Accessible Reading Material for the Visually Impaired

ECE4871 Senior Design Project

Blindle

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Executive Summary

Blindle is a portable e-reader tablet that is capable of storing reading materials in its internal memory drive and outputting them to a display containing an array of braille characters for those who are visually impaired and cannot read printed text. The system consists of four main parts: electrodes that will produce the lettering by providing stimulation where the dots are supposed to be raised, internal devices for storage, buttons to control the settings of the display and parse thru selection options, and an interface to translate text to braille and download the reading materials from. The expected manufacturing cost of the device will be $98.

Current displays that perform similar functions are not portable because of their size and are generally costly because of the tiny actuators that are used to create physical bumps in the displays. The method of using electrotactile stimulation will cut down the cost of such a reader and make them more accessible for widespread consumer use. Current research shows that electrical stimulation in the fingertips is accurate enough to pinpoint the location and number of the sensation which is key to this design [1].

A display that is able to read and output a single line of braille and toggle between lines would be considered a success for this project because it demonstrates proof of concept on a smaller scale, however the ultimate goal is to build a full sized prototype. Moving forward, replacing the removable microSD with an internal flash storage drive to prevent the possible loss of the card and allow for a cabled interface rather than moving the microSD back and forth between a computer would be the next step. In addition, further improvements could be made in a wireless interface that allows users to access libraries of books available for direct download onto the e-reader from the internet, entirely forgoing the intermediate step of connecting to a computer as well as the possibility of needing an help if audio assist unavailable.

Accessible Reading Material for the Visually Impaired

1 Introduction

Blindle is an e-reader that will use electrotactile stimulation to output the dots, or elements, of a braille display to allow visually impaired individuals easier access to reading materials. The team is requesting $98 to develop a prototype of the system.

1.1 Objective

The team will design and prototype an e-reader tablet that takes in text files which it then translates to braille and outputs to a display, where each braille character contains of six electrodes that provide stimulation rather than the physical studs typically found in braille devices. The display will be an array approximately 14 letters across and 6 letters down with a narrow bar on the left to allow for optimal location tracking on the user's end. 5 push-buttons will be utilized to go forward and backward between pages, return to the home page to select reading options, and turn the e-reader on/off. A potentiometer will be used to toggle the intensity of the electrical output. In order to place reading materials onto the reader, an application will need to be developed that allows for the downloading of text and subsequent translation into braille. Ideally, this would be done using an internet connection, however the ability to accomplish this task is outside of the current project schedule.

1.2 Motivation

There are approximately 285 million people in the world that are visually impaired, with about 39 million who are blind [2]. Braille reading materials are hard to come by and are often expensive because of the process needed to print them, which is why the system is being taught less and less to those who would need it to read [3]. Blindle hopes to provide a cheap, easy, and portable way for those who are visually impaired to access reading materials that previously would only be widely available through an audio output function.

1.3 Background

Although ideas for braille tablets do exit, Blindle hopes to take into consideration the trade offs that each of the designs have. Current braille e-reader solutions that have an array of characters are costly due to the large number of actuators within them to create the raised bumps and are often too large to be easily portable. Furthermore, these designs consume large amounts of power and often have either a short battery life or must be plugged in to remain functional.

Figure 1: Current braille tablet available from American Thermoform for $2500.

There are prototypes of smaller single character readers the size of a TV remote, however studies have shown that having only a single letter is hard to follow while reading and trying to piece together full words [4].

2 Project Description and Goals

The team intends to design a working prototype electronic braille board containing 14 braille cells laid out horizontally, with each cell containing six electrical pins capable of outputting a 1 KHz, 20V signal with a 20% duty cycle, current limited to 4mA. Each of these pins will be spaced according to the standard dimensions of a braille cell and placed in a fashion that allows braille readers to transition from reading printed braille books with minimal effort. Each of these pins will be powered via software programmed onto a microcontroller, and the device will finally be encased in a non-conductive plastic. In designing this, the team aims to effectively deliver text to visually impaired braille readers via electrical stimulation without unpleasant sensation and at a reasonably low price $98.

2.1 User Priorities

- Users should be able to read text from the device at a speed comparable to the average braille reading rate of 70-100 words per minute.
- Text should be read from the device as accurately as possible, with a reading accuracy threshold of 90% being a base requirement.
- The device should have a predicted cost no greater than ¡price¿ to prioritize user affordability.
- Braille readers should generally be capable of reading from the device with little adjustment or aid from other people.
- Reading from the device should be possible with minimal user discomfort, measurable by human trials and post-trial surveys. To quantify this, the team aims to have users report their experiences using the device, and aim for a satisfaction rating greater than 85%.

2.2 Stakeholders

In creating the device, there are a number of communities and individuals that the team aims to consider as closely as possible. The most influential and vested of these stakeholders will be our faculty advisor, Georgia Tech ECE Professor Jennifer Hasler, as well as the larger hard-of-seeing community which the device will be made for. The team aims to uphold these connections by regularly updating professor Hasler with our progress, and also by consulting local schools for some of the broader design approaches taken in the future. Additionally, while they will not have as much of a direct hand in our design process, the team will be completing this task for the ECE4781 Senior Design course at Georgia Tech and remaining in close contact with the relevant professors and TAs. Finally, we will be designing the device with intent to display our results at the engineering expo during the Spring semester, and aim any progress we made to aid the broader braille device engineering community.

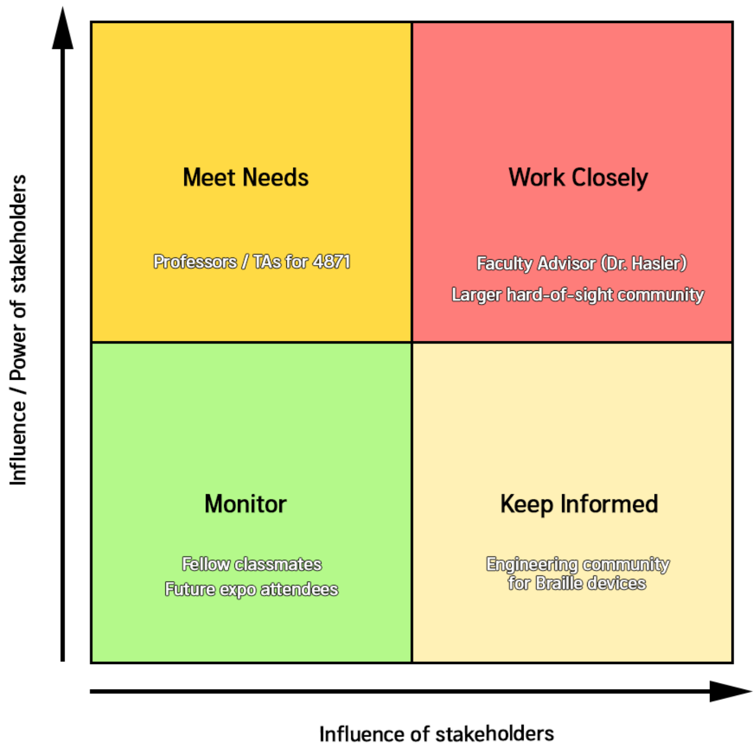

Figure 2: 2x2 Stakeholder Chart outlining the parties considered in the team's design process.

3 Technical Specifications

The three important features of the Blindle are the board dimensions, electrical signal, and electrode placement.Table 1 displays the dimension specifications for the board. Table 2 displays the the specifications of the electrical signal to be emitted to the user. Adhering to these specifications is important to ensure the electrical signal produces a comfortable sensation for the user. Table 3 displays the specifications of each braille cell. These specifications must be met for the Blindle to accurately mimic a braille interface.

Feature	**Specification**
Height	>= 7 cm
Width	>= 10 cm
Number of Buttons	6

Table 1: Contains the approximate dimensions of the board for the final product.

Feature	**Specification**
Current	< 4 ma
Voltage	20 V
Duty Cycle	20%
Frequency	1 KHz

Table 2: Contains the approximate specifications of signal emitted by the electrodes for the final product.

Number of Electrodes	6
Electrode Diameter	>= 1.4 mm
Electrode to Electrode Vertical & Horizontal Distance	>= 2.34mm
Center to Center in Adjacent Cells	>= 6.2mm
Center to Center in Adjacent Lines	>= 10mm

Table 3: Contains the approximate spacing for braille cells.

4 Design Approach and Details

4.1 Design Approach

Blindle is designed with maximum accessibility in mind, simplifying our device to include a Braille interface, five buttons and one knob. This will allow the user to seamlessly traverse any book from a digitally stored collection on demand.

4.1.1 Braille Interface

When deciding the optimal way to implement a Braille interface, much consideration was given to distinguishing Blindle from similar prototypes and products on the market. Current Braille e-readers use some combination of actuators to raise and lower elements of the Braille display, yet actuators are expensive and often burn out quite quickly, a design weakness that could be capitalized on. Blindle works by using electrodes on the board to stimulate a sensation of pressure in the user's finger. Electrotactile interaction is a field of research that governs the use of voltage and current to make the user "feel" something that isn't actually there, with applications towards technologies like virtual reality and assistance for the visually impaired [5]. Studies have shown that electrotactile interaction, when calibrated properly, is not uncomfortable for the user and can deliver the intended signal very accurately. In fact, studies have constructed a small Braille interface and reported a pleasant user experience using a 1 kHz, 20V signal with 20% duty cycle, current limited to 4mA [5]. To begin with, early prototypes of Blindle will replicate such stimulation.

Blindle's design features a board that is capable of supporting six rows of 14 characters, with each character being composed of six electrodes to represent the six dots in each Braille element. This format was chosen to mimic the way that Braille is read normally, where the reader traces the letters across the page. Although an alternative option was considered, whereby the reader would rest one finger on a pad that would change automatically with the text, a full board was selected in light of studies demonstrating that users better understood Braille when they traced the text with their finger, as Braille is traditionally understood.

4.1.2 Additional User Interface

Traditional e-readers have two buttons, one on each side of the device, that allow the reader to toggle the page. This design choice will be imitated by Blindle due to its ease of use and understanding. However, Blindle will also feature a rotary knob, located near the top of the device, for allowing the user to change the volume of the stimulation received. Similar to toggling the brightness of an LCD display, this design choice allows the user to increase the volume of the stimulation if the Braille is not easily understood and decrease the stimulation if it is in any way uncomfortable. It is unrealistic to expect every user to interact with Blindle in the same way, just as it is unrealistic to expect every seeing person to have the same brightness settings on a computer screen, so it is important to add another degree of accessibility to the product.

It is also important to note the presence of a power button, a select button and a home button. Notably, the home and select will allow the reader the ability change books whenever they feel like it, allowing for easier use. The envisioned design of the Blindle is shown in Figure 3.

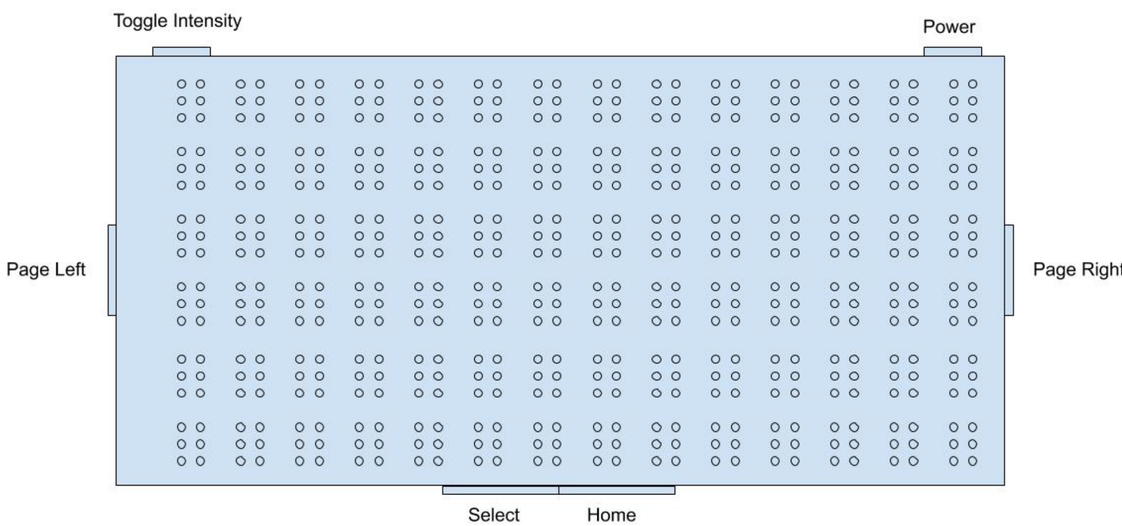

Figure 3: Roughly sketch of the Blindle, demonstrating the Braille board and the User Interface

4.1.3 Writing to Electrodes

A Braille device that contains a 6x14 array of cells with each cell containing 6 electrodes, will need to write a low or high signal to 504 electrodes. This will be handled through some basic digital logic, whereby a microcontroller will write data one cell at a time. A front end application will convert input data into the Braille format, which will then be stored on an SD card to be placed on the device. While the team considered storing the text as plaintext on the SD card, it made more sense to have the conversion be done by a front end application to save memory on the microcontroller.

Originally, it was intended that each cell would have its own state and would be updated and clocked sequentially so that the elements could be held until the next reset. However, a steady state was inconsistent with electrotactile stimulation requiring a sinusoidal current to function, making this technique impracticable without space intensive logic. Attention was also paid to how LCD screens function, but many LCD screens function on a principle of rapid refreshing to hold the state. Rapid refreshing is principally power intensive, but would also be computationally challenging to deliver a sinusoidal input to each element.

Ultimately, a technique imitating flash memory was decided upon to perform this task. Flash memory operates on the principle of a special type of depletion mode MOSFET with two gates, a "control gate" and a "floating gate" [7]. When a voltage is applied to the control gate, electrons flowing between the source and the drain tunnel through a thin oxide barrier and get trapped in the floating gate. These electrons create a strong enough field to deplete the channel and prevent current from passing through the transistor [7]. The type of transistor is depicted in Figure 4.

Blindle will sequentially write the value of each electrode by sending a digital signal from the GPIO pins of the MCU to the control gate of each element, cell by cell. This value will then be held until the next page reset, when all of the values will be overwritten by the microcontroller. This approach allows us to use a single microcontroller to program our board, saving space on the board to implement the simple logic. The only thing that remains to be planned is exactly how the sequentially updates will take place.

Each electrode will be connected to the source of a single transistor, while drain will be connected to an oscillator that will be designed and implemented on our board to operate at the 1 KHz signal frequency determined by electrotactile Braille studies to be comfortable and effective [5]. A potentiometer will connect between the oscillator and the drain to allow the user to control the

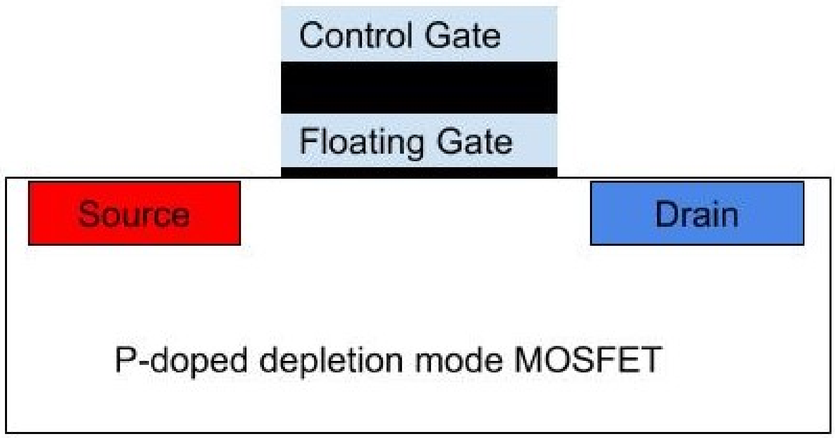

Figure 4: Diagram of transistor to be employed in holding the state of each element in the Blindle

intensity of the stimulation. It is important to remember that the current supplied to each electrode will decrease as the number of electrodes in parallel increases. While it is reasonable to assume that the number of electrodes on at any time should be normally distributed, given that there are 500 electrodes on the board, it may be valuable to change the current provided by the oscillator to keep it roughly the same given the number of elements that draw current at any one time. It is currently undetermined how this can be performed, but it is likely that a pin on the microcontroller can be reserved to control this current.

4.1.4 Internet Connection

Getting data on the e-reader will require a connection to the internet. Although it would be possible for the user to connect to the internet through the Blindle, it is important to remember that the key consideration made was easy of accessibility, and thus we require as simple of an interface as possible. Blindle itself will not be internet equipped, but will have an SD card slot allowing for the interfacing of the Blindle with any computer that has an SD card slot. This means that a visually impaired could have a seeing person assist them in downloading media, but also will be able to load books for themselves through the use of a computer that is designed for the visually impaired.

4.2 Codes and Standards

To best imitate Braille, it is important to recognize the constraints on the language. Most obviously, there are six dots per character, each either raised or flush with the medium, with each unique permutation of all six dots corresponding to a different letter, number or character [6]. Note that all six dots mean there are technically 64 possible combinations, corresponding to the 26 letters in the alphabets, numbers 0-9, different forms of punctuation, and common words (ex. and) and letter combinations and words (ex. "sh" and "but") [6]. There are multiple standards of Braille, with Blindle using the Grade 2 standard. Beyond this, Braille is also rigidly defined in size. Note, each character in Braille is referred to as a cell. The diameter of each dot should be 1.44mm, while the vertical or horizontal distance from dot to dot in the same cell should be 2.34 mm [6]. Corresponding characters in adjacent cells should be 6.2mm [6]. Likewise, the distance from center to center in adjacent cells between lines should be 10mm [6].

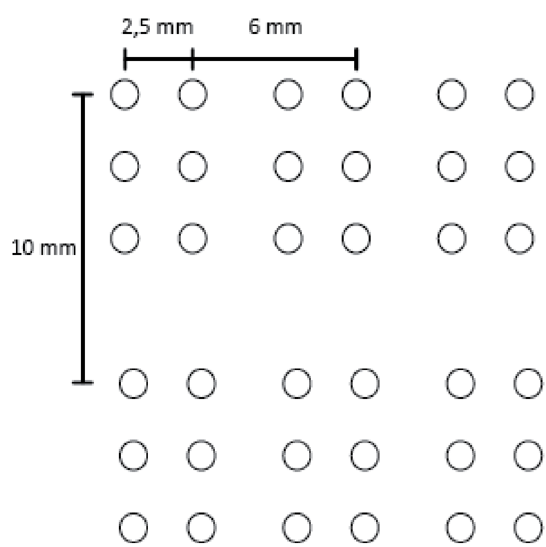

Figure 5: Spacing and size of braille cells.

To best aid the reader, Blindle has been designed with those distances in mind. With these dimensions in mind, it is possible to estimate the total width of the Blindle as being around 10cm (accounting for each of the Braille buttons as well as a margin down the side for use of another hand as guidance), and a height of roughly 7 centimeters, making this device firmly pocket sized and transportable, which was the original design goal.

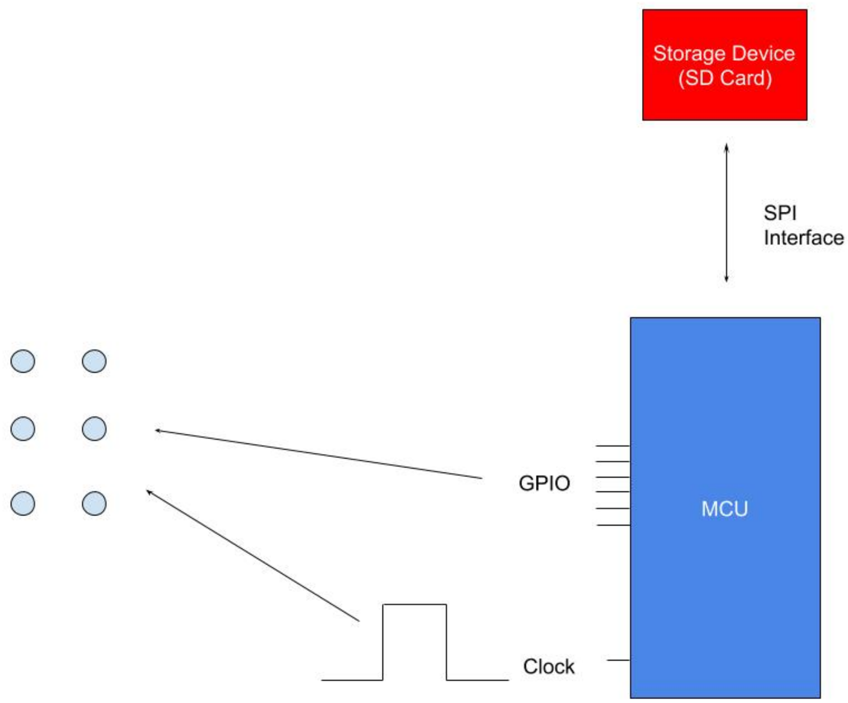

Figure 6: Interaction between the storage device, microcontroller and the electrodes in each element

4.3 Constraints, Alternatives and Tradeoffs

Blindle aims to be a portable Braille reading device that can store a library of books and output them to an electrotactile stimulation interface. The current design will require the product to take the translated library of books and output each bit from a given subset of a given book to individual board elements for the reader to interact with and learn.

One of the clearest constraints on Blindle is the size of Braille characters. Due to each character being roughly 4mm in width, it is important that the machining on the device is precise, and the electronics will need to fit in a confined space. If it is impossible to design something to fit in such a small space, it is possible to make the cells bigger. For example, Braille on signs is conspicuously larger than Braille standards mandate, indicating size is not critically important for comprehension.

It is also important to make a consideration for how Blindle will write six rows of 14 cells, with each cell containing 6 electrodes. This means that every time the page is refreshed, 504 signals will have to be written to the electrodes, with each electrode needing circuitry to hold its current state. It may be required to limit the number of electrodes on the board to avoid incurring large amounts of costs in the production of the Blindle. As mentioned before, a popular approach in similar devices is to use actuators to raise the individual pins. However, each Braille element would require four actuators, meaning that 2016 actuators would be needed for a design of this scale, unless some structure was developed to move actuators around the board. In addition, actuators have notoriously short life spans, meaning that the user would incur large costs in maintenance of the device. However, if it is found that the user cannot adequately understand the electrode interface, then it might mean that Blindle has to pivot to use some sort of mechanical device to form the Braille cells. Prototyping Blindle should not carry any major external factors. Most of the parts can be ordered from an external source, and the HIVE has great resources for printing and machining materials to construct the physical shell of the Blindle, as well as work stations for assembling the Blindle prototype. One important factor is the need for trialing of the device among actual blind individuals. The team has already contacted many different blind foundations but received no response. Future efforts will be needed to form a connection with some of these institutes to trial a product like this effectively.

4.3.1 Engineering Analyses and Experiment

Blindle is a very modular device that can be split into three major parts: The MCU, the Braille elements and the signal generator.

Oscillator

The signal generator will be easy to prototype and test. A small prototype can be constructed on a breadboard, and it will be validated if it operates at 1 KHz and the current can be adjusted. It is important to ascertain that this works first because this is fundamental to the electrotactile stimulation. While it would be possible to test the electrode interface with DC inputs and a multimeter, it is ideal to have a functional oscillator so that early tests of the electrode interface can best model how the device will actually be used.

Electrode Interface

Testing the Braille interface will be performed only after the oscillator is determined to be functional. If it can be shown that a single Braille character can be adequately controlled by a transistor described in figure 4, then the design can be scaled up to a whole cell and then a row of cells. If a row of cells functions properly, then it can be considered that the prototype of the cells works. A row of cells is considered the gold standard for efficacy because this allows for adequate determination that the interface can be programmed properly, but also allows for testing to determine if the Blindle will be fundamentally readable. If a row of cells is not readable to a visually impaired individual, then it is imperative that the design be reconsidered.

Microcontroller Integration

The last thing to be tested will be the microcontroller. If the microcontroller can program each of the elements in a cell with the correct value, then it should be assumed that the design works, and the final design, as described in this paper, can be implemented. Once there is proof that the microcontroller can program the interface, and the previous prototypes have all successfully passed, then the final Blindle will simply be a scaled up version of the prototypes described in this section.

5 Schedule, Tasks, and Milestones

Since the team aims to complete the design of the device by the end of the Fall 2020 term, the prototype will be developed and refined through the Spring 2021 term. The Gantt chart in Appendix A breaks down all of the critical tasks into a waterfall model with sequential phases for the build of each component. It also contains the team member(s) responsible for leading specific tasks, and the respective risk levels for each. The PERT chart in Appendix B decomposes the project time line further by providing detailed information about the start date, end date, and number of days allocated to a given project activity.

6 Project Demonstration

To demonstrate the functioning of this device, the team aims to hold in-person, socially distant trials involving the hard of seeing. Users will read a short, predetermined passage of a reasonable 5th grade literary complexity using the device with minimal guiding from trial conductors, verbally reporting the text they read as they go along. This will allow the team to assess how accurately and easily the user is able to read the text, as hesitations in speech or word mismatches would signal difficulty reading or reading inaccuracy.

At the conclusion of reading this passage of text, users will be surveyed regarding their overall ease and comfort using the device, and the proportions of positive responses will be considered to measure the general ease of use and discomfort in the final design. The team has set preliminary goals of 90% reading accuracy (that is, 90% of words read are read accurately on the first try) as well as proportions of 95% and 80% for user comfort and ease. If these metrics are met, this will demonstrate overwhelming ease of use, minimal discomfort and reading accuracy.

7 Marketing and Cost Analysis

7.1 Marketing Analysis

Currently there are portable braille readers which exist on the market. The Orbit Reader 20 is a portable braille display which costs $599.00 [8]. It is equipped with a 20-cell braille display which supports six and eight dot braille code in any language. There is also the Hims Smart Beetle which costs $995.00 and receives data through a Bluetooth connection. [9]. Both products display braille text via pins with actuators and have note-taking capabilities.

There are three key factors which make the Blindle unique. First, the Blindle uses electrodes in place of actuators to display braille to the user. Second, the Blindle's lack of note-taking hardware allows for more cell rows to fit on the display, thus making it a more efficient reading device than current competitors. Third, the Blindle is significantly smaller than its competitors with length and width dimensions of 10 cm by 7 cm.

7.2 Cost Analysis

The total parts costs for the Blindle comes out to an estimated $98. Table 4 provides a cost breakdown for the prototype. The costs for the PCB, Mbed Microcontroller and SanDisk 128 GB microSD are exact while the cost for the 1.5 mm Copper Wire is an estimate. Exact costs will become clear as the team moves forward with prototype development.

Product Description	**Quantity**	**Unit Price ($)**	**Total Price ($)**
PCB[10 cm x 7 cm] [10]	1	5	5
MBed LPC1768 (Cortex-M3) [11]	1	55	55
Block Single Core 1.5mm diameter Copper Wire,(electrodes) [12]	1	18	18
SanDisk 128GB Ultra microSDXC [13]	1	20	20
Total Cost			98

Table 4: Part Costs

Table 5 provides a breakdown of predicted labor hours and associated costs. Assuming the average starting salary of $65,000 per year or $32 an hour for Georgia Tech ECE graduates, the total labor cost comes out to $29,250 [14]. With accessibility and reliability being high priority attributes, it is predicted that Physical User Interface Design, and Testing/Debugging will be the most time intensive tasks.

Product Component	Labor Hours	Labor Cost ($)
Front End Application Design	30	4875
Electrode Array Design	30	4875
Micro controller and Flash Memory Implementation	20	3250
Physical User Interface Design	40	6500
Testing and Debugging	40	6500
Deliverables	10	1625
Group Meeting	10	1625
Total	180	29250

Table 5: Labor Costs

Total Development costs are estimated to be $83870. This is calculated assuming fringe benefits of 30% and overhead of 120%. A breakdown of the development costs are found in Table 6 below.

Development Component	Cost ($)
Parts	98
Labor	29250
Fringe Benefits, % of labor	8775
Subtotal	38123
Overhead, % of Material Labor, & Fringe Benefits	45747
Total	83870

Table 6: Development Costs

Blindle production will consist of 5,000 units sold over a five year period at a price of $619 with a profit margin of $50 per unit Thus, over the five year period will generate $250,000 in revenue. Technical associates will be hired to assemble and test each unit at $30 dollars per hour with 30% fringe benefits and 120% overhead. Sales expenses will make up 5% of selling costs at $30. At $619 per unit, the expected revenue is $3,095,000 with a profit of $50 per sale. Table 7 provides a breakdown of the costs for an individual unit.

Expense or Income Component	Cost ($)
Parts	98
Assembly Labor	20
Testing Labor	10
Total Labor	30
Fringe Benefits, % of Labor	9
Subtotal	167
Overhead, % of Material, Labor, & Fringe Benefits	200
Subtotal, Input Costs	534
Sales Expense	30
Amortized Development Costs	5
Subtotal, All Costs	569
Profit	50
Selling Price	619

Table 7: Selling Price and Profit Per Unit (Based on 5,000 unit production)

8 Current Status

In order for the Blindle team to move forward with the implementation of the device, further research into the field of electrotactile stimulation is needed to help determine the best design approach for the dimensions of the aforementioned Braille display. This is because from the data found thus far, the voltage levels required to comfortably deliver an accurate signal to a user are unrealistically high for any type of portable device.

Since the interface is the Blindle's most important feature, the team will be prioritizing the design of the electrode array until the end of the Fall 2020 term. The order for the various parts and components of the prototype is to be placed once a clear and detailed design of the display has been established so that implementation can begin at the start of the spring term.

9 Leadership Roles

Team Leader → **Annie Luo** : Assigns and coordinates work between team members and advisors to make sure deadlines are properly met and work is done to the highest quality.

Documentation Coordinator → **Jordan Altaffer** : Summarizes all research findings into single library for easy access by the team.

Expo Coordinator → **Emmy Perez** : Coordinates any plans related to presentation and display for the required spring expo.

Webmaster → **Annie Luo** : Updates the project website to keep recent findings and work available.

Hardware Lead → **Dimitry Jean-Laurent** : Delegates hardware work that the project may require.

Design and Validation Lead → **Emmy Perez** : Delegates work pertaining to the product design and checking that all components are working.

Software Lead → **Cameron Davis** : Delegates software work that the project may require.

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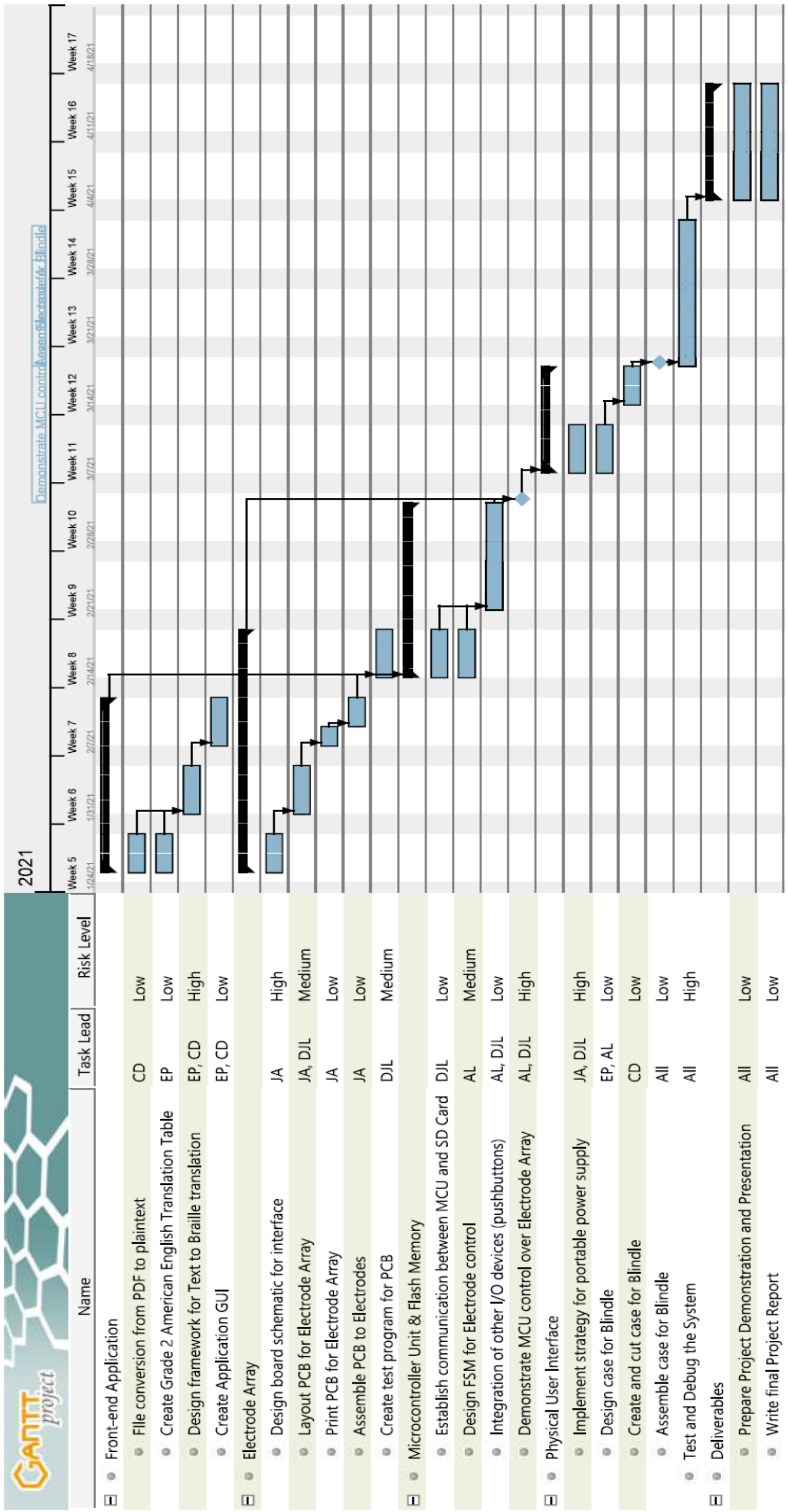
Appendix A - Project Gantt Chart



Appendix B - Project PERT Chart