Accessible Reading Material for the Visually Impaired

ECE4871 Senior Design Project

Blindle

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Executive Summary

Globally, there are 250 million visually impaired people, of which 40 million are blind. While these individuals can consume written media through Braille characters, current options are cost prohibitive and space intensive. Analogous to the invention of the Kindle and other "e-readers" in the last two decades, Blindle seeks to provide an affordable, portable and enjoyable reading experience by storing a library of books in Braille and allowing the consumer the flexibility and convenience to read whatever material they want.

While current e-readers for the visually impaired are commercially available or in the development pipeline, these solutions are often expensive, unwieldy, difficult to understand and not particularly durable. Conventional models use actuators, which are electromechanical devices that raise and lower pins, to simulate Braille cells. Blindle attempts to distinguish itself from these solutions by using electrotactile stimulation to simulate the sensation of the dots on a Braille pad using a small, safe amount of electricity.

Blindle's new take on e-reading is still in its nascent stage but has already demonstrated its potential to deliver an effective solution. Experiments conducted by the team have yielded promising results about an individual's ability to distinguish different sensation patterns presented by multiple electrodes that presented 70V of contact voltage, demonstrating viability for reading Braille characters on the pad.

Moreover, Blindle is far more affordable than its competitors, with a predicted final manufacturing cost of roughly $300. While a retail price has not been set yet, this manufacturing price allows for a market price that compares favorably to the $600 cost of alternative e-readers.

While work still needs to be done to condense Blindle into a smaller package and thus fit more Braille cells onto the display, this is a viable prototype in its current form. Although the high voltage nature of this device yields challenges in producing a compact solution, these are workable parameters for designing a good product.

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 $1500 to develop a prototype of the system.

1.1 Objective

Blindle was originally designed to provide a cost-effective, portable and durable device to store and translate a library of reading materials into Braille, a format that visually impaired individuals can interpret. In other words, Blindle is analogous to an e-reader for the visually impaired. While current options for similar e-readers exist either commercially or in the development pipeline [15], these approaches are some combination of unwieldy, expensive and fragile as a result of being produced using actuators and other electromechanical means of raising and lowering pins to write Braille characters to a pad. To distinguish itself from these other options, Blindle was designed to make use of electrotactile stimulation to simulate Braille cells: By introducing a small section of human skin to a contact voltage, a small amount of current will flow into the body and stimulate the user's nerve cells, generating a slight tingling or stinging sensation in the finger. This approach has been explored and shown to be viable in other publications [5]. In addition to the cutting-edge electrotactile stimulation system, Blindle is also designed to interface with a front-end web application that can convert PDFs into a text format for storage on the device. This is the main interface for loading reading materials onto the board, and is the only step of the process that requires external assistance from either a visually abled person or a specialized computer for the visually impaired.

Further work would look at combining the two prototypes into a single 6 by 14 braille cell display with a narrow bar on the left to allow for optimal location tracking on the user's end as well as adding 5 push-buttons to go forward and backward between pages, return to the home page to select reading options, and turn the e-reader on/off and a potentiometer 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 with text-to-audio capabilities.

The driving force behind the Blindle project is the ability to empower the visually impaired by providing a portable product for convenient and easy reading in a diverse variety of environments. By providing an entire library of books to the blind, a service that most individuals take for granted, Blindle is improving accessibility and helping a large section of the global community that often goes unseen.

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]. Existing braille e-readers that implement mechanical actuators to raise the braille lettering are often delicate and comes at a high cost, both initially and for repairs. 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 exist, Blindle hopes to take into consideration the trade offs that each of the designs have.

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

There are three types of braille e-readers that currently exist, all of which contain mechanical actuators that contribute to a high cost and very high maintenance requirements for the device. A multiple line, multiple character display is the easiest to use, however it is not a portable option due to the delicacy of the actuators and the inability to easily repair individual components. Smaller, more portable devices that are a single character or eight character display are cheaper options but are harder to comprehend by the user due to the fragmented nature of the display.

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, Customer Specifications, and Goals

The team has developed two separate prototypes: one to demonstrate the hardware and one to demonstrate the software. Ultimately the two aspects were split to better manage the project timeline and hardware challenges were limiting the ability to perform software tests. The hardware prototype consists of a single Braille cell that can be charged and discharged to the voltage levels empirically established by the team for electrotactile stimulation. While a larger 2 by 4 model was designed and fabricated as a printed circuit board, it was not received in time for assembly before expo.The software prototype is a 2 by 4 braille cell array made with LEDs that uses logic level voltages and integrated circuits to depict where the display would be outputting to. This prototype handles the translating of a .txt file to braille through the use of a lookup table and combines the smaller 3 by 2 boolean arrays, one indicative of a node and zero of nothing, into a larger array to be displayed. Through the use of the SD card reader, text files were able to be stored and then read by the software and a button allowed the pagination of the text.

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 $300 to prioritize user affordability.
- The device should be easily portable with a long battery life to allow accessibility when the user pleases.
- 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 were 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 upheld the former of these connections by regularly updating professor Hasler with our progress, however while attempts were made to contact schools for the hard of seeing, none were able to participate in any final testing process. As such, we tested our signals using the group members for this project. Additionally, while they did not have as much of a direct hand in our design process, the team completed this task for the ECE4781/2 Senior Design course at Georgia Tech. The team developed two prototypical devices for the purpose of displaying the engineered functionality of the device as well, with both prototypes being used as demos in our final presentation for Capstone Design Expo.

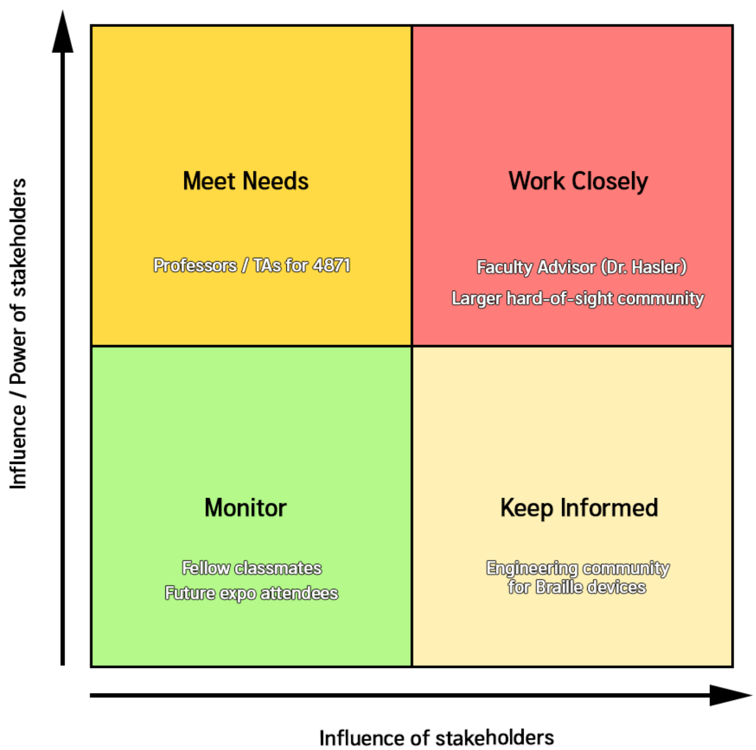

Figure 2: 2x2 Stakeholder Chart outlining the parties considered in the team's design process.

2.3 Constraints

Although electrotactile stimulation is effective in accuracy of the sensation, the idea of getting shocked at high voltage levels in order to read might dissuade users and the potential lawsuits that might occur if the shock were to get too strong are things to consider when marketing and development. It is critical that Blindle comes up with ways to mitigate potential threats to user safety, such as interacting with the pad with an exposed wound or using in a wet environment. To address this, we did extensive testing on sensation with regards to the electrodes on each of our group members and added a potentiometer to control the strength of the device's output signals. Higher conductivity due to finger wetness or other abnormalities, however, are still cases that need to be addressed properly.

3 Technical Specifications and Verification

The three important features of the Blindle are the board dimensions, electrical signal, and electrode placement.Table 1 displays the dimension specifications for the ideal final board. Table 2 displays the specifications of the electrical signal to be emitted to the user through the electrotactile stimulation. 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.

Feature	Specification	Measured
Height	<= 8 cm	9 cm
Width	<= 11 cm	15 cm
Buttons	5	1
Potentiometers	1	0
SD Card Readers	1	1

Table 1: Contains the specified dimensions of the board for the final product and the measured dimensions.

Feature	Specification	Measured
Current	< 4 ma	Varies By Stimulation
Voltage	60 – 100 V	72 V
Duty Cycle	20	100%
Frequency	1 KHz	0 Hz (DC)

Table 2: Contains the approximate specifications of signal emitted by the electrodes for the final product and the measured values of 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 was designed with maximum accessibility in mind, simplifying our device to include a Braille interface, five buttons and one knob. This final goal will allow the user to seamlessly traverse any book from a digitally stored collection on demand and control the level of sensation that they feel. Currently, the functionality is greatly limited as it is broken into two prototypes, but we believe that it is possible to still reach this performance.

4.1.1 Electrotactile Stimulation

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 quickly, a design weakness that could be iterated 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].

One of the first steps in the design process was for the team to either experimentally corroborate these results or find a stimulation technique that was more effective. The above research was tested using a function generator, outputting a 1Khz, 20V signal with a 20% duty cycle, but no members of the team reported any sensation at this voltage. Ultimately research was able to identify a voltage range where stimulation was uncomfortable. The results of our research are briefly summarized in Table 4 and Table 5.

The current Braille hardware prototype is capable of supplying stimulation on the magnitude of 70V to the user for sensation purposes.

Stimulation Voltage	Individual 1	Individual 2	Individual 3
50V	No Sensation	No Sensation	No Sensation
55V	No Sensation	No Sensation	No Sensation
60V	No Sensation	No Sensation	No Sensation
65V	Slight Tingle	No Sensation	No Sensation
70V	Slight Tingle	Slight Tingle	No Sensation
75V	Slight String	Slight Tingle	No Sensation
80V	Uncomfortable	Slight Sting	Slight Sting
85V	Stopped Testing	Uncomfortable	Slight Sting
90V	Stopped Testing	Stopped Testing	Slight Sting
95V	Stopped Testing	Stopped Testing	Slight Sting
100V	Stopped Testing	Stopped Testing	Slight Sting

Table 4: Experimental results for identifying acceptable Braille stimulation levels at DC .

Trial Number	Interpretation	Comments
Trial 1	Correct	Knew instantly
Trial 2	Correct	Knew instantly
Trial 3	Correct	Took a moment
Trial 4	Correct	Correctly Identified but second guessed
Trial 5	Incorrect	Correctly identified that only one cell was active but picked wrong one

Table 5: Experiment results of identifying stimulation patterns with two Braille cells powered to 70V.

4.1.2 Braille Interface

Blindle's current prototype design features a board that is capable of supporting two rows of four characters, with each character being composed of six electrodes to represent the six dots in each Braille element. This format was chosen to strike a balance between between the way that Braille is read normally, where the reader traces the letters across the page while using one hand to identify a starting point for the reading row, and keeping a compact design. These characters use stimulation on the range of 60 to 100VDC, as chosen by the user, to depict the text. Ultimately, the team wants to scale this size up to a full board of six rows and 14 columns.

4.1.3 Additional User Interface

Traditional e-readers have two buttons, one on each side of the device, that allow the reader to toggle the page. We transferred this design to the blindle via a 'scroll' button that the reader can press to advance in the text, however an extra back scroll button would need to be added to a finalized product. Implementation of this should be somewhat trivial as the forward scroll feature is already fully functional. Blindle also features a rotary knob located near the top of the device for allowing the user to change the strength of the stimulation received. Similar to toggling the brightness of an LCD display, this design choice allows the user to strengthen the signal if the Braille is not easily understood and soften 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 allows 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.

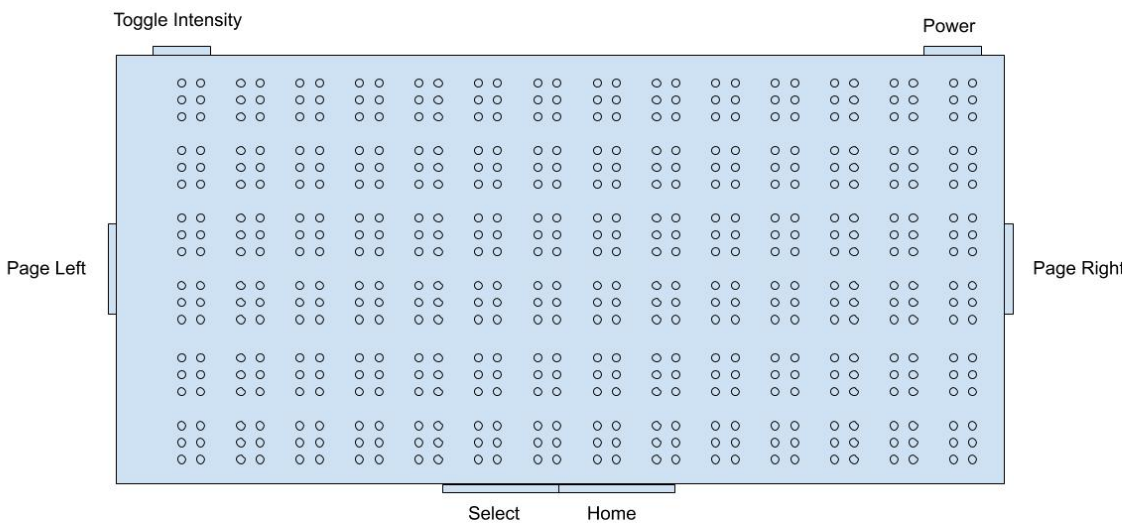

Figure 3: Roughly sketch of the Blindle, demonstrating the Braille board and the User Interface

4.1.4 Writing to Electrodes

Our prototype is a Braille device that contains a 2x4 array of cells with each cell containing 6 electrodes will need to supply power to maximum of 48 electrodes. These 48 electrodes exist on the intersection of the lines of a crosspower array, as shown in Figure 4.

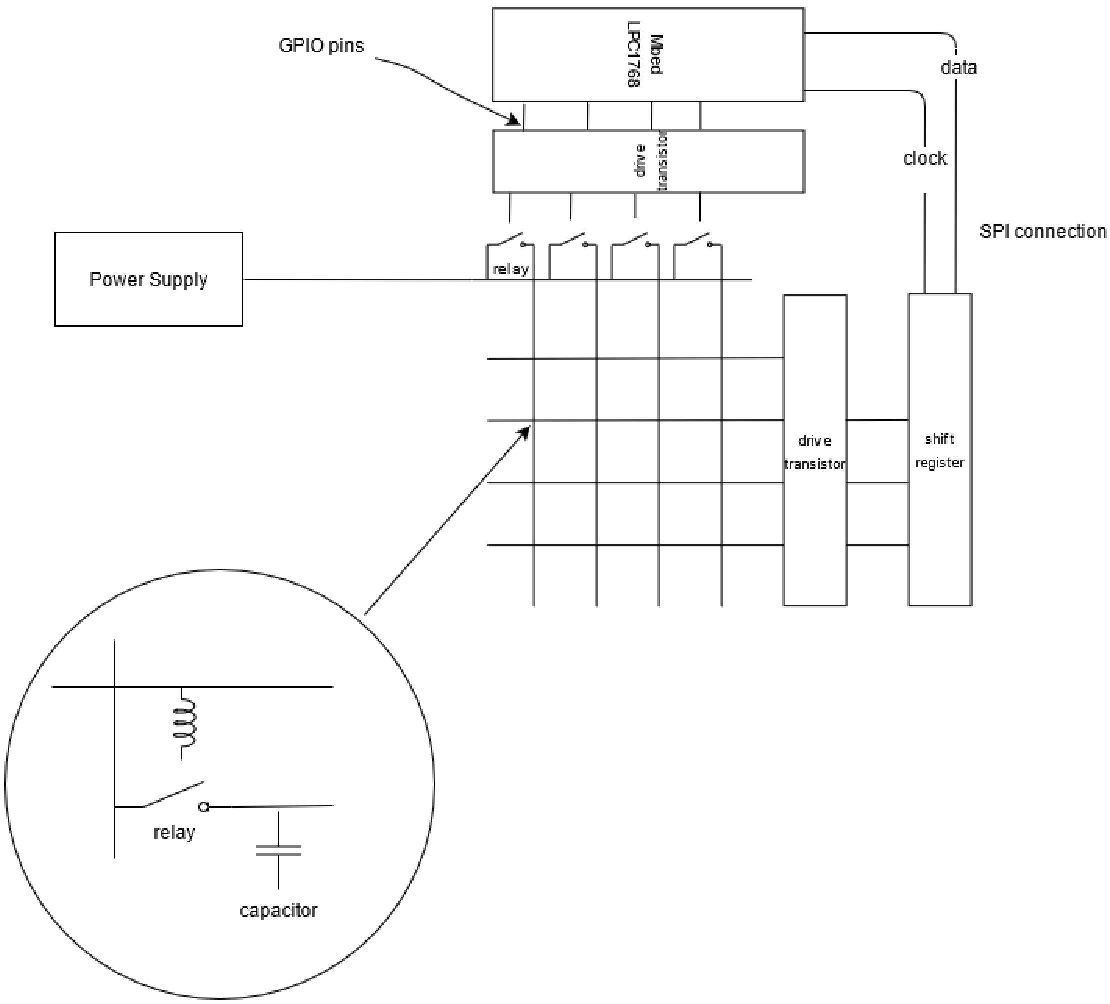

Figure 4: Sketch of the crosspower array used for charging the capacitors in the Braille pad.

In the crosspower array, the GPIO pins of the microcontroller control the column relays. By outputting a signal from the GPIO pins to the close the relays, each column of the cross power array that receives a high signal will close, powering the entire column. In a 2x4 Braille cell array where each cell is made of 3x2 Braille elements, this translates to 8 columns. It is important to recognize that the GPIO pins do not have enough current to close the relay, so driver Bipolar Junction transistors are used to amplify the current from the microcontroller and close the relay.

Simultaneously a high signal is loaded into the shift register, corresponding to the first row of the array, or the first row of individual Braille elements. In a 2x4 Braille cell array, made of 3x2 element Braille cells, will have 6 rows. The signal in the shift register is then shifted through all of the outputs, which will sequentially close all of the relays in a given row. If a relay is in a column that has a closed column relay, power can then flow from the power supply to the node and charge the capacitor on that node. Once the capacitor charges and the row relay opens again, that capacitor will remained charged until it is discharged into the readers hand.

A potentiometer will connect between the oscillator and the drain to allow the user to control the 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.

4.1.5 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 or text-to-audio translation

. A front end application that we developed can convert input data into the Braille format, which can 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.

4.2 Design Concept Ideation, Constraints, Alternatives, and Tradeoffs

The first discussion for the Braille pad was how the team wanted to display the text to the user. Initially the team considered two options: One where a full board was constructed, containing six rows of 14 columns, and one where the reader would rest one finger on a pad that would change automatically with the text. The team initially wanted a full board in light of studies demonstrating that users better understood Braille when they traced the text with their finger, as Braille is traditionally understood. However, due to space considerations and bulky nature of the components used in the board, this approach was scrapped and a small board of 2 rows of four elements was introduced instead.

Initially, the team began with two designs for the signal select. One idea hinged around using demultiplexers to feed "AND" gates, allowing for the microcontroller to sequentially select a row and a column and write a value to that spot. The other idea functioned very similar to how an LCD screen works [16], where a transistor array is controlled by a data bus to write values to each individual cell in the Braille pad. In both cases, this value would toggle an oscillator on or off, meaning that the stimulation could be precisely controlled. The output voltage of the oscillator would then be amplified by a compact amplifier, likely a CMOS inverter.

While the results in Tables 4 and 5 did confirm that electrotactile stimulation was possible, with the second study demonstrating an 80% pattern recognition at a less sensitive voltage, the high voltage requirements force the team to reconsider some design aspects.

For one, the high voltage requirement made it very challenging to produce a small, compact amplifier that provides variable output and produces a peak-to-peak voltage in excess of 60V. This led to the team pivoting from toggling oscillators to sequentially charging capacitors. By charging these capacitors to high voltages, small amounts of charge could be locally introduced into the users skin to stimulate the nerve cells. The charging of these capacitors was performed by the signal select system.

Because of the high voltages present in the charging process, the demultiplexer signal select idea was no longer practical. Logic level chips would not be able to control a signal as large as 60V DC, as these components are usually rated for no more than 10V. Likewise, a microcontroller would not be able to output a signal at such a large potential. This led to the team pivoting to focusing on the transistor array.

The design process struggled to create an array that used two cascaded transistors to control power in the range of 60-100V, however. The team experienced issues with having a load increase in voltage as the capacitor charged, and also being able to drive up the gate voltage to switch off the transistor if the source was exceeded 80V. Given these difficulties, the team switched to using relays. It is worth noting that the team had a third idea for signal select initially that ultimately received little attention.

A technique imitating flash memory was discussed to function as a form of signal select. 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 voltage is applied to the control gate, electrons flow in 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 5.

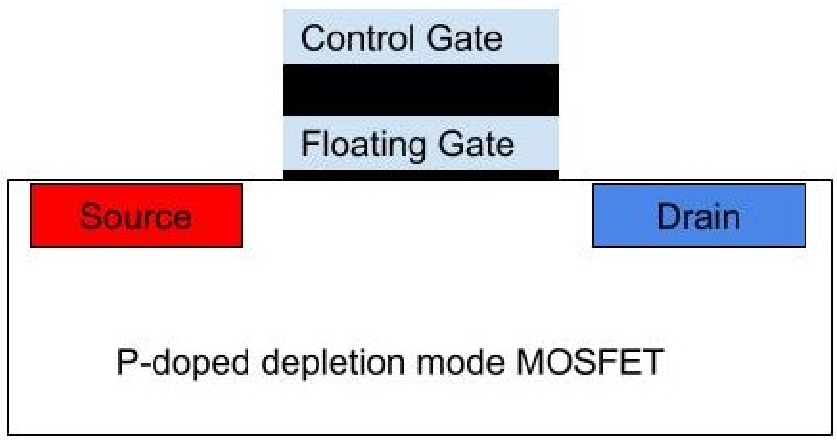

Figure 5: Diagram of transistor to be employed in holding the state of each element in the Blindle

It was thought that the signal select algorithm could either open or close the channel of these special transistors, which would allow for the distribution of an AC or a DC signal. However, this approach was scrapped due to these floating gate transistors not being commercially available. 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 requires the product to take the translated library of books and output a subset of text from a given book to individual board elements for the reader to interact with.

While the team initially suspected that the major constraint on Blindle's dimensions was the size of Braille characters, our experimentation found that the greatest design constraint was the size of the relays. Each Braille character is roughly 4mm in width, but the relays used by the team are closer to 1cm in width. This means that these dimensions, as well as the dimensions of the other components, will require far more space than the Braille itself. Making the cells bigger to avoid extra space was discussed by the team, but, even though this approach is at times taken in everyday braille signage, we opted to remain consistent with Braille standards.

Due to the small size of each Braille cell, it is very important that the machining is precise to ensure the dimensions are to standard. It is desirable for the product to be as accessible as possible, so uniformity in size is vital.

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. Additionally, these actuators tend to be prone to malfunctioning and wear down over time, which means that they need to be replaced somewhat frequently (if not the entire braille board). While we initially considered these ideas as backups if the electrotactile stimulation did not work out, we had enough confidence in our results to continue using this method as a superior design to competing ideas.

4.3 Codes and Standards

To best imitate Braille, it is important to recognize the constraints on the language. Most importantly, 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 six dots mean there are technically 64 possible combinations, corresponding to the 26 letters in the alphabet, numbers 0-9, different forms of punctuation, as well as common words and letter combinations(ex. "sh" and "but") [6]. There are multiple standards of Braille, with Blindle using the Grade 2 standard, which directly transcribes each individual alphabetic character in a text to braille individually. 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].

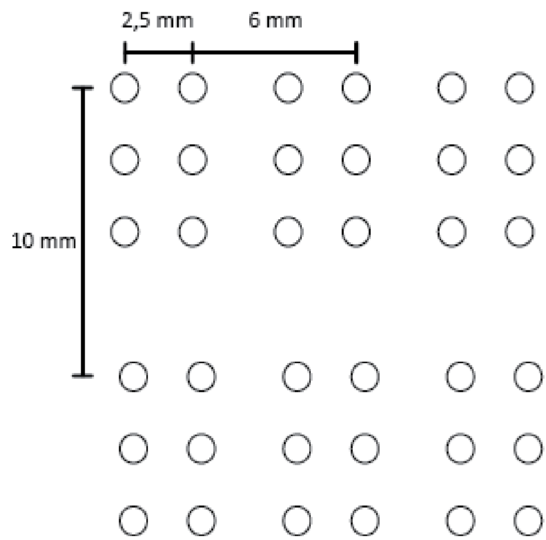

Figure 6: Spacing and size of braille cells.

To best aid the reader, Blindle has been designed with those distances in mind. Originally, we had used these standards to estimate the total width of the a pad of 500 cells 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. In practice, the control circuitry was very large, meaning that the limiting factor for size is not the Braille, but the hardware.

5 Project Demonstration

Initially, the team devised a single blind testing scheme where one individual would only charge certain electrodes of the Braille cell, and the other user would have to touch the pads in the cell and determine which pattern was presented. These tests were conducted at 70V, and the user was able to identify the correct pattern 80% of the time, while mistakes in evaluation usually came down to not knowing exactly where the stimulation was coming from.

The team had also aimed to hold in-person, socially distant trials involving the hard of seeing, however time constraints did not permit such experimentation. Schools for the hard of seeing were reached out to, however none were able to participate in out planned experiment at this time.

6 Marketing and Cost Analysis

6.1 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.

6.2 Cost Analysis

The total parts costs for the Blindle comes out to an estimated $240. Table 6 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[15 in x 9 in] [10]	1	60	60
LPC1768 [11]	1	20	20
Board Components	1	140	140
SanDisk 128GB Ultra microSDXC [13]	1	20	20
Total Cost			240

Table 6: Part Costs

Table 7 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 7: Labor Costs

Total Development costs are estimated to be $84225. This is calculated assuming fringe benefits of 30% and overhead of 120%. A breakdown of the development costs are found in Table 8 below.

Development Component	Cost ($)
Parts	240
Labor	29250
Fringe Benefits, % of labor	8775
Subtotal	38123
Overhead, % of Material Labor, & Fringe Benefits	45747
Total	84225

Table 8: Development Costs

Expense or Income Component	Cost ($)
Parts	240
Assembly Labor	20
Testing Labor	10
Total Labor	30
Fringe Benefits, % of Labor	9
Subtotal	344
Overhead, % of Material, Labor, & Fringe Benefits	413
Subtotal, Input Costs	757
Sales Expense	30
Amortized Development Costs	5
Subtotal, All Costs	792
Profit	50
Selling Price	842

Table 9: Selling Price and Profit Per Unit (Based on 5,000 unit production)

Theoretical Blindle production could consist of 5,000 units sold over a five year period at a price of $842 with a profit margin of $50 per unit Thus, over the five year period would generate $250,000 in profits. Technical associates would 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 $842 per unit, the expected revenue is $4,210,000 with a profit of $50 per sale. Table 9 provides a breakdown of the costs for an individual unit.

This cost is slightly above what we would like to produce Blindle for, however we also understand that as the demand for the product were to increase then the selling price could also be adjusted.

7 Conclusion and Current Status

The Blindle project, while intellectually stimulating and exciting, was not without several challenges. While a general product idea was fleshed out as early as November 2020, and research into how to transform small battery voltages into large potentials to be presented to the user through pads continued throughout December and early January, the team entered late January with little technical planning completed. There was no knowledge of what voltage levels were actually required for this project, aside from anecdotal readings and studies, no ideas for how to actually produce the stimulation, and no plan for controlling this large power and selecting which signals would presented to the user. The first ideal change to be made would be to have identified the necessary contact stimulation for voltages as far back as November. This was a key blunder on the behalf of the team.

When testing for stimulation intensity was occurring, testing of various methods for producing stimulation was also ongoing. This resulted in a strange situation where the team was unable to determine if the stimulation was not strong enough or the method of delivering power was not effective and caused significant delays until these topics were addressed separately. In retrospect, it made a lot more sense to divide this testing and it would have been better had this necessary division occurred earlier.

Lastly, the team had difficulties with time management due to issues formulating ideas on how to move forward with the aspect of the signal select and spent way too long trying to work through the problems rather than moving forward with testing.

Still, the team came a long way over the course of this semester. Ultimately, Blindle became two separate prototypes, one to test the hardware feasibility of the design and one for the software feasibility. Despite also undergoing a lengthy design process that culminated in fabricated printed circuit boards, our final demonstration ultimately was performed on a solderless breadboard due to delays in the shipping process.

The hardware prototype demonstrated the ability to charge the capacitors in a single Braille cell to a high enough voltage for electrotactile stimulation, as well as discharge when completed. This voltage could then be interpreted by the reader and a pattern could be discerned.

The software prototype demonstrated the ability to store reading data and program this data onto a 4x2 pad of Braille cells. This prototype also including the ability to paginated the data.

Perhaps most disappointingly, this project was mere days from completion. Perhaps another week before expo would have allowed for the integration of the hardware and software prototypes, as well as the completion of the final printed circuit board. Regardless, Blindle is a project full of potential that this team has barely scratched the surface on, and would be a great project for future engineers to pick up and run with to help build an affordable and enjoyable e-reader experience for the visually impaired.

8 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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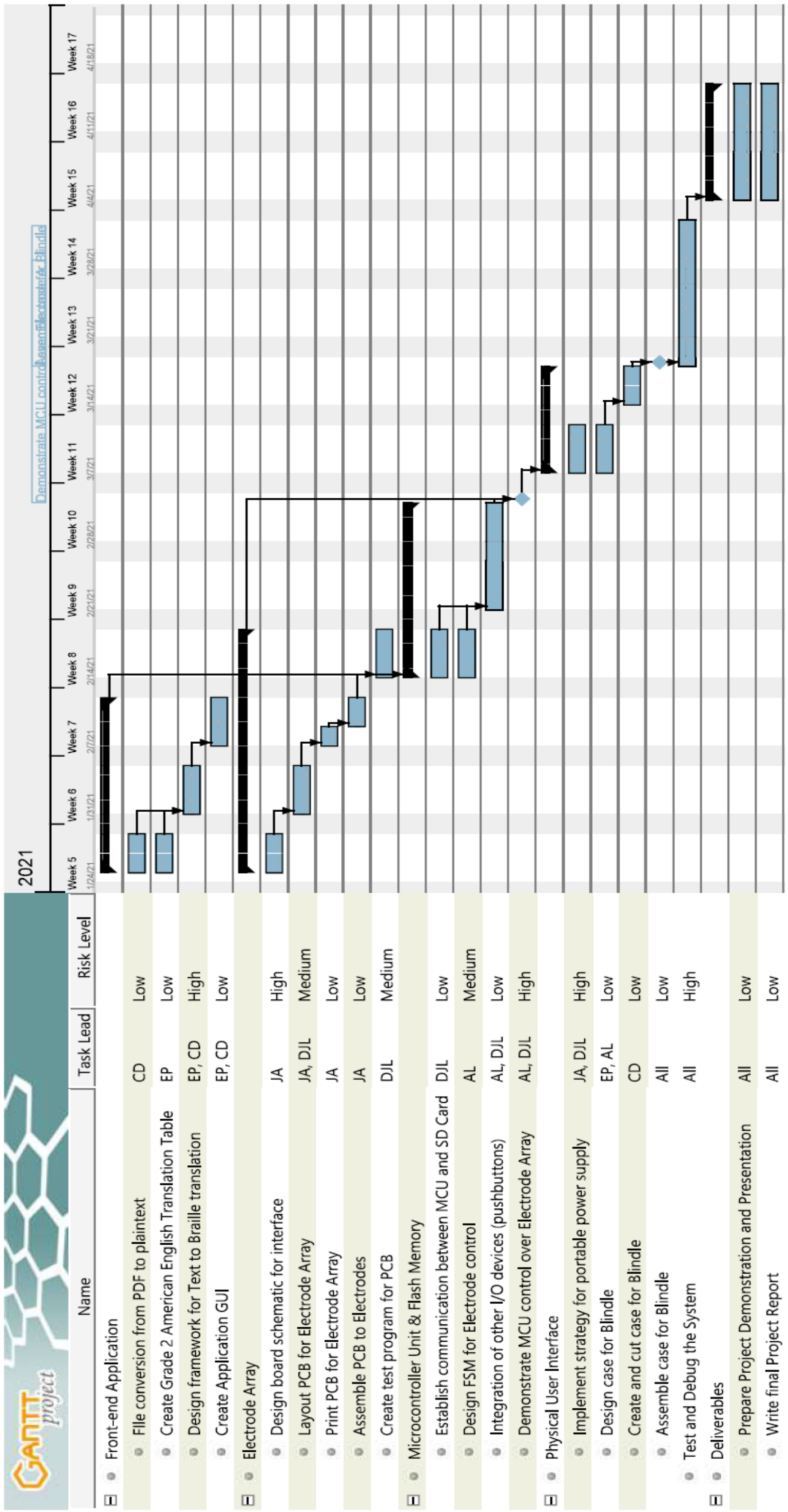
Appendix A - Project Gantt Chart



Appendix B - Project PERT Chart