Braille Tablet

by

Lilit Yerknapeshyan and Varoujan Anbarson

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1. Introduction

1.1 Project Description

1.1.1 Background

Accessing reading materials can be hard for visually impaired and blind people. Text-to-speech software has grown in popularity, but gadgets with textile writing have not developed to the extent that they can become commercial. It is important that the former is being properly developed, to make everyday technology more accessible for visually impaired and blind people. However, the braille system should not be neglected when it comes to inventing accessible tech.

One of the reasons being that gadgets that support textile writing enables the blind to obtain and understand information in a way that speech cannot. Information is better retained through reading. Retaining information is a complex process, and the ability to remember is dependent on how focused one is. Being focused can lead to better information retention and one study that analyzed the differences between reading and listening to audiobooks has concluded that maintaining focus on the task at hand is done a lot better when reading than when listening. Whether we're reading or listening to a text, our minds occasionally wander. If you're reading, it's easy to go back and find the point at which you zoned out. It's not so easy if you're listening to a recording.[1] Especially if you're grappling with a complicated text, the ability to quickly backtrack and re-examine the material may aid learning, and this is likely easier to do while reading than while listening. Lastly, not all books are available in audio version, and mere text to speech conversion of the book may not be pleasant to listen to. From these, comes the need for a tablet with Braille encryption.

Of course, tablets that use Braille engraving exist, but they have several problems. They are mostly expensive and inaccessible to many blind people, one example costing 2500 dollars, and needing constant external power supply to be operational[2].

The system is designed so that the dots do not need constant power supply to keep the required state (up/down), it is only needed for changing the state. This is achieved by utilizing permanent and electro- magnets. Each dot is moved using an inductive coil, and the magnet that is part of the dot attaches to a metallic washer to hold itself in the same position without any voltage supply.

For this capstone, the tablet will be operated by a power supply and not a battery, because batteries available to us were not able to provide enough current. In the future a simple, integrated 12 V battery will be enough to power the system for some time (depending on how fast a person reads) and the user will just need to charge the tablet occasionally, like in a usual Kindle. Finally, the overall design and the components to be used are chosen to keep the cost of the final product low.

1.1.2 Assumptions and Constraints

- The pins, washers and the coils are assembled by hand and no machines are involved. That causes asymmetry in each individual pin, and also causes differences between the pins. The asymmetry in the pin makes it difficult for the magnetic force to move the pin strictly up/down and if the force is not large enough the pin would instead go sideways. This causes the second constraint.
- The dimensions of Braille characters are larger than the printed braille standard due to the absence of out of the shelf miniature electromagnetic actuators that are strong enough to push/pull the pin. The smallest inductive coil that we could make and with which the system was operational has 8 mm diameter. For this reason the character we made is significantly

larger than the braille standard. However, as it is not wider or longer than the index and middle fingers, so the character is still readable.

1.2 Overview of the Envisioned System

1.2.1 Overview

The system that will be presented for the capstone project will be a box-like tablet capable of displaying physical braille characters in a row (a line). Currently a line consists of one character, however it can be easily expanded with time. That is enough to prove that the proposed mechanism is working and that the project is scalable.

The tablet also provides an interface for reading process control. The buttons will also have a braille encryption on them, so the user knows the purpose of each button.The buttons give the user the ability to turn on/off the table, go to the next/previous page. The table also has an SD card slot to load the book into the tablet.

1.2.2 System Scope

The final system is quite small: a tablet consisting of a single line and process control buttons. The one letter has the following dimension:

- Length - 2.8 mm
- Width - 1.4 mm
- Height - 26 mm

Currently the system also includes a power supply and an Arduino. The characters combined with the circuitry have the following (not including the Arduino and the power supply):

- Length - 150 mm
- Width - 90 mm

- Height - 27 mm

The tablet is not complex to operate, the user will not have a hard time making the system work. There are not many external factors required to operate the system. We would only need another PC from time to time, to upload a text with a .pdf extension in the SD card or a USB flash drive and then insert it back into the gadget.

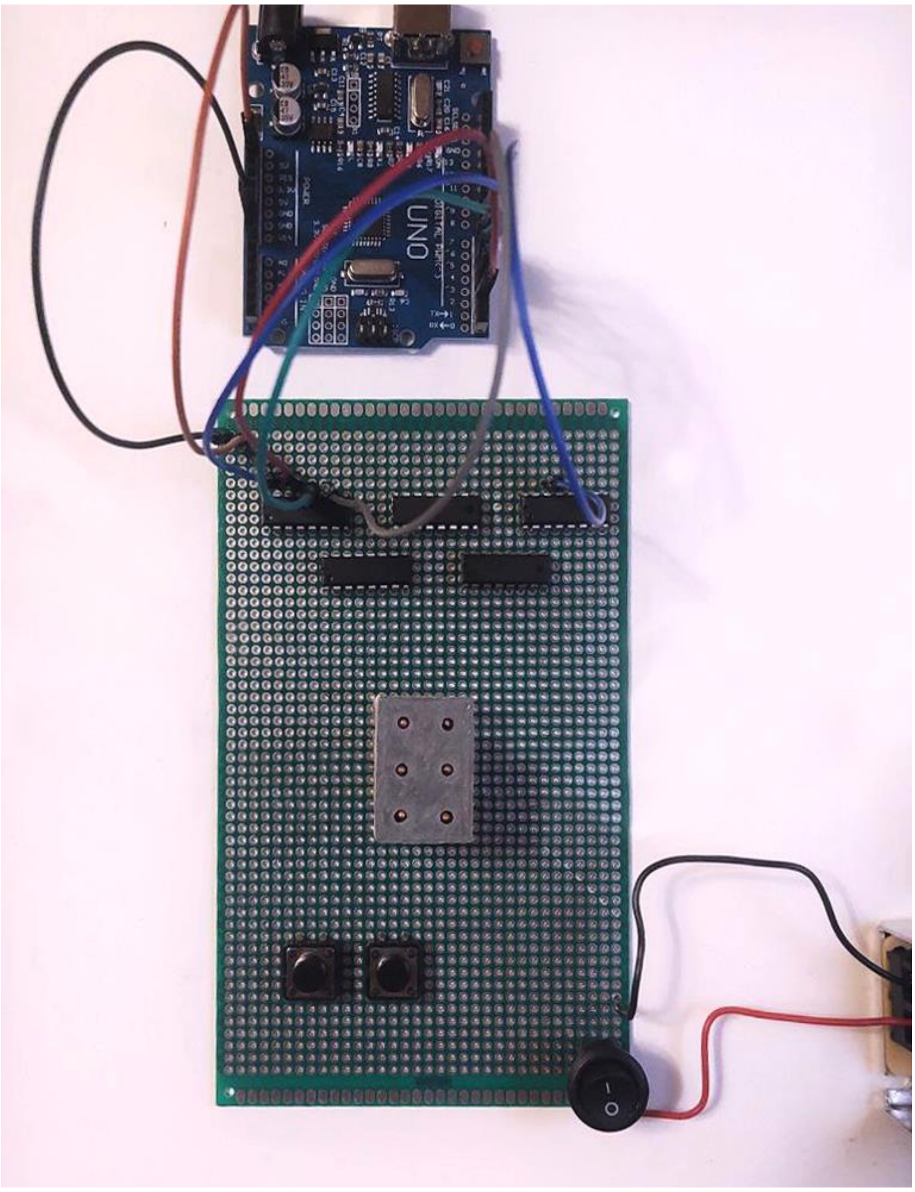


Figure 1. Final Design of the Tablet without a Cover

2. Description of Envisioned System

2.1 Needs, Goals and Objectives of Envisioned System

As mentioned, at first we intended for the tablet to have 14 characters. Within the English Dictionary 92.5% of the words are 13 letters and less [3], as can be seen in Figure 3. However, by creating a histogram on the number of letters present in each word for famous books such as the Harry potter series, the histogram in Figure 4 shows the percentage to be 99.987% which will cover most words. Hence the braille tablet needs to have a minimum of 14 cells. 13 of which will be used to form a word and the other one will be used to capitalize the first letter.

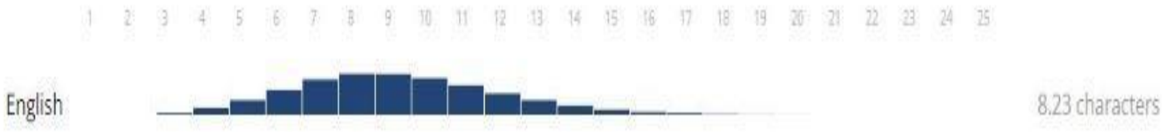


Figure 2. Histogram for the Length of Each Word in the English Dictionary

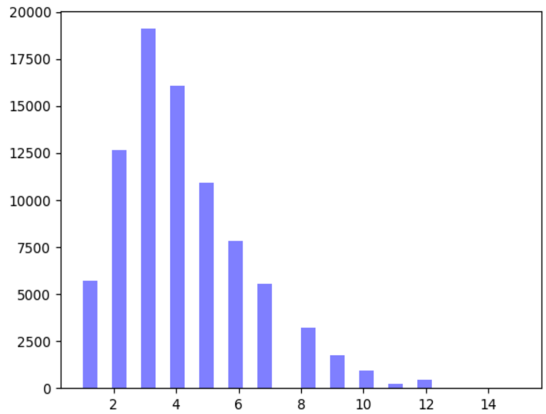


Figure 3. Histogram for the Length of Each Word in First Chapter of Harry Potter

The scale was later reduced due to time and resource constraints.

Needs:

- To be readable by the user
- To be fast with little delay between the page turns
- To have a port for external data transfer

Goals:

- To create an affordable alternative braille tablet than the tablets currently on the market
- To create a system that would be battery efficient
- To create a braille tablet that can be small in dimensions, so it is comfortable for the user to hold it and that is light enough to be carried around

Objectives:

- Use electromagnets to move the pins instead of the expensive alternative, piezoelectric actuators

2.2 Overview of System and Key Elements

The system will consist of two main parts, electrical and mechanical.

Electrical Parts:

- The tablet will operate with the help of an Arduino controller. The program for:
  - Changing the pin state depending on the text to be displayed
  - Executing the button commands

is loaded into the Arduino via PC. After that it is powered by an external power supply.

- Shift registers: to reduce the amount of digital output pins provided by the microcontroller and to transfer data to the electromagnets
- H-Bridges: to control the polarity of the electromagnets, to drive the pin up or down, based on the command.

Mechanical parts:

Each cell consists of six dots. Dots are enclosed in a capsule. For the initial presentation of the prototype, the sides are open, so that the electromagnet and some part of the pin is visible. The dot itself is thick copper wire. Two washers, one metallic, one plastic are firmly attached to it and a magnet with a hole is placed between them. The copper wire has a small cylindrical magnet attached at the bottom. The magnet is partially inside the inductive coil. A nail is placed inside the coil, to strengthen its magnetic force. The upper plastic pin has the purpose of preventing the cylindrical magnet from touching the nail. Otherwise, we would not be able to drive the pin upwards.

2.3 Interfaces

Since the tablet is made to target people with visual impairments, there will not be any digital interface that will affect the system through a screen.

For transferring data, the tablet will be connected to an external device such as a computer or a phone by transferring data through a micro-SD card. Help from another person is necessary as interacting with others will cause a problem for the blind.

Mechanical Interface includes buttons such as the on/off and next page or previous page help users to interact with the system.

2.4 Modes of Operations

The Braille tablet has two main operation modes:

Active mode: This mode comprises the pins positioned to their rightful altitudes using electromagnets, based on the desired braille symbol.

Rest mode: This mode nullifies any mode that was previously being used, by pulling down all the pins to their original positions.

2.5 Proposed Capabilities

The tablet provides the following capabilities:

- Replaceable cells

Both the coils and the pins can be easily replaced if they become faulty.

- Scalability

The system can easily be expanded in terms of hardware (number of displayed characters) by exploiting modular design, each character is designed to be as a single module, which can be easily attached to the system. The software provides the scalability functionality through a configuration file.

- Load and translate books to a braille system

The user only needs to put the book in SD card, the braille translation is done by the tablet

- Affordable

The price of all components combined was around 135$. Although we made one character, the amount of components bought would be sufficient for a 14 character tablet. So the price is affordable for the product.

3. Method of Implementation

3.1 Pin Movement

Being able to actually move the pin was quite challenging and took the majority of the time of the development process. We went through many different designs of the pin changing materials and schematics. The wires used for the coil were also changed several times, before a working configuration of both the pin and the coil were found. Below are presented the four main versions of the pin that were created.

First Design

At first, we used the following design:

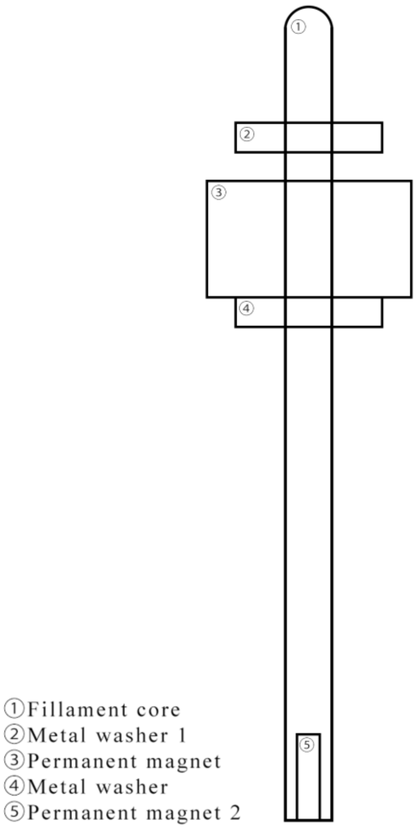


Figure 4. First Design of the Pin

The core was made from a 3D printer filament, and a 1 mm drill bit was used to create a hole at the bottom for the cylindrical magnet. The gasket rings were made from nail heads and a 1.4 mm drill bit was used, to drill a hole in the nail head. The gasket rings were attached to the core using a super glue.

Two different copper wires were used to make the inductive coils: 0.071 mm diameter and 0.3 mm diameter. The coils were wrapped by hand, around a plastic piece. The 0.3mm wire was too thick for an inductive coil. Even just 30-40 turns made the coil too large. Several coils that had 100,150, 200,..350 turns were created with the 0.071 mm wire. Below is an example of the coils that were used.

The bottom part of the pin (which had the cylindrical magnet inside) was put in the coil. The coil was supplied 5V from the PC via a USB cable. The pin did not move, but the coil did. Meaning that the magnetic force was not enough to move the pin, but was enough to pull the coil toward the pin (or push it away, depending on the polarity). We tried a coil with 350 turns, the force was visibly bigger, but still not big enough to move the pin.
Later on, 0.16 mm copper wire was also used. The results were similar.

Second Design

A decision was made to change the design of the pin to be able to achieve the desired up and down movement. The 3D printer filament was replaced with a thick copper wire (1.8 mm diameter), as the filament would heat up and deform. The ring magnet was replaced by a smaller one, with the following dimensions:

- Outer diameter - 5 mm
- Inner diameter - 2 mm
- Height - 2 mm

The cylindrical magnet was replaced with a bigger one, with the following dimensions:

- Diameter - 2mm
- Height - 5mm

The metallic gasket rings were made from a slimmer metal piece, to lessen the strength with which the magnet is attached to it. Below you can see the pin in its capsule.

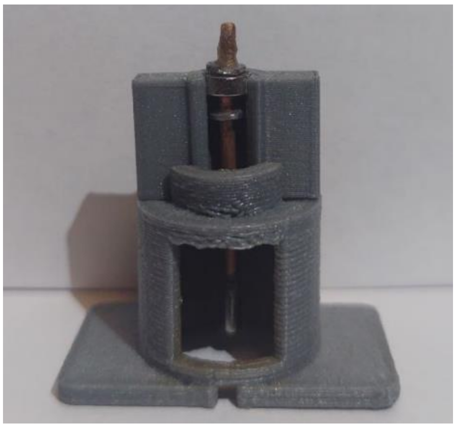


Figure 5. Second Design of the Pin

The coils were made exclusively with the 0.16 mm diameter wire. It was supplied with 12 V and current was increased up to 1 A. It was still not possible to achieve the up and down movement of the pin. A new coil was made with a 0.22 mm diameter wire, created by wrapping two 0.16 mm wires together. A plastic piece was put between the metallic washers and the magnet as can be seen in the picture:

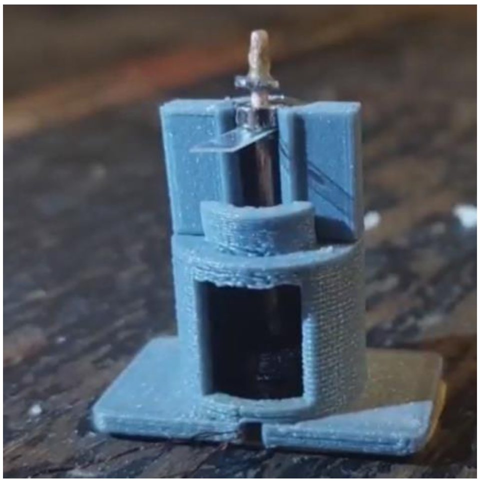


Figure 6. The Plastic Piece in Between the Washer and the Magnet

This was done in order to lessen the strength with which the magnet is attached to it. Finally, 12 V and 0.83 A was enough to move the pin in both directions. However, it wasn't desirable to have something between the magnet and the washers, so we moved on to a new design.

Third Design

To strengthen the force of the inductive coil, we added an iron core (a nail). The upper metal washer was replaced with a plastic one, as the attraction force between the iron core and the bottom magnet was enough to keep the pin in the lower position, and the washer was only needed so that the pin did not go down too much and touch the nail.

A 0.23 mm copper wire was used to wrap a new coil, in hopes of getting better results, however the coil was not strong enough and was too big, so we proceeded to use the 0.22 mm wire that was being used previously.

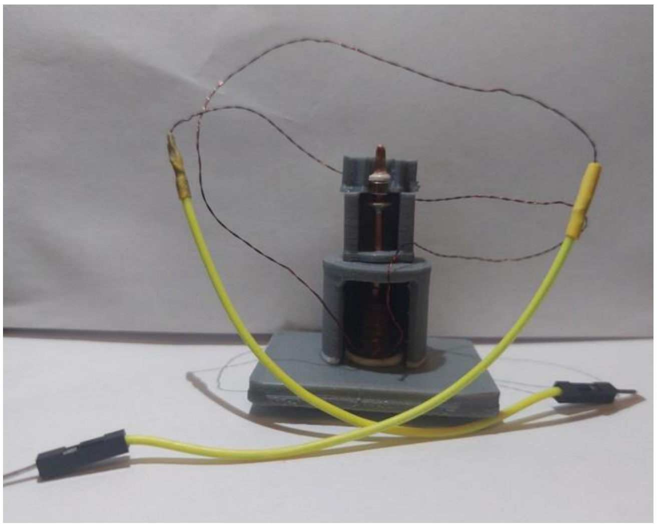


Figure 7. Third Design of the pin

Final Design

The overall design for the final version is similar, only the dimensions were changed, as can be seen in the schematic below:

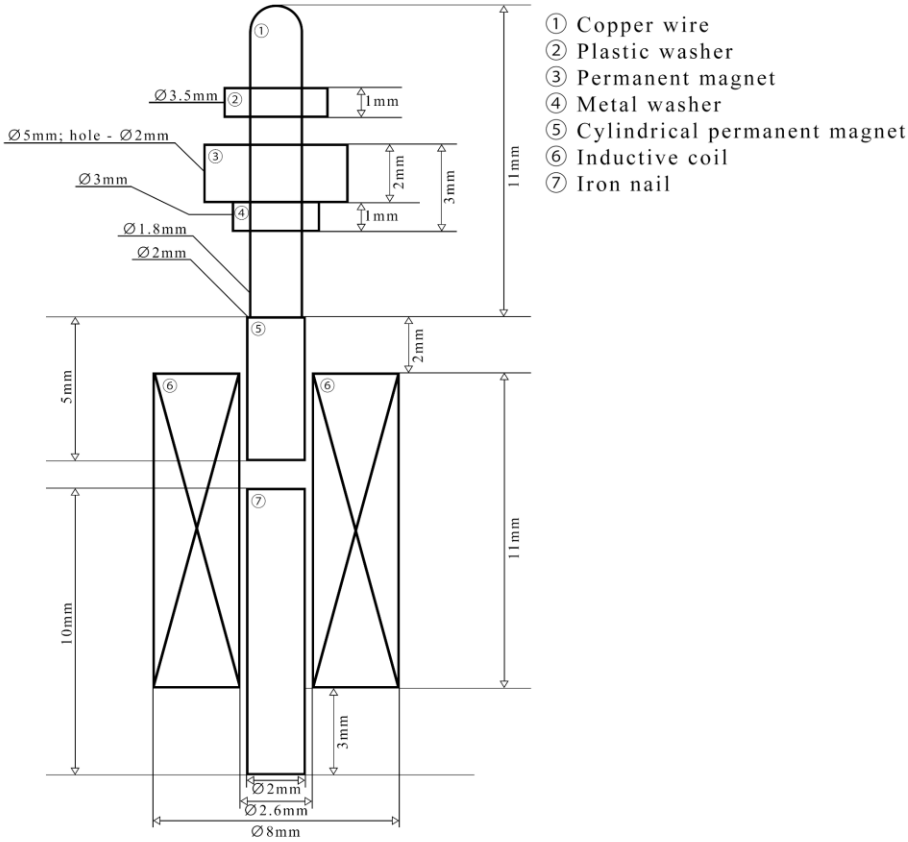


Figure 8. Schematic of the Final Design with Dimensions

Through experiments we found that the current pin is capable of moving up and down when operated with the coil of the following dimensions:

- Outer diameter - 10 mm
- Inner diameter - 2.5 mm
- Height - 9.5 mm
- Wire diameter - 0.22 mm
- Wire Length - 8 m

As we needed to wrap the 8 m of the wire, we were able to minimize it only by increasing the height. The smallest working coil currently has the following dimensions:

- Outer diameter - 8 mm

- Inner diameter - 2.5 mm
- Height - 11.5 mm

The coil also needs to be supplied with 0.9 A current to be able to move the pin. The supply is not directly connected to the coils, rather an h-bridge is connected to the supply, and then powers up the coil. Considering the internal resistance of the h-bridge, the coil (5 Ohm) a 12 V and 5 A power supply was chosen to be able to move the pin. The power supply can be replaced by a battery with the same characteristics.[4] As mentioned, the battery life is not expressed by hours, but by the number of pages that can be displayed until the battery needs to be recharged.

Based on the current rating of 0.9 L239B h-bridge was chosen for operating the coil, as it can supply 1A of continuous current. In our case, the pin requires only a 10ms impulse of 0.9 A current to move up or down, and then it keeps its current state without any power consumption, until the page is changed. Below you can see the calculations of the battery life for a tablet with 14 characters.

- Current consumed for displaying one page ($\underline{I}$) = $0.9 * 14 * 6 = 75.6\ A$
- Supplied Voltage $(V) = 12\ V$
- Time required for the pin to switch (t) = $0.01 * 14 * 6 = 0.84\ s$
- Energy required for switching (E_{sw}) = $\underline{I} * V * t = 762\ V * A * s$

For the referenced battery (Combination of four 3.7 V and 5000mAh batteries):

- Energy stored in the battery (E_B) = $5 * 14.8 * 3600 = 266400\ V * A * s$

Number of pages that can be displayed, without needing recharging =

$350\ pages$

This calculation does not consider that other schematics also take up current during the reading, however that number is small and won't affect the overall result by a lot.

Below are the standard braille cell dimensions:

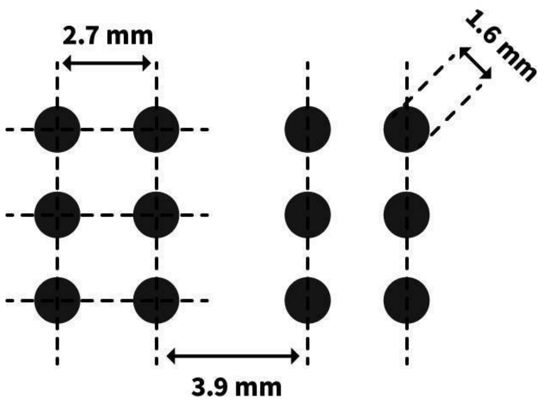


Figure 9. Standard Dimensions of the Braille Cell

Below are the final dimensions of our cells:

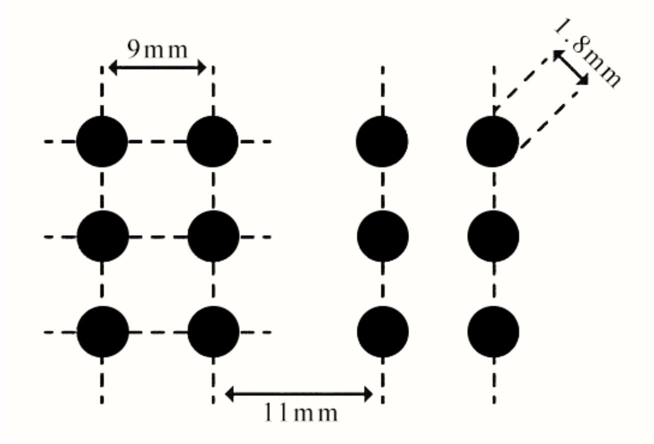


Figure 10. Dimension of the Our Braille Cell

The size of our character is significantly larger, however it is readable (all pins can be felt by one finger). There are several reasons for the size difference. First, the smallest magnets we could find and used had a 5 mm diameter, so the standard dimensions were impossible to achieve. The pin was made and filed down by hand. The washers (both plastic and metallic) were also made by hand. The nails were cut and filed down by hand as well with the help of the drill bit. As the entire pin is made by hand and are not identical, the nail height has to be adjusted for each one separately, so making even one character is very time consuming.

The coil was wrapped using a drill bit. All this can cause asymmetry both in the pin and coil. The asymmetry makes the movement harder, as instead of moving the pin up or down, the coil would move it sideways. This would make the pin touch the ring magnet and this results in friction. To overcome this friction, we use a larger and stronger coil. Hence the overall size of the cell becomes larger.

If the creation of the pin and the coil becomes more automated, reducing any asymmetry and making the system components more identical, the size can be reduced.

3.2 Circuit Components

The system circuit consists of two components:

- 74HC595 shift register to transfer the data obtained from the Arduino. One shift register can transfer data to eight pins. The shift registers are powered by the Arduino (5 V).
- L293B h-bridges to drive the pins. H-bridges were used, so that the polarity of the coil can be changed. One H-bridge can supply power to two pins. The h-bridge Power 1 (Logic) is powered by Arduino (5 V). The h-bridge Power 2 (the supply that actually drives the pins) is powered by a 12 V power supply.

Overall, two shift registers and four h-bridges are used to control the one cell that will be presented for this project. Since each H-bridge controls the direction via a pair of input pins, the first shift register sends a signal to the first pin of each pair and second shift register sends to the second pin for each pair. The second shift register is called the “inverse shift register” due to the fact that if the first register sends a HIGH value signal then the inverse shift register will send a LOW signal to the rest of the pins. This allows the control of the direction of each inductor.

Below you can see the circuit for a single cell, made in TinkerCAD with the purpose of simulation and testing of the connections and the code.

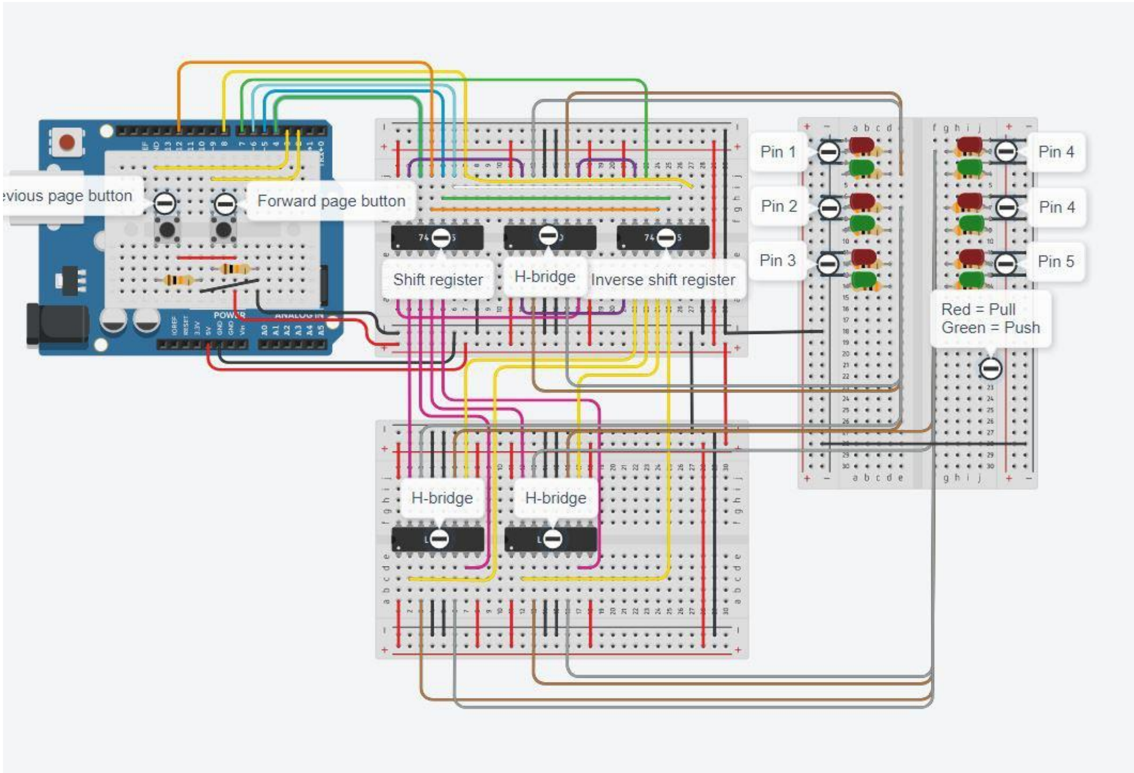


Figure 11. Prototype Circuit Design Simulation for a Single Character

The motors in the picture are stand-ins for the pins. In the diagram, L293D is used instead of L293B as the latter is not available in TinkerCAD. The two have the same pinout, the main difference is the continuous current rating.

An SD card is connected to the Arduino for reading the text.

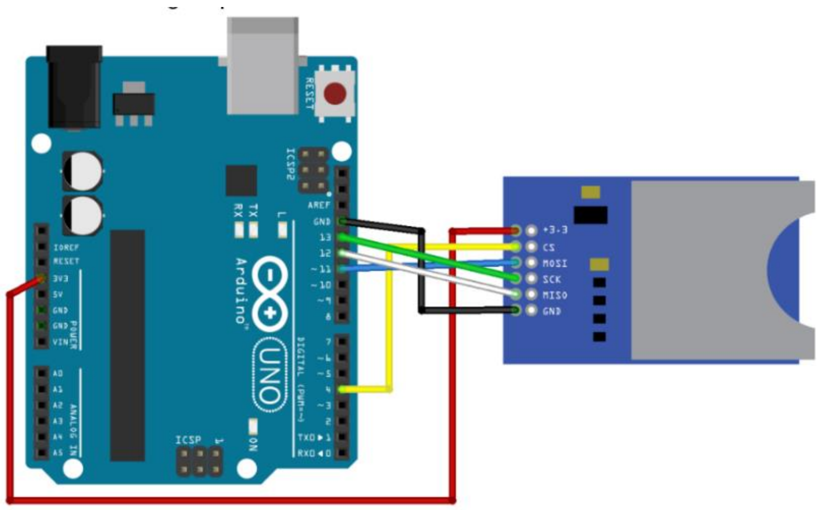


Figure 12. SD Card Connection Diagram

The entire system, including the Arduino, is supplied with a 12 V 5 A power supply. As the pins do not require a continuous supply of voltage to keep their current state, the power supply can be replaced by a battery that has the same characteristics as the power supply. This makes the tablet portable. As the required current and voltage ratings for the pin were found quite late, we did not have the time to order these batteries, but they are available in the market (reference).

There are three buttons on the tablet. One for turning on, one for going to the next page and the other for going to the previous page.

3.3 Software

The flowchart below (Figure 13) explains the process the software goes through. Right after the user starts the tablet, it goes through an initialization stage, where it receives the information of the book that is placed in the sd card and the size of a single "page" (which is the maximum number of characters the tablet has). In order for the tablet to find the book from the sd card, the user must first add a text file with the name "Book.txt" in the sd card.

The text file should include the text of the book of their choosing. If the user does not add the text file ten the tablet will not do anything and just return an error message in the software.

After the tablet finds the file, it first sets its position to 0. This position is a cursor that shows where the text file the tablet will be receiving information from. In this case, position 0 means it is at the beginning of the book. After setting up the position, the tablet then takes a number of letters from its current position, the number of letters depending on the size of the "page". This makes the tablet adaptable/modular.

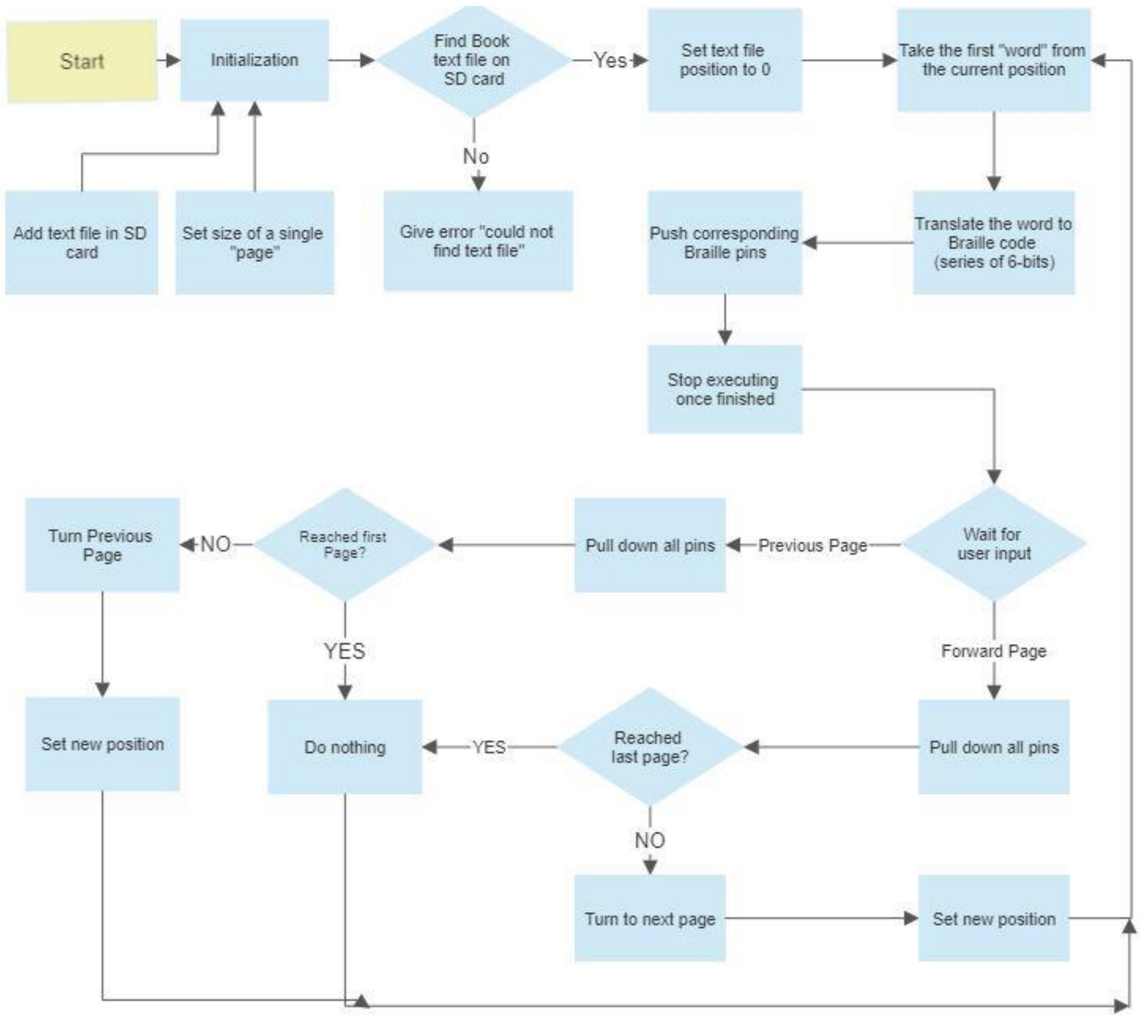


Figure 13. Code Flow Chart

The tablet reads the letters by their ASCII value, which it translates to the appropriate braille value, in binary format. in the binary value, the 1's shows which pins will be activated (pushed up) and the 0's show which pins will remain inactive. The left most bit represents the first pin on a character and the 6th both represent the last pin. Figure 11 shows the location of each pin by their associate number, from pin 1 to pin 6.

After determining the braille code, the tablet begins the execution process. which is the activation of the appropriate pins on the tablet. Figure 14 shows a visual understanding of the process.

Once the prior conditions are met, the process of execution starts:

1. The tablet sends a bit with a value of 1 into the Data input of the shift register, which is located under pin 1.
2. The tablet then checks the braille value for pin 1. If the bit value of pin 1 is equal to 1 then a signal is sent to the shift register's enable pin, which lets current pass through the pin 1 motor.
3. After ample time (10 ms) the the enable pin is turn off, leaving the physical pin to stay up due to the magnets holding it in place
4. The tablet then inserts a bit with the value of 0 into the shift registers Data input. This makes the previous bit with the value of 1 to be shifted to the right, under pin 2. As shown in Figure 14
5. The process continues until the last pin is reached

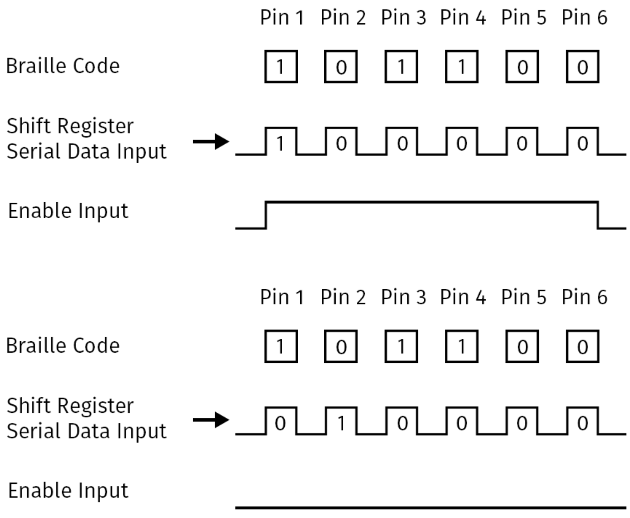


Figure 14. Braille pin execution using shift register enable input

After it's done executing the braille code. the tablet waits for the user input, in this case the user either presses the *forward page* button or the *previous page* button. Once the user presses any of the two buttons. The tablet then pulls down all the pins, the process is the same as the execution process, however the only difference is that the bit is inserted into the inverse shift register shown in Figure 11.

If the user presses the *forward page* button, then the position within the text file is updated, increasing the number by an amount determined by the “page” size. and decreasing the number by the same amount when pressing with the *previous page* button.

In both cases, a safety measurement code is written, which allows the tablet not to update its position when trying to access a page beyond the range of the text file.

As shown in Figure 13.

The software then loops back to receiving information from the text file in the new position and continues the process as mentioned previously.

3.4 Cover Models

As there were several pin designs, various covers were designed to hold the pin to help perform tests. All of the designs were made in SolidWorks. All of the prints were made using ABS or PLA filament.

First Design

Below is the 3D model of the first cover:

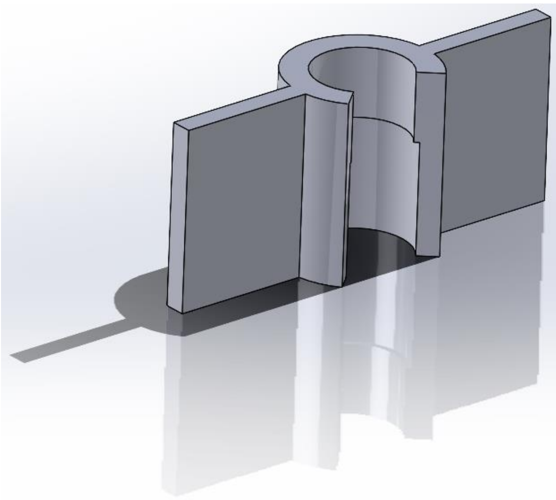


Figure 15. 3D Model of the First Design

As can be seen, it only holds the magnet and there is no base for the pin to stand on its own and no holder or enclosure for the coil. This made the testing quite tedious, as we had to hold the pin and the coil so they were stationary, as it is supposed to be.

Second Design

Based on the problems with the previous design, a base was added to the capsule, so that the pin can stand on its own and there was a larger area at the bottom, where the coil could fit.

However, there was no place to attach the coil to and, because of that, during the tests the when connected to supply the coil would move instead of the pin.

Also, the metal washers would touch the walls of the cover, causing friction which would prevent the pin from moving up/down.

Third Design

For the third model, the cover consisted of three different parts. The top part would hold the magnet and the diameter above the magnet is larger, so that the washer moves without touching the wall. The middle part was for holding the pin and for the movement of the bottom washer. It also had a diameter larger than that of the part for holding the magnet. Again, so that the washer could move freely without touching the walls. The third component was a rectangular piece to which we attached the coil. All of the three components were glued together afterwards.

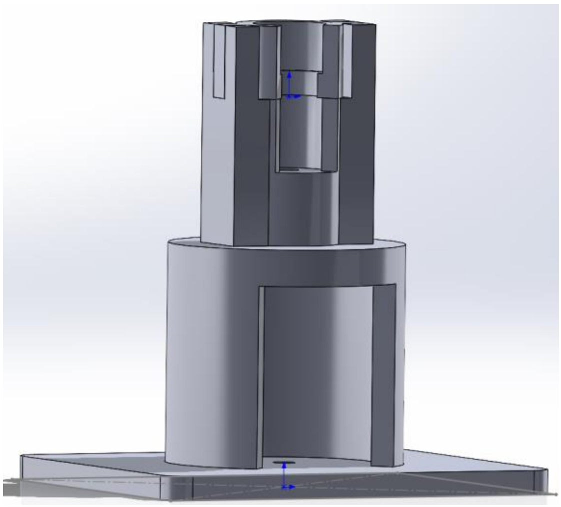
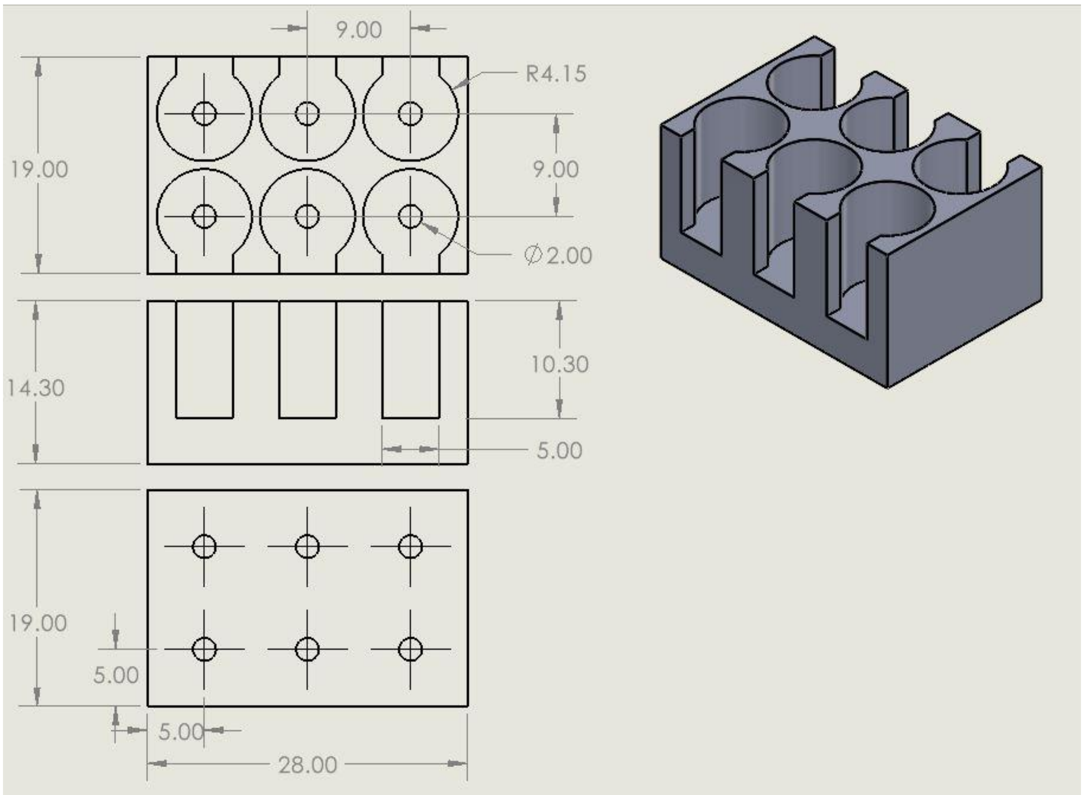


Figure 16. 3D Model of the Third Design

Final Design

The final cover has the six pins next to each other. It consists of three parts. The base, which is holding the coils and for each, right in the middle, there's a 2 mm hole for the iron core. The sides are open, so the coils are visible for presentation purposes. The second layer is holding the bottom half of the pin and the magnet. The third layer sits on top of the second layer, holding the top half of the magnet. The top layer has six 2 mm holes, so that the pins can protrude through them and the user can read the letter. The top and middle layer are the same, just inverted.



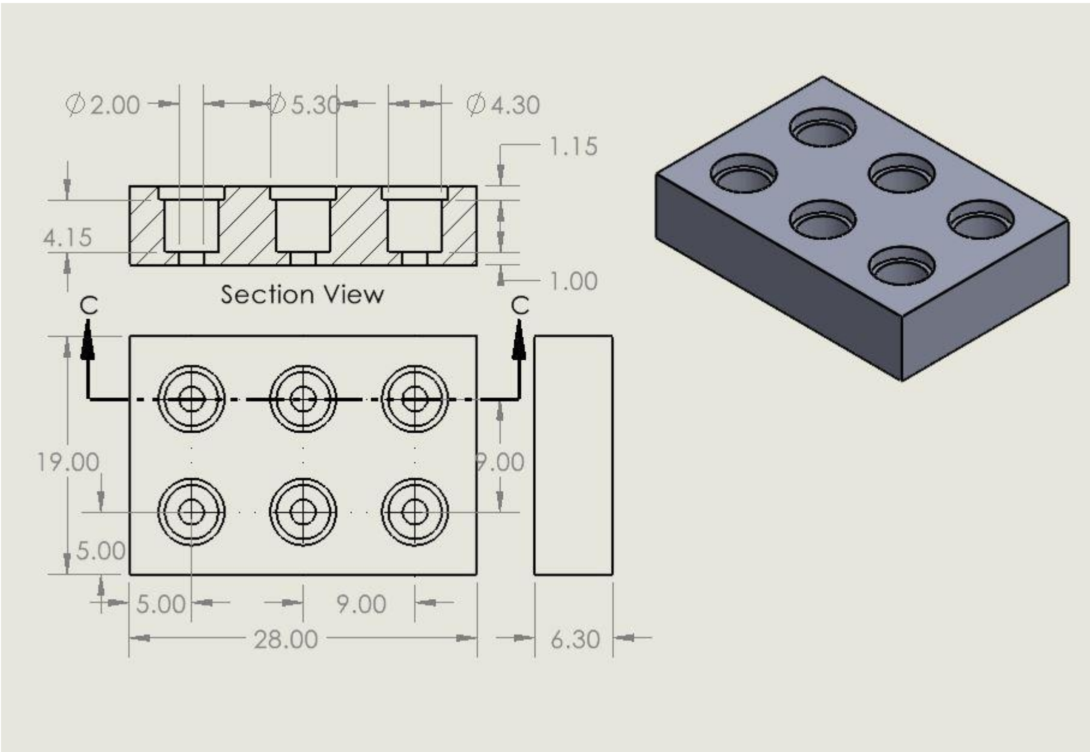


Figure 17. 3D Models and Dimensions of the Individual Components

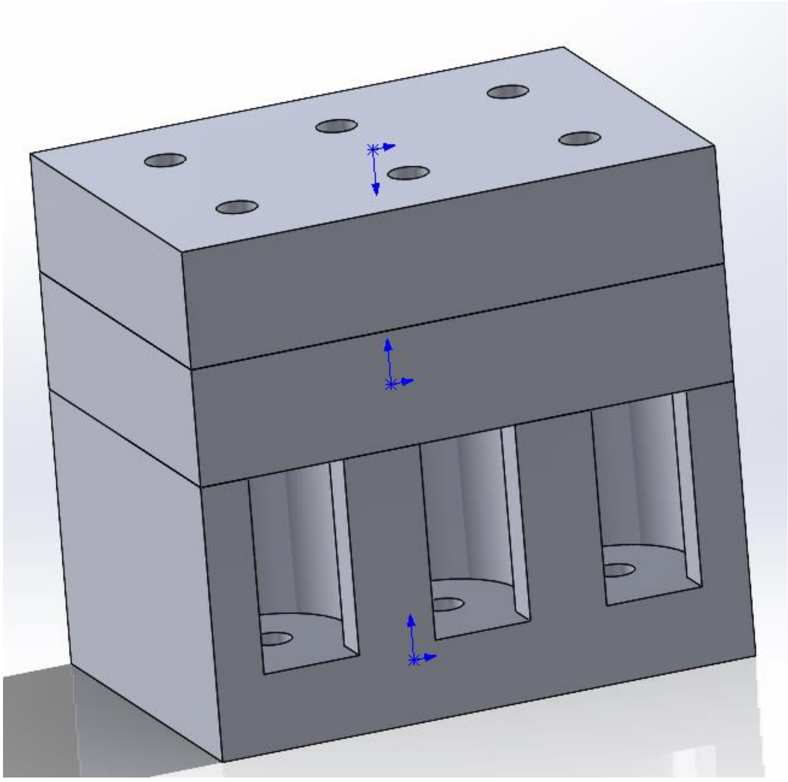


Figure 18. 3D Model Assembly of the Final Design

4. Physical Environment

The tablet is made for everyday use, under normal physical conditions. Therefore, it will not be made to withstand very high temperatures, pressure, or radiation and will not be operational in space. All of the aforementioned factors can affect the magnetic characteristics of the permanent and electro- magnets. Wind would not interfere with the work of the system. For now, the system will not be waterproof. Because the working principle of the system is based on the permanent and electrical magnets, it will not be operational in high magnetic fields. The system should be handled carefully. If dropped, might be displaced and will not be able to move properly. If this happens, each malfunctioning character or component should be replaced as soon as possible to avoid damaging other components. Upon repair other components should be checked to make sure that other components are not damaged as well.

5. Support Environment

All individual components of the system are modular, meaning they can easily be replaced by someone from our team lest anything should happen to them, and that will not affect the operation of the rest of the system. This pertains to both mechanical and electrical components.

If characters are to be added on the tablet, besides adding the hardware, the source code of the controller will also require minor modifications in configuration.

Currently the system works with a power supply. However, it can also be powered by Li-Ion rechargeable batteries.

6. Operational Scenarios, Use Cases and/or Design Reference Missions

Upon the proper implementation of the system's hardware, the tablet is able to identify the SD card being inserted. The pins are able to move easily, with almost no friction disrupting its movement. Currently, occasional errors are possible, but upon further development those will be rare. The magnets are able to hold the pins in their positions when little pressure is applied by the user with no use of electrical current, but they are relatively easy to push down. This will also be fixed in the future.

The system's software, loaded in the Arduino, is able to read the information provided by the SD card, translate it to a braille system, and separate each character to fit properly within the tablet.

7. Impact Considerations

7.1 Environmental Impacts

The case of the tablet is made of ABS filament, to make the system as light as possible. The first issue with this will be the mining of the material from the Earth and also the disposal of plastic after the use. Both can be environmentally damaging.

The tablet consists mainly of magnets. Unfortunately, magnets play a role in global pollution and climate change. Magnets are made from non-renewable resources like metals and rare-earth metals, which are mined directly from the Earth, a process that causes significant destruction to natural ecosystems.

7.2 Organizational Impacts

If the system becomes a commercial product, we will need mechanical and electrical engineers who would further develop the tablet to add new features to it. We would also need embedded systems engineers to constantly upgrade the program according to hardware updates (even without the hardware upgrades, some new features may be added).

7.3 Scientific/Technical Impacts

We are not making any new scientific discoveries and the concept of the pins we use is not new as well. What we did is apply known technology to an existing problem. Of course, other technology in this field exists, but the research shows that the systems are often very expensive, heavy, and cannot be used without constantly being connected to a power source. The technical impact of the system is the implementation of the magnet-controlled pins which makes the tablet light, portable, cheap and energy efficient.

8. Risks and Potential Issues

Size: Since the dimensions of each cell are rather small in scale (a few millimeters), our components such as the magnets and the coils need to fit within certain parameters. However, small scale components were hard to find.

Magnet strength: One of the key features of our tablet is that it allows the magnets to hold the pins in place without the use of electricity. While the magnets can hold the pins up, it might let loose after touching the pins when reading.

Imperfections and human error: For the prototype phase, we made the tablet by hand, which might result in unforeseen issues. For example, the inductive coil is not exactly uniform, or the pin and the washers are not symmetric which creates friction that affects the pins from moving up and down. Normally, such imperfections are negligible, but since our cells are small in scale, the errors these imperfections cause are significant.

9. References

9.1 Applicable Documents

- [PDF] An innovative idea for low cost Braille e-reader
- [PDF] A Portable eBook Reader for the Blind
- (PDF) A cost effective electronic braille for visually impaired individuals
- Inductive Coil

9.2 Reference Documents

[1] Daniel, D. B., & Woody, W. D. (2010). They Hear, but Do Not Listen: Retention for Podcasted Material in a Classroom Context. *Teaching of Psychology*, *37*(3), 199–203.

[2] Canute Braille E-Reader

[3] Distribution of Word Lengths in Various Languages

[4] Li-Ion 3.7 V 5000 mAh Batteries

Appendix A: Acronyms

SD - Secure Digital

USB - Universal Serial Bus

PC - Personal Computer

Appendix B: Glossary of Terms

Character - a single letter that is comprised of 6 braille pins

Cell - A container that holds the mechanical components to write a single character

Appendix C: Bill of Materials

Bill of Materials