or questions.

While the Expressiv and Cognitiv testing programs are being run the result from each test is output to an external csv file. This file contains the command that was called, which time the command was called, what other extraneous command signals were picked up and if the correct command was detected. Furthermore, the csv file displays the strength of each of the signals called. All of this information was logged into a Qualtrics survey that is specific to each trial subject. The principal investigators will then perform statistical analysis and cross correlation.

5.2.2 Testing the Emotiv ROS Driver Code

Once the modifications to the existing Emotiv Expressiv ROS Driver code have been made, the new implementation needs to be tested to determine its accuracy and efficiency, and compared to the existing driver to have a head-head comparison. Two different tests was conducted to quantify how accurate and effective the new modifications are.

Accuracy Trials

The first set of trials that was conducted was similar to the general Emotiv trials that were done for both the Expressiv and Cognitiv commands. The same general setup procedure for the headset and computer was taken. The student investigator will load the trial program that utilizes the modifications made in the drive code. Once the subject has arrived, he/she was told about the testing procedure, how to use the headset, and asked to fill out the waiver.

The main difference with this trial program and the previous ones is that now instead of being prompted to perform certain expressions, the subject was prompted to perform a certain action (i.e. “Move Forward”. Once the user has the headset on, the student investigator will explain to the subject how to trigger each of the six different commands: move forward, move backward, stop, rotate left, rotate right, and pause/activate the wheelchair base. When the subject feels comfortable in performing each of these actions and feels like their expressions are accurately being portrayed on the SDK, the investigator can begin the program. Depending on which one the subject found to be more accurately portrayed on the SDK, they can choose during the program start up to use ‘Look Left’ and ‘Look Right’ for the rotation commands, or use ‘Smirk Left’ and ‘Smirk Right’ The subject was asked to run through 10 rounds of the trials.

Once completed, the student investigator will load the trial program that tests the pre-existing Emotiv ROS driver code. This code has different methods in how it performs the actions, so the investigator will explain to the student how to accurately pick up each of these commands. When the subject feels comfortable performing each of the required expressions to perform these commands, the trials began. The subject was asked to run through another 10 rounds of the trials. At any time after a round is completed for both set of trials, the subject can take a break.

Similar to the previous trials, the results are being outputted to an external CSV file while the trial is running. This file contains the action that was called, which time the action was called, what other extraneous actions were picked up and if the correct action was detected. There was a total of five subjects who will conduct the trials. The principal investigators will then perform statistical analysis to determine how accurately each action was registered. With this, the investigators was able to make a head-head comparison between the two sets of code and determine how much more accurately one program will pick up the commands performed by the user.

Time Trials

The second set of trials will measure how efficiently a user can navigate around its surroundings. There was an environment that the user was asked to navigate around. The team will set up an obstacle course with tables that will force the subject to use the various commands of controlling Anna to successfully navigate around the course.

Since these trials was conducted after the accuracy trials, the user will already be familiar with the headset and have trained their expressions. The student investigator will explain the course to the subject, and also show the subject how to use the emergency stop located on the wheelchair in case anything goes wrong. Once the subject is ready, the investigator will start the program and start timing the user. The subject will need to first toggle to active mode and then navigate the obstacles. Once the subject is at the finish line, they will need to toggle back to pause mode and only then will the investigator stop the clock. This trial was conducted a total of three times, and then the investigator will switch to the other program. Before starting the trial for this program, the investigator needs to make sure that the connection of the headset remained the same. Then, the investigator will explain how to issue each command with this program and then the user will navigate the course three more times while being timed.

5.2.3 EMG Testing Procedure

The purpose of this study is to determine which muscle movements for the EMG to have the highest rates of success in terms of controlling Anna's movement. These trials aim to assess the success of a various inputs on various users and determine the minimum voltage threshold in detecting a muscle flexing. Then the data was analyzed utilizing basic statistical analysis. This was accomplished by analyzing the output signals from various users of different arm muscle movements. At this time human subjects will comprise of members of the team. The team will then determine which movements constitute optimal output for the majority of users then implement these commands to Anna.

When testing the board all components must be in use. This test requires a voltage source, oscilloscope, EMG board, 3 electrodes, electrode pads and a human subject. To begin the test the board must have a power source and the electrodes must be attached. Attach the oscilloscope to board outputs. The voltage range should roughly be 0 to 3.3V and the time scale should be approximately 0.5 seconds. Then attach the electrode pad to a muscle. The Red pad should be at the beginning of the muscle and the black pad should be at the end of the muscle. The white pad is the reference. Then the power should be turned on and ideally the oscilloscope was outputting a flat signal. The subject will flex the muscle and a voltage peak will appear.

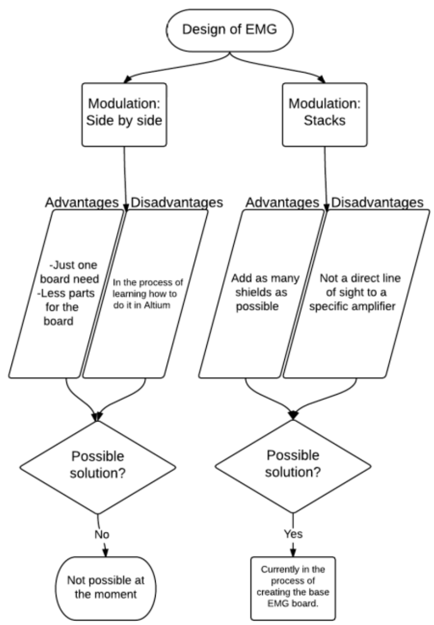


Figure 23: Decision Diagram for the EMG board design

5.3 Results

The Emotiv commands, after being optimized had 85% accuracy with a 4% false detection rate. The remaining 11% was no detection when a command was being issued. The

EMG did not meet the initial goal of integration, but the design was improved over several variations.

5.3.1 Emotiv

This section outlines the results and analysis of using Expressiv and Cognitiv control with the Emotiv headset. The Expressiv commands consist of different facial movements that manifest itself in EMG signals. In contrast Cognitiv commands consist of different conscious thoughts that manifest itself as EEG signals.

Overall Results from Expressiv

There are three types of commands that the Expressiv Mode monitors which include the following: Upper Face Movement Commands, Lower Face Movement, and Binary Eye Commands. The Upper Face Movement Commands include Furrow and Eyebrow (raise eyebrow). The Lower Face Movements consist of Clench, Smile, Laugh, Left Smirk and Right Smirk. The Binary Eye Commands are: Blink, WinkLeft, WinkRight, LookLeft and LookRight. They are called such because unlike the other commands which exhibit a "strength value" from 0 to 1 these commands only output as zeros or ones.

For this experiment, 29 subjects with the Upper Face Movement Commands and the Lower Face Movement Commands were tested. 10 subjects were tested for the Binary Eye Commands. As stated in the previous section, subject health characteristic data was taken as well. The following table, Table 4, displays the percent of the window active when the command is requested. For the Binary Eye Commands subjects were asked to rapidly complete a given command at two designated intervals within a 4.9 second window. For the Upper Face Movement Commands and the Lower Face Movement Commands, the subjects were asked to complete the command by sustaining a movement for as long as they could for the 2.9 second window given. Therefore, the numbers represent a percentage of the respective window that the command was correctly detected. For the Binary Eye Commands the actual value in seconds the window was active with the correct command is the given number multiplied by 4.9 seconds. For all other commands, the actual value in seconds the window was active with the correct command is the given number multiplied by 2.9 seconds. These numbers were calculated from the average amount of durations from 10 subjects. It is evident that if a command was requested it was typically detected by the Emotiv Headset once the user underwent training. It is important to consider when observing these values that when the Binary Eye Values were completed it was requested that the subjects complete these commands rapidly. It was show in the data that the Binary Eye duration values are much less than the other command duration values.

Table 4: Percent of Each Window Active for Expressiv Testing

Command	Percent of Window Active
Blink	0.0808
WinkLeft	0.0195
WinkRight	0.0317
LookLeft	0.0507
LookRight	0.0575
Eyebrow	0.2687
Furrow	0.3567
Smile	0.1593
Clench	0.4014
SmirkLeft	0.2528
SmirkRight	0.2251
Laugh	0.2546

Table 4 displays the results on the various accuracies of eye movements. The first column indicates which command each subject was requested to perform or as it has been termed was “Expected Commands.” The other columns indicate which commands were actually detected, as such have been termed “Actual Results.” One can read the table by looking at the first column to see which command was the Expected Command and then move across that specific row to see what was actually detected. It is important to specify how these numbers were derived.

For the Binary Eye Commands each user was prompted during the requested command to do the eye command twice during two specific intervals. Since there were 10 trials it is expected each user to do the specified Binary Eye Command at total of 20 times. Since there were two separate windows as long as the command was detected at least once within a window it was counted as one instance. If the command was not detected at all in a window it was counted as a zero. Thus, it could be concluded if the eye command was intentional and detected. Thus to calculate the eye commands, simply used the following equation:

$$AverageDetectionRate = \frac{EyeCommandDetected}{TotalNumberofIntervals}$$

Equation 1: Average Detection Rate for Binary Eye Commands

Table 5: Actual Commands Captured for Binary Eye Commands

Expected	Blink	WinkLeft	WinkRight	LookLeft	LookRight
Blink	0.6707	0.0593	0.0936	0.02	0.005
WinkLeft	0.2143	0.1664	0.0121	0.0436	0.0593
WinkRight	0.1164	0.0321	0.2471	0.04	0.0571
LookLeft	0.15	0.005	0.1421	0.2686	0.3121
LookRight	0.0957	0.035	0.105	0.2393	0.42
Eyebrow	0.165	0.0471	0.0814	0.0793	0.06
Furrow	0.06	0.02	0.1071	0.035	0.0943
Smile	0.3786	0.025	0.04	0.02	0.02
Clench	0.1221	0.055	0.035	0.04	0.015
SmirkLeft	0.2443	0	0.01	0.03	0.02
SmirkRight	0.15	0.025	0.0321	0	0
Laugh	0.4486	0.1193	0.1021	0.0543	0.0436
Neutral	0.2107	0.0221	0.0121	0	0

For the Upper Face Movement Commands and Lower Face Movement Commands a different approach was used to tabulate the efficacy and success of each command. For these commands the subject was instructed to do the command and had a 3.9 second window to do so. In addition for these commands the signal strength could range from 0 to 1 depending on how well the signal was detected. Thus an integral system was utilized to evaluate the strength of each command. If a signal was detected the signal strength was multiplied by the duration of that signal. Each of these integrals was added for each trial and then divided by 3.9*1*10. This value was used because 3.9 is the highest obtainable integral considering if there was a window of 3.9 and a perfect signal of 1 was detected the whole time. And there are 10 trials so it was multiplied by 10. This was able to provide a weighted average of all the signals and their strength values. Table 6 displays the results of this testing.

$$SignalStrength = \sum \frac{duration\ of\ signal * signal\ strength}{total\ time * highest\ signal\ strength}$$

Equation 2: Signal Strength Calculation for Expressiv Commands

Table 6: Signal Strength for Actual Commands for Expressiv Testing

Expected	Eyebrow	Furrow	Smile	Clench	SmirkLeft	SmirkRight	Laugh
Blink	0.0094	0.1391	0.016	0.002	0.0555	0.074	0.0101
WinkLeft	0.0105	0.126	0.0252	0.0045	0.0883	0.0846	0.032
WinkRight	0.0162	0.1265	0.0122	0.0073	0.0281	0.1245	0.0441
LookLeft	0.0114	0.203	0.0284	0.0022	0.0775	0.092	0.0146
LookRight	0.0133	0.1606	0.0123	0.0009	0.0306	0.1462	0.0316
Eyebrow	0.1667	0.044	0.0157	0.0454	0.0122	0.0119	0.0912
Furrow	0.0253	0.1693	0.0135	0.0104	0.0274	0.0282	0.023
Smile	0.0044	0.0586	0.1323	0.0032	0.067	0.1382	0.0742
Clench	0.0591	0.0122	0.0298	0.3119	0.0227	0.0416	0.0492
SmirkLeft	0.0032	0.0995	0.0467	0.0007	0.2121	0.0789	0.0227
SmirkRight	0.0112	0.0781	0.0528	0.0006	0.0615	0.2881	0.0316
Laugh	0.0065	0.0504	0.059	0	0.0547	0.1123	0.1826
Neutral	0.0066	0.0689	0.0172	0.0014	0.06	0.1082	0.0137

Table 7 gives the signal average strength for the expected state and its respective correct command.

Table 7: Average Correct Signal Strength

Expected State	Correct Signal Strength
Blink	0.6707
LookRight	0.42
Clench	0.3119
SmirkRight	0.2881
Laugh	0.2881
LookLeft	0.2686
WinkRight	0.2471
SmirkLeft	0.2121
Furrow	0.1693
Smile	0.1693
Eyebrow	0.1667
WinkLeft	0.1664

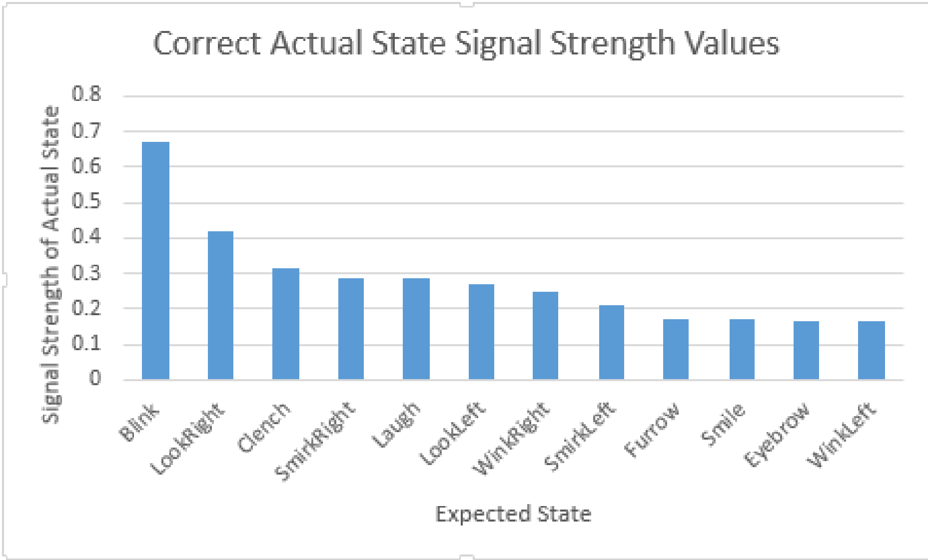


Figure 24: Graph of Correct Actual State Signal Strength Values

As seen in Figure 24, the correct detections states were the highest for Blink, Look Right, Clench, Smirk Right, Laugh, and Look Left. This is not taking into consideration if these commands have high false detection rates. Furthermore, this is merely a weighted average of the signal strength. This means that if a command was implemented such as Furrow the threshold for acting upon this command would need to be lower than the weighted average which is around .16. Some commands although they have high rates of detection cannot be implemented because they are not a distinct enough facial movement. Figure 8 displays the average false detection signal.

Table 8: Average False Detection Signal Strength

Expected Command	Average False Detection Signal
SmirkRight	0.036908333
Furrow	0.037016667
Clench	0.040141667
Blink	0.040333333
Neutral	0.043408333
SmirkLeft	0.046333333
Eyebrow	0.054433333
WinkRight	0.054954545
WinkLeft	0.058366667
Smile	0.0691
LookRight	0.072541667
LookLeft	0.086525
Laugh	0.087566667

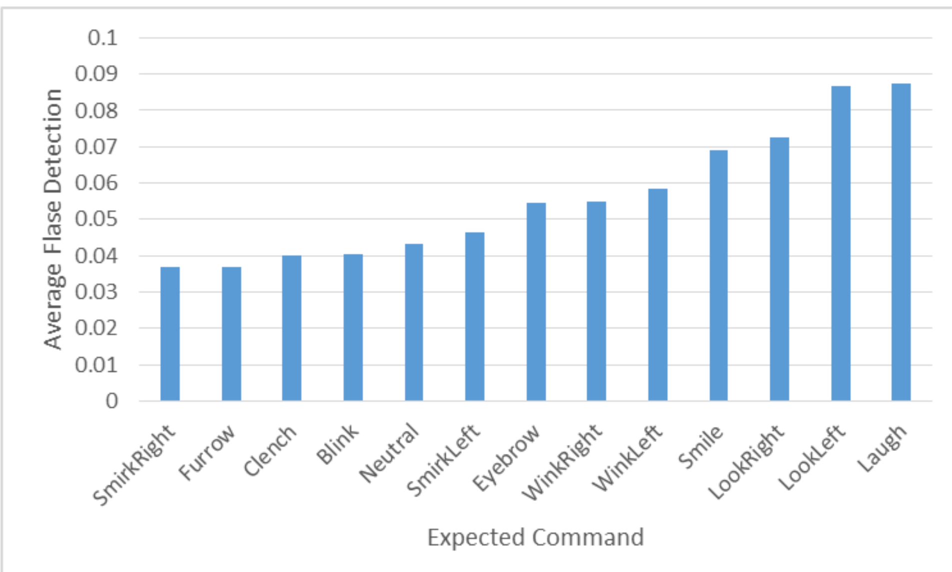


Figure 25: Graph of Average False Detection Signal

As seen in Figure 25, Smirk Right, Furrow, Clench, Blink, and Smirk Left were all the commands with the least amounts of false detection. This is important to take into consideration because a command cannot be implemented simply because it has high rates of detection. It must read that signal when Anna's user has intended it to occur.

Creating Correlations

Given that the data was linear and associated with a time, it was possible to do cross correlation with each different command and then assess if a positive correlation coefficient was found. This was computed in Matlab by using the 'corr(X,Y)' function. This function returns a p1-by-p2 matrix containing the pairwise correlation coefficient between each pair of columns in the n-by-p1 and n-by-p2 matrices X and Y. In this case X would be an expected command and Y would be an actual command. Below depicts the actual formula that this command computes. Mean values μ_X and μ_Y and standard deviations σ_X and σ_Y of each of the matrices is defined as such. This command will compute the Pearson correlation coefficient between the two values. This allows one to determine if there is linear dependence between these commands. The coefficient value can range from 1 to -1. 1 Indicates that there is a perfect correlation and -1 indicates a negative correlation. Meanwhile 0 will indicate that there is no relationship.

$$\rho_{X,Y} = \mathrm{corr}(X,Y) = \frac{\mathrm{cov}(X,Y)}{\sigma_X \sigma_Y} = \frac{E[(X-\mu_X)(Y-\mu_Y)]}{\sigma_X \sigma_Y},$$

Equation 3: Covariance

Below are the values that had a correlation coefficient above 0. These are listed because although there is not a perfect linear relationship between these values there is some positive relationship. This demonstrates that certain commands have a greater affinity to be mistaken for other commands. This occurs often for movements that include a similar type of movement.

Table 9: Positive Correlation Coefficients between Correct Commands

Expected	Actual	Correlation Coefficient
Furrow	**Eyebrow**	0.2347
Smile	**SmirkLeft**	0.0104
Smile	**SmirkRight**	0.3376
Clench	**SmirkRight**	0.348
SmirkRight	**Laugh**	0.0149
SmirkRight	**Smile**	0.3789

As shown in Table 9, Raise Eyebrow was detected often when Furrow was expected. Smirk Left and Smirk Right were often detected when Smile was expected. Smirk Right was detected when Clench was expected. Laugh and Smile were detected when Smirk Right was requested. This information was important because when integrating these commands into Anna it is important to note which commands are apt to be misread by the Emotiv. It is pertinent that the incidence of false commands is minimized as much as possible.

Drawing Trends

In addition to gathering data overall results were differentiated by various health information. Given the setting of the experiment it was found that characteristics that could affect results the most were male versus female results and long hair versus short hair results. Table 10 shows the signal strength differences for male and female subjects.

Table 10: Correct Signal Strength for Females vs Males

Expected State	Correct Signal Strength for Females	Expected State	Correct Signal Strength for Males
Eyebrow	0.161	Eyebrow	0.1244
Furrow	0.1895	Furrow	0.1948
Smile	0.0508	Smile	0.123
Clench	0.1759	Clench	0.3173
SmirkLeft	0.1236	SmirkLeft	0.2053
SmirkRight	0.0373	SmirkRight	0.2564
Laugh	0.1301	Laugh	0.1439

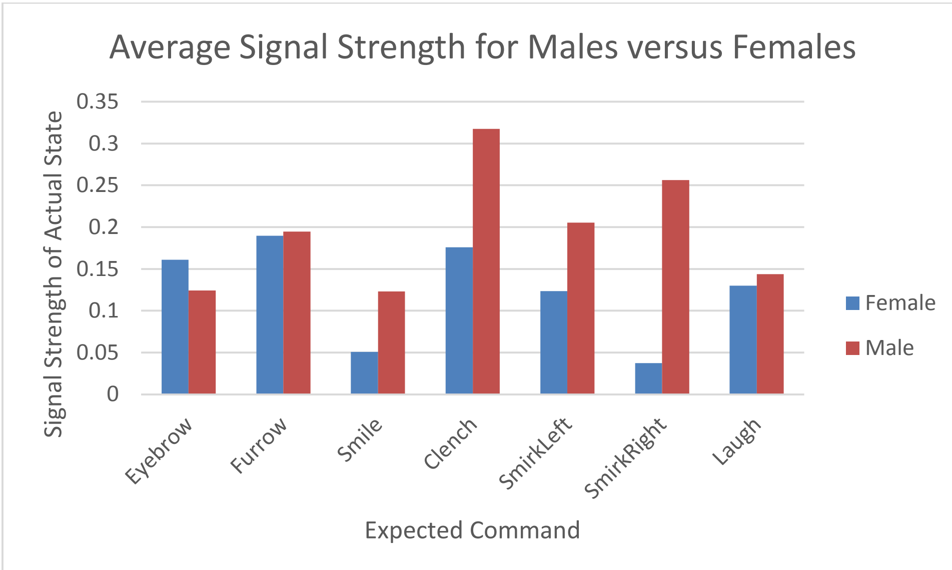


Figure 26: Average Signal Strength for Males versus Females

By looking at the data in Figure 26, it appears that the commands such as Eyebrow, Furrow, and Laugh have similar averages for females and males. However, Clench, SmirkLeft, Smirk Right and Smile have substantially higher averages for males. Based on the testing this could be inferred that since males typically have shorter hair the electrodes have much better contact with the scalp. In addition, the false commands for males and females are shown below in Table 11 and Figure 27. The false commands were added and averaged to filter them out.

Table 11: False Detections for Female and Males

Expected Command	Average False Detection Signal for Females	Expected Command	Average False Detection Signal for Males
Eyebrow	0.03674286	Eyebrow	0.04061429
Furrow	0.0219	Furrow	0.02357143
Smile	0.05311429	Smile	0.05345714
Clench	0.03794286	Clench	0.02388571
SmirkLeft	0.03411429	SmirkLeft	0.0357
SmirkRight	0.05114286	SmirkRight	0.0363
Laugh	0.04157143	Laugh	0.04492857

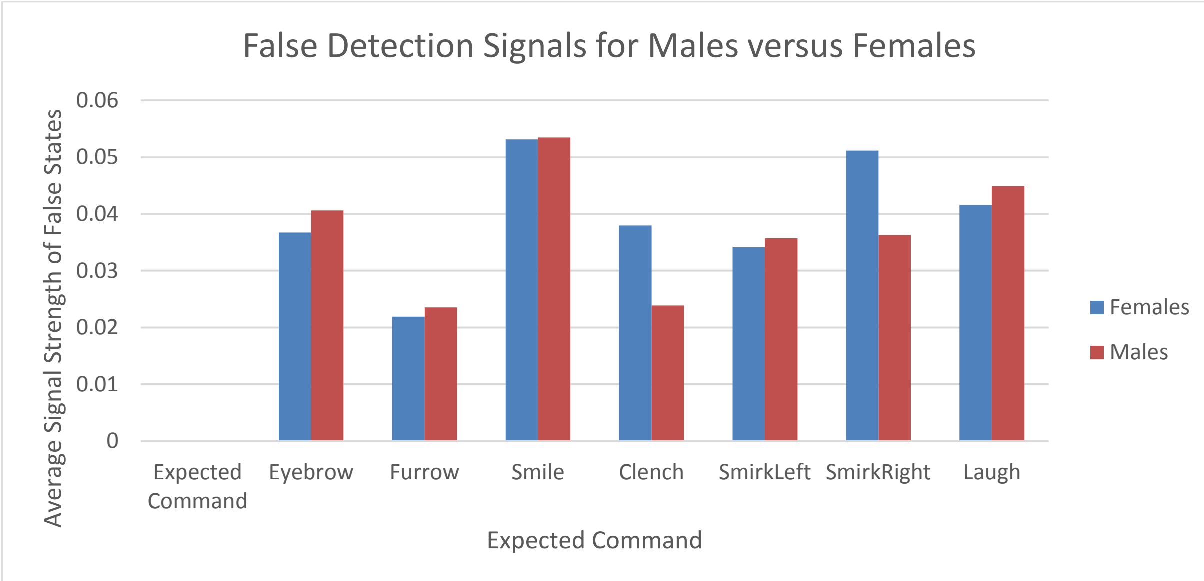


Figure 27: False Detection Signals for Males versus Females

Observing the false detection signal averages the averages do not seem substantially different from one another on a holistic level. One could predict females would have higher false averages since the correct averages were much lower than the male correct averages but this does not appear to be true. This may because movements in general were much harder to detect on females, thus reducing false detections as well.

Table 12: Correct Signal Averages with Various Hair Length

Expected	Correct Signal Average for Subjects with Hair >2in	Expected	Correct Signal Average for Subjects with Hair >2in
Eyebrow	0.1218	**Eyebrow**	0.1581
Furrow	0.2267	**Furrow**	0.1702
Smile	0.1095	**Smile**	0.0683
Clench	0.355	**Clench**	0.1699
SmirkLeft	0.2157	**SmirkLeft**	0.1273
SmirkRight	0.2703	**SmirkRight**	0.0559
Laugh	0.127	**Laugh**	0.1322

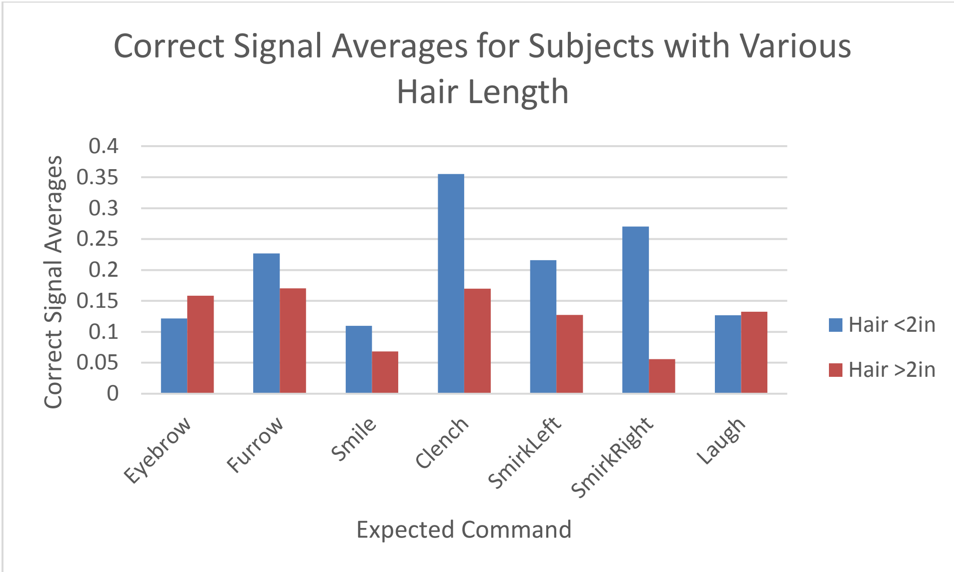


Figure 28: Correct Signal Averages for Subjects with Various Hair Length

In addition, throughout this experiment, hair length was recorded. While conducting the experiment, it was found that it was difficult to maintain good contact with subjects that had longer hair lengths. Good contact can be defined as that at least twelve of the electrodes were a green color which indicates the best contact possible.

Looking at the information in Table 12 and Figure 28, it is clear that for all expressions other than Eyebrow and Laugh subjects with a hair length of less than 2 inches had substantially higher signal averages. This was expected because if a subjects hair is shorter the electodes will have a much better contact with the scalp. In addition, since the electrodes are soaked in saline it was often found that the hair in contact would absorb the saline solution and dry out the electrodes. This was especially an issue in cases where an individual had longer and thicker hair. This aspect should be considered as it could cause variability amongst users of the Emotiv

In addition, it was requested by stakeholders that this experiment compare the performances of the subjects during the first five trials as well as the performance during the last five trials. It was hypothesized that perhaps subjects will tire during the last five trials and be more prone to error.

Table 13: Correct Signal Averages for First Five Trials versus Last Five Trials

Expected	Correct Signal Average for First Five Trials	Expected	Correct Signal Average for Last Five Trials
Blink	0.74	Blink	0.8778
WinkLeft	0.15	WinkLeft	0.2333
WinkRight	0.28	WinkRight	0.2556
LookLeft	0.27	LookLeft	0.3778
LookRight	0.39	LookRight	0.6667
Eyebrow	0.2015	Eyebrow	0.1674
Furrow	0.1819	Furrow	0.2144
Smile	0.1376	Smile	0.118
Clench	0.2795	Clench	0.3239
SmirkLeft	0.1956	SmirkLeft	0.2365
SmirkRight	0.2535	SmirkRight	0.3564
Laugh	0.1508	Laugh	0.2318

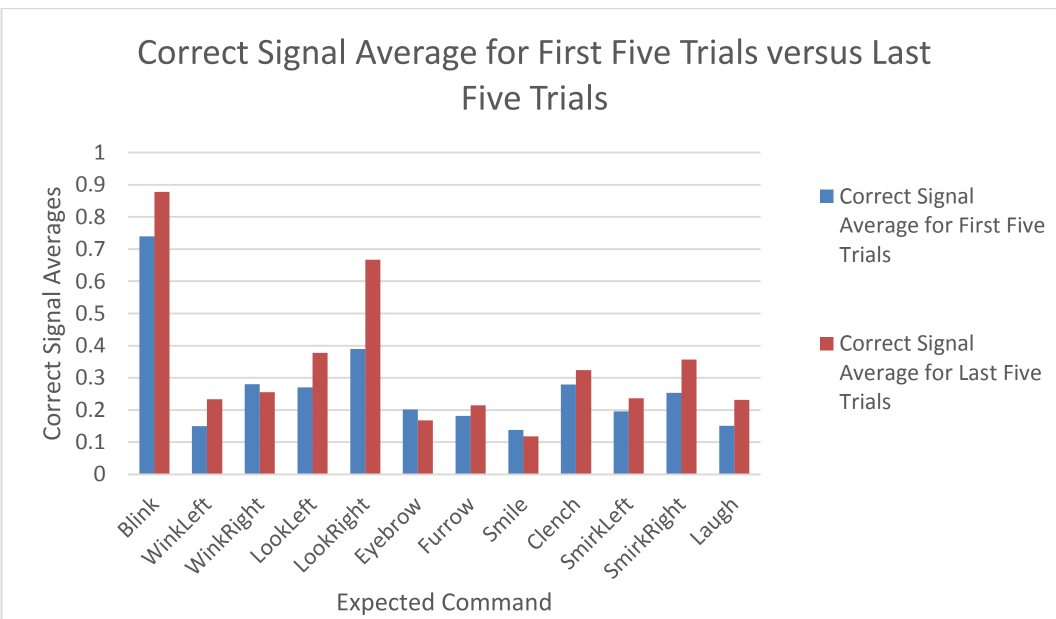


Figure 29: Correct Signal Average for First Five Trials versus Last Five Trials

This hypothesis seems to be unsupported. For the last five trials the signal strengths of Blink, Wink Left, Look Left, Look Right, Furrow, Clench, Smirk Left, Smirk Right and Laugh were all much higher during the last five trials. These numbers were found by simply averaging all users signal strengths during the first five and last five trials. This may suggest that users may be more adept at executing certain commands in later trials. This may be because users have had practice and have acclimated to the system although definite reasoning can not be concluded from this data.

Cognitiv Results and Analysis

There are four types of Cognitiv commands which were tested for this experiment: Right, Left, Push and Neutral. These commands were completed by allowing the subjects to train these four command for a maximum time of 20 minutes. For the Cognitiv commands only three commands can be stored in the user signature at a time and the team agreed that these three commands would be the most intuitive. This experiment was more limited and five subjects were tested.

As with the Expressiv commands the following table displays the percent of the window active when the command is requested. The subjects were asked to complete the command by sustaining a movement for as long as they could within the 9.9 second window given. Therefore, the numbers shown are a percentage of the respective window that the command was correctly detected. The actual value in seconds the window was active with the correct command is the given number multiplied by 9.9 seconds. These numbers were calculated from the average amount of durations from five subjects. These values are shown in Table 14. It is important to note how low all of the values show are in comparison with the Expressiv values. Although each subject was asked to sustain the command it is clear that the command was difficult to sustain for such an extended period of time.

Table 14: Average Percent Active During Trial

Expected	Right	Left	Push
Right	0.0854	0.0172	0.0692
Left	0.0835	0.0912	0.0349
Push	0.0452	0.0202	0.196
Neutral	0.0627	0.0323	0.0066

In the following table the first column indicates which command each subject was requested to perform or as they have been termed "Expected Commands." The other columns indicate which commands were actually detected, as such, have been termed “Actual Results.” One can read the table by looking at the first column to see which command was the Expected Command and then move across that specific row to see what was actually detected. It is important to specify how these numbers were derived. For the Cognitiv commands the subject was instructed to do the command and had a 9.9 second window to do so. In addition for these commands the signal strength could range from 0 to 1 depending on how well the signal was detected. Thus an integral system was utilized to evaluate the strength of each command. If a signal was detected strength of the signal was multiplied by the duration of that signal. Then the integrals of each trial was summed. This sum was divided by 9.9*1*10. This value was used because 3.9 is the highest obtainable integral considering if there was a window of 9.9 and a perfect signal of 1 was detected the whole time. And there are 10 trials it was multiplied by 10. This was able to provide a weighted average of all the signals and their strength values.

Table 15: Average Signal Strengths of Cognitiv Trials

Expected	Right	Left	Push
Right	0.0339	0.0054	0.0355
Left	0.0332	0.0426	0.0175
Push	0.0179	0.0073	0.1184
Neutral	0.022	0.0095	0.0025

By viewing the values in Table 15 it is clear that the cognitive signal strengths are relatively low values compared to the Expressiv signal strength values. Furthermore the values, shown in Table 15 are so low that the correct expected signal strength values are nearly indiscernible from the incorrect actual outputs. For example when ‘Right’ is expected the correct signal strength value is 0.0339, however when ‘Right’ is expected the actual signal strength for Push is 0.0355. This is higher than the average for the correct value. This is not the same case for ‘Left’ and ‘Push’ however the correct signal strength values in these cases are not substantially higher than the false actual signal strengths.

Emotiv Driver Accuracy Trials

After testing five subjects with both the modified driver program and the existing program, the two programs were directly compared and the enhancements made were quantified.

Table 16 shows the average results from the original program and Table 17 shows the average results from the modified program.

Table 16: Trial Results from Original Emotiv Driver Program

Expected	Stop	Forward	Left	Right	Back	Pause
Stop	96%	20%	12%	4%	2%	22%
Forward	80%	68%	10%	10%	8%	10%
Left	24%	16%	60%	38%	0%	8%
Right	24%	14%	32%	56%	2%	14%
Back	70%	60%	4%	8%	4%	10%
Pause	X	26%	14%	8%	0%	54%
Neutral	18%	6%	6%	4%	0%	4%

Table 17: Trial Results from Modified Emotiv Driver Program

Expected	Stop	Forward	Left	Right	Back	Pause
Stop	98%	2%	0%	2%	16%	0%
Forward	10%	92%	2%	2%	2%	0%
Left	2%	0%	70%	4%	0%	0%
Right	0%	0%	0%	76%	0%	0%
Back	**X**	6%	0%	0%	82%	4%
Pause	8%	0%	4%	0%	0%	92%
Neutral	0%	0%	0%	0%	0%	0%

In Table 16, there is an X under Expected Pause / Actual Stop because in order to execute pause, stop would have to be executed three separate times. Because of this, the value of Expected Pause / Actual Stop would be very high, but it doesn't affect the behavior of Anna. The same is done in Table 17 for Expected Stop / Actual Back; in order to execute 'Move Backward', the user needs to hold their eyebrows elevated which would also trigger 'Stop'.

The colors on the tables represent several criteria. The yellow diagonal is used to represent the desired output. Boxes in red represent any percentages over 30% that are not the expected output. Boxes in orange represent any percentage between 20-30% that is not the expected output. Also, since the expected output for neutral is desired to be very low so there are less false detections, any percentage above 10% in the expected state neutral is highlighted.

5.3.2 EMG Control

This section outlines the results and analysis of developing and using the EMG board as a control system on Anna. The goal of the EMG board was to have an interface from which the user can control the JACO Arm. The premise of this segment of the project was to design the circuit onto a printed circuit board and integrate it with Anna. A circuit was already created and tested from a previous undergraduate project involved with the RIVER Lab. The printed circuit board went through three design phases before finalization.

First Design phase

The first circuit board was a 2 by 2.5 inch board that was designed to fit on top of the Tiva C-Series LaunchPad board using pin headers. The input signals from the electrodes are received at the top of the board. On the board, there are two electrode units. Each unit contains a positive, negative and reference electrode that measures the electrical activity in each muscle. The inner pin headers are for the wireless XBEE module. The wireless XBEE module is to connect the TIVA board to a wireless transmitter. Originally, the XBEE was going provide the board different ways to connect with Anna.

Using the testing method describe previously, the board was tested on a forearm to determine if it can detect and amplify the muscle electrical activity. The reason for choosing the forearm was because of the connection of the ring finger connected to one of the arm tendons. Moving the ring finger flexed the tendon without having the flex the entire arm. The voltage output signal ranged from the board ranged from 2 Volts to 3 Volts. However, it was observed that voltage fluctuation was not caused by the forearm tendon flexing. One hypothesis as to why the voltage was fluctuating was because the two footprints of the INA118U operational amplifier on the board were flipped backwards. The next step for the board was to fix the design flaws, and produce a smaller simpler board with less components.

Second Design Phase

The second iteration of the EMG board was similar to the first but now surface mount components were used. The original board had through-hole components, which have a bigger footprint that surface mounts components. An important part of the second design phase was that a cleaner board layout was created. Due to the fact that the previous board made it difficult to determine what was connected to each component, the second board had sequential components that were laid out horizontally. Figure 30 shows the difference between the first and second design.

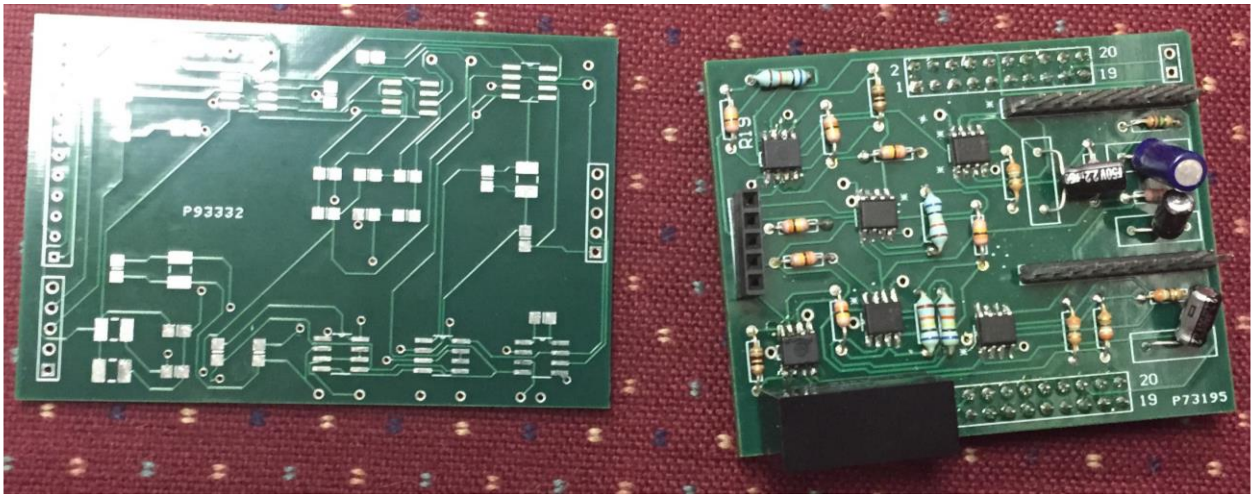


Figure 30: PCB Configuration

The input from the electrodes was received on the left side of the board along with the input voltage and ground. The 5 volt power supply was connected to the DC-to-DC converter to reduce the voltage to 3.3 volts. The output voltage from the circuit is received from the right side of the board.

There were still issues with the output voltage on the board. The voltage was settling around 0 Volts. To determine if this was an issue with the DC-to-DC convertor, 3.3 volts was directly applied to the circuit. It was noticed that the circuit still need an input voltage reference to the INA118U amplifier so 2.5 volts were directly connected. With a voltage around the 3.3 volts, the circuit was tested to determine if it would detect the muscle electrical activity. The circuit did not detect the muscle activity.

Third Design Phase

Due to time and manufacturing constraints, the next design was transferred to a Peripheral board instead of a printed circuit board. Figure 31 shows the simpler version of the circuit that contains one unit circuit.

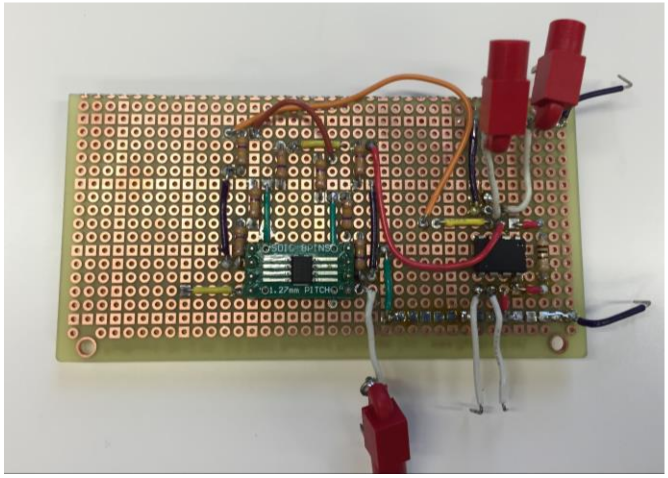


Figure 31: Third Iteration of the EMG Board

The circuit produced a signal around 3.3 Volts and responded to the muscle flexing. The signal was sensitive enough to display voltage spikes of both the ring finger and pinky moving. The next step in testing the board was to see if the board could detect muscle electrical activity in the neck area. The electrodes were place along the neck muscle. This muscle was chosen due to the presumed range of movement the target user may have. The output voltage signal for the neck movement was not as sharp as the muscle movement on the forearm, however, the electrical activity could be activated for longer periods.

Original Plan

Originally, the plan was to have the output voltage from the EMG board is connected to the Tiva launch pad as well as powered it. To determine whether a muscle was flexed, the voltage values are converted to digital values through the ADC on the Tiva launch pad. The values are map to an index values from 0 to 4095. To determine if the voltage spiked, indicating that a muscle was flexed, the data values from the Tiva Launchpad were averaged every 10 data points and compared to the previous average set. Both the average of the set and an indicator was prints to the serial port. With the averaging code loaded onto the Tiva Board, a ROS node was created to take the average values and publishes them to a node.

Sensor Board

The original plan for the integration of the EMG board and Anna was to connect the EMG board to the Tiva Launchpad. However due to limitations, it was decided that the Sensor

Hub would be used to connect the EMG with Anna. This did, however, present some connection issues.

To solve the issue with the Tiva LaunchPad, the Team used a previous MQP project's module called the WAMNET Sensor Hub. The Sensor Hub is a board that provides low level sensor hardware a way to communicate to a high level computer. One of the advantages to using the Sensor Hub was that there were already drivers and templates that were created in ROS.

Using the Sensor board, a script and launch file was created that would take in the average of the ADC values over a small period of time. From testing, it was decided was would be the threshold average ADC value that would determine whether a muscle was flexed. Whether the muscle was flexed or not, the script published a string command of either "forward" or "stop".

5.4 Discussion

5.4.1 Emotiv

It is evident that when choosing signals a variety of factors must be taken into consideration. It is important the command have a relatively high signal average such that when integrating into the Anna system the signal threshold for executing a command does not activate frequently. A threshold would mean a command needed to be recognized for a certain amount of time reliably before it was executed. In addition, a very important factor is that a given command is not prone to eliciting false signals. This could be dangerous if a command is not intended and executes it could potentially harm the person using Anna. For example if smile has a high signal average but it also has a high average false detection average it should not be utilized. In addition, one must consider the normal range of expressions a person uses on a day to day basis. For example a command such as Blink was difficult to implement since individuals blink so often. If a command such as this is to be used one must implement a specific pattern. Such as Blink 30 times within a one minute window and then Anna will move.

In addition, although limited subjects were used based on the given data it is not recommended that Cognitiv commands be used as a control scheme. The duration times are extremely low comparatively speaking. In addition, the signal strengths a very low and the correct signal strengths are nearly undiscernible from the false signal strengths. This would make it very difficult to integrate this with Anna considering that thresholds must be created.

Given the current data the most reliable commands are Smirk Left, Furrow, Clench, and Smirk Right. Although these commands do not necessarily have the highest signal strength averages they do have the lowest false detection averages. This means that when the user intends to do one of these commands it is picked up and other user expressions are not misconstrued as these commands.

Modifying the Emotiv ROS Driver Code

After consulting with the group advisor and testing the existing driver code, there were several issues that were determined that are listed below. Each of these issues was addressed to make the program more accurate and efficient.

Issue 1: Performing 'Rotate Left' and 'Rotate Right' is unreliable, because the headset is not very accurate in detecting 'Looking Left' and 'Looking Right'.

According to the Emotiv Expressiv trial data, 'Looking Left' and 'Looking Right' are only accurately detected 27% and 42% of the time, respectively. Furthermore, the data shows that 'Looking Right' was wrongfully detected 31% of the time when the user looked left, and 'Looking Left' was wrongfully detected 24% when the user looked right. When the users tried to perform the action of 'Rotating Left' and 'Rotating Right', they were able to do so 60% and 56% of the time, respectfully. The false detections rate, however, was high suggesting that this method was unreliable. When 'Rotate Left' was expected, 'Rotate Right' was executed 38% of the time. Vice versa, 'Rotate Left' was executed 32% of the time when 'Rotate Right' was expected.

The trial results for 'Smirk Left' and 'Smirk Right' came out fairly accurate; there were no expressions that had a higher weighted average than each of these commands when they were the expected command. Logically, using these two commands to control the rotation of the wheelchair made sense since 'Smirking Left' would 'Rotate Left' and 'Smirking Right' would 'Rotate Right'. In order to prevent false detections, a moving average filter was used to trigger the actions based off of their respective expressions. The moving average window is two seconds long. The program creates a queue for all of the 'Smirk Left' and 'Smirk Right' values and timestamps that are sent to it. It takes the average of all of these values, and if the value is above the set threshold value, it will trigger the action. The program self-manages this queue; once the first element in the queue is over two seconds away from the last element, it will pop the first element out and keep popping out if needed until the time is less than two seconds. The threshold that the program is set to was determined by the weighted average values of 'Smirk Left' and 'Smirk Right' from the initial trials. Since this value represented the weighted average per second, the threshold is set to double that value since it is a two second window.

The accuracy trials show that this new method for detecting 'Rotate Left' and 'Rotate Right' is more accurate than the old method. 'Rotate Left' was accurately detected 70% of the time, and 'Rotate Right' 76% of the time. Their percentage of false detections for the opposite direction was decreased to 4% and 0% respectively.

Issue 2: The program's method for toggling between pause and active is unreliable and difficult to perform.

The existing code used a pattern detection method to toggle between pause and active mode. The user would need to perform the following pattern to trigger this action: 'Raise Eyebrow', 'Neutral', 'Raise Eyebrow', 'Neutral', 'Raise Eyebrow'. This action was only accurately detected 54% of the time by the trial subjects. Also, this action had a relatively high false detection of 'Move Forward' with this command being executed 26% of the time when 'Pause' was expected.

Since the other actions are performed using lower or upper facial movement, it was decided that using an eye movement to trigger this action could be an effective method. Using the Emotiv Expressiv Trial Data, the headset is fairly reliable in detecting 'Blink'; this expression was detected accurately 67% of the time. Studies show that an individual blinks 15-20 times per minute, which is roughly one blink every 3 to 4 seconds. The modified program requires the individual to repeatedly blink in a short window of time to trigger this command; approximately five blinks in five seconds should trigger this command. The trial data shows that the subjects were able to perform this action accurate 92% of the time, which is 38% more accurate than how it was being done before. The percentage of false detections was also significantly reduced; the highest percentage of false detections for this command was now 'Stop' at only 8%.

Issue 3: False detections for 'Stop' are frequent, because it triggers off of any non-zero value for 'Raise Eyebrow'.

While the accuracy of issuing the 'Stop' command for the existing driver code was high at 96%, there were also a significant amount of false detections. When 'Stop' was expected, 'Pause' was executed 22% of the time, 'Move Forward' 20% of the time, and 'Rotate Left' 12% of the time. In order to decrease this number of false detections, a moving average filter was used similar to the one talked about in issue 1 and set a threshold which stop had to be above. The accuracy of this method was 98%, and the percentage of false detections decreased for most of the other commands. The only command that saw an increase in false detections was 'Move Backward' which rose to 16%. Additionally, the code was modified that it would not repeatedly publish stop if the user kept their eyebrows' raised.

Issue 4: 'Move Forward' and 'Move Backwards' could accidentally be mistaken for each other since they rely on the same expression.

The existing program requires the user to hold the 'Clench' expression for anywhere between 0 to 1 seconds to trigger 'Move Forward'. In order to trigger 'Move Backwards', the user needs to hold the 'Clench' expression for anywhere between 3 to 4 seconds. The accuracy trial data shows that the users were able to perform these actions 68% and 4% accurately, respectively. For false detections, 'Move Backward' was triggered 8% of the time when 'Move Forward was expected, and 'Move Forward was triggered 60% of the time when 'Move Backward was expected. Since the desired actions results in movement in the complete opposite direction, it is not logical to make it so the same expression would control both movements.

The new method for detecting backwards relies on continually holding the 'Raise Eyebrow' expression. Since the only other action that relies on this expression is 'Stop', the wheelchair would only be able to move backwards if it is currently stopped, which is logical. While the user is raising their eyebrows, the program is taking the weighted average of this signal and if that signal passes a certain threshold, it triggers the back movement. The program uses a resetting moving average filter; once a signal of zero is detected for 'Raise Eyebrow', the wheelchair stops moving backwards and this weighted average is set back to zero. The accuracy trial results show that this method for detecting 'Move Backward' is 82% accurate, which is 78% greater than the old method.

The new method to detect ‘Move Forward’ is similar to how ‘Rotate Left’, ‘Rotate Right’, ‘Stop’, and ‘Toggle Pause’ are detected using the moving average. The program puts the values for ‘Clench’ into a queue, self manages the queue, takes the weighted average, and triggers once it is above the average. The accuracy trials show that ‘Move Forward’ was accurately detected 92% of the time, which is 24% greater than with the old method.

Issue 5: The program uses the universal signatures for each expression as opposed to giving the user the option to use their own trained signatures.

The existing program does not have the option to use a custom profile that has the user’s trained signatures recorded. Training the expression allows the headset to more accurately detect the expressions by customizing the detection to the user’s EMG signals. The new program gives the user the ability to have his/her custom profile in place and detect the expressions based off of this profile. In order to use this new program, the user must open the Emotiv Control Panel SDK and connect to the EmoEngine. From here, the user can create and manage profiles, and train each expression. Then, the user can start the Emotiv ROS Driver as usual, and the program will connect to the control panel.

Issue 6: The program is not customizable.

The existing method does not allow the user to have the ability to change what expressions trigger what actions, or to change the thresholds required to trigger these actions. The new program is much more user friendly and allows the user to control the expressions that are used, the thresholds for each commands, and the moving windows for each command. All of these values can be changed in a YAML file and then the program can be run like normal. Users for this program need to follow the protocol currently defined in order to properly configure the program.

5.4.2 EMG Control

The EMG was not able to be fully integrated with Anna. One problem that occurred was that the electrode Pads were unreliable in detecting muscle electrical activity. For a period of time the electrode pads would pick up the muscle activity and then the signal would be dropped. It was inferred that electrode pads did not continue to have full contact with the skin or the gel in the pads became dry. For the future, there will need to be testing of different electrode pads to determine which electrode Pad will work with the circuit.

Another issue was integrating the circuit and the Sensor Hub into one whole module. Currently the circuit is mounted on a temporary board, ideally the circuit will be successfully integrated on a PCB board. There are currently new board prints read to be manufactured.

6. Social Implications

This project aims to assist individuals that have less muscle control and need an alternative control system. During this project, the team had the opportunity to meet with someone who needed a specialized wheelchair. Because of his cerebral palsy, this individual could not fully move his fingers and arms, making controlling the wheelchair difficult. Anna would be able to assist him by providing the alternative methods of control. He would be able to more fully interact with his environment due to the object manipulation system that was added. This project seeks to help those with LIS increase their self-sufficiency by providing them with the tools to do so. This project was tested in an apartment-style environment so show that such an environment could be properly navigated and interacted with. At the culmination of this project, all control schemes have been tested and human subjects were able to have been used. The next steps in this design process would be fully integrating each control scheme and creating testing Anna in a holistic manner as well as adding different environment manipulation functionalities.

7. Conclusions

This project was a hybrid of robotic, computer science, electrical and biomedical principles. The system requirements that were agreed upon at the start of this project have been achieved. At the culmination of this project various aspects of Anna have been innovated and or improved. Currently Anna now has autonomous self-feeding capabilities available for its user. This is complete with a working model of the environment to prevent collision and a camera capable of recognizing various surrounding objects. Furthermore, Anna is equipped with two intuitive interfaces. The first of which is Emotiv Control. By completing substantial human trials the team was able to identify the most optimal commands for navigating Anna with five degrees of freedom. In addition, the EMG Control can also be integrated in the future so minor neck movements can initiate the arm or drive Anna. The final system design can be shown in Figure 32. The diagram shows the string inputs and the resulting motions for both the wheelchair base and the robotic arm.

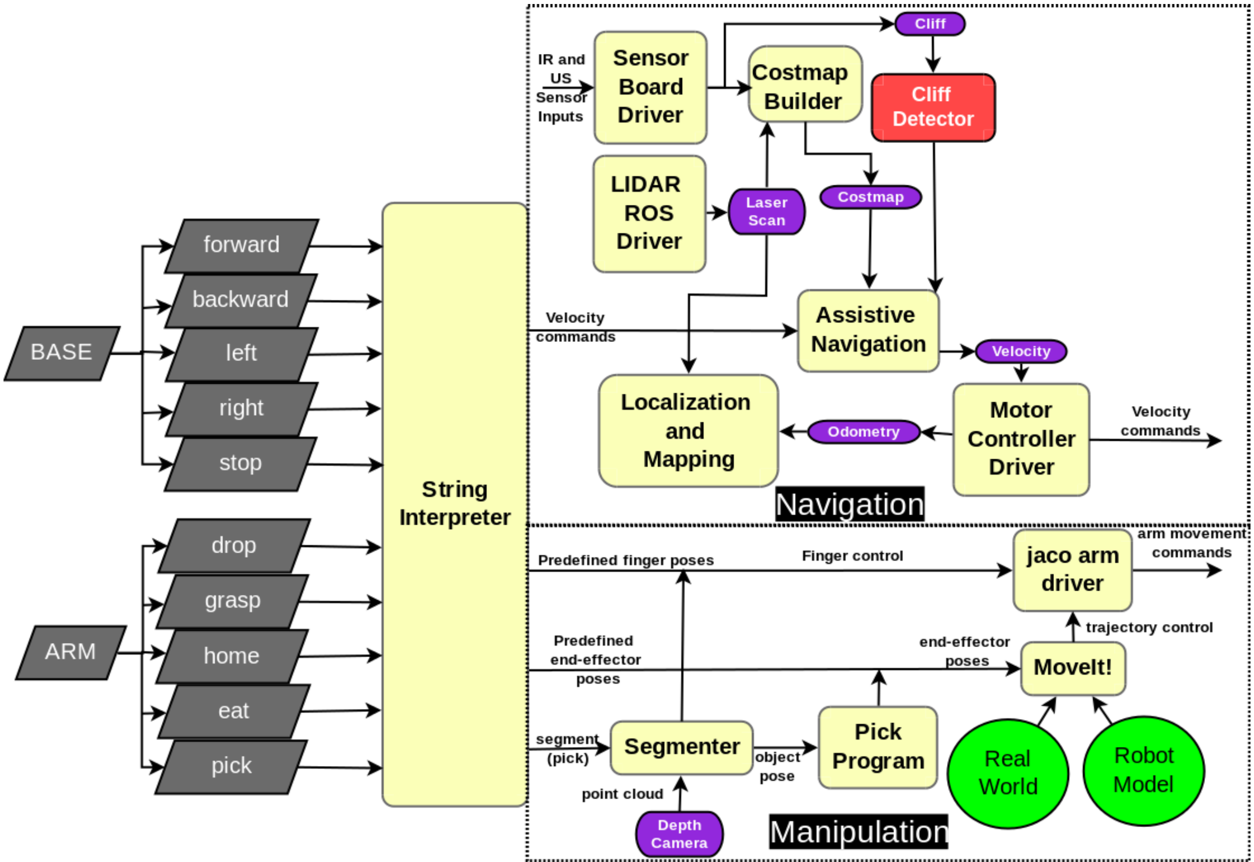


Figure 32: System Diagram for Anna

8. Citations

[1] “Muscular Dystrophy: Hope Through Research". Retrieved September, 2014 Available: http://www.ninds.nih.gov/disorders/md/detail_md.htm?css=print

[2] "Facts about Muscular Dystrophy". Retrieved September, 2014 Available: http://www.cdc.gov/ncbddd/musculardystrophy/facts.html

[3] “Multiple Sclerosis". Retrieved September, 2014 Available: http://www.ncbi.nlm.nih.gov/pubmedhealth/PMH0001747/

[4] "NINDS Cerebral Palsy Information Page". Retrieved September, 2014 Available: http://www.ninds.nih.gov/disorders/cerebral_palsy/cerebral_palsy.htm

[5] "Cerebral Palsy (CP)". Retrieved September, 2014 Available: http://www.cdc.gov/ncbddd/cp/

[6] M, "Diseases and Conditions: Cerebral palsy". Retrieved September, 2014 Available: http://www.mayoclinic.org/diseases-conditions/cerebral-palsy/basics/definition/con-20030502

[7] Smith, E, "Locked-in syndrome". Retrieved September, 2014 Available: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC549115/pdf/bmj33000406.pdf

[8] “Amyotrophic Lateral Sclerosis (ALS) Fact Sheet". Retrieved September, 2014 Available: http://www.ninds.nih.gov/disorders/amyotrophiclateralsclerosis/detail_ALS.htm#267334842

[9] Mount, I, "A thought controlled Wheelchair for Quadriplegics". Retrieved September, 2014 Available: http://www.smartplanet.com/blog/global-observer/a-thought-controlled-wheelchair-for-quadriplegics/

[10] Teller, S, "Autonomous WheelChair". Retrieved September, 2014 Available: https://www.csail.mit.edu/videoarchive/research/robo/autonomous-wheelchair

[11] University of California, "Mobility Device Statistics," 22 April 2013. [Online]. Available: http://www.disabled-world.com/disability/statistics/mobility-stats.php. [Accessed 23 September 2014].

[12] Kinova, “Jaco Robotic Arm,” Specifications, 28 September 2014. [Revised 2013].

[13] “LIDAR—Light Detection and Ranging—” NOAA 28 April 2014. [Online]. Available: http://oceanservice.noaa.gov/facts/lidar.html [Revised 2013].

[14] “JACO: Research Edition,” Accessed 23 September 2014. [Online]. Available: http://kinovarobotics.com/products/jaco-research-edition/

[15] “Kinect for Windows Features,” Accessed 24 September 2014 [Online]. Available: http://www.microsoft.com/en-us/kinectforwindows/meetkinect/features.aspx

[16] T. Li et al., “3D Object Detection with Kinect,” Cornell Univ., New York, 2011, Available: http://www.cs.cornell.edu/Courses/cs4758/2011sp/final_projects/spring_2011/Li_Putchakayala_Wilson.pdf

[17] T. Darrell et al., “A Category-Level 3-D Object Data Set: Putting the Kinect to Work,” UC Berkeley, California, 2011, Available: http://www.eecs.berkeley.edu/~barron/B3DO_ICCV_2011.pdf

9. Appendix A: LiDAR Relocation

LiDAR System Requirements

ID	Requirement	Description	Cost	Source	Prio-rity
%ran	Viewing range	The system shall be capable of view 180° in front the wheelchair	High	$user	5
%mind	Minimum viewing distance	The system shall be able to view objects within 0.01 m of the front of the wheelchair	High	$user	4
%movec	Wheelchair movement	The system shall be not inhibit the wheelchair's ability to move	Low	$user	5
%objav	Object detection	The system shall be able to detect objects higher than 0.15m from the ground and within 3 m of the wheelchair	HIgh	$user	5
%gnd	Ground clearance	The system shall not decrease the wheelchair's ground clearance			

LiDAR Relocation Requirements

The main categories of concern for relocating the forward pointed LiDAR sensor are location and protection. The final design solution for relocating the LiDAR sensor must meet the requirements described below.

Location

Mounted in the new location, the LiDAR sensor shall:

- have an unobstructed viewing range of or exceeding 180 degrees from the front edge of the footplate
- be capable of sensing objects greater than 0.15m in height that are in contact with the ground
- be capable of sensing objects within 3m of the front edge of the footplate
- not decrease the clearance height between the current footplate position and the ground
- permit the current footplate to fully return to the upright stowed position
- not obstruct the motion of the front wheels on wheelchair

Protection

The new location design must:

- protect the LiDAR sensor from its surroundings on ALL (6) sides
- protect the LiDAR sensor from collisions, including but not limited to:
- the user striking the sensor when mounting/dismounting the wheelchair
- the sensor striking objects, walls, bystanders, etc. in it's path
- objects, bystanders, etc. striking the sensor
- include some mechanism for heat dissipation
- include a mechanism for absorbing shock to protect the sensor from abrupt stops when the footplate goes from the stowed to open position*

*Requirement only necessary if the sensor is mounted on/in the footplate

Configuration Options

Currently, there are two proposed relocation options, each with two configurations. All options and configurations are designed to use a SOKUIKI sensor because of it's size, range, and cost.

Relocation Option 1

Option 1 places the sensor inside the existing steel footplate frame. The top and bottom plates of the footplate would enclose the sensor thus effectively protecting it on all sides. This option would increase the thickness of the footplate but not change the current clearance height under the footplate. A metal plate would be mounted under the sensor to the steel frame to dissipate heat. The sensor would have a near complete 180 degree viewing area obstructed only by existing support bolts in the foot plate that could be removed. The two configurations for this option include mounting the sensor with the laser closer to top or bottom of the footplate.

Advantageous:

Reinforced protection from the existing steel

Protected on all 6 sides

Heat is dissipated

Can sense objects greater than 0.15m in height

Can sense objects within 3m of the front edge of the footplate

Limitations:

180 degree viewing area not free from obstructions

Current sensor boards would be relocated

Relocation Option 2

Option 2 places the sensor at the center of the front edge of the footplate. The top and bottom plates of the footplate and front edge of the existing steel frame would enclose the sensor on 3 sides. The remaining edges would be protected by a bar that screwed directly to the steel frame. This option would increase the thickness of the footplate but not change the current clearance height under the footplate. A metal plate would be mounted under the sensor to the steel frame to dissipate heat. The sensor would have a complete, unobstructed viewing range exceeding 180 degrees. The two configurations for this option include mounting the sensor with the laser closer to top or bottom of the footplate.

Advantageous:

Protected on all 6 sides

Heat is dissipated

Can sense objects greater than 0.15m in height

Can sense objects within 3m of the front edge of the footplate

Viewing range greater than 180 degrees

Current sensor boards don’t have to move

Limitations:

No reinforced protection from existing steel frame

The advantages and disadvantages are discussed in the decision diagram shown in the figure below.

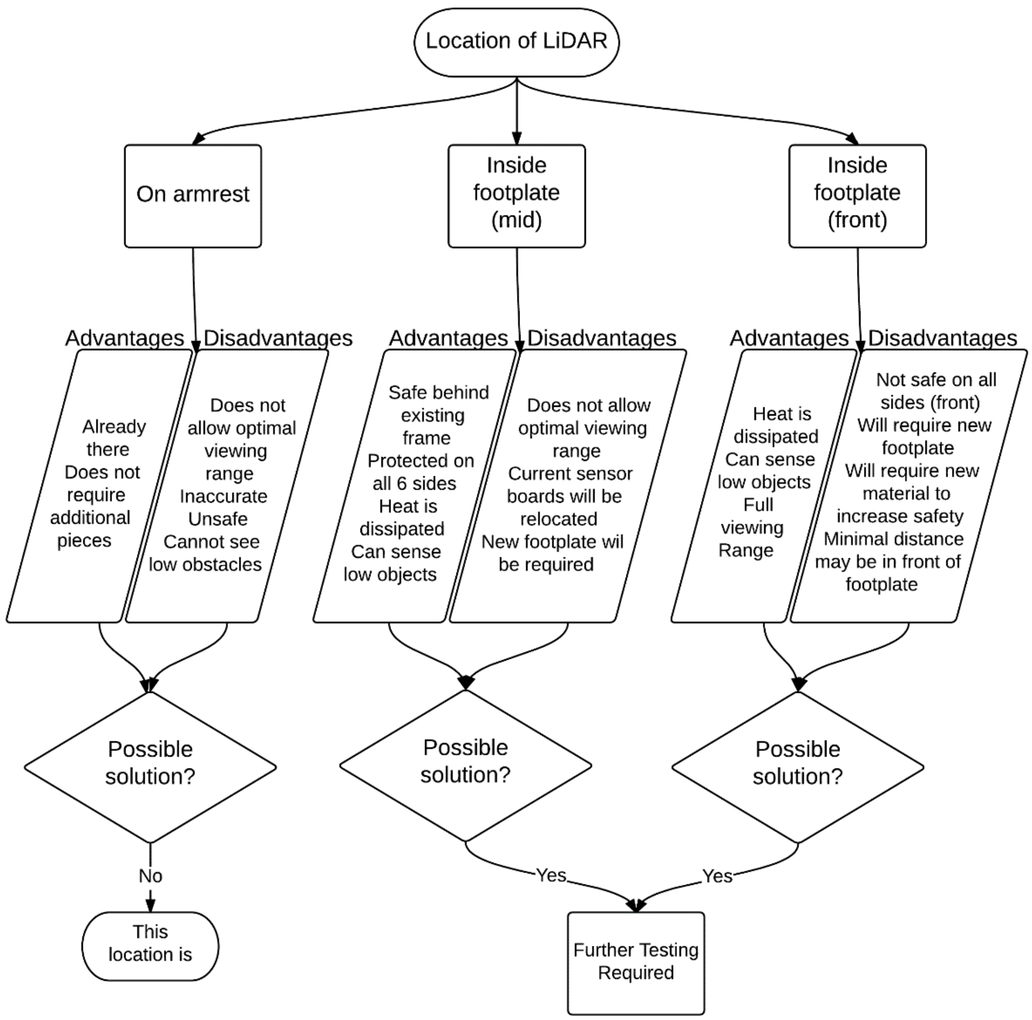


Figure 33: Decision diagram for the LiDAR location

10. Appendix B: Emotiv Control System

IRB Testing Documents

Purpose of Study:

The purpose of this study is to determine which facial and cognitive commands for the Emotiv headset have the highest rates of success in terms of controlling Anna, a semi-autonomous wheelchair system. This project aims to create an assistive wheelchair for individuals that have little to no movement of arms and some movement of facial muscles. There are a number of conditions and diseases that limit said movement. Since this device is multimodal, it will be useful to individuals with various conditions. This project is generally targeted toward those that have Locked-in Syndrome. Locked-in Syndrome (LIS) is a condition in which a person is conscious and alert but unable to communicated or interact with the world. This is why an Emotiv headset would be useful in navigating the chair.

The Emotiv headset is used to monitor facial expression and conscious thoughts. These will serve as inputs to the wheelchair navigation. A current issue is that the previous project did not collect sufficient data to evaluate the full capabilities the Emotiv headset has. There were a very limited number of trials conducted and there is no background data concerning each subject. In addition the previous team did not investigate the full capability of the Emotiv in terms of using it in the Expressiv and Cognitiv mode.

These trials aim to assess the success of a various inputs on various users. Then the data was analyzed utilizing cross-correlation. This was accomplished by gathering information about a subjects pigmentation, fatigue and other health statistics. Then the subjects was given a training session on how to use the EPOC Emotiv headset. Then the subjects will attempt to control the wheelchair using given commands. Each subjects success with accomplishing each command was recorded. Then the data was analyzed.

Study Protocol

Below is a breakdown of what each trial will consist of:

Steps	**Description**	**Allotted Time**
1	Fill out required preliminary information sheet. The sheet will be filed in a secure location	3
2	Explain what the procedure consists of (shown below). Ask the subject if there are any questions or concerns	10
3	Have headset with the applied saline (each node with will be wet) on nodes already ready. Explain to subject that the headset will have to be on head and ask permission to adjust headset	5
4	Boot up headset. Adjust headset for best possible connection via the nodes on the subject	5
5	Record the connection state of each node. The available states would be: No connection (gray) Poor connection (red) Okay connection (Orange) Good connection(Yellow) Complete connection (Green)	2
6	Explain what the Cognitiv suite test is to the subject	2
7	Begin with a two minutes of rest for the subject.	2
8	Begin practice test for each of the cognitive skills. There are # of tests:	15
9	Allow the subject 5 minutes of rest.	5
10	Test and record the reaction times and accuracy the subject cognitively choosing what to do with the Cognitiv suite	15
11	Thank subject for participating in study and cautiously remove the Emotiv headset	c

Total expected time: 1 hour and 10 minute

The University of
Science and Technology.
And Life.™

Informed Consent Agreement for Participation in a Research Study

Investigators: Tanishq Bhalla, Marisa Warner, Rashida Nayeem

Contact Information: ECE Department
WPI
100 Institute Road
Worcester, MA 01609
Tel. 508-831-5555, Email: jqworcester54@wpi.edu

Title of Research Study: Intuitive interface of an Assistive Controlled Wheelchair

Sponsor: WPI RiVER LAB

Introduction:
You are being asked to participate in a research study. Before you agree, however, you must be fully informed about the purpose of the study, the procedures to be followed, and any benefits, risks or discomfort that you may experience as a result of your participation. This form presents information about the study so that you may make a fully informed decision regarding your participation.

Purpose of the study:
The purpose of this study is to determine which facial and cognitive commands for the Emotiv headset have the highest rates of success in terms of controlling Anna. This project aims to create an assistive wheelchair for individuals that have little to no movement of arms and some movement of facial muscles. There are a number of conditions and diseases that limit said movement. Since this device is multimodal, it will be useful to individuals with various conditions. This project is generally targeted toward those that have Locked-in Syndrome. Locked-in Syndrome (LIS) is a condition in which a person is conscious and alert but unable to communicated or interact with the world. This is why an Emotiv headset would be useful in navigating the chair.

The Emotiv headset will be used to monitor facial expression and conscious thoughts. These will serve as inputs to the wheelchair navigation. A current issue is that the previous project did not collect sufficient data to evaluate the full capabilities the Emotiv headset has. There were a very limited number of trials conducted and there is no background data concerning each subject. In addition the previous team did not investigate the full capability of the Emotiv in terms of using it in the Expressiv and Cognitiv mode.

These trials aim to assess the success of a various inputs on various users. Then the data will be analyzed utilizing cross-correlation. This will be accomplished by gathering information about a subject's pigmentation, fatigue and other health statistics. Then the subjects will be given a training session on how to use the EPOC Emotiv headset. Then the subjects will attempt to control the wheelchair using given commands. Each subject's success with accomplishing each command will be recorded. Then the data will be analyzed.

.

Procedures to be followed:
You will be seated in front of a laptop and Emotiv headset. You will be asked wear the Emotiv headset. The nodes on the headset will be covered in saline. You will be asked to perform various cognitive exercises and facial gestures. After a period of rest you will be asked to repeat the exercises and gestures which the student investigators will record the time and accuracy of each task. Certain exercises and gestures will require much less effort than others. Rest will be provided between each exercise and gesture. Your participation will last for a maximum of 2 hours.

Risks to study participants:

There is some possibility you may also experience mental fatigue from the concentration required to complete the tasks.

Benefits to research participants and others:
There is no direct benefit to you.

Record keeping and confidentiality:
Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators, the sponsor or it's designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. Any publication or presentation of the data will not identify you.

Compensation or treatment in the event of injury:
In the unlikely event of physical injury resulting from participation in the research, you understand that medical treatment may be available from WPI, including first aid emergency care, and that your insurance carrier may be billed for the cost of such treatment. No compensation for medical care can be provided by WPI. You further understand that making such medical care available, or providing it, does not imply that such injury is the fault of the investigators. You do not give up any of your legal rights by signing this statement.

Cost/Payment:
You will not receive any payment for the completion of the study.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact:
Prof. Jane Q. Worcester, ECE Department, WPI, 100 Institute Road, Worcester, MA (Tel. 508-831-5555). You may also contact the chair of the WPI Institutional Review Board (Prof. Kent Rissmiller, Tel. 508-831-5019, Email: kjr@wpi.edu) or WPI's University Compliance Officer (Michael J. Curley, Tel. 508-831-6919).

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit. Data obtained in this experiment will become the property of the investigators and WPI. If you withdraw from the study, data already collected from you will remain in the study.

By signing below, you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

______________________________ Date: ____________________
Study Participant Signature

____
Study Participant Name (Please print)

____ Date: ____________________
Signature of Person who explained this study

Protocol for Using the Modified Emotiv_ROS_Driver

1) Determine if user has run through the full Emotiv Expressiv Trials
2) If no to #1, skip to #5
3) Look up the Eye Movement and Expression tables
4) Open the emotiv_ope.yaml file. Follow the steps below and change the values of the variables in **bold**, and then save the file

Key: C = Clench, RE = Raise Eyebrow, SL = Smirk Left, SR = Smirk Right, LL = Look Left, LR = Look Right
I = Intended, A = Actual Example: SLI = Smirk Left Intended
Highly Suggested > Suggested > Not Suggested

If (Look Left Intended / Look Left Actual > 0.7) && (Look Left Intended / Look Right Actual < 0.1)
LookLeft = Highly Suggested
Else if (Look Left Intended / Look Left Actual > 0.5) && (Look Left Intended / Look Right Actual < 0.2)
LookLeft = Suggested
Else
LookLeft = Not Suggested

(FOLLOW SAME FOR LOOK RIGHT)
If (Smirk Left Intended / Smirk Left Actual > 0.30) && (Smirk Left Intended / Smirk Right Actual < 0.05) && (Neutral Intended / Smirk Left Actual < 0.1)
SmirkLeft = Highly Suggested
else if (Smirk Left Intended / Smirk Left Actual > 0.20) && (Smirk Left Intended / Smirk Right Actual < 0.1) && (Neutral Intended / Smirk Left Actual < 0.1)
SmirkLeft = Suggested
else
SmirkLeft = Not Suggested

(FOLLOW SAME FOR SMIRK RIGHT)

If (LookLeft > SmirkLeft) && (LookRight > SmirkRight)
goLeftExpression = "LookingLeft"
leftThreshold = 0.1

goRightExpression = "LookingRight"
rightThreshold = 0.1
else if (SmirkLeft > LookLeft) && (SmirkRight > LookRight)
goLeftExpression = "EXP_SMIRK_LEFT"
leftThreshold = 2 * SLI/SLA

goRightExpression = "EXP_SMIRK_RIGHT"
rightThreshold = 2 * SRI/SRA

else if (The values are equal to each other)
The user can pick either the eye movements or the smirks depending on what they feel more comfortable with. Be sure to set the values for the threshold accordingly to as shown in the previous conditions depending on what has been selected.
else
it is advised that the user re-trains their expressions and calculate the data again.
forwardThreshold = 2 * Clench Intended / Clench Actual
stopThreshold = 2 * Neutral Intended / Raise Eyebrow Actual
backwardThreshold = 4 * Raise Eyebrow Intended / Raise Eyebrow Actual

5) Start the EmoEngine and connect it to the Emotiv Control Panel SDK
6) Make any adjustments in trainings until the user feels that the control panel is accurately depicting their actions
7) Launch roslaunch emotiv_epoc_driver emotiv_ope_combo_exp.launch

11. Appendix C: EMG Control System

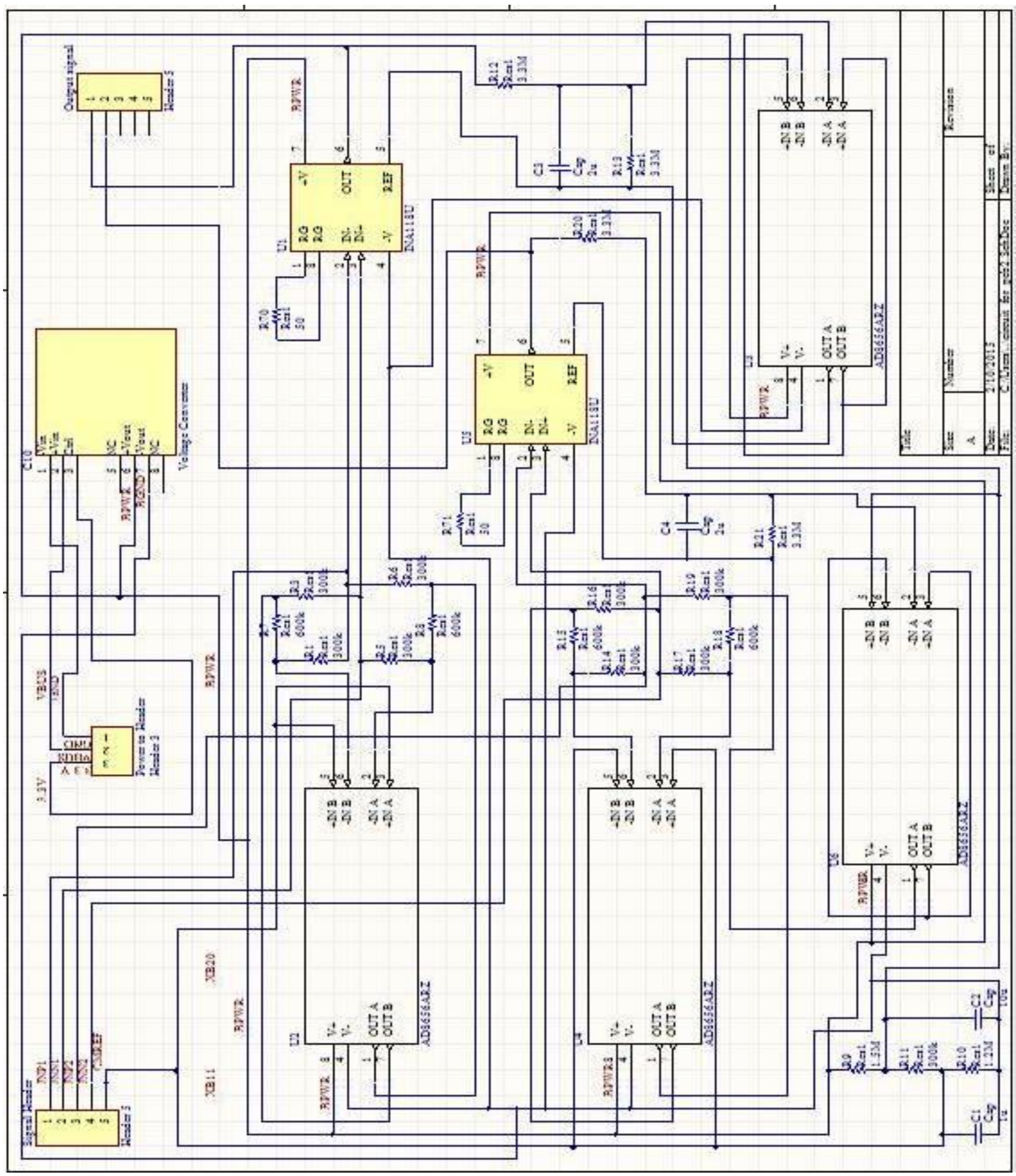


Figure 34: EMG Board Schematic

12. Appendix D: Terminology

Term	Meaning
Affectiv	One of the three modes that the Epoc Emotiv Headset uses. This mode can detect emotional states from electroencephalogram signals and classify them.
Anarthria	A loss of control of the muscles of speech, resulting in the inability to articulate words. The condition is usually caused by damage to a central or peripheral motor nerve.
Anna	A wheelchair-manipulator system developed by RIVeR Laboratories which will allow locked-in individuals, who are unable to interact with the physical world through movement and speech, to perform activities of daily living (ADL). The future directions of Anna include designing a modular, semi-autonomous robotic wheelchair platform with a 7-DOF robotic arm, control through a Body/Brain Computer Interface (BBCI) and developing obstacle avoidance
Cognitiv	One of the three modes that the Epoc Emotiv Headset uses. This mode can detect conscious thoughts from electroencephalogram signals and classify them.
Correlation (variable)	A statistical relationship between two random variables or two sets of data
Cost Map	This is a Robot Operating System Package This package provides an implementation of a 2D cost map that takes in sensor data from the world, builds a 2D or 3D occupancy grid of the data and inflates costs in a 2D cost map based on the occupancy grid and a user specified inflation radius.
Degree-Of-Freedom (DOF)	The number of directions in which an independent motion can occur.
Delrin	An engineering thermoplastic used in precision parts
Electromyography (EMG)	An electro diagnostic method for calculating and chronicling the electrical activity created by skeletal muscles.

Epoc Emotiv	A brain computer interface developed by Emotiv systems that measures EEG and EMG signals from a user and then classifies them into different states. The headset is capable of operating in three different modes which include Cognitiv, Affectiv, and Expressiv.
Expressiv	One of the three modes that the Epoc Emotiv Headset uses. This mode can detect and classify facial expressions from electromyography signals.
Image Segmentation	The process of partitioning a digital image into multiple segments (sets of pixels, also known as super pixels). The goal of segmentation is to simplify and/or change the representation of an image into in order to analyze the data.
IR	Infrared
IRB	Also known as Institutional Review Board, this is a committee that was established to help investigators understand and comply with the ethical guidelines and regulatory requirements for research involving human subjects. The IRB's overall goal is to promote and support efforts to conduct innovative research at WPI which protects the rights and promotes the welfare of human subjects.
Jaco Arm	A robotic arm developed by Kinova systems that has six degrees of freedom with unlimited rotation on each axis. There are three under actuated fingers that can be independently controlled as well. The arm can be controlled via Robot Operating System.
Kinematic Chain	An assembly of rigid bodies connected by joints that is the mathematical model for a mechanical system.
LiDAR	Also known as Light Detection and Ranging, is a remote sensing technology that measures a distance by illuminating a target with a laser and analyzing the reflected light.
Localization	Locating obstacles in the environment with respect to Anna.
PCB	A printed circuit board that mechanically supports and electrically connects electronic components.

Point Cloud	A set of data points that are in a three-dimensional (X, Y, Z) plane and typically represent the external surface of an object.
Quadriplegia	A condition resulting in the paralysis of all four limbs or all physical movement below the neck.
Red Green Blue Depth (RGB-D) camera	Depth sensing technology that captures Red Green Blue (RGB) images as well as per-pixel depth information.
Robot Operating System (ROS)	A framework of libraries and tools for open source robotic control.
Rviz	A visualization tool available in Robot Operating System.
Sensor Board	A board developed by a previous Major Qualifying project that connects low level hardware to a high level computer. It was designed to integrate sensors onto Anna
Trajectory	The path of a moving object through space as a function of time.