Digital Reader: A New Approach to Modern Reading for the Visually Impaired

SR-EAST2-135

Abstract:

Visually impaired people often have difficulty reading documents. Current technologies support converting digital text documents into braille or audio for them to use. This product provides visually impaired people with more options for reading printed texts, such as books, at a relatively low cost compared to current braille displays available on the market.

Software-hardware interactions will be the primary area of exploration for this research project. The product will first collect text from paper and, using Python algorithms, detect and convert the text into electronic signals. These signals will be transmitted through a USB-to-TTL adapter to power an electromagnet that displays braille. 3D printed structures will serve as the braille dots and braille brick during the display process, they will lift up due to the magnetic field which imitates a non-refreshable braille brick.

The detected and final braille outputs will be compared with the original text to analyze the product's validity. Data will be manually collected to calculate the detection accuracy. The product achieves its intended purpose while maintaining low usage costs, as some of the required materials are easily found in households.

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List of Abbreviations:

AI	Artificial Intelligence
USB	Universal Serial Bus
EMALS	Electromagnetic Aircraft Launching System
MOSFET	Metal-Oxide-Semiconductor-Field-Effect-Transistor
TTL	Transistor-Transistor Logic
RPI	Raspberry Pi
CAD	Computer Aided Drawing
GPIO	General Purpose Input/Output
PCB	Printed Circuit Board

1 Introduction

1.1 Background

Around 2.2 billion people around the world have a visual impairment. About 40 to 45 million people are completely blind and require assistive technologies. Reading is a critical part of daily life, blind people read by feeling braille on their fingertips. A braille version of printed text, say books, is needed for blind people to read. Braille costs extra money and resources to create, which means more expensive. The high cost decreases the accessibility of information to the blind, lacking the same opportunities as normal people in places like the workplace.

Current solutions toward the hardship are mechanical braille displays; one braille cell requires six mechanical arms to display, with over twenty cells per board. This design has a high risk of breaking, and they are nearly immovable. Most importantly, they are insanely expensive, with up to 3000 dollars per display. Another solution is an audio converter. Audio converters are effective, but they lack privacy. When blind people are reading personal documents that require audio conversion, there's a risk of it being overheard by others.

Using the inspiration from current designs, a system using electromagnetic power can complete tasks of braille display effectively. They do a better job at quick conversion tasks due to the low latency. Electromagnetic displays are lighter than mechanical displays, and provide more privacy than sound converters, making them a better and a new solution for modern reading for the visually impaired.

1.2 Modern Applications of Electromagnetic Mechanisms

Magnets exert repulsive forces towards the side with the same dipole force, N repels N and S repels S. Engineers use this trait magnets to create trains that don't have wheels and go up to 430 km/h.

Repulsion in magnets is also used militarily. EMALS exploits the repulsive forces to launch aircraft on aircraft carriers like the USS Gerald R. Ford, constructed in 2015. Traditional approaches for aircraft launching are steam-powered launchers. They are heavier compared to EMALS, and they consume more energy than EMALS. EMALS is also able to launch heavier aircraft as the repulsion force can be adjusted.

1.3 Magnetic Forces to Lift Braille

Ampère's right-hand rule states a magnetic field (B) is created by a coiled wire carrying current (I). Figure 1.1 represents a wrapped hand mimicking an electric coil on a conducting cylinder, where magnetic fields are found on both ends of the cylinder, which is the direction the thumb is pointing.

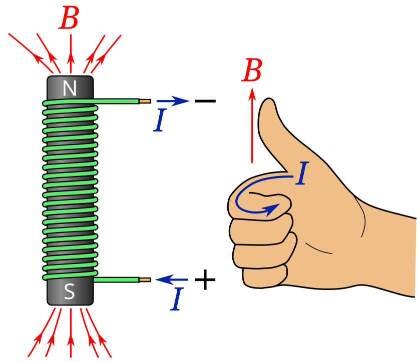

Figure 1.1

A wide application of electromagnetism is to use it as a solenoid. A solenoid turns electric power into mechanical work by using the magnetic field created by the introduction of an electric current into the coiled wires. The magnetic field can be calculated by Formula 1.1, where *B* is the flux of the magnetic field, *n* is the number of turns of wire in the solenoid, and $\mu 0$ is a constant with a value of $4\pi\times10^{-7}$.

$$B=\mu_0 nI$$

Formula 1.1

Magnetic force between the magnets can be calculated through Formula 1.2, where F_{mag} is the magnetic force between two magnets, B_1 and B_2 are each magnet's magnetic flux, and A is the area of the magnets.

$$F_{mag}=\frac{B_1 B_2 A}{2\mu_0}$$

Formula 1.2

Now the number of coils on a solenoid needed can be calculated.

1.4 Hypothesis

Camera-captured images can be transformed into signals that control current flow into electromagnets which ultimately lifts braille cells to have the users feel and be able to read texts.

1.5 Data Analyzing Method

Manual data collection is required for this project. Displayed brailes are compared to actual scanned text to test their accuracy. Figure 1.2 shows a braille alphabet that is used for comparison. Formula 1.3 calculates the percent accuracy of the displayed text. Data will be used for future optimization.

$$Accuracy = \frac{\#\ Detected\ Accurate}{\#\ Detected\ Text} \times 100\%$$

Formula 1.3

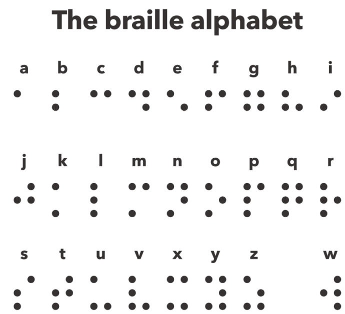

Figure 1.2

1.6 Purpose

Create an affordable, easy-to-carry, user-friendly braille display device that seamlessly integrates software and hardware to benefit the visually impaired community by maintaining the cost of manufacture under $120 and a dimension of 4×5×4 inches cubed.

2 Method

List of Materials:

Raspberry Pi
Soldering rod and soldering iron
Python 3.12
1 mm height and 2 mm diameter cylindrical neodymium magnet
Various paper clips
0.1 mm copper wires
3D printed structures
Jumper wires
6×MOSFETs
Windows laptop
720p USB camera module

2.1 Assembly of Electromagnets

Paperclips are good materials to use for constructing an electromagnet. The conductivity and flexibility allow it to be reshaped into a thin metal rod. A plier applies force to curved parts to straighten them. A coil is necessary to make an electromagnet. To satisfy the size constraint of this project, thin copper wires are ideal. A 120-turn coil of copper wire is tested for repulsion strength against a neodymium magnet and turns out successful at repulsion. Figure 2.1 is the initial electromagnet created.

2.2 Image Capture

To capture images for text recognition and processing, a camera is necessary for its fundamental functionality. A 720p USB camera module from Amazon functions properly. An adjustment of the focal point is needed to achieve the purpose of image capture at a fixed distance. Figure 2.2 is the camera module with adjusted focal length.

2.3 Structures

3D printing technologies are utilized in this project. CAD software Autodesk Inventor provides thorough functions necessary for the development of components. The dimensions of the camera are taken into account for a customized structure of the camera holder. Figure 2.3 shows the initial computer prototype of the camera holder.

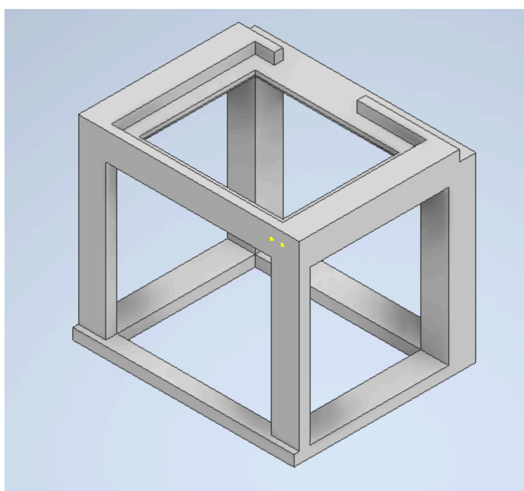

Figure 2.3

The first prototype contains design flaws. The legs are too weak, and cannot hold a heavy pressure exerted onto them. An enhancement of durability is applied by adding the thickness of the leg. The braille displays utilized 3D printed technologies, also. Figure 2.4 is the initial prototype of the camera holder and braille display printed. The first prototype was a failure. The printer made errors due to technical issues.

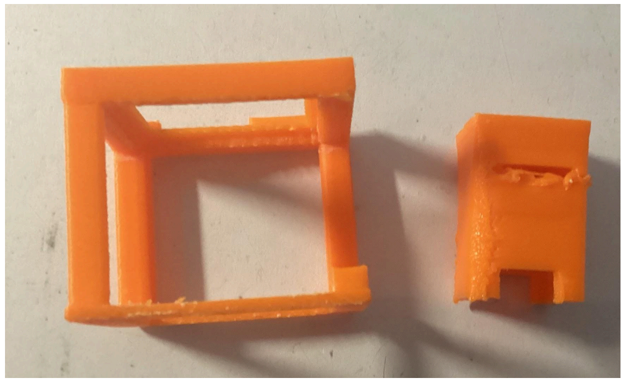

Figure 2.4

Another attempt was made, but due to technical issues with the printer, the holes to fit braille cells did not print. Figure 2.5 shows the lack of holes.

Figure 2.5

To print these small structures accurately, a high-precision printer is needed. TE Connectivity liquid printer was utilized. Liquid printers allowed high precision of up to 0.5 mm of structures. The printers at a local technology company printed all necessary parts, including the camera holder, braille board, the braille cell with holes to fit magnets, and the stand for electromagnets. Figure 2.6 shows all the printed components used.

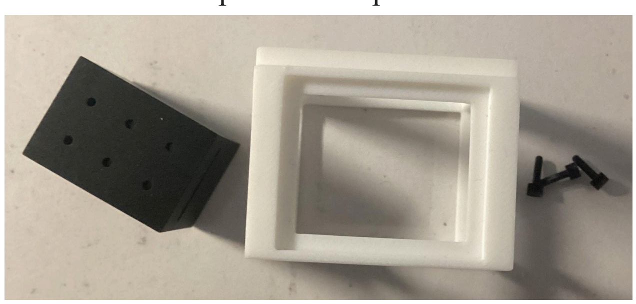

Figure 2.6

2.4 Software/Hardware

Python is chosen as the programming language utilized for this project. DeepSeek AI is used for assistance with the composition of the software section of this project. The software framework with the logic is presented in Figure 2.7.

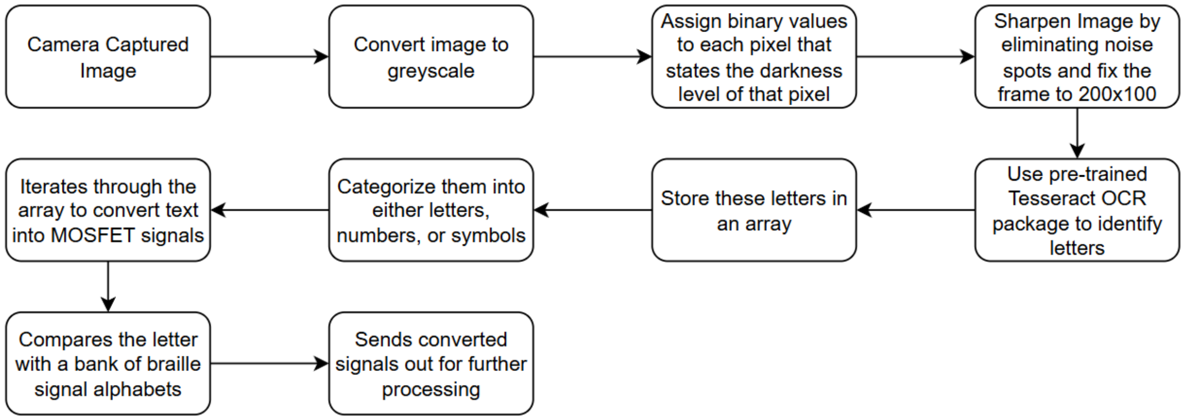

Figure 2.7

An RPI is needed for signal processing. Signals are delivered to a USB to TTL converter, the TTL converters deliver the signals to RPI's GPIO pins. Signals delivered by the TTL converter cannot control individual braille cells, thus an external computation is needed. RPI is specifically chosen due to its customizability, the vast amount of GPIO pins, and its ability to multiple GPIOs at the same time. A framework integrating RPI is represented in Figure 2.8.

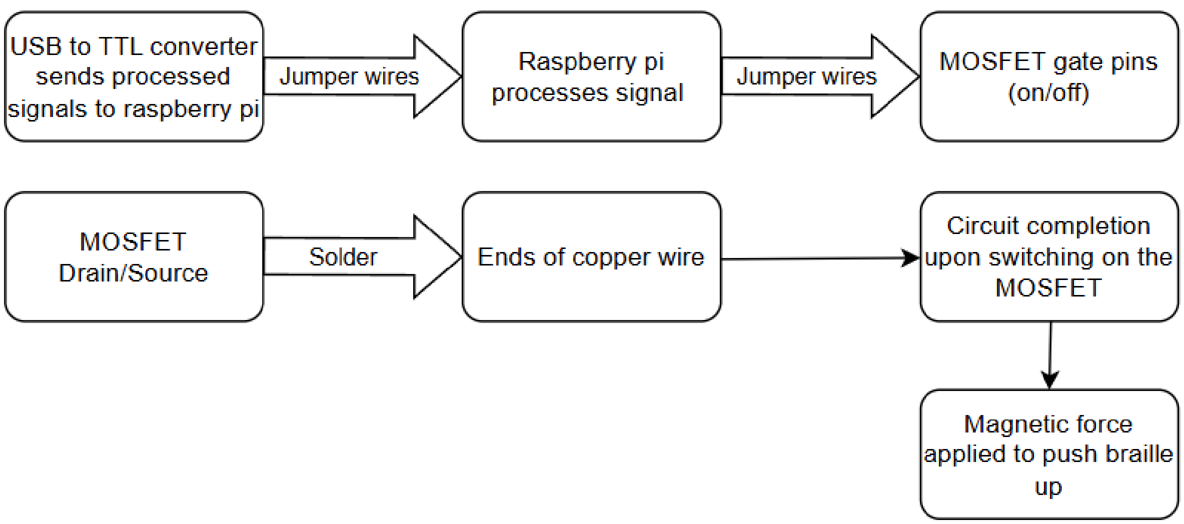

Figure 2.8

2.5 Assembly and Testing

The Python program is fed with text and calculates its accuracy. The entire prototype is connected and tested for the accuracy of the braille display. Figure 2.9 is the completed product.

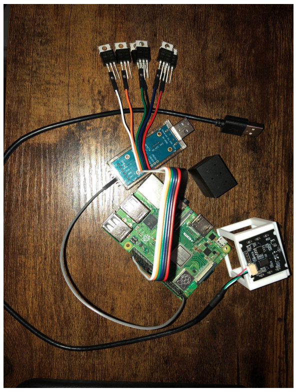

Figure 2.9

2.6 Statistical Testing

The selected text with 214 pages was used to test. To randomly select a piece of 40-word text, the Texas Instruments calculator TI-84 Plus CE was used to generate a random number between 1 and 214 to locate the page number for text recognition. Since there are, at most, 26 lines of text, a random number between 1 and 26 is generated to locate the line number for word sampling. The sample starts from the first character of the line and consists of 30 characters. If the 30-character limit exceeds the next page, move to the next page for more characters. A one-sample z-interval for the proportion test will be run to test the confidence interval for the accuracy of text detection, and using that data, a one-sample z-test for the proportion test will be run to reject/fail to reject the null hypothesis. All conditions for a one-sample z-interval test and a one-sample z-test are met. The goal for accuracy, or the proportion of correct identification, is 98%, or 0.98. The significance level, α-value, is 0.05 for a z-test.

3 Results/Discussion

3.1 First Attempt

The TI-84 Plus CE generates 74 for the page number and 26 for the line number during the first attempt. The algorithm detects 23 of the 30 characters correctly. The 95% confidence interval lies between 0.61532 and 0.91802, so we are 95% confident that the true proportion of accurate detection lies between 61.5% and 91.8%, far below the goal of 98% accuracy. Figure 3.1 depicts the calculator output.

Figure 3.1

The one-sample z-test provides a chance of getting the result just by random chance, assuming the null hypothesis is true. When the probability of getting the current result is below the significance level, in this setting is 0.05, it is suggested that the alternate hypothesis is true. The null hypothesis will be $p=0.98$ and the alternate will be $p<0.98$. Figure 3.2 calculates the probability of getting a 23 out of 30 accuracy if the true proportion of accuracy is 0.98.

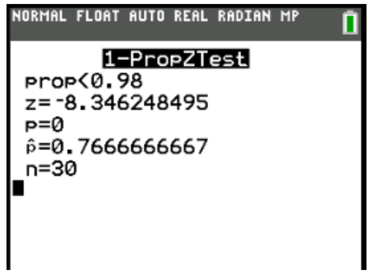

Figure 3.2

A p-value of 0 (in this case, it was so small that it exceeded the precision of the calculator), gives strong evidence that the alternate hypothesis is true, as there is almost no chance for 23 out of 30 characters detected by a 98% accurate algorithm. This further proves that the algorithm needs refinement.

3.2 Second Attempt

DeepSeek assisted in finishing the refinement of the algorithm to increase accuracy. The second time, the calculator chose page 173 and line 25. Out of the 30 characters, the algorithm can detect 28 characters. A 95% confidence interval includes (8.4407, 1.0226), which does include 0.98. So now the true proportion of the refined algorithm may be any value in between the bounds of the confidence interval. Figure 3.3 represents the data analysis of the refined algorithm.

Figure 3.3

To further verify the validity of the refined algorithm, a one-sample z-test is utilized. A significance level of 0.05 is still used and the alternate hypothesis is still $p<0.98$. Figure 3.4 displays the calculator output.

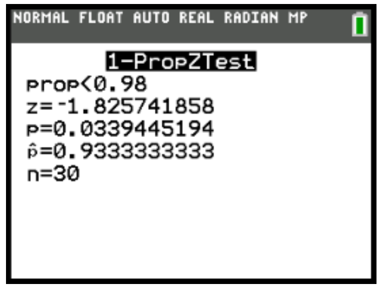

Figure 3.4

The p-value of 0.03 is still less than the 0.05 significance level, meaning the chance of obtaining a 98% accuracy is not successful. The algorithm needs to be refined again to achieve the goal.

3.3 Final Attempt

Final Attempt was performed and the results were a 30/30 accuracy at a singular sample on page 45, line 15. A 30/30 indicates solid accuracy of text detection, but a test is needed to be sure that the next step of analysis can be used. A 95% confidence interval calculated would give (1,1), the calculator is sure that the proportion of accuracy of the sample is 100%. As indicated by Figure 3.5.

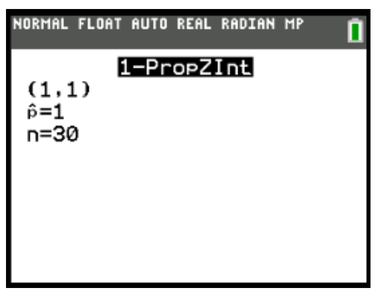

Figure 3.5

A z-test to determine the probability of getting $p<0.98$ is implemented using current data. Where the calculated results are shown in Figure 3.6.

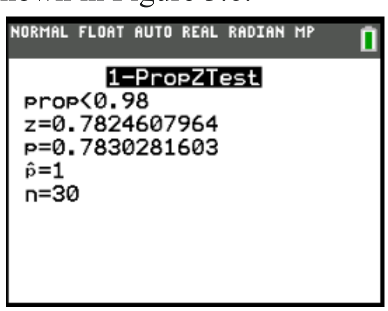

Figure 3.6

The p-value is now boosted to 0.78, above the significance level of 0.05. The null hypothesis cannot be rejected as there is no sufficient evidence to prove the null hypothesis of the proportion of accurate detections being 0.98 wrong. This leads to further testing on the braille display part of the project.

The summarized data are presented below in Table 3.1.

	Trial 1	Trial 2	Trial 3
p-value	≈0	0.0339	0.7830
Below α?	Yes - reject null	Yes - reject null	No - fail to reject null
95% confidence	(0.61532, 0.91802)	(0.84407, 1.0226)	(1,1)
Include 0.98?	No	Yes	Above 0.98

Table 3.1

3.4 Hardware Testing

Since the refinement of the program included the refinement of MOSFET control, the first attempt achieved an accuracy of 30/30. Since the statistical test has been performed and concluded that there is no evidence to reject the null hypothesis, the hardware is deemed valid. The project prototype achieves the intended goal of accurately displaying braille.

3.5 Discussion

The results of this prototype demonstrate the capability of magnetic levitation on braille movement. There are more and more applications of magnetic forces in the world, they are everywhere. Magnetic forces are versatile and flexible. They appear in mechanical components such as rotational motors.

The malfunction of the printer was a crucial issue during the completion of the project. It prevented a quick and efficient manufacturing process of the braille display.

RPI uses an SD card for system storage. The RPI wouldn't boot initially as the system in the SD card corrupted. Technical assistance was needed to resolve the technical issues on the RPI.

Future development includes a refinement of the appearance of the prototype, moving the computation to a more mobile device to achieve the same purpose everywhere possible.

4 Conclusion

The results agree with the hypothesis that images captured by a camera can be converted into signals that control electromagnets, which lift braille cells, enabling users to feel and read the text, while maintaining the cost under $120 and a dimension of 454 inches cubed.

The statistical results suggest that electromagnets with 100 coils can provide enough magnetic force to push away miniature neodymium magnets that allow users to feel to obtain information. The software algorithm accurately converts printed text into braille signals.

A different approach for the completion of the project would be to use a customized PCB board to construct all the circuit systems after the signal processing. The project would then be more expensive but would benefit from the stronger structures. Due to budget constraints, a customized PCB cannot be achieved.

Acknowledgments

First and foremost, I would like to take this opportunity to thank my parents for supporting me throughout the creation of this project, economically and mentally.

I also want to thank my friends for providing the resources and hardware required for this project.

I would like to express my gratitude towards the local technological company for the technical support during my 3D printing process.

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Lastly, I would like to thank DeepSeek Inc. located in Hangzhou, China. They helped me save time when debugging the code.

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