Final Report

Team 16: Text2Touch

ENGR 340

Professor Tubergen

20 April 2023

Executive Overview

Each year 75,000 people lose all or part of their vision.[1] Despite this reality, only ten percent of the 1.3 million people who are legally blind in the United States read braille.[2] These statistics outline a braille literacy crisis occurring the United States. According to the National Federation of the Blind, "seventy percent of blind adults are unemployed, and as many as half of blind high school students drop out of high school." Limited access to braille reading materials and printing methods is a contributing factor to these statistics and this is largely due to the heavy cost burden associated with current braille printers. Although braille may seem less important due to computer voice guidance and other accessibility technologies, "eighty-nine percent of teachers of blind students agree that technology should be used as supplement to braille rather than as a replacement."[3] The ability to read braille provides many benefits that are not met using audio technology, including the development of areas of the brain involved with sight. We designed a braille printer with affordability and usability as our highest priority to fulfill a need in the visually impaired community.

[1] National Federation of the Blind
[2] Ibid
[3] Ibid

Table of Contents

Tables and Figures

1. Introduction to the Project

The ability to print and read documents quickly and easily is a luxury that many people overlook. We recognize that those with visual disabilities do not have this ability as readily accessible, due to cost and rarity of braille resources. Currently, braille printers are still very expensive and only located in a few of libraries. According to a study that investigated access to accommodations for visually impaired users in public libraries, there is a “clear lack of digital resources and assistive technology in serving disabled/blind users in both libraries”.[4] In fact, there is only one publicly available braille printer in Grand Rapids, located at the Wyoming Public Library. The cost of braille printers is also a major barrier for people seeking a personal braille printer for home use because one third of all blind men and one half of blind women in the United States live in poverty.[5]

In the United States, there are currently 1.3 million legally blind people.[6] While only a fraction of this population currently reads braille, we recognize the importance of learning and reading braille and want this technology to be obtainable for all individuals who would benefit. Braille is a writing system composed of raised dots on a page in a two by six pattern to form letters, numbers, and punctuation felt and transcribed by the fingertips. For those with visual disabilities, learning braille is equivalent to learning to read and write. The positive implications on the brain that result from an individual learning to read have been studied for centuries. Likewise, tactile reading using braille has a multitude of positive effects on the developing brain. Although audio guidance is an extremely resourceful tool for the visually impaired, it does not utilize and promote brain activity in the same manner that reading a language does. Tactile reading also allows blind or partially sighted people with a tool to “access information, education and culture.”[7] Furthermore, studies have concluded that “those who learned to read using braille were more employable than those who were not”.[8] Due to the countless positive implications of braille, there is a place in the market for a product that will allow tactile reading to flourish with affordability at

[4] Abutayeh et al.
[5] National Center for Policy Research for Women and Families
[6] National Eye Institute
[7] Marcet et al. 2016
[8] Apurva et al.

the forefront of design. We are looking to meet the needs of the blind community as a whole, while simultaneously focusing on the user and their individual needs.

Our project expands on some ideas of a previous senior design team. While we took a different approach to the solution, we took into consideration some ideas and information gathered from the previous team's work. As a result, we designed and built an affordable braille printer with the intention of it being sold and consumed to be used in the home, at schools, or in libraries. The printer weighs 26.3 pounds and has dimensions of 24"x11"x13," which is a little bit larger than an at home ink printer. Most recent tests have printed at one character per second and averages about 75 decibels when running.

2. Introduction to the Team

Anthony Nykamp is a mechanical engineering student at Calvin University. This past summer, he interned at JR Automation, where he was responsible for CAD design work and some machining. He learned about project management, the project life cycle, and the manufacturing process. He is excited for the opportunity to pursue the design and implementation of a braille printer because he has a passion for using technology to help people better apply themselves. His background in machine design and machining will be utilized in the application of the braille printer. On the team, his role was CAD mechanical design as well as component selection, testing, and implementation. After graduation, Anthony plans to move to Corpus Christi, Texas and work in a mechanical engineering design position.

Aubree Jo Peters is studying mechanical engineering with a minor in biomedical engineering at Calvin University. Previously, she had a manufacturing engineering internship at Viant Medical, a company that produces medical devices where she learned about cycle-time studies, production processes, sustaining lines, and more, as well as the importance of communication, leadership, and organization. She was able to apply the knowledge from these experiences to the design and production of the braille printer. On the team, her role was project manager, as well as construction, testing, and implementation of the design. After graduation, Aubree Peters will be working at Ignyte Designs, in the architecture and engineering field.

Christine Van Oyen is a senior mechanical engineering major at Calvin University. She is also an intern at Dematic, where she works on material handling systems. In addition to her mechanical engineering degree, she is also minoring in biomedical engineering. Taking biomedical engineering classes has made her more interested in looking at the way humans interact with their surroundings, which has made her excited to build a braille printer. Christine was involved in the mechanical design features, as well as the testing and implementation of the design.

Owen Pruim is an electrical engineering major with a minor in computer science. Owen currently works at Apex Controls in Hudsonville where he works in controls engineering doing PLC programming and electrical design and will start working for Apex full time after graduation. Owen used his controls and software knowledge to do the programming and electrical design for the braille printer.

3. Presentation of Solution

3.1 Description of Goal

The goal of our project was to create a braille printer that is widely accessible to individuals, families, schools, libraries, and other public facilities. The printer was designed to be functional, reliable, affordable, and sustainable, so that more people with visual impairments can have the ability to print in braille.

3.2 Key Specifications

One of the key specifications of our project is the ability to print braille characters according to the Americans with Disabilities Act (ADA) specifications shown in Table C2 in Appendix C. This specification was achieved by implementing standardized embossing pins and an embossing surface that satisfies ADA standards. It was also specified that the printer will receive text from a computer, translate the text into braille and output the braille characters by punching dots into standard braille paper. In addition, the printer must accurately print translated braille text from a text file and take no longer than a half-hour to print a one-page document. These specifications were satisfied. In order to be accessible to our intended market, it was initially specified that the printer must cost no more than $2,000. After completion of the printer, it was determined that the printer would cost between $500 and $1000, satisfying this specification. The printer is intended for use in an office setting, much like a regular ink printer, so the printer should not exceed sixty decibels. Currently, the printer's average noise level is 70 decibels. Detailed specifications accompanied with the testing plan and results can be referenced in Appendix C.

3.3 Design Decisions

3.3.1 Embosser

We considered several different design options for the embossing mechanism in regard to the punching of each dot. Each of the following design considerations involves one or more solenoids providing the punching force. Another design alternative considered was a design using an XY table and one solenoid, like the previous team. While this design would keep costs down and would be relatively easy to program, it did not have enough of a financial benefit to justify the much slower printing speed. While this braille printer is designed for cost effectiveness, it also needs to be useful, meaning that printed documents cannot take too long to print. Additionally, if only one dot was printed at a time, it would require the printer to have two axes of translation, which would mean a much larger printer.

A second design option was to split the braille cell in half vertically, and punch three dots at one time. The left side of the cell would be punched first, followed by a minor translation to complete the other half of the cell. This requires an embossing element with three solenoids, each with a punching pin attached. This design option would increase the characters per second printing speed. Much like the second design option, a third design option was to create an embosser with six dot punching pins, each connected to a solenoid. This design can produce a full character at one time, resulting in the fastest printing speed. Although increasing the characters printed per second is a goal, there is a space constraint due to the size of the braille character application area and the much larger size of the solenoids.

We made a decision matrix to compare the different design alternatives, comparing the options of making one dot, one cell, and one line of braille at a time. This can be found in Appendix D. We also compared using an XY table to position the characters on the page and translating the punching mechanism while feeding the paper into the printer.

3.3.2 Embossing Surface

The embossing surface, or backing, to be utilized in the design is important for several reasons, such as to ensure that a good quality braille dot is produced meaning the pin does not puncture the paper. It also is important that the backing is not too rigid, because then the paper will not deform. These requirements presented three design options, a punched piece of aluminum, a rubbery, mousepad like surface, and a braille writer. A braille writer is a plastic piece injection molded to ADA standards, used by those with visual disabilities to write braille by hand. A design matrix was utilized to evaluate these design alternatives as shown in Appendix D.

3.3.3 Electrical

Some electrical design decisions had to be made to select what components were to be used for the design. An Arduino Uno microcontroller was chosen to be the controller used for the printer because it was affordable, available, and easy to program and use. Also, the Uno board had the right number of digital pins for the project. The stepper motors that came with the XY table used for our printer were used to move the embosser carriage and the paper feed mechanism. To avoid interfacing with the motor controllers and microcontroller that came with the XY table, the motors were controlled directly from the Arduino using L293D stepper motor chips, this also allowed for more direct and specific control of the motors. A 12-volt power supply was used to power the solenoids and the paper feed motor. It was clear that 12 volts would be needed to pull the paper after testing the system with 5 volts. It was also determined that a 12-volt power supply would be needed for the solenoids because 12-volt solenoids were chosen to actuate the punches based on the amount of force they output.

3.3.4 Software

One important software design decision that was made was the method by which to control the stepper motors. Initially, it made the most sense to use the Arduino “Stepper.h” library to control the stepper motors. However, through prototyping and testing, it was found that the function to control the stepper motors from the Arduino stepper motor library would not move the motor if the distance was any less than five steps. This was a problem as the printer had to continuously check the encoder for its position and move very small distances until it reached the exact position it needed to be in. The solution was to write a custom function to move the stepper motor for the embosser carriage that manually controlled the digital outputs and used a state machine to keep track of the position of the inner motor.

3.4 Final Design

For the final design, the CAD model of the final printer design can be found in Appendix A and the bill of materials can be found in Appendix B.

3.4.1 Embossing Mechanism

After considering alternatives, we found that the best design approach for our project is using three solenoids to punch half of a braille character at once. The solenoids move together horizontally to punch braille characters across the page. To visually show this design, a CAD model as well as an image of the embossing mechanism are shown below.

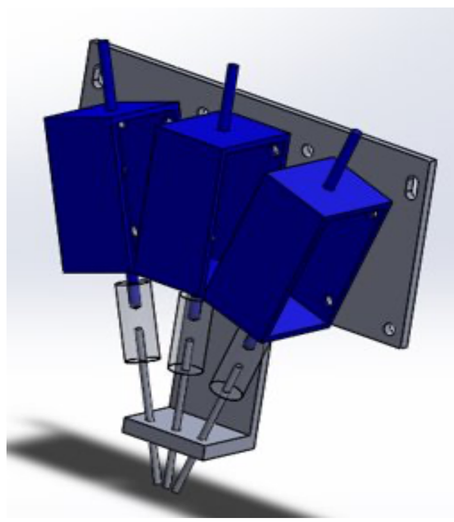

Figure 1. *Braille Printer Embossing Mechanism CAD Model*

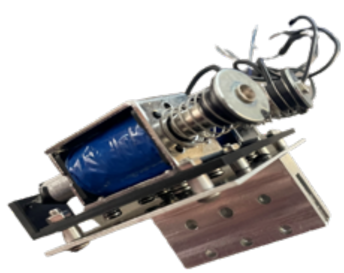

Figure 2. *Braille Printer Embossing Mechanism Final Prototype*

We chose Baomain BM-Z05 Solenoids, due to their low cost and availability. These solenoids had a voltage rating of 12 volts, a stroke of 10 mm, and a maximum force of just under ten pounds. As mentioned previously, a force of about two pounds was needed in order to punch a dot into paper. We decided on solenoids that exceeded our force requirements due to our need to punch the upper and lower dot of a cell on an angle as well as our desire to incorporate a safety factor so that a dot would be punched even if the solenoid encountered extra unexpected resistance. The 10 mm stroke allowed the braille pins to accelerate a little before hitting the paper, enhancing the likelihood of producing a quality braille dot.

The 3D printed part on which the solenoids are mounted to was designed to mount the middle solenoid vertically and the outer two solenoids at a 22-degree angle, which we found was the smallest angle that would keep us from having to extend the rods unreasonably far while still being able to provide enough force and accuracy to still form a dot. This was found by testing punching at different angles and visually checking the quality of the dot. At the base of the part are angled holes to guide the pins to the correct locations. In addition, the top mounting holes on the 3D printed part are slotted to account for any tolerance issues in hole locations. We chose to 3D print this part due to the manufacturability advantages of additive manufacturing. Because we needed the guide holes to be precisely angled, machining this part from steel or aluminum would have been difficult, as drilling holes that are not perpendicular to their surface often does not produce a quality hole. Additionally, a metal mounting plate would have resulted in a much heavier carriage and a larger moment applied to the rails.

To mount the embossing mechanism to the rest of the printer, a machined aluminum block was created to mimic the hole locations of the parts used from an XY plotter kit, which is explained in more detail in section 3.4.4. Aluminum was chosen due to its machineability and tight tolerances as well as its relatively low density when compared to steel.

3.4.2 Horizontal Translation

The embossing mechanism travels across a braille page horizontally, first punching half a character, then moving and punching the second half. The horizontal translation is powered by a stepper motor and belt system designed to be used in an XY plotter, which the embossing mechanism is mounted to. Due to the extra load on the motor as a result of the weight of the embossing mechanism, the stepper motor experienced periodic slipping. To mitigate the effects of this issue, a rotary encoder is also used to track the exact position of the embossing mechanism. This replaced the previous design which required the Arduino to move the stepper motor a preset number of steps. We used a limit switch to set the embossing mechanism’s zero position, which it returns to upon completing a line.

3.4.3 Paper Feed Mechanism

The punching mechanism translates horizontally, with the paper fed into the printer using a second stepper motor, also controlled by the Arduino. When the printer finishes punching a line, the embossing mechanism returns to its zero position, and the paper feed stepper motor moves the paper to its next line position. By using the paper feeder to move the paper for each new line instead of moving the embossing mechanism up and down the page, the printer will be able to keep line spacing more consistent. The paper feed mechanism utilized recycled paper rollers from old paper towel dispensers. The rubber surface on the paper rollers grips the paper well without slipping and the stepper motor gives the ability for the paper to be accurately moved across through the printer. Braille paper is typically tractor fed and is connected in an accordion style, so once a page is finished printing, the printer will continue printing onto the next page.

3.4.4 Embossing Surface

For the backing, we decided to use the purchased plastic braille writer, as it already had the indentations for printing on that met ADA standards. The hard backing stops the solenoids from punching too far and punching through and tearing the paper. Because of the rounded shape of the dots and the rounded tips of the braille styli, the braille writer also acts as a self-correcting feature for the printer, so that if a punch is a fraction of a millimeter off its mark, the slight flex in the solenoid rod will allow the stylus to be guided to the correct location. We cut the braille writer to the desired shape and size, and press fit it into the paper feed mechanism to provide the embossing mechanism a sturdy, seamless surface to punch onto. Figure 3 shows the embossing surface integrated with the paper feed system.

Figure 3. *Embossing surface (green) integrated with paper feed system*

3.4.5 Housing

In order to keep the user from having his or her hands come in contact with the moving parts of the printer, the components of the printer were housed in a case constructed of T-slotted aluminum frame and clear plexiglass panels. We chose to encase our printer in clear plexiglass to show the inner workings of the printer. The T-slotted aluminum framing made assembling the printer simple and gave the printer a clean, finished look.

Working together, the embossing mechanism and paper feeder give the printer the ability to print an entire page of braille text. Figure 4 shows an image of the printer design once it had been assembled.

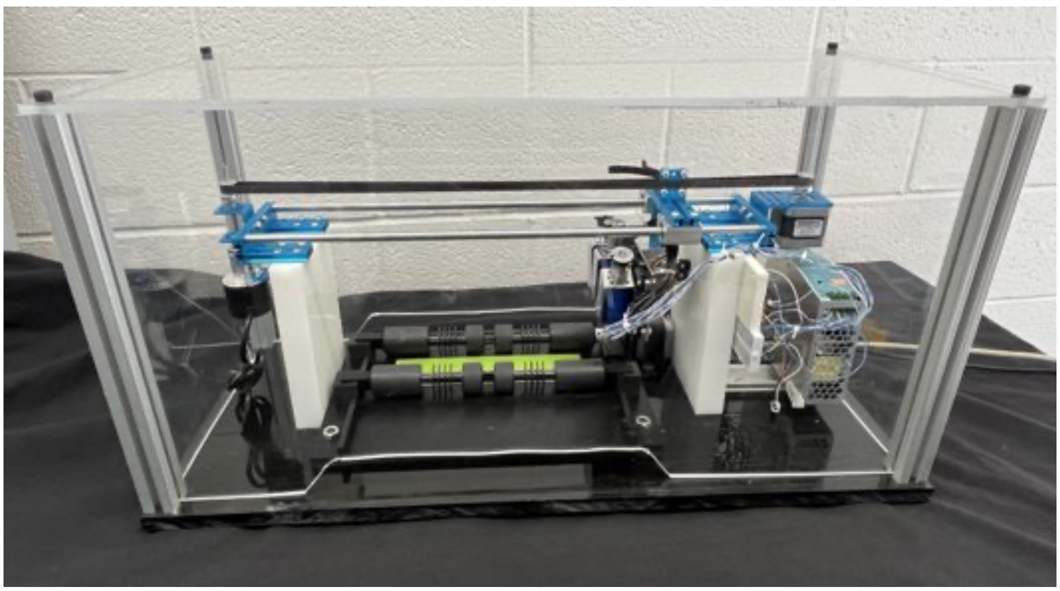

Figure 4. *Braille Printer Assembly*

3.5 Testing and Integration

As an initial prototype, we created software for an Arduino board that translates ASCII text from the USB serial port into six-bit characters of braille and activates the appropriate outputs which were eventually used to drive the solenoid punches. This was tested by sending various messages to the Arduino from a computer via the USB serial port and connecting LEDs to the six outputs used in the design to show that the correct outputs were being driven for the braille message, as shown in Figure 5.

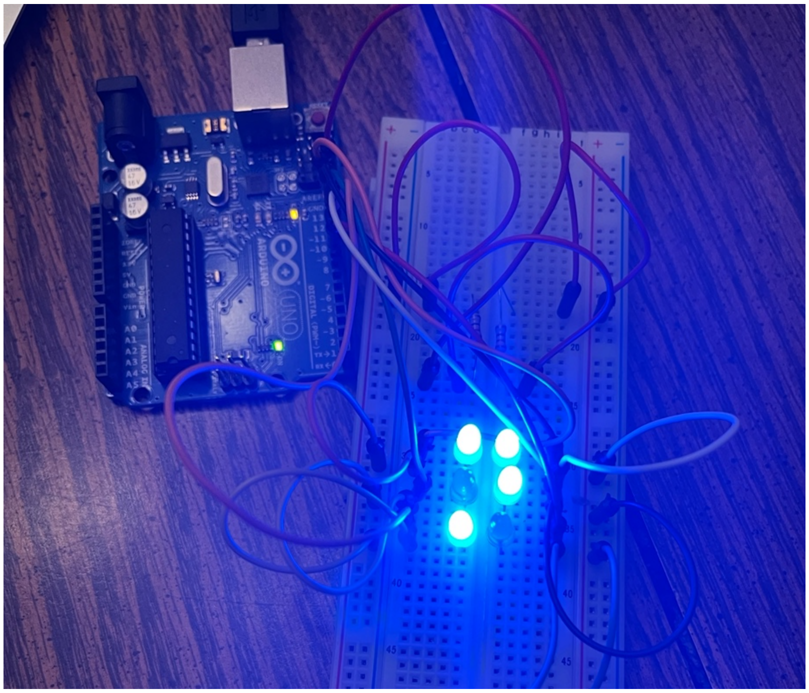

Figure 5. *Setup used for testing braille translation software, showing the letter N.*

We validated our punching design by performing tests to determine the amount of force required to create a dot on braille paper. We modified a center punch to resemble a braille dot and used the tool to find the force required to create a dot in braille paper. The end of the tool had a diameter of 0.06 inches, while braille dots have a diameter of 0.057 inches. To find the force necessary to form a braille dot, we dropped a weight on the tool from different heights and documented the results. It was documented whether no dot was made, a good dot was made, or if a hole was punched through the paper. Using the momentum of the weight, we calculated the force required to form a readable braille dot in a sheet of braille paper. We performed this test using different backings for the tool, including a premade punch in a piece of aluminum sheet metal and a mousepad. We found that the mousepad produced the more consistent braille dots of the two methods, although it required more punching force to create the dot. From this initial testing we were able to purchase solenoids that meet the punch force requirement. Table 1 displays the results of this testing.

Table 1. *Testing results for the force required to form a braille dot.*

Height [in]	Force [lbf]	Dot Created [Yes/No]
3.82	1.92	Yes
1.85	1.78	Yes
1.06	1.71	No

The stepper motors that came with the XY plotter were also tested to validate that they would be sufficient for our design. It was vital that the stepper motor would be able to translate distances very accurately so that the braille dots would be punched in the right locations. To test the stepper motor, a pen was attached to the horizontally translating carriage, which is controlled using the motor and belt system of the XY table. As the motor moved the carriage back and forth, the pen drew a line on a piece of paper and this line was then measured. After many trials and moving the motor by various step counts, it was concluded that the embossing carriage could accurately be translated by 0.1 mm. Given that the distance between braille dots is 2.5 mm, the stepper motor is accurate enough to be used in our application.

4. Schedule

Using the ENGR 339 course schedule with scheduled project workdays as well as meeting outside of class, we created a schedule outlining the project. Table 2 shows the schedule for the project. A detailed Gantt chart can be found in Appendix E.

Table 2. *Major Deadlines.*

Event	Deadline
Software Completion and Debugging	February 1, 2023
Punching Mechanism Completion and Verification	March 1, 2023
Completion of Paper-feed Mechanism	March 31, 2023
Prototype Completed	April 6, 2023
Final Presentation	April 15, 2023

5. Budget

We were allocated $900 in funding for the completion of the project. We received $400 from the Eric DeGroot fund and $500 from Calvin University. In total, about $370 was spent from the allocated funds. The materials used to construct the printer cost about $380. The reason for the discrepancy between these two values was the fact that a lot of the materials used in the design were obtained for free from either the machine shop or given to us for use for our project. A breakdown of the money spent can be seen below in Table 3. A detailed budget can be found in Appendix F, including a breakdown of what was actually spent.

Table 3. *Cost of Materials.*

Category	Equipment	Amount
Mechanical – Structure	XY table, plexiglass, T-slotted aluminum frame, etc.	$72.40
Mechanical – Design	3D printing, rollers, solenoids	$83.50
Electrical	Components, motors, Arduino	$161.50
Miscellaneous	Paper, braille writer, braille stylus	$63.04

Total = $380

6. Conclusions

The design of the Text2Touch braille printer was feasible with the given funding and resources. Throughout the design of this printer, deliberate decisions were made in order to build a functioning prototype that meets the specifications and achieves the goals of the project. The final prototype printed ADA compliant braille characters at about one character per second. The printer is 25x11x13" and weighs 26.3lb. The sound level produced by the printer is in the range of 70 dB. The final cost of materials to build the printer was $380, but by adding in the costs of labor and other overhead manufacturing costs, the total production cost is estimated to be closer to $500. This is still much cheaper than current market options.

7. References / Bibliography

Abutayeh, Noor, and Berta García-Orosa. "Emerging Services for the Visually Impaired in Academic Libraries." *Library Philosophy and Practice* (2021): 1-12. *ProQuest.* Web. 9 Nov. 2022.

Ana Marcet, María Jiménez & Manuel Perea (2016) Why braille reading is important and how to study it / Por qué es importante la lectura en braille y cómo estudiarla, Cultura y Educación, 28:4, 811-825, DOI: 10.1080/11356405.2016.1230295

Apurva, A. Anupam, M., Palash, T. "Aiding the Visually Impaired: Developing an efficient Braille Printer". Manipal Institute of Technology.

"Eye Health Data and Statistics." *National Eye Institute*, U.S. Department of Health and Human Services, 15 June 2022, https://www.nei.nih.gov/learn-about-eye-health/eye-health-data-and-statistics.

In America - National Federation of the Blind. https://nfb.org/images/nfb/documents/pdf/braille_literacy_report_web.pdf.

"Quick Reference Guide to ADA Signage". *Accent Signage Systems, Inc.* 2012.

https://www.accentsignage.com/wp-content/uploads/ADA-Quick-Reference.pdf

8. Appendices

Appendix A – CAD Model

Appendix B – Bill of Materials

Appendix C – Specifications and Testing

Appendix D – Design Decisions

Appendix E – Business Issues & Cost Breakdown

Appendix F – Budget, Schedule, and Work Breakdown Structure

Appendix G – Initial Validation of Solution

Appendix H – Ethics of the Problem and Solution

Appendix I – Summary of Key Research

Appendix A – CAD Model

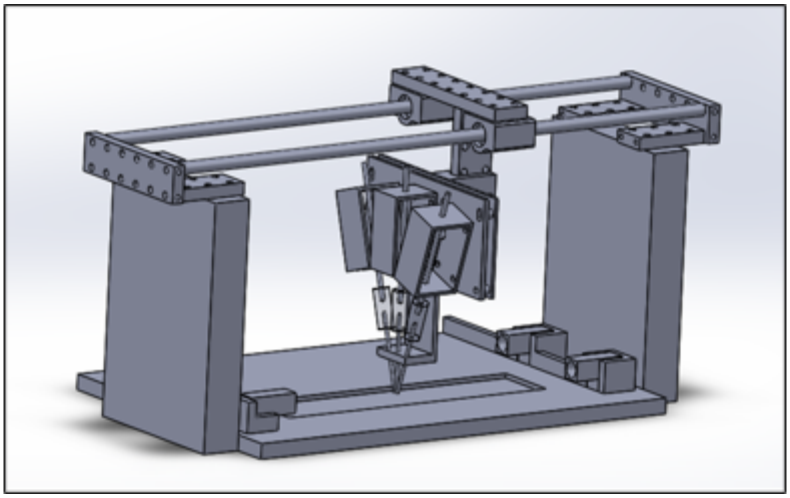

Figure A1. *CAD model assembly of the final printer design.*

In order to determine the appropriate lengths and dimensions for machined parts, a CAD model of the printer was constructed in SolidWorks. The CAD model was constrained to work how the final printer design works, with constrained translation, and constrained solenoids with functioning punching.

Appendix B – Bill of Materials

Table B1. *Bill of Materials.*

ITEM	QUANTITY	NAME
1	1	H-BRIDGE
2	1	ARDUINO
3	3	BRAILLE STYLUS
4	1	BRAILLE SLATE EMBOSSING SURFACE
5	3	SOLENOID Z05 DC 12V PUSH TYPE
6	1	3D PRINTED BASEBOARD
7	1	3D PRINTED EMBOSSING MOUNT
8	6	ALUMINUM SPACERS
9	1	POWER SUPPLY
10	1	TRANSISTORS
11	1	STEPPER MOTOR DRIVE
12	1	COUPLING 4MM TO 6MM
13	1	ROTARY ENCODER
14	2	STEPPER MOTOR
15	2	UHMWPE SUPPORT LEGS
16	1	TIMING BELT
17	2	PAPER TOWEL ROLLER
18	2	ALUMINUM CARRIAGE ROD
19	1	TIMING PULLY/BELT MOUNT
20	1	BASEPLATE
21	1	BREADBOARD

Appendix C – Specifications and Testing

Table C1. *Specifications and Testing.*

Braille Printer Requirement	Testing Process	Result
Characters sent from the PC shall be received by the printer's computer	Send a character to the Arduino via the Word add-in and send it back to the computer via serial.	Printer is capable of receiving text via serial
The printer's computer shall output characters in braille	Send a braille character to the Arduino and use 6 LEDs to represent a Braille character.	The printer is successful in outputting braille characters.
The system shall be able to print 1 page every five minutes	Print a page of braille, measure the time it takes to print, and if the time is longer, adjust speed and delays accordingly	The printer can print 1 page in 11 minutes and 40 seconds.
Paper jams shall not occur.	Print 10 pages in a row without a jam.	The printer can print without paper jams.
The braille dot depth shall be within specifications set by the ADA.	Measure dot depth using a caliper to determine that the dot depth and diameter meet the requirements.	Braille dot depth is in compliance with ADA standards.
The braille cell spacing shall be within specifications set by the ADA.	Measure spacing between the braille cells using a caliper to determine that the spacing meets the regulations.	Braille dot spacing is in compliance with ADA standards.
Line spacing of the braille characters shall be within specifications set by the ADA.	Measure the produced line spacing using a caliper to determine that spacing meets the regulations.	Braille line spacing is in compliance with ADA standards.
Translation software shall accurately translate electronic text to braille.	Text will be input to the custom braille translation software and the output will be compared to the same text translated from a braille translation software from a reputable source.	The printer can accurately translate ASCII text into braille
Motors shall not exceed temperatures of 140 degrees Fahrenheit.	Run the printer motors continuously under maximum operating conditions for 1 hour and check temperature of the motor.	Motor operates within specified temperature range

Printer will not exceed 110 F surface temperature	Run printer and monitor with an infrared temperature sensor.	Printer surface remains within specified temperature range during operation

Table C2. *ADA Standards.*[9]

Standard	**Measurement [inches]**
Dot height	0.025 to 0.037
Dot diameter	0.059 to 0.063
Spacing between dots	0.090 to 0.100
Vertical cell spacing	0.395 to 0.400
Horizontal cell spacing	0.241 to 0.300
Dot shape	Domed or Rounded

[9] Quick Reference Guide to ADA Signage 2012

Appendix D – Design Decisions

Design decisions were made using a decision matrix for several major features of the printer. Different weights were attributed to each characteristic of the design, such as cost, simplicity, and efficiency. Scores were allotted to each design alternative and weighted based on the relevant design criteria weight. Results of these design matrices are displayed in Table D1 and Table D2.

Table D1. *Dot punching decision matrix.*

Design	Single Pin		Half Cell		Braille Cell		Braille Row	
Criteria	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted
Cost (10)	10	100	8	80	4	40	1	10
Design Complexity (7)	2	14	5	35	3	21	1	7
Speed (6)	1	6	3	18	6	36	10	60
Character Consistency (5)	3	15	5	25	10	50	10	50
Score	135		158		147		127	

Table D2. *Dot backing decision matrix.*

	Aluminum Punch		Mousepad		Braille Writer	
Criteria	Score	Weighted	Score	Weighted	Score	Weighted
Cost (10)	10	100	9	90	6	60
Design Complexity (7)	2	14	5	25	8	56
Dot Quality (7)	1	7	8	56	10	70
Material availability (4)	8	32	10	40	9	36
Score	153		211		222	

Appendix E – Business Issues

The printer design provides a lower-cost alternative to braille printers currently on the market which will improve access to braille printer technology for schools, libraries, and homes in need of braille printing technology.

Pains experienced by the customer include operating the printer while visually impaired. While the printer will have a simple design, learning how to operate a new piece of technology may still be difficult. However, there are many gains associated with the braille printer as well. The customer will be able to take their Microsoft Word document and print directly to braille. This printer will not require the customer to purchase additional Microsoft Word extensions for this process, saving the customer hundreds of dollars.

There are many similar products on the market, both to our printer design and the extension designed to print from the computer to the printer. Existing braille printers range from $3000 to $4000 for small volume personal models up to over $60,000 for high volume printers. As our printer is designed for affordability ($1000), we are looking to create a similar product to the personal models.

One existing software for converting Word text to be printed in braille is called Tiger. This software costs $50 per month, which also builds up the cost of owning and operating a braille printer. Our Word add-in would either be a one-time purchase with the printer or free if it were marketed.

Appendix F - Budget and Schedule

Below is a table discussing the allocation of the budget for the project. The money allocated to the team was divided between mechanical, electrical, testing, and miscellaneous purchases. In table F1., the left column shows the teams estimated allocation of funds, and the right column shows the actual spending of the team.

***Table F1**. Budget Breakdown.*

Category	Equipment	Estimate	Actual
Mechanical - Structure	XY table, plexiglass, T-slotted aluminum frame, etc.	$150	$72.40
Mechanical - Design	3D printing, rollers, solenoids	$150	$83.50
Electrical	Electrical components, motors, Arduino	$400	$161.50
Miscellaneous	Paper, braille writer, stylus, testing, tools, materials, unforeseen costs	$200	$63.04
		Total = $900	Total = $380

Table F2 displays the team's detailed budget for the length of the project. It should be noted that costs of various items are shown to be $0 in the total price column and not deducted from the budget because they were donated to the team. These items are still included in the total cost to make the printer as seen in Appendix E.

Although the team was granted $900 to spend towards the design and prototype of this printer, only $346.84 was spent on components and materials. This is due to several costly items being donated to the project. The XY plotter that served as the structure for the printer was obtained from the previous group's work. The power supply, transistors, and various other components were donated to the project. These materials can be observed in Table F2 as the total cost of the item is $0 and not deducted from the budget.

Table F2. Detailed budget for braille printer.

Item	Category	Quantity	Unit Price	Total Price	Funding Remaining
Electrical component - H-bridge	Electrical	1	$ 9.53	$ 9.53	$890.47
Arduino	Electrical	1	$ 64.69	$ 64.69	$825.78
Braille Paper	N/A	1	$ 24.49	$ 24.49	$801.29
Stylus (removable tip)	Testing	3	$ 2.95	$ 10.00	$791.29
Braille Slate and Stylus	Testing	1	$ 11.99	$ 11.99	$779.30
Solenoids - Baomain Solenoid Electromagnet BM-Z05 DC 12V 2A Push Type Open Frame 10mm 45N 9.9LB	Final Model	3	$ 13.49	$ 40.47	$738.83
3D Print	Mechanical	1	$ -	$ -	$738.83
Arduino Replacement (board)	Electrical	1	$ 20.00	$ 20.00	$718.83
Aluminum Spacers	Mechanical	6	$ 1.84	$ 11.04	$707.79
Solenoids - Baomain Solenoid Electromagnet BM-Z05 DC 12V 2A Push Type Open Frame 10mm 45N 9.9LB	Mechanical	3	$ 13.49	$ 40.47	$667.32
Power supply	Electrical	1	$ 23.99	$ -	$667.32
Braille Slate and Stylus	Mechanical	1	$ 11.99	$ 11.99	$655.33
Transistors	Electrical	1	$ 8.99	$ -	$655.33
Stepper motor driver	Electrical	1	$ 10.19	$ -	$655.33
3d printed base	mechanical	1	$ 28.94	$ 28.24	$627.09
XY table	mechanical	1	$ 210.00	$ -	$627.09
Couplings 4mm to 6mm	Mechanical	1	$ 14.94	$ 14.94	$612.15
Rotary encoder	electrical	1	$ 18.99	$ 18.99	$593.16
T-slotted aluminum frame	Final Model	1	$ 20.00	$ 20.00	$573.16

A detailed Gantt chart was made to track the overall progress of the design process. The Gantt chart outlines the necessary work on the project from the research phase until completion. Table F3 outlines a monthly project schedule for the braille printer design and prototyping.

Table F3. *Detailed Gantt chart for the design of a braille printer.*

Task	Subcategory	Oct	Nov	Dec	Jan	Feb	Mar	Apr
1. Research								
1.1 Existing Options								
	Cost of Current Options							
	Visit a braille Printer							
	Current Specs							
	Cost of Components							
1.2 Braille Language								
	Alphabet							
	Numbers							
	Punctuation							
	Contractions							
1.3 Software, Hardware								
	Single board computers							
	Braille conversion							
2. Design								
2.1 Electrical, Software								
	Electrical Design							
	Front End Software							
	Embedded Software							
2.2 Mechanical								
	Punching Mechanism							
	Paper Feeder							
	Housing							
	Translation							
2.3 Cost Analysis								
	Component Comparisons							
	Budgeting							

	Parts Ordering							
2.4 Life Cycle Analysis								
	Research							
	Design Influence							
3. Prototype								
3.1 CAD								
	Base Model							
	FEA							
	Import Purchased Parts							
	Drawings							
3.2 Testing								
	Required Punch Force							
	Paper Feed							
	Software Testing							
	Com. with computer							
3.3 Physical Model								
	Ordering Components							
	Machining Components							
	Building a Physical Model							
4. Final Protoype								
4.1 Final Design								
	Final Parts Ordered							
	Final Parts Machined							
	Final Build							
4.2 Final Testing								
	Final Debugging							
	Calibration							
	Final Setups							
	Final Print Tests							
4.3 Project Showcase								
	Prepare Presentation							
	Deliver Presentation							
	Project Showcase							

A work breakdown structure (WBS) was created. The WBS helps break down larger tasks, into smaller, more manageable tasks. The main categories include research, design, prototype, and final prototype. The WBS can be seen in Figure F1 below.

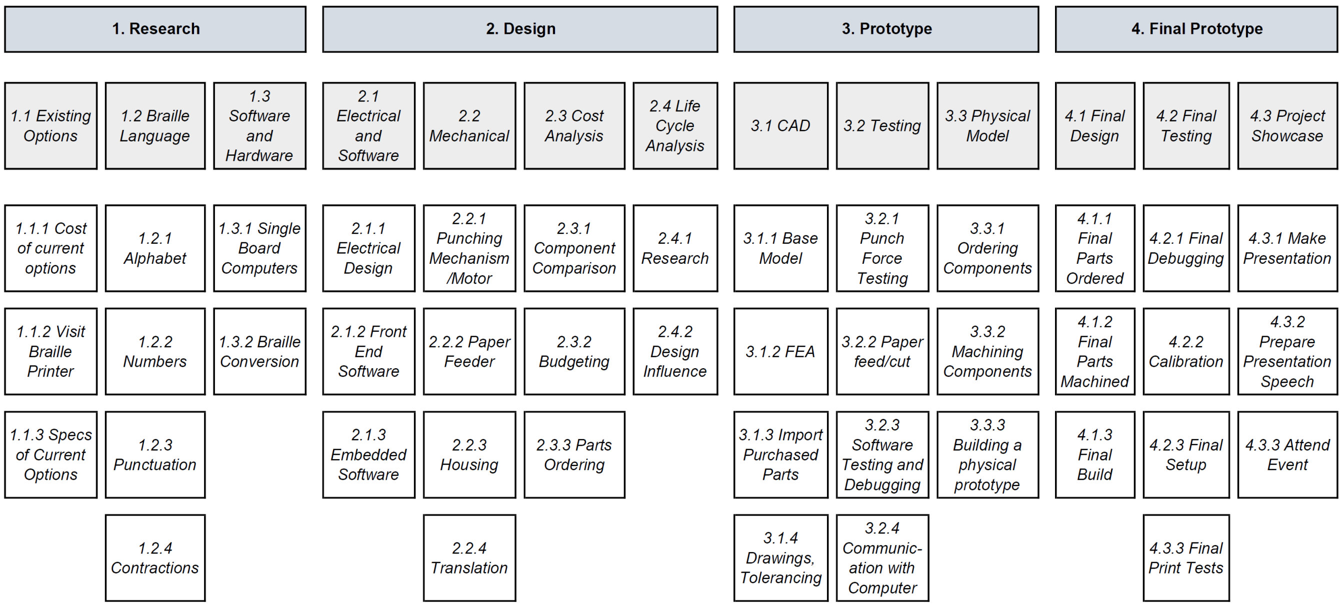

Figure F1. *Detailed WBS for the design of the braille printer.*

Appendix G – Initial Validation of Solution

Software for an Arduino microcontroller was developed to read in ASCII text from the serial port and translate it into a code that the machine can easily print to braille. The software also drives the six outputs that will eventually be attached to the six solenoids used to punch the braille character into the paper. A simple circuit consisting of six LEDs connected to the Arduino outputs was constructed to test the translation software and provide a visual representation of the braille characters produced by the Arduino. The overall system will consist of the elements shown in the block diagram below.

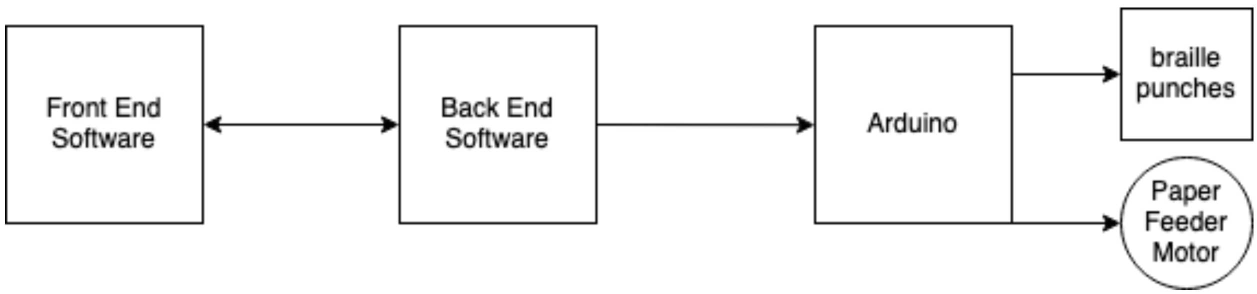

Figure G1. *Block Diagram of Electrical Hardware and Software*

To find a rough estimate of the force required to make a dot of braille, the team created a testing apparatus which required a steel ball to be dropped on a braille tool from various heights. The momentum of the ball was found using $P = m * V$, which is the change in force over time. This change in force was added to the weight of the braille tool, so $F = m_{ball} * V + m_{tool} * g$. Using this formula, it was found that the minimum force required to create a braille dot was about 1.78 lb_f. This testing was done using an aluminum backing with a divot created where the braille dot was to be. Table G1 below shows the various drop heights used, as well as the force associated and whether or not a braille dot was successfully created.

Table G1. *The force required to create a dot in braille paper based on testing results.*

Height [in]	**Force [lb_f]**	**Dot Created [Yes/No]**
3.82	1.92	Yes
1.85	1.78	Yes
1.06	1.71	No

Appendix H – Ethics of the Problem and Solution

For the braille printer, there are many things to consider in terms of social context and the ethics of the project as a whole. Currently, there are not many braille printers available for the public to use. A visually impaired person may have to travel many miles to find a braille printer. Other people may find that there are no braille printers available at all. In these scenarios, someone may choose to purchase a braille printer of their own. However, the high price of these printers—often exceeding $3,000 even for lower end models—may prohibit the ability to purchase such printer. Ethically, it is important to provide services, such as braille printing, to those in need.

While it has been established that there is an ethical problem with the current availability of braille printers, it is very important to ensure that the solution to this problem is ethical. One of the engineering design norms is 'cultural appropriateness'. In this situation, it is very important to make a braille printer that fits the community that will be using it. Therefore, the printer shall be easy to use, especially by those who are visually impaired. While all design norms are important, 'caring' is another norm that stands out. As said in Philippians 2:3-4, "Do nothing out of selfish ambition or vain conceit. Rather, in humility value others above yourselves, not looking to your own interests but each of you to the interests of the others". A goal of this project is to be caring and to provide a solution that is ethical and beneficial for the blind community. A third applicable design norm being considered in the design is stewardship, as we are looking to create this printer sustainably, reducing the impact the creation of this design has on creation.

Appendix I - Summary of Key Research

Key research for the design of the braille printer began with understanding the reading and writing system and the requirements for printing the system. These braille standards and requirements from the American Braille Association were used as a foundation for the continuation of research. From here, the team set out to answer questions about the necessary paper, the current use of printers, availability of printers, the designs of current models, and so forth. These questions as well as relevant sources are listed in Table I1. Answering these questions and learning about the design of current braille printers have guided the team in their design process.

Table I1. *Research Questions to guide design of Text2Touch braille printer.*

	Question	**Sources**
1	Braille Paper Type - does it matter?	https://braillo.com/braille-paper/
2	Uses of braille printers	https://nfb.org/images/nfb/documents/pdf/braille_literacy_report_web.pdf
3	Existing braille printer designs	https://nelowvision.com/
4	Braille standards	ADA.com
5	Do all schools have braille printers?	https://www.teachingvisuallyimpaired.com/braille-technology.html
6	Costs of braille printer - low end and high end	https://www.loc.gov/nls/resources/blindness-and-vision-impairment/devices-aids/braille-embossers/
7	Can a 100% blind person use braille printer?	https://www.loc.gov/nls/resources/blindness-and-vision-impairment/devices-aids/braille-embossers/ ** link has pricing ranges for all types of braille printers
8	Why is it **important** to learn braille	https://www.proquest.com/docview/2712296560?pq-origsite=gscholar&fromopenview=true
9	Why are we capitalizing braille?	https://www.pathstoliteracy.org/resource/should-word-braille-be-capitalized/
10	Existing braille Printer Speeds	https://www.loc.gov/nls/resources/blindness-and-vision-impairment/devices-aids/braille-embossers/
11	What are the dimensions of typical braille printers?	https://www.loc.gov/nls/resources/blindness-and-vision-impairment/devices-aids/braille-embossers/
12	What population reads braille?	https://www.afb.org/blog/entry/how-many-braille-readers

13	How is XY table programmed?	https://www.instructables.com/Internet-Arduino-Controlled-T-Slot-XY-Table/
14	How do other printers convert word documents to braille?	https://tbase.com/how-do-you-convert-a-document-to-braille/
15	What type of motor is needed for a normal ink printer?	https://www.youtube.com/watch?v=AMv2tbyZyX4 - video on how to use stepper motor from printer with Arduino
16	Current braille printer prices	https://www.afb.org/blindness-and-low-vision/using-technology/assistive-technology-products/braille-printers
17	Braille translators?	https://www.afb.org/blindness-and-low-vision/using-technology/assistive-technology-products/braille-translators

Additional sources used for the development of the braille printer design include the articles listed below. The majority of the research was performed using Hekman Library's databases including ProQuest and EBSCO, as well as Google Scholar. An influential resource in the design process has also been the final report of Team 10, from Calvin University's 2020 senior design class. Ideas from this group's project have been referenced and expanded upon.

The team visited Wyoming Public Library in October to look at and to use the braille printer that they have available for the community. This printer model was a VP EmBraille that is on the market for $2,000 to $2,700. This printer prints 25 characters per second. Seeing this braille printer function in person was a valuable experience. The design decisions made by the manufacturer of the printer will influence the decision of the Text2Touch printer. Certain features such as the word add-in and the paper cutter used at the end of the print will be incorporated into the design of the Text2Touch printer.

Journal Articles

"Aiding the Visually Impaired: Developing an efficient Braille Printer" Apurva et al.

"A Review of Braille Printers" JD Leventhal

Relevant Patents

US Patent US 3598042 A – Braille printing System.

US Patent 5527117 A - Braille printing solenoid housing.

US Patent 4183683 A – Line Printer for the raised-dot language of Braille Characters.

Valuable Contributors

1. Final Report Team 10 – Text2Touch, ENGR340, Calvin University 2020
2. Shelly Roossien – Accessibility and Inclusion Director at Wyoming Public Library mroossien@kdl.org
3. Professor Renard Tubergen – Faculty Advisor, Calvin University
4. Chris Sorensen – Wood and Machine Shop Technician
5. Matthew Rabadi – Engineering Lab Manager
6. Eric DeGroot Fund