July 12, 2018
Dr. Andrew Rawicz
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RE: ENSC 405W/440 Design Specification for OptiCue

Dear Dr., Rawicz,

This document describes the design specifications for implementing a wearable device that provides audio feedback of social cues to the user, as outlined in our Project Proposal and Requirements Specification. Our goal is to create a light, easy to carry device that will track the facial expressions of the person that the user is talking to using a small camera that can be clipped onto the front of a shirt and provide the user with social cues via a headphone.

This document will outline our designs we have for both our electronics components and the software system. We will detail each electronic component separately, followed by how they will be controlled. The software modules and the libraries used will also be outlined.

Our team, consisting of 4 engineers spanning several concentrations including electronics, systems, and computing, includes Ricardo Dupouy, Steven Lippmann, Maggie Parkhurst-Bartel, and Greyson Wang. The mix of software, electronics, and systems expertise will allow us to realize this proposition.

Our team would like to thank you in advance for taking the time to review our design specification. If you have any questions, please feel free to email me at mparkhur@sfu.ca.

Sincerely,

Maggie Parkhurst-Bartel
CEO
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Design Specification:

OptiCue

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Abstract

This document describes the design specifications of the wearable device for facial expression recognition, OptiCue. We will present the preliminary design specifications for each of OptiCue's components and describe the tentative future design specifications as well. The goal of this document is to provide the reader with a justification for the design choices our team has made.

OptiCue is made up of 3 major physical subsystems: the controller which handles the image processing and the I/O, the camera to gather input images, and the audio output to provide feedback on the image processing. The device also includes a large amount of software which will be run entirely on the controller. OptiCue will include a simple and intuitive user interface while abstracting the physical components inside a small enclosure to keep the device as simple to use as possible.

This design specification will focus on the technical details of OptiCue including hardware, software, mechanical, and operational components including an analysis into how our design choices are justified. This document will also include several subdocuments in the appendix that detail our final proof-of-concept test plan, our user interface, and our 440-development plan. Our final proof-of-concept device will be presented and delivered by August 2nd, 2018.

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Glossary

Term	Definition
ABS	Acrylonitrile butadiene styrene. Plastic that is known for its heat and shatter resistance.
Alexithymia	Alexithymia is defined as the inability to recognize emotions and their subtleties and textures in the self and in others
Autism	Autism refers to a range of conditions characterized by challenges with social skills, repetitive behaviors, speech and nonverbal communication, as well as by unique strengths and differences.
ASD	Autism spectrum disorder
CNN	Convolutional Neural Net, a class of deep, feedforward artificial neural networks, most commonly applied to analyzing visual imagery.
Dlib	A modern toolkit containing machine learning algorithms and tools for creating complex software to solve real world problems.
Haar Cascades	A machine learning based approach where a cascade function is trained from a lot of positive and negative images.
Single-board computer	Small computing system with basic processor, several peripheral devices, and a set of I/O pins.
OpenCV	A library of programming functions mainly aimed at real-time computer vision.
PCA	Principal Component Analysis, a technique used to emphasize variation and bring out strong patterns in a dataset. It's often used to make data easy to explore and visualize.
PETG	Polyethylene Terephthalate Glycol. Plastic like that used in water bottles but modified to lower its melting point.
PLA	Polylactic Acid. Plastic made from renewable resources (i. e. corn starch, tapioca roots, or sugarcane).
PWM	Pulse Width Modulation
IC	Integrated Circuit

1 Introduction

The OptiCue device uses powerful and cutting-edge single-board computer technology to provide the user with a small, portable device that can still perform complex facial expression recognition in real-time. This allows individuals who cannot recognize social cues to receive immediate feedback on the emotional state of the individual they're speaking to.

The OptiCue device includes 5 main subsystems: First, the controller subsystem which includes a Raspberry Pi 0W single-board computer to handle all I/O including camera input, audio output, LED output, and button input. Second, the software system that will run on the controller and use the OpenCV library and a neural net to perform the image processing and facial expression detection. Third, the camera subsystem which includes a Raspberry Pi Spy Camera, a small camera module with a native resolution of 5 megapixels to discreetly capture high resolution images. Fourth, the audio subsystem which includes a low pass filter to filter unwanted noise from the Raspberry Pi output pins. Fifth, the power subsystem that includes a battery and a charging circuit which makes the device portable.

This design specification document discusses the technical details of the design requirements for each of the major subsystems of this device to meet the requirements of the proof-of-concept.

1.1 Background

According to the centre for disease control, recent studies in Asia, Europe, and North America have revealed that between 1 and 2% of the global population have been diagnosed with autism [1], this translates to a global population of 76 million autistic individuals. One of the main difficulties facing these individuals is social impairment and communication [2]. This means that many autistic individuals can find social interaction quite challenging, since many of the subtle aspects of interaction such as facial expression, body language, or tone of voice can be difficult to detect or understand.

Our company's goal is to provide a tool to make social interaction easier. The OptiCue will perform facial expression detection, provide feedback on the subject's mood, and help the user to avoid miscommunication.

1.2 Scope

This document supports and relies on the requirements specification document for the OptiCue. It provides a detailed explanation of design specifications for each of the major subsystems listed above. This document outlines the design choices and provides a justification for the design. This document also includes the Proof-of-Concept Test Plan in Appendix A, the

User Interface Requirements in Appendix B, and the 440 Project Development Plan in Appendix C.

1.3 Intended Audience

This document serves as OptiCue's design specification for Aperture Solutions Inc. members, its potential clients and partners, Steve Whitmore, Dr. Andrew Rawicz, and any possible teaching assistants. Future revisions will draw from the framework detailed in this document.

1.4 Design Classification

The requirements in this document will follow the following convention:

Des {Section}.{Subsection}.{Requirement Number} {Stage of Development}

The different stages of development are outlined below:

Encoding	Stage of Development
C	Proof of Concept
P	Prototype
F	Final Product

Table 1.4.1 - Development Stage Encoding

2 System Overview

The OptiCue is a small, wearable device that is designed to help those with a condition known as alexithymia, sometimes referred to as emotional blindness. This device will use a discreet camera system to track the facial expressions of those to whom the user is interacting. The system will process the facial expressions and send the user alerts, indicating the meaning of the current expression. The system proposed uses a simple headphone jack to send the user information, however, more alerting options could be made available to cater to those with certain sensitivities or preferences. One such alerting option, that will not be covered in the scope of this project, would be a Bluetooth enabled bracelet with LED indicators or a vibration motor. A concept of the OptiCue in the prototype stage is shown in Figure 2.1 below.

Figure 2.1 - OptiCue Concept

The OptiCue can be viewed as two main systems that work in parallel. The first system is the power management system. The power management system will handle charging the onboard li-ion battery pack, boosting the output voltage of the battery from 3.7 V to 5 V, providing power to the internals, and handle sending power information to the processing system. The second system, the processing system, is the main framework of the device that handles input from the camera, processes the image data, determines the facial expression and outputs audio to the headphones. The processing system will also manage notifications from the power

management system, user input via the push buttons and it will report system status via LED indicators on the front of the device.
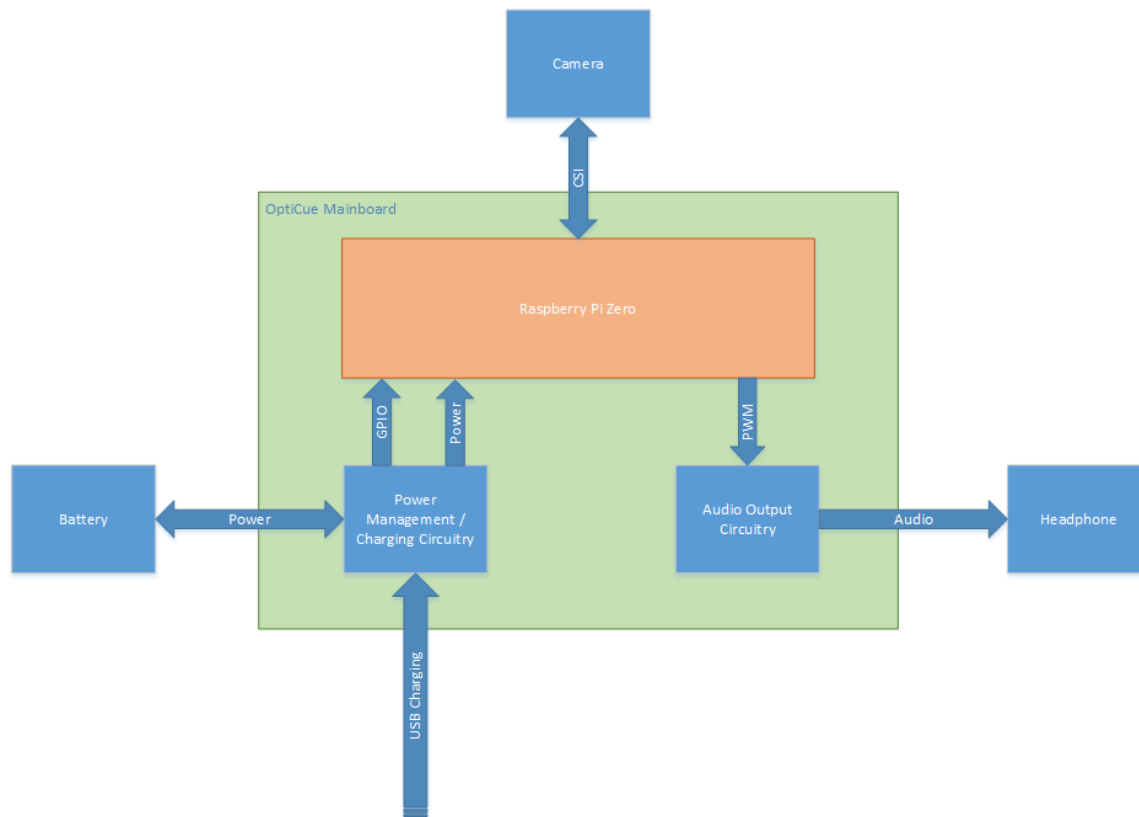

Figure 2.2 - System Block Diagram

Since this device is wearable and battery powered, the OptiCue must meet many strict specifications to be considered a useable product. The main specifications we need to meet are, size, battery life, and of course safety, while still performing accurate expression recognition. The various components in figure 2.1 will enable OptiCue to meet all the system design specifications listed below.

Design ID	Design Specification Requirements
Des 2.1 C	The device will recognize a face from an image.
Des 2.2 C	The device will recognize the primary face from an image containing multiple faces.
Des 2.3 P	The device will recognize the emotion of the primary face.

Des 2.4 P	The device will provide audio feedback on the emotion of the primary face.
Des 2.5 P	The device will have a battery life of ~8 hours in standby mode.
Des 2.6 P	The device will provide visual feedback on current state via LEDs.
Des 2.7 P	The device will contain buttons to control volume and power.
Des 2.8 P	The device will cost under 200$

Table 2.1 – System Design Requirements

3 Electrical Design

3.1 Main Computer

Design ID	Design Specification Requirements
Des 3.1.1 C	Processor capable of running complex image processing software
Des 3.1.2 C	Includes Camera Module interface
Des 3.1.3 C	Includes enough GPIO pins for audio feedback and LED indicators
Des 3.1.4 P	The device must easily fit in the OptiCue enclosure

Table 3.1.1 - Main Computer Design Requirements

At the heart of the OptiCue is the main processing unit, a Raspberry Pi Zero. This powerful single board computer runs at a speed of 1GHz and has 512MB of memory. The Raspberry Pi has been top choice for electronics projects since it was first released in 2011. With a cheap and efficient design, it is the perfect prototyping tool. The Raspberry Pi Zero operates with a 5V supply and draws about 750mA-1A when fully operational, making it ideal for portable applications.
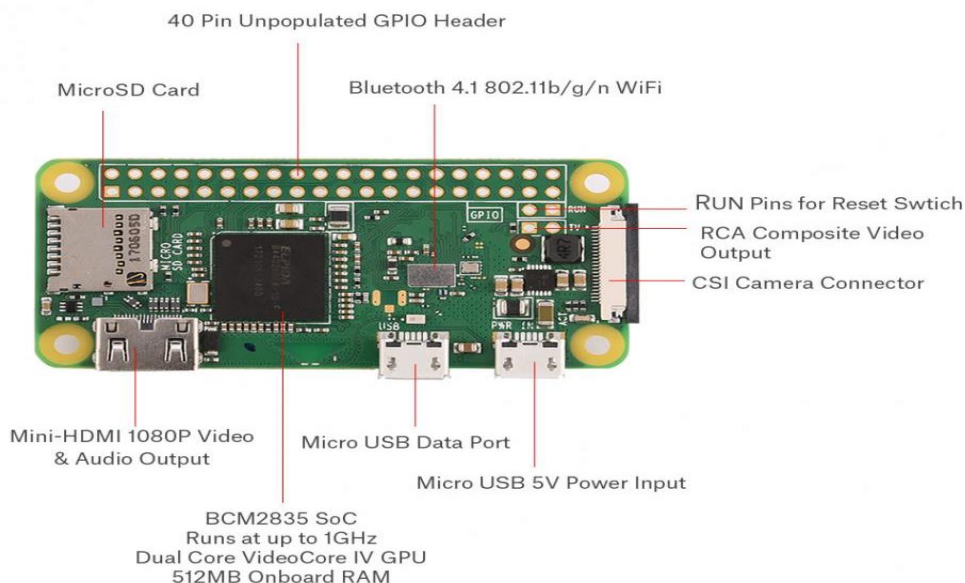

Figure 3.1.1 - Raspberry Pi Zero W

The Raspberry Pi Zero model is the smallest in the device tree. The central processor is equally powerful, but the board is designed for efficiency, keeping only the essential I/O. This development board includes a CSI Camera Connector that allows us to supply real time video information to the CPU for image processing. Lastly with a 40 Pin GPIO Header, the Raspberry Pi Zero also allows us to control all the feedback features of the OptiCue. We use the available pins to send the audio feedback signals to the user, as well as powering the various LED indicators present in the OptiCue enclosure.

3.2 Audio Feedback

Design ID	Design Specification Requirements
Des 3.2.1 C	Output audio feedback signal to user
Des 3.2.2 C	Filter unwanted high-frequency noise
Des 3.2.3 C	Limit current draw from Raspberry Pi pins
Des 3.2.4 P	Allow user to adjust the volume of the audio signal

Table 3.2.1 - Audio Feedback Design Requirements

The Raspberry Pi Zero does not have a built-in audio jack, nor does it have any analog pins. However, we make use of the Pulse Width Modulation output pins of the Pi to generate the desired audio signal, one pin for the left audio signal and the other for the right. To successfully generate the audio signal, the PWM frequency must be at least ten times higher than the largest audio frequency in the signal (about 20kHz).

The basic topology of the audio feedback circuit is shown in **Figure 3.2**. The peak to peak amplitude of the generated signal will be around 3.3V, a basic voltage divider between resistors R1-R2 and R3-R4 brings the signal down to the desired 1V peak to peak signal used for audio. To filter the high frequency noise generated by the PWM switching a basic RC low pass filter is constructed using resistor and capacitor R1-C2 and R3-C4. Finally, we protect the output pins of the Raspberry Pi from any unwanted static using the diode configuration shown.
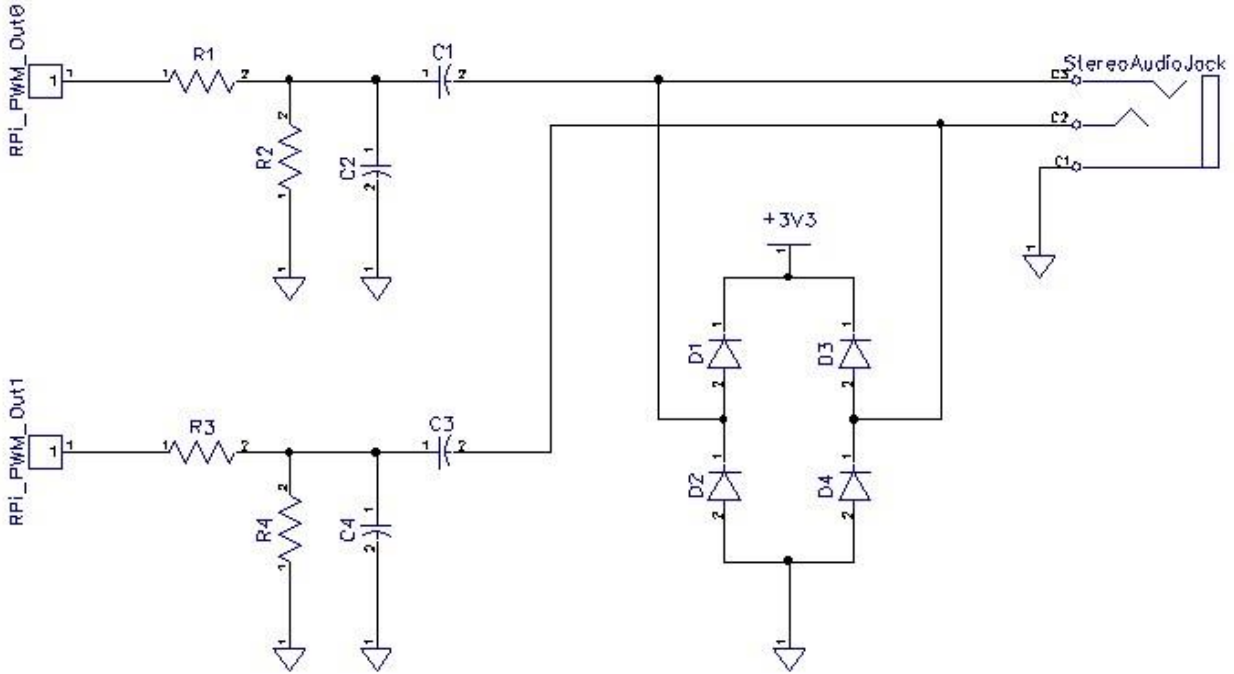
Figure 3.2.1 - Audio Feedback Circuit Diagram

3.3 Camera Module

Design ID	Design Specification Requirements
Des 3.3.1 C	Interface with Raspberry Pi Zero
Des 3.3.2 C	Discrete lens
Des 3.3.3 C	High resolution

Table 3.3.1 - Camera Module Design Requirements

The camera chosen for this design was the SainSmart 5MP Pi camera. This camera module was built to be used with the Raspberry Pi Zero allowing use to interface with our CPU easily. Specifications for this camera include a ¼" lens, 5 Mega Pixel image, and 2952 x 1944 resolution.

Figure 3.3.1 - Raspberry Pi Zero and Camera Module

3.4 Power Supply

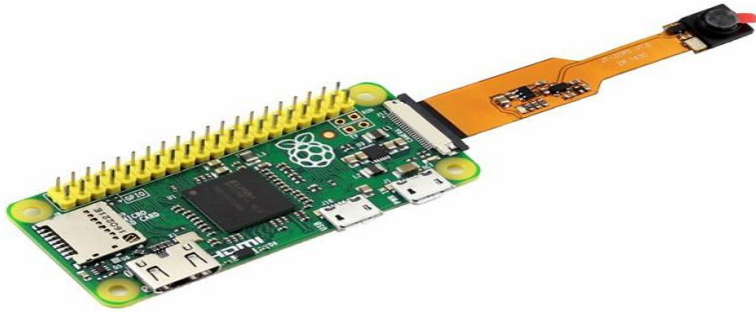| Design ID	Design Specification Requirements
Des 3.4.1 P	Small cylindrical battery capable of supplying operating voltages for the CPU
Des 3.4.2 P	Battery can supply up to 1 Ampere of current
Des 3.4.3 P	Battery life lasts for a few hours
Des 3.4.4 P	Rechargeable battery
Des 3.4.5 P	Regulated DC voltage supply

Table 3.4.1 - Power Supply Design Requirements

The central energy source of the device is a Lithium Ion cylindrical rechargeable battery operating at 3.7 Volts and a nominal current capacity of 2.2 Amperes. The small cylindrical shape of the battery allows it to fit into the battery cavity of the OptiCue enclosure. The 3.7V of the battery will be regulated using a DC/DC Boost converter that will bring the supply voltage for the subsystems up to 5V [9]. When operated at 220mA the battery can last for 10 hours. In order to maintain a battery life of a few hours the total current draw of the system should be kept below 750mA.

Figure 3.4.1 - 3.7V 2200mAh Rechargeable Lithium Ion Battery

A DC/DC Boost Converter topology is used to supply a regulated 5V to the Raspberry Pi. The circuit diagram in Figure 3.4.2 shows the typical configuration of the switching regulator using the cheap and efficient TPS61090 synchronous boost converter [10]. This circuit will allow for a stable voltage at the power rails, adjustable output voltage, and low battery detection.
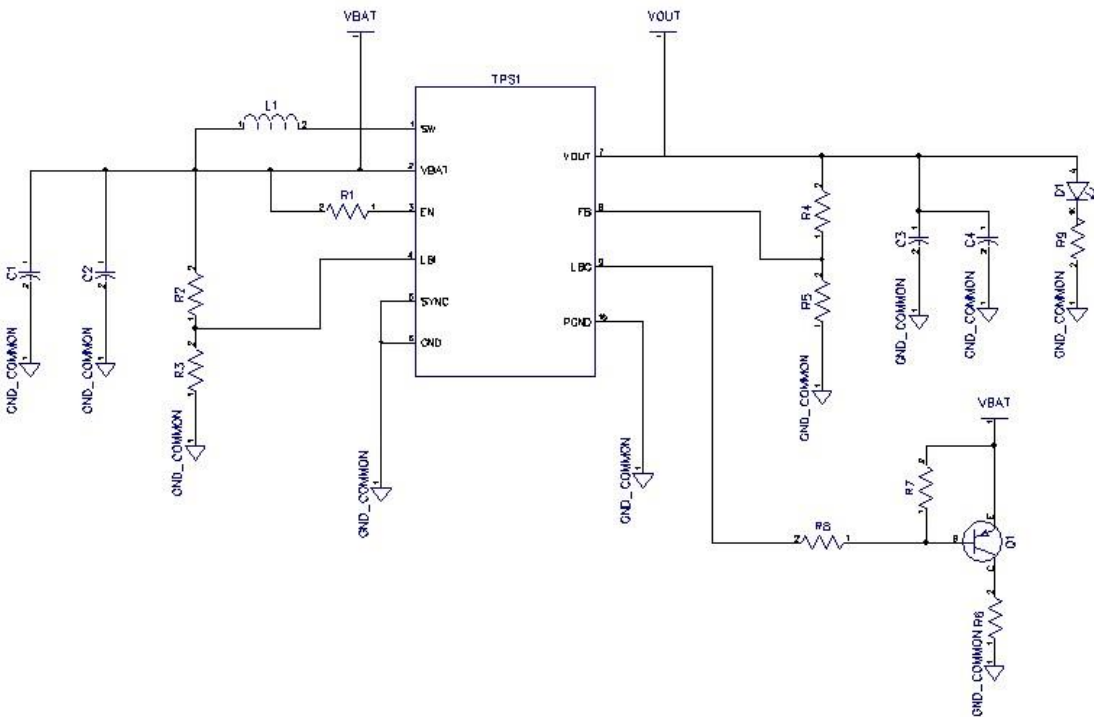
Figure 3.4.2 - DC/DC Boost Converter Circuit Diagram

Lastly, the OptiCue will have an internal battery charging circuit allowing the user to charge the device using a micro-USB port. The circuit diagram in Figure 3.4.3 shows a typical implementation of a Lithium Ion battery charger using a specialized charging IC [11]. At the center of this circuit is a MCP73831 charge management controller which interfaces the micro-USB port and ensures that the battery is charged at the constant required rate of 1A.

Figure 3.4.3 - Battery Charger Circuit Diagram

4 Software Design

OptiCue has 4 main software components. The first software component is responsible for capturing the images and performing the face and facial landmark detection algorithm. The second software component performs image compression. The third software component uses a trained convolutional neural network (CN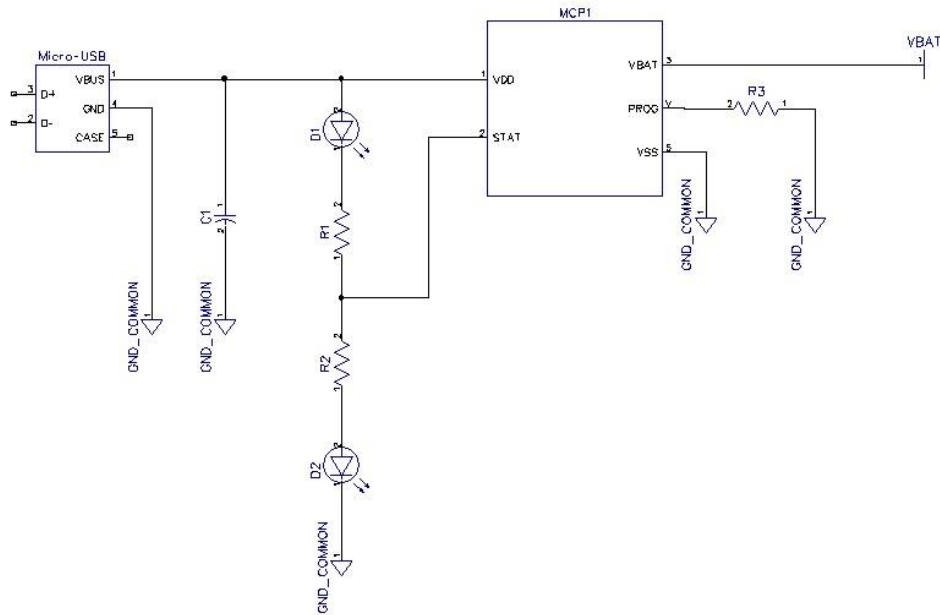N) to analyze the facial image data and determine the facial expression of the individual the user is speaking to. The fourth software component handles the interface between the software and the controller including the I/O, device state, and more.

4.1 Face and Facial Landmark Detection

Design ID	Design Specification Requirements
Des 4.1.1 C	The device will recognize a face from an image.
Des 4.1.2 C	The device will recognize the primary face from an image containing multiple faces.
Des 4.1.3 C	The device will recognize the facial landmarks of a face image
Des 4.1.4 C	The device will recognize if the face in an image is smiling

Table 4.1.1 - Design Requirements for Face and Facial Landmark Detection

To detect any faces that might be in the image, the software firsts initialize the camera peripheral attached to the Raspberry Pi 0W through the OpenCV library. It then performs object detection using Haar feature-based cascade classifiers [3], a cascade function that has been trained from many positive and negative images. The OptiCue face detection software uses the pre-trained function to detect faces in real time and reduce processing.
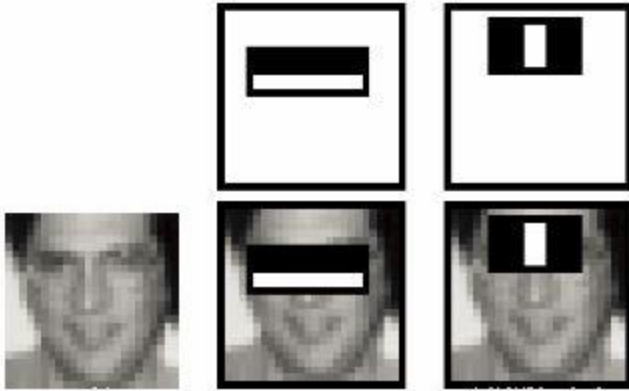
Figure 4.1.1 - Haar Feature Detection

The cascade function returns a list of all the faces in the image and their dimensions and locations. The program sorts the list of detected faces and saves the image data of the largest face detected; the remaining faces are considered background faces.
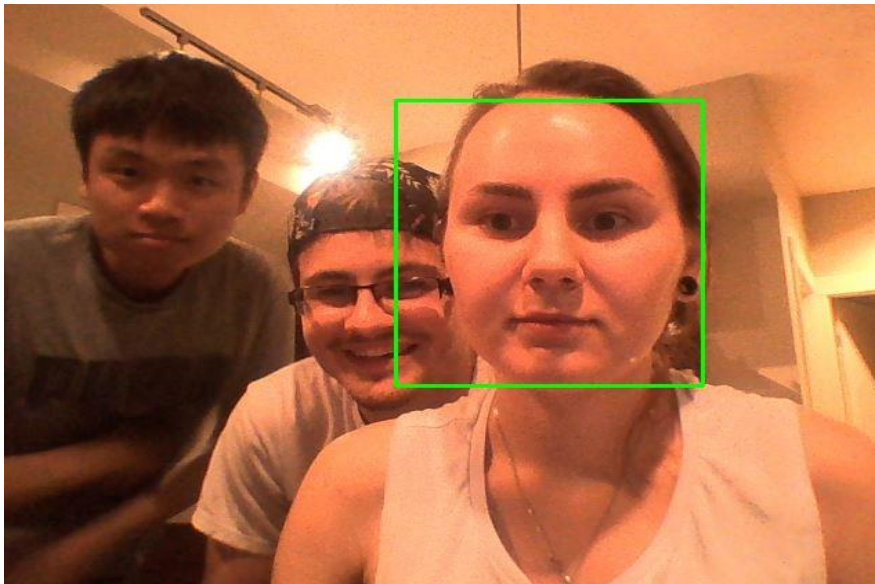
Figure 4.1.2 - Example Detected Face with Ignored Background Faces

After retrieving the facial image data for the largest face, the program performs facial landmark detection to gain basic information on the individual's current emotion to meet our 405-deliverable requirement. To retrieve the facial landmarks of the face image, the software uses the "dlib" library and a pretrained landmark detector function to map the face using 68 coordinates [4]. A visualization of this mapping is shown below in figure 4.2.
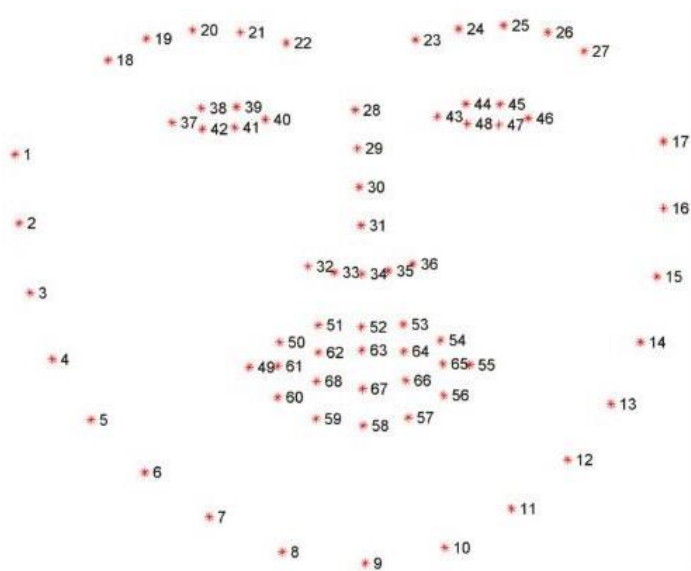
Figure 4.1.3 - Sample Mapped 68 Facial Coordinates

After using the pretrained function to get the coordinate values of the facial landmarks, the software checks the values of coordinates 49, 50, 54, and 55 to detect if the individual is smiling. This basic functionality of smiling vs. no smiling serves as a first step in detecting various facial expressions (happy, sad, angry, etc.) and works as a proof of concept to see whether our device can perform real time facial expression detection in real time.

4.2 Image Compression

Design ID	Design Specification Requirements
Des 4.2.1	The software shall use principal component analysis to reduce the dimensionality of the image
Des 4.2.2	The software shall collapse the RGB values into black and white to reduce image size

Table 4.2.1 - Design Requirements for Image Compression

The second component is the image compression using principal component analysis with the scikit-learn library. Principal component analysis reduces the dimensionality of the image while retaining most of the important data by finding principal components of the data. The first principal component is the vector along which the data has maximum variance, and subsequent principal components are orthogonal to the first component and includes as much of the remaining variance as possible. The data is then mapped to these new axis [5].

For the sample two-dimensional data shown below, the principal component is shown in red, which captures the maximum variance of this data set. This data set can then be reduced into a one-dimensional data set by collapsing the data along the purple vector, which is orthogonal to the principle component and has minimal variance.
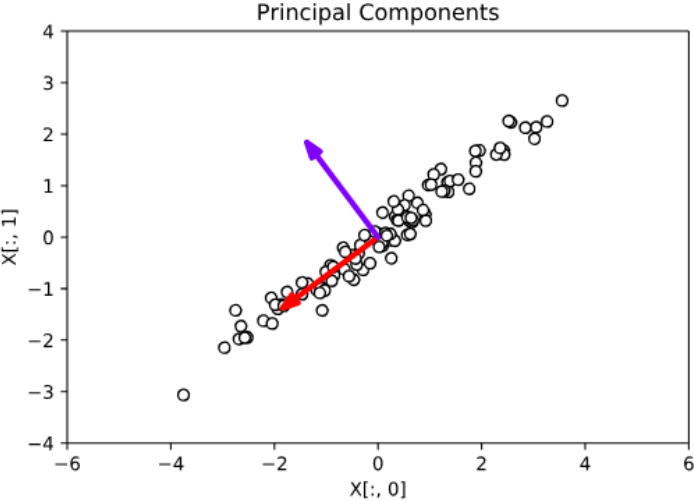
Figure 4.2.1 - Reduction of Example Dataset using PCA

This will produce a lossy compression but can produce significant image size compression with minimal loss of important data. This can significantly reduce our memory usage in the Raspberry Pi Zero, neural net training time, and the time it takes to classify the image.

For example, using PCA to reduce the following image from 11750 down to 250 dimensional features gives the results in figure 4.4.   Even with such a large reduction, most of the important facial features have been maintained.

Figure 4.2.2 - Transformation of Image using PCA

Using Support Vector Machines with a linear kernel function to train and classify both the original images and the images compressed with PCA, we can see in table 4.2.2 that very little accuracy was lost from applying PCA to the images, but the training time was significantly reduced when training on the compressed images [6]

Method	Accuracy	Time
Full Image Data	83.4%	7.8 s
PCA Reduced Image Data	82.5%	1.5 s

Table 4.2.2 - Processing Time and Accuracy for Compressed vs. Full Datasets

4.3 Emotion Recognition

Design ID	Design Specification Requirements
Des 4.3.1 P	The device will recognize the face's current emotion within some degree of accuracy
Des 4.3.2 P	The device will use a trained convolutional neural network to recognize the emotion.
Des 4.3.3 P	The device will send audio feedback on the face's current emotion

Table 4.3.1 - Design Requirements for Emotion Recognition

After the image has been compressed, the emotional classification will be done using a convolutional neural network, which is designed to work with images. A convolutional neural network consists of neurons containing adjustable weights and biases. The neurons are organized into sets called hidden layers, which are organized into three dimensions, with each neuron connected to neurons within a local region of the next layer [8].
Convolution is performed on the input data and a filter known as the kernel, as defined by equation 4.3.1 [8] which is included below:

$$\text{feature map} = \text{input} \otimes \text{kernel} = \sum_{y=0}^{\text{columns}} \left(\sum_{x=0}^{\text{rows}} \text{input}(x-a, y-b)\, \text{kernel}(x,y) \right)$$

Equation 4.3.1 Feature Map Equation

This produces a feature map, where the important features of the images are detected. The feature maps from convolving the inputs with various filters are then combined into the output of the convolution layer. An activation function is also used to add a bias to the weighted sum of the inputs and normalize the outputs [7].

After the convolution layer, a pooling layer is used to reduce the number of dimensions of the data. Finally, the classification layer takes these results and assigns probabilities for each possible output.

4.4 Device Interface

Design ID	Design Specification Requirements
Des 4.4.1 P	The device will contain a power button to transition between off, active, and standby states.
Des 4.4.2 P	The device will contain a power LED to inform the user of the current state of the device.
Des 4.4.3 P	The device will contain a battery LED to inform the user of the battery level and if the battery is charging.
Des 4.4.4 P	The device will contain an error LED to inform the user if the device is experiencing an error.
Des 4.4.5 P	The device will contain a volume up button to increase the volume of the audio feedback
Des 4.4.6 P	The device will contain a volume down button to decrease the volume of the audio feedback

Table 4.4.1 - Design Requirements for the Device Interface

The last component of the software design is the interface between the hardware and software components. This aspect of the software controls the current device state, button response, and LED state. The possible states of the device are OFF, ACTIVE, and STANDBY. The OFF state is self explanatory, the device will be shut down. The ACTIVE state is defined as the device being powered on, actively capturing images, and performing all the image processing. The STANDBY state is defined as the device being powered on but not capturing images or performing any facial detection. To transition between device states, the user uses the "power" button. The defined interactions with the buttons to transition between states are defined below in figure 4.6.
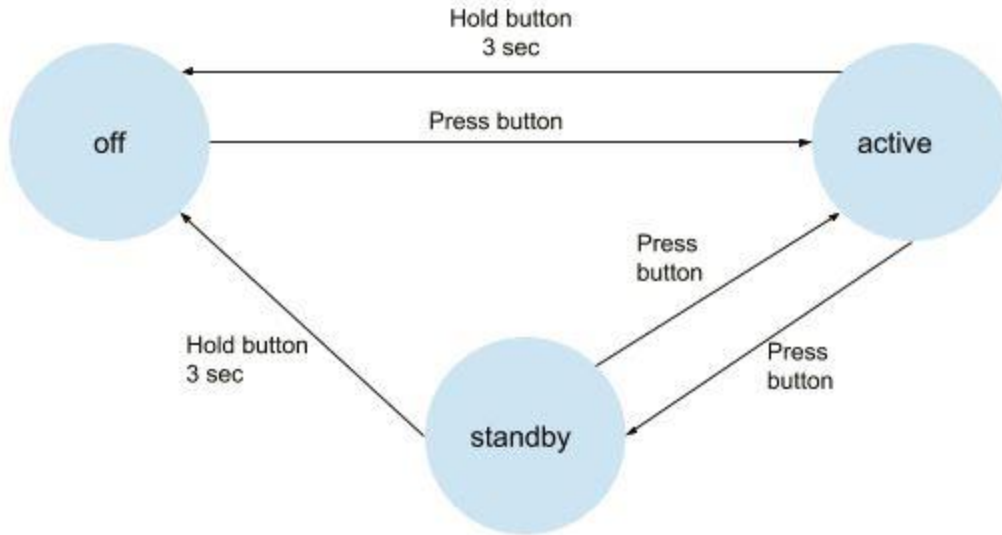
Figure 4.4.1 - Device State Diagram

The software also provides the definition for the power LED, the error LED, and the battery LED. These LEDs provide basic feedback on the device and are defined as seen in table 4.0 below.

LED Colour	Power LED	Error LED	Battery LED
Green	Active	-	Charging
Yellow	Standby	-	-
Red	-	Error Detected	Low Battery
Off	Off	No Error	Battery Fine

Table 4.4.2 - Power, Error, and Battery LED Definitions

The software mentioned above will handle all button presses including the volume up and volume down buttons. The volume will increase or decrease by 5-10% if the user presses the volume up or volume down button respectively. There exists an intuitive python module which can be used to set the volume in the event of a button press. Logic will also be included to debounce the button presses in software to ensure precise control of the volume.

5 Mechanical Design

The mechanical design of the OptiCue needs to be planned carefully. Not only do we want the internal components to be protected against the environment, we also want to provide users with a robust device that does not need to be meticulously cared for. Aside from protecting the device, it is also crucial to provide the user with a device that is comfortable as well as functional.

5.1 Environmental Considerations

Environmental conditions the OptiCue should be able to withstand are, high and low temperatures, and modest amounts of dust and moisture. In terms of temperature, we want users around the world to be able to use our device without having to worry about enclosure malfunctions based on the design decisions and/or construction materials. This means that in hot climates, we expect the construction material to remain strong and not become overly soft or flexible. Additionally, in cold climates, the material should not become too inflexible or brittle.

3D Printable Plastics		
Plastic Code	Pros	Cons
PLA	- Easy to 3D print - Inexpensive - Biodegradable [12]	- Lowest temperature resistance (up to 55°C) [12] - Low moisture resistance [13] - Brittle [12]
PETG	- Moderate temperature resistance (-20°C - 80°C) [14] - High strength [15] - Flexible - Recyclable - Chemical resistant (including water) [15]	- Difficult to 3D print - Slightly more expensive than PLA or ABS
ABS	- Highest temperature resistance (-20°C - 105°C) [16] - Inexpensive - High strength [16] - Flexible [16]	- Very difficult to 3D print - Oil based (not environmentally friendly) [17] - Toxic printing fumes [17] - Might warp during printing

Table 5.1.1 - Material Properties Pros and Cons

With the above-mentioned design constraints and given some of the more common and inexpensive 3D printable plastics, the obvious enclosure material choice is PETG. PETG will provide the necessary strength in all reasonable temperature ranges. It will also make our enclosure water and chemical resistant which makes the OptiCue even more robust. Of course, being that PETG is also recyclable and, sourced from certain vendors, be made from 100% recycled plastic.

Design ID	Design Specification Requirements
Des 5.1.1 P	Humid environments will not adversely affect the device.
Des 5.1.2 P	Dust will not be able to collect on internal components.
Des 5.1.3 C	Device enclosure will not warp in hot climates nor become brittle in cold climates.

Table 5.1.2 - Mechanical Environmental Design Specifications

5.2 User Considerations

The user of the OptiCue should not need any expertise to get the device working. We would like to provide a simple intuitive user experience. To make the OptiCue as user friendly as possible from a mechanical point of view, we would like to use a material that is visually appealing and is comfortable to hold. The surface finish of the device will be a soft-touch rubberized layer to provide a more pleasant feel as well as added grip in the hand and on clothing. The OptiCue will have a convenient clip on the back of the device that can be used to attach the OptiCue to the user's clothing.

Since the OptiCue is stationary with respect to the user, the camera needs at least one degree of freedom to allow the user to adjust the view of the camera. To achieve the necessary amount of adjustment, we decided to include a wheel on the front of the device that changes the upward angle of the camera. This wheel will also click into position every few degrees to make sure the adjustment is stable and repeatable.
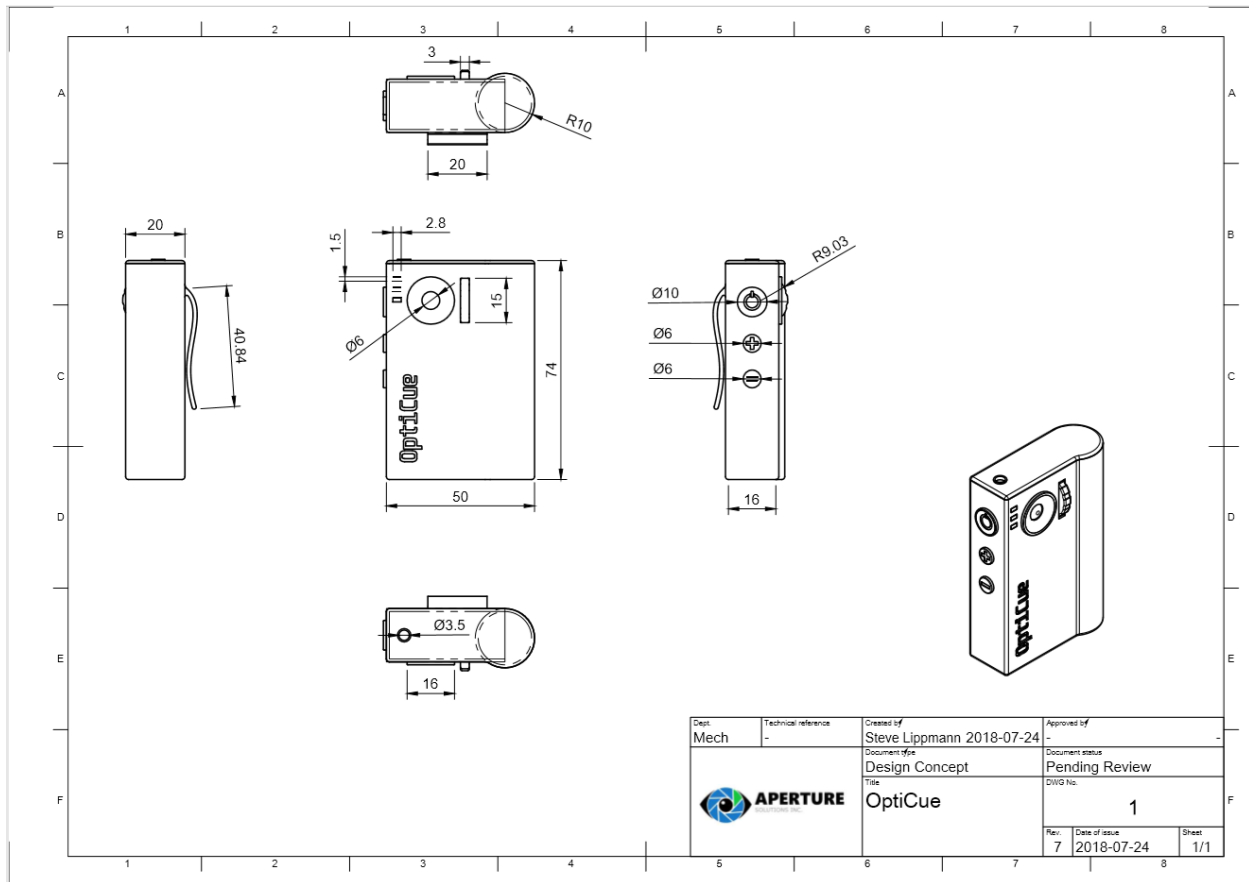
Figure 5.2.1 - OptiCue Schematic

Finally, the buttons should give the user enough feedback. There will be three buttons on the device, a power button and two volume buttons. Each button will have a tactile and audible click to indicate to the user that the button was successfully activated. Each button will also have an engraving that will indicate to the user its function.

Design ID	Design Specification Requirements
Des 5.2.1 C	Clip on the back of the OptiCue will not break under weight of the device.
Des 5.2.2 P	The camera angle will be user adjustable from the front of the device.
Des 5.2.3 P	The camera adjustment will have several set positions.
Des 5.2.4 P	The buttons will have a tactile and auditory click.

Table 5.2.1 - Mechanical User Design Specifications

6 Conclusion

The OptiCue is a small and intuitive device that performs real-time facial detection to act as a tool for those unable to recognize social cues. Using readily available electronic components such as a Raspberry Pi 0W and a SainSmart pi cam, this device is relatively inexpensive and designed to be as accessible as possible for anyone experiencing an inability to recognize emotion.

The OptiCue design is comprised of three subsystems:
1. The Electronic Design:
   a. Single-board Computer: Controls the peripherals and performs image processing.
   b. Audio: Provides feedback to the user.
   c. Camera: Captures images of the person the user is interacting with.
   d. Power: Provides a battery and charging to enable portability.

2. The Software System:
   a. Face and Facial Landmark Detection: Detects a primary face and its facial landmarks in an image
   b. Image Compression: Performs principal component analysis to extract features and reduce image data
   c. Emotion Recognition: Utilizes a convolutional neural net to identify the emotion of the primary face.

3. The Mechanical System:
   a. Device Enclosure: An enclosure for all the electronic components that will protect them from the environment.
   b. Camera Adjustment Mechanism: Allows the user to manually adjust the tilt of the camera.
   c. Clothing Clip: A clip on the back of the device that allows the user to attach the OptiCue to their clothing.

This design specification will serve as a reference document for Aperture Solutions as the team begins developing the prototype for the OptiCue in the coming months. These designs will serve as a guideline but may change throughout the development cycle for the prototype device.

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8 Appendix A: Test Plan

8.1 Introduction
This appendix document details the test plan for the OptiCue as a whole, as well as each of the device's individual subsystems.

8.2 User Testing
The following tests will be performed on the user interface. These tests will span all the device's functionality and subsystems.

Date:	Test Name: Active/Standby Transition
Test Description: Press the power button to cycle through the states while the device is on.	
Expected Outcome: The device should be switching between states which will be demonstrated by the power LED switching between green and yellow.	
Actual Outcome:	

Date:	Test Name: Power Cycling
Test Description: Press the power button to turn the device on from its off state, once device has powered on, hold the power button for 3 seconds to turn it off.	
Expected Outcome: Once device powers on, it should go from Off the Active mode, turning the power LED from off to green. Once device has powered down, it goes from Active to Off, turning off the power LED.	
Actual Outcome:	

Date:	Test Name: Battery Charging
Test Description: Plug in the cord to the battery charging circuit.	
Expected Outcome: The battery LED should turn green.	
Actual Outcome:	

Date:	Test Name: Error Detection
Test Description: In active mode, ensure there are no faces in the frame.	
Expected Outcome: The software should not recognize a face and therefore the error LED should turn on.	
Actual Outcome:	

8.3 Electronics Testing

The following tests will be performed on the electronic components of the OptiCue device. These tests will span all the device's electronic functionality but may include functionality from other subsystems.

Date:	Test Name: Regulated Output Efficiency
Test Description: Measure the output of the Boost Converter and compare against expected values. Monitor variations in the output voltage	
Expected Outcome: 5V output voltage, no noise is expected at the output of the regulator	
Actual Outcome:	

Date:	Test Name: Current Draw Measurements
Test Description: Measure the current draw of the peripherals (camera, audio feedback, regulator IC, charger IC) as well as the system as a whole	
Expected Outcome: The entire system should not draw more than 1A of current	
Actual Outcome:	

Date:	Test Name: Audio signal quality
Test Description: Perform a frequency sweep on the audio feedback circuit	
Expected Outcome: Frequencies higher than the audio band (200Hz-20kHz) should be attenuated	
Actual Outcome:	

Date:	Test Name: Battery Charging
Test Description: Allow battery to discharge and connect to charging circuit, monitor the battery voltage. Monitor output voltage and current of the charger IC	
Expected Outcome: Battery should take a couple of hours to charge. Output voltage and current of the charger IC should be constant (about 1A)	
Actual Outcome:	

Date:	Test Name: Battery Overcharging Protection
Test Description: Monitor Battery voltage until it has reached the nominal level and leave the device connected	
Expected Outcome: Once the battery is fully charged the IC should stop sending any charge	
Actual Outcome:	

8.4 Software Testing

The following tests will be performed on the software components of the OptiCue device. These tests will span all the device's software functionality but may include functionality from other subsystems.

8.4.1 Face and Facial Landmark Detection

Date:	Test Name: Multiple Faces Found
Test Description: Test camera by placing several faces in front of it.	
Expected Outcome: The camera should detect each face and ignore all but the largest face, determining that to be the primary face.	
Actual Outcome:	

Date:	Test Name: No Faces Found
Test Description: Test by setting the device to active mode and ensure there are no faces in front of the camera.	
Expected Outcome: The camera should not detect any faces in the image data.	
Actual Outcome:	

Date:	Test Name: Detect Smiling
Test Description: Test the facial landmark mapping by placing a smiling person in front of the camera.	
Expected Outcome: The software should recognize the smiling face and output that it is smiling.	
Actual Outcome:	

8.4.2 Expression Detection

Date:	Test Name: Testing on labeled dataset using trained model
Test Description: Use the trained neural net on a new set of labeled data	
Expected Outcome: The software should achieve an accuracy of at least 60%	
Actual Outcome:	

Date:	Test Name: Real-Time Detection on Face
Test Description: Use the trained neural net on a human face	
Expected Outcome: The software should achieve an accuracy of at least 60% in finish in less than 1 second.	
Actual Outcome:	

Date:	Test Name: Description of Changing Expressions
Test Description: Present a face that changes expressions every 10 seconds	
Expected Outcome: The software will only alert the user if there is a change in the facial expression of the speaker.	
Actual Outcome:	

8.5 Mechanical Testing

The following tests will be performed on the mechanical components of the OptiCue. Some of the tests will be performed on the device as a whole, and others will only be performed on the specific mechanical component. Each test will indicate which parts of the device are necessary to obtain valid results.

Date:	Test Name: Drop Test
Test Description: Drop weighted enclosure on several different surfaces from about 1.5 metres and check for catastrophic failures. It is not necessary to include the internal electronics.	
Expected Outcome: The enclosure should not contain any cracks or significant dents	
Actual Outcome:	

Date:	Test Name: Dust Test
Test Description: Expose the device to extreme dust conditions for 1 hour and check for internal dust collection. For realistic results, the internal electronics will be installed.	
Expected Outcome: The device should contain next to no dust internally. No dust build-up should be visible	
Actual Outcome:	

Date:	Test Name: Moisture Test

Test Description: Leave device enclosure in a humid environment for several days and check for any structural weaknesses. To protect the electronics, they will not be included in this test.

Expected Outcome: The enclosures mechanical properties should perform the same as initial tests show

Actual Outcome:

Date:	Test Name: Camera Adjustment Test

Test Description: Adjust camera up and down repeatedly and make sure the set positions still hold with enough force. The camera should not move without human interaction. For accurate results, the electronics will be installed.

Expected Outcome: The camera adjustment mechanism will continue to function well and hold its position

Actual Outcome:

Date:	Test Name: Clothing Clip Test

Test Description: Hold the enclosure by the clip on its back and load it with weight. More weight than the internals will realistically add to test extremes. The electronics are not necessary in this test.

Expected Outcome: The clip will not fail even if the weight applied reaches 5 times the devices weight

Actual Outcome:

9 Appendix B: User Interface

9.1 Introduction

This appendix will detail the design of OptiCue's user interface. We will explain the design choices for the user interfaces, analyze how our users will use the product, and discuss design considerations based on Don Norman's "Seven elements of UI Interaction" - namely discoverability, feedback, conceptual models, affordances, signifiers, constraints.

Users of OptiCue will have cognitive disorders, and it is critical for our device to take this into account if our users are to adopt our product. Common characteristics of these cognitive disorders include repetitive behaviour and susceptibility of distractions [1][2]. Repetitive behaviour means that our device should be designed to limit the variety of actions available to the user and focus on a uniform and consistent use case each time. Susceptibility of distractions means that our device should perform as autonomously as possible, with very little action required from the user once the device is active.

To make the user interface discoverable, we will model our user interface on common household electronic devices, such as smartphones. This will make the user interface seem familiar, with UI elements have functionality consistent with what users will expect.

9.1.1 Purpose

The purpose of this appendix is to explain the design of OptiCue's user interface and provide an overview of the UI's main components and their functionality.

9.1.2 Scope

This appendix will focus on the prototype's user interface. It contains an analysis on our users and how they will interact with our device.

9.2 User Analysis

OptiCue is designed for both children and adults with cognitive disorders, who will likely have no prior knowledge or experience with a similar device. However, given the prevalence of smartphones and tablet computers, our users will likely have experience with using these devices, and be familiar with its user interface, including the way a smartphone powers on and off with a long push on the power button, the ability to turn the screen on and off with a short push on the power button, and a button on the side to control the volume. If our user interface differs too much from these common household smart devices, our users may find the device foreign and be deterred from using it. This is especially true for autistic people, who enjoy the familiar and repetitive, and would not welcome something too different from what they are used to.

Some design principles are drawn from W3C's inclusive design concepts for making interface easy to use. This includes avoiding any buttons or elements that "pop" or stand out on the device, and using large buttons with clear icons, while avoiding multi coloured icons [3]. We will, however, keep to the expected conventions for our LED lights, which will use green for ok, yellow for standby, and red for error. Since these LED lights are not very bright, they won't become a distraction.

9.3 Technical Analysis

This section will analyze OptiCue's user interface based on Don Norman's Seven elements of UI Interaction, which includes the following design factors: discoverability, feedback, conceptual models, affordances, signifiers, mappings, and constraints [4].

9.3.1 Discoverability

Discoverability encompasses how easily a user can locate various user interface elements when they are seeing the product for the first time, and discover what they can do with these buttons, switches, and other elements. OptiCue's user interface is designed with minimalism in mind, providing a clean interface with only the essentials, such as the power button, volume control, and LED displays to indicate the status of the battery and any errors that occur. These buttons are placed on the device based on common smartphone designs, which will make them intuitive to find for the user.

Figure 9.3.1 shows the outer casing of OptiCue. A large power button with the familiar power on icon has been placed on the side of the device, along with the volume control buttons. The scroll wheel is placed beside the camera to adjust the camera's angle. Following popular convention, the LED's will use green for ok, yellow for standby mode, and red to indicate an error.
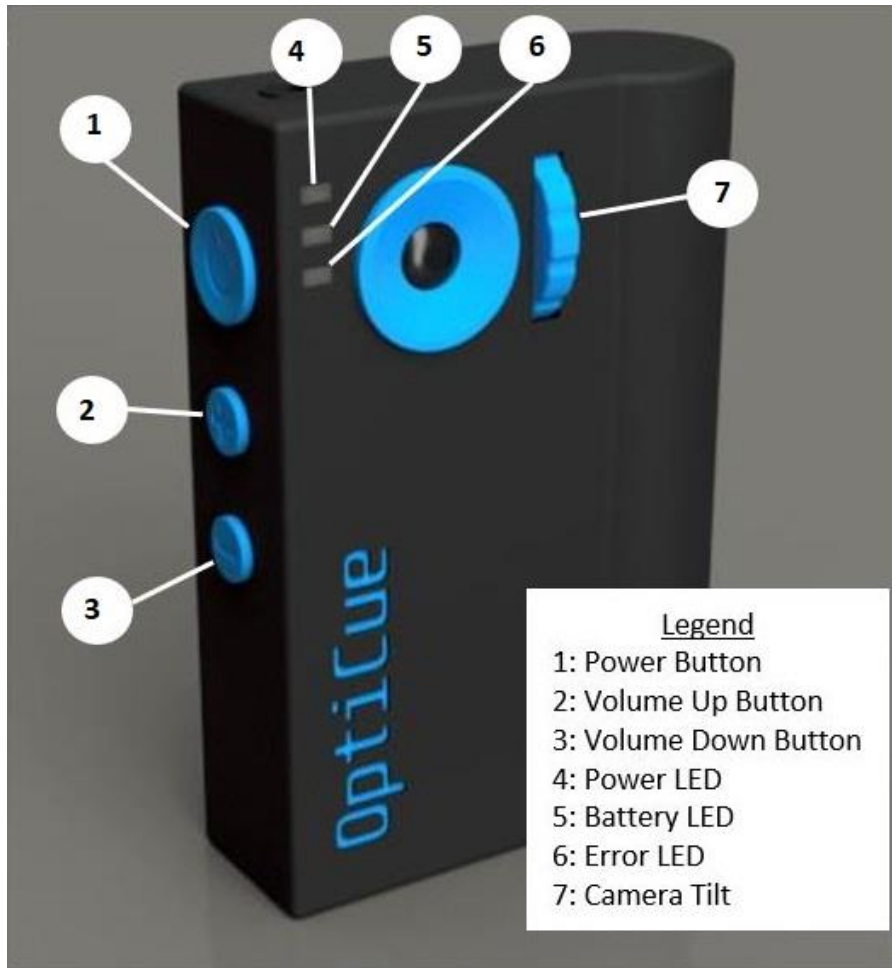
Legend
1: Power Button
2: Volume Up Button
3: Volume Down Button
4: Power LED
5: Battery LED
6: Error LED
7: Camera Tilt

Figure 9.3.1 - OptiCue's user interface

9.3.2 Feedback

The primary source of feedback will be provided to users by audio. This includes the results of the emotional analysis, low power in the battery, and whether an error has occurred. Secondary feedback is provided by the three LED's, which includes an error LED to signify whether the device is still currently in error state. After the user is informed of an error via audio, they can check the error LED to see whether the device is still in error state. The power LED will indicate whether the device is in active or standby mode in case the user has forgotten. Green will indicate active mode, while yellow indicates standby. Finally, the battery LED displays the standard battery bar to indicate what percentage of the battery is left.

9.3.3 Conceptual Models

A device's design should project the information needed for the user to intuitively understand how to use the device's features and capabilities and allow the user to build a conceptual model.

Prior experience with using electronic devices, such as smartphones, will help the user build a conceptual model of our device. A lack of input required from the user will also help build the conceptual model, with the device being fully operational after being powered on into active mode without any other action required from the user.

9.3.4 Affordances

The affordances specify the actions that are possible for the device. OptiCue affords the user information on social cues based on facial analysis of the person the user is talking to. Don Norman also introduces perceived affordance in his text "Psychology of Everyday Things", which refers to actions that the user thinks is possible for the device [5]. With our user interface designed to be deliberately sparse, the user's perceived affordance is unlikely to deviate from the actual affordance.

9.3.5 Signifiers

Signifiers are used to provide extra information on how to use the product's main elements. OptiCue's signifier includes a clip to indicate that the device should be clipped onto a shirt. Common symbols for UI elements such as power are also used to provide the user with extra information on what each button does.

9.3.6 Mappings

Mappings considers how intuitively UI elements are placed so that locating them to perform a specific action feels natural. As mentioned previously, the key UI elements are placed similarly to where they are found on smartphones, making them consist what the user's expectations.

9.3.7 Constraints

Constraints limit the actions that the user can perform and can prevent the user from using the product inappropriately. Our few UI elements provides a physical constraint on what actions a user can perform on the device. Power and volume control symbols provide a physical and logical constraint, since they are universal everywhere that almost anyone can recognize and will be intuitive for anyone who has used a smartphone.

9.4 Engineering Standards

To create the most intuitive user interface for the OptiCue, the team at Aperture Solutions will be following several Engineering Standards throughout the development of the prototype and the user interface. Note that some of the standards pertain to the user interface while some pertain to general safety guidelines.

Standard	Description
ANSI C 18.2M	Portable Rechargeable Cells and Batteries - Safety Standard
C22.2 NO. 0.23-15	General Requirements for Battery-Powered Appliances
IEC TR 61997	Guidelines for the User Interface in Multimedia Equipment for General Purpose Use
IEEE 1012-2012	System and Software Verification and Validation
IEEE 1621-2004	User Interface Elements in Power Control of Electronic Devices Employed in Office/Consumer Environments
ISO 20282	Ease of Operation of Everyday Products
ISO 9241-210	Ergonomics of Human-System Interaction
RoHS	Directive on the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment

Table 9.4 User Interface Engineering Standards

Our device will also follow several common-sense guidelines in the development of the user interface including:
- Containing all electronics, wires, etc. within the enclosure to abstract the device.
- A simple interface with just a few buttons and LEDs to maintain ease of use.
- Ensuring the device is as small and light as possible to enable portability.

9.5 Analytical Usability Testing

For the analytical usability testing, our team will look for any errors or nuisances with respect to the user interface. We will perform a series of tests to determine if the UI is sufficiently intuitive and functional. Any design flaws that we find will be discussed with all members before proposing fixes. Once all design changes are proposed the best design will be chosen by popular vote among the team. The tests below will be performed.

Buttons

- The power button will transition the device from off to active with a press of any length
- The power button will transition the device from active to standby with a short press (under 3 seconds)
- The power button will transition the device from active or standby to off with a long press (over 3 seconds)
- The power button will be engraved with the appropriate symbol for power to clearly indicate its purpose
- The volume + button will increase the headphone volume by 10% with a short press
- The volume + button will increase the headphone volume by 10% every 500ms that the button is held
- The volume - button will decrease the headphone volume by 10% with a short press
- The volume - button will decrease the headphone volume by 10% every 500ms that the button is held
- All buttons will have tactile and auditory feedback when pressed

LED Indicators

- The power LED will glow green if the device is in active mode
- The power LED will slowly flash amber if the device is in standby mode
- The power and error LEDs will be off if the device is powered off
- The battery LED will glow green if the battery is charging
- The battery will glow red if the battery is low
- The error LED will glow red if the software enters an error state

Camera Tilt

- The tilt wheel will turn with relative ease
- The tilt wheel is well labelled to indicate its purpose
- The tilt wheel will lock into several positions and will not move without user interaction

Battery Charging

- The charging port is well supported to ensure the port does not break or weaken over time if power cable is pushed in with "excessive" force
- The charging port is well labelled to indicate its purpose
- The charging port is easily accessible on the device, so it can be charged while in use

9.6 Empirical Usability Testing

Feedback from our target market will play a major role in the development of our device. Individuals diagnosed with ASD are sensitive to different types of stimulus. Given that our project relies heavily on real time feedback to the user, the means to convey information must be carefully selected.

The current design relies on audio messages to convey any feedback to the user. Given that users may respond differently to stimuli, alternative feedback options (such as tactile and/or visual) could be implemented after initial assessment from our target market. Throughout the development stages of our prototype, the design team will be in contact with various individuals and organizations to evaluate the state of the design and to identify any needs from the user that standard analytical tests fail to establish.

9.7 Conclusion

As a learning tool, the UI of our device is a crucial aspect of the product. The OptiCue was designed to execute all the main processing tasks without any user input, thus minimizing any unintended use. The device will be elegant, intuitive, and non-intrusive to allow the user to focus on the social situation in front of them.

At the proof of concept stage, we will merely demonstrate the processing capabilities of our system. As such, user interaction will be minimal, limited to visual and audio feedback. Our final prototype however, will fully showcase all the key features of the device. The device will allow the user to adjust the camera angle and volume of the audio feedback. The prototype will also provide visual indicators of the status of the device using LED's.

The minimal design of the OptiCue will allow users of all ages to operate the device with ease. More importantly, as an educational tool for individuals diagnosed with ASD, we have produced a device that can be easily introduced into day to day activities to complement social situations without being overly disruptive.

9.8 References

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10 Appendix C: 440 Development Plan

10.1 Introduction

Using facial detection algorithms coupled with a convolutional neural network, Aperture Solutions' OptiCue will be able to detect the facial expressions of those with whom the user is interacting using camera input. After the OptiCue has determined the expression of the subject, it will provide the user with feedback on the expression via the audio jack on the device. Using readily available components including a single-board computer, camera, buttons, and LEDs, Aperture Solutions will be able to provide a compact and intuitive device while keeping costs lows. Our team's goal is to provide a tool that is accessible to anyone who is not able to recognize social cues.

This appendix will cover the necessary background information for the OptiCue, scope of the project, risks involved and the benefits of our device. We will also provide information regarding market research and any existing competition. We will show a breakdown our team in terms of responsibility and show a timeline for 440. Lastly this appendix will give an estimate for budgetary management moving forward including any purchases made to date.

10.2 Background

According to the centre for disease control, recent studies in Asia, Europe, and North America have revealed that between 1 and 2% of the global population have been diagnosed with autism [1], this translates to a global population of 76 million individuals with autism. One of the main difficulties facing these individuals is social impairment and communication [2]. Many individuals that suffer from alexithymia (more commonly known as emotion blindness) can find social interaction quite challenging, since many of the aspects of interaction such as facial expression, body language, or tone of voice are very subtle and, therefore, can be difficult to detect or understand. The team at Aperture Solutions is committed to providing a tool to make social interaction less intimidating.

10.3 Scope

This document provides a detailed plan for the development of the final prototype for ENSC 440 over the coming months. The development plan outlines all necessary information about the project such as funding, timelines, intended market, and responsibilities for each team member.

10.4 Risks and Benefits

10.4.1 Risks:

Interprets Wrong Face

Since the OptiCue can not tell the user which face it is analysing at any given time, there is a chance that the OptiCue will be analysing the face of a person that is in the background. In this case, there may be a miscommunication between the user and the speaker, causing confusion for both parties. To minimize the probability of this occurring, the OptiCue will use both the proximity of the faces and their location in frame to determine who the user intends to communicate with.

Interprets the Wrong Emotion

The team at Aperture Solutions will try to provide users with a device that is as accurate as possible, however, because of the complexity of human interaction, there will always be some percent error involved. If the OptiCue misinterprets someone's facial expression, similar to the example above, the user will not be aware of the error and may not react appropriately to the actions of the other person. Efforts will be made to reduce the probability of a miscommunication like this, but unfortunately no guarantees can be made.

Lighting or Movement Reduce Accuracy

Because the OptiCue uses an optical sensor to detect facial expressions, lighting has a large impact on its ability to do so. In poor lighting conditions, the camera will not be able to pick up the subtle details of the face, and similarly in very high light situations, the camera image may be too bright and encounter the same problems. Also, if the speaker is moving too much, the image of their face may distort causing the OptiCue to misinterpret the expression.

Overheating

The OptiCue is a fully sealed device with no airflow over the electronic components. Because of this, the device is at risk of overheating. If the OptiCue does overheat, the device may not perform as well, and may enter a thermal protection mode where it will completely shutdown. To prevent damage to the device and injury to the user, the device automatically reduces processor speed and will shutdown if necessary.

10.4.2 Benefits

Teaching Aid

If introduced in a classroom setting, the OptiCue can help young people suffering from alexithymia to learn what key emotions look like in the facial expressions of others. Ideally, the OptiCue would be used by children who would learn the basics of communication before moving on to elementary or high school.

Limited Competition

Currently there is only one other product on the market that does what the OptiCue will be capable of. The other product on the market is an interactive application that runs on Google Glass. The application is called Empower Me and uses game mechanics to help kids with autism to learn the meaning behind basic facial expressions. Being that Google Glass is around $1500, the much cheaper OptiCue still has a large portion of the market to occupy.

Low Cost

Since all the parts used in the OptiCue are widely available and mass produced, the cost of building each unit is very low. Compared to our competitor, Empower Me, our device will be less than 15% of the cost while providing a very similar service.

Research and Innovation

Since there is not much competition in this field, it is the hope of Aperture Solutions that our innovation will push this technology forward. We hope to drive the market in a positive direction that will help youths around the world suffering from alexithymia at a minimal cost.

10.5 Market and Competition

10.5.1 Competition

The AR game called Empower Me, is OptiCue's main and sole competitor. It uses google glasses to create an augmented reality game where children learn how to recognize facial expressions. Although Empower Me provides children with a fun and interactive way to learn, the incredibly high price for a pair of Google glasses makes a commodity not everyone can afford.

10.5.2 Market

ASD is reported to occur in 1 of every 59 children, of all ethnic and socioeconomic groups [1]. On average people diagnosed with ASD spend 4-6 times more on medical expenditures [1]. The OptiCue is meant to be an affordable product for everyone, not an expensive treatment.

The OptiCue can be marketed to families for use with young people and children in their development years, as well as in schools and daycares. The OptiCue can be introduced as a form of training or therapy during these development years. The OptiCue will aid the user in identifying social cues as they occur and therefore create a constant learning environment.

Our product will be designed with inexpensive components, carefully chosen to efficiently complete a task. Therefore, the OptiCue comes at a low cost that allows us to market our product to all economic groups.

10.6 Personnel Management

This section describes the development teams for the prototype development of OptiCue.

Maggie Parkhurst-Bartel:

With a background in systems engineering, real-time embedded systems, and automation, Maggie will be a member of the software development team. She will be responsible for image processing including face and facial landmark detection, development of emotion recognition using convolutional neural network, and creating the hardware interface definition for the user interface.

Steven Lippmann:

With a background in systems engineering, real-time embedded systems, and CAD design, Steven will be a member of the hardware development team. He will be responsible for mechanical enclosure design, CAD modelling, and 3D printing. He will also assist Ricardo in the battery and audio circuit design.

Ricardo Dupouy:

With a background in electronics engineering, analog and digital circuit design, and ASIC development, Ricardo will be a member of the hardware development team. He will be responsible for the audio feedback circuit and power supply hardware.

Greyson Wang:

With a background in computer engineering and agile software development, Greyson will be a member of the software development team. He will be responsible for image processing including principal component analysis for image compression, development of emotion recognition using convolutional neural network, and the software to provide audio feedback.

10.7 Time Management

Figure 10.7.1 below shows Aperture Solutions' Gantt chart for the development of the OptiCue prototype. The timeline spans September to December and covers all important milestones.
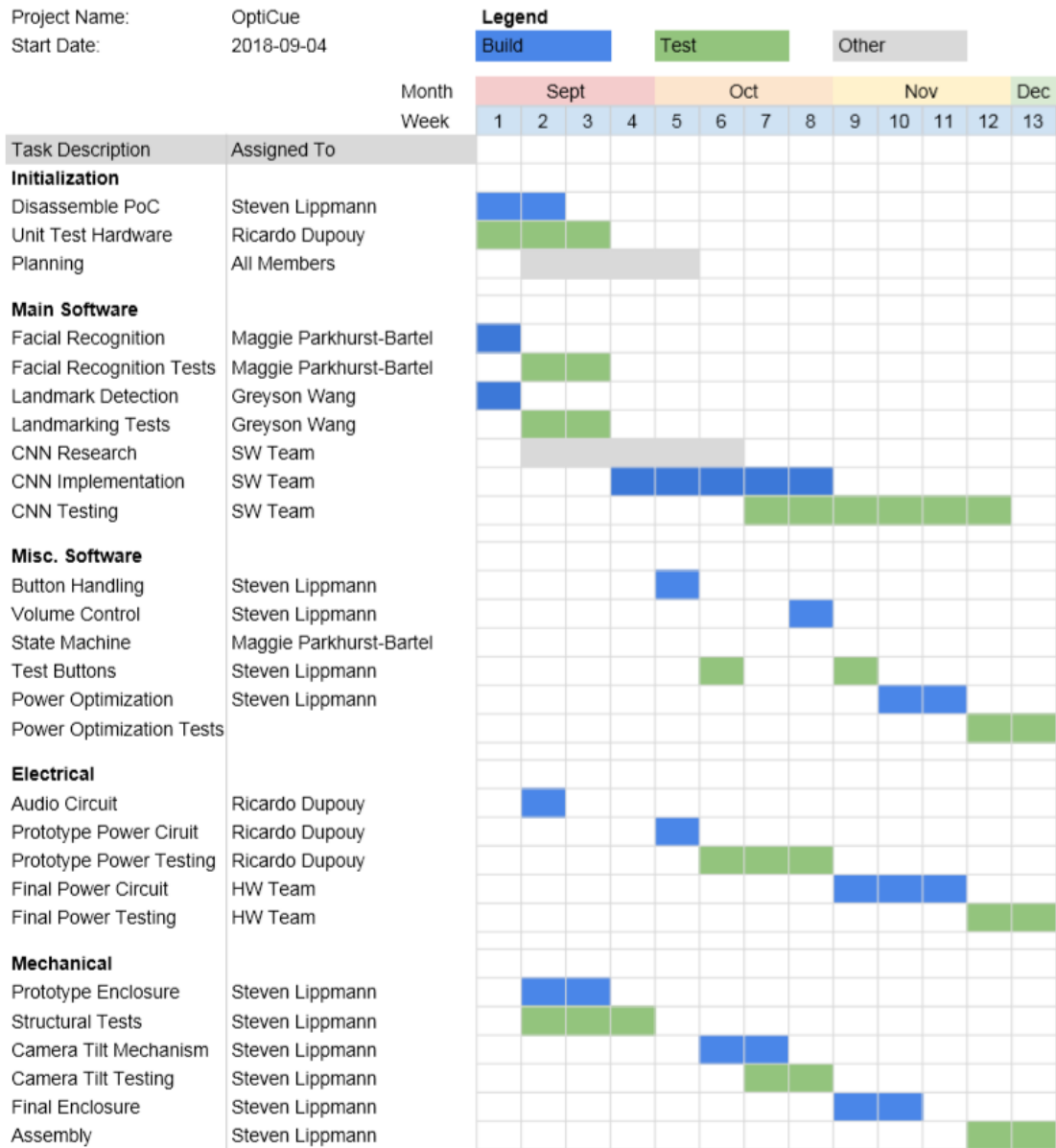
Figure 10.7.1 - Timeline for ENSC 440

10.8 Budgetary Management

At the prototyping stages of the project we expect very small costs after we have completed a proof of concept. The system requires few building blocks most of which we have purchased previously such as the Raspberry Pi Zero and other components needed. Any spending done in the prototyping phase of the project will be for smaller components such as resistors, capacitors, or small IC's that may come up in design throughout the semester.

Any spending is left to the discretion of the head of the respective design team and may be subject to review from the other department heads. Members of the team have agreed to split costs for any purchases made after unanimous approval of the company chairs.

As an affordable product the design budget for the OptiCue is small. With a readily available components and our own efficient designs we expect to meet our budgetary goals without any issues. For any large unexpected costs, the company would request funding from any available resources from the school such as the Wighton Engineering Development Fund, administered by Andrew Rawicz and the Engineering Science Student Endowment Fund.

10.9 Conclusion

The OptiCue is meant to be an educational aid, a tool to help the emotional development of those diagnosed with Autism and similar disorders. Our user-friendly, intuitive, and non-intrusive device acts as an accessory during controlled social situations, to complement the emotional development of the user.

The cost effective and efficient design make for an affordable device available to consumers from all economic groups. Aperture Solutions believes in leaving a mark, we strive to come up with solutions to real problems. With attention to detail and careful planning, we provide quality products held to the highest of standards.

As a company we look forward to the development of the OptiCue. An innovative idea that has the potential to make a difference in the lives of those diagnosed with Autism and similar disorders. The Aperture team will deliver an innovative design with a potential market viability as a consumer product.

10.10 References

[1]   N/A, "Autism Spectrum Disorder (ASD) Prevalence", 2018, [Online]. Available: https://www.cdc.gov/ncbddd/autism/data.html [Accessed 27 July 2018]

[2]   N/A, "Autism Spectrum Disorder Fact Sheet", 2017, [Online]. Available: https://www.ninds.nih.gov/Disorders/Patient-Caregiver-Education/Fact-Sheets/Autism-Spectrum-Disorder-Fact-Sheet [Accessed 27 July 2018]