Product: BraillEd
Team: UpliftEd

Abstract

*"**BraillEd** – Bridging the gap in **Braille Ed**ucation"*

BraillEd is a robotic device to help blind and partially sighted people learn braille, by allowing them to enter text via a braille keyboard or voice recognition and learn its corresponding characters on a refreshable braille display. The braille keyboard is supported with auditory feedback to allow users to verify their text. The robot also translates printed material to braille through a fixed camera to understand visual texts.

The previous demo showcased an exposed and partially Lego-based robot. For this demo we moved away from this, manufacturing a casing which the components are secured within to protect the user from movements. We have also changed the Lego railing in the second demo for a metal railing operated by a stepper motor for accuracy. Along with speech-to-braille used in demo 2, a vision-to-braille system was introduced which converted visual text to braille using computer vision. A scissor lift was introduced to interact with the display to also combat accuracy issues.

1. Project management update

1.1. Achievement of goals

- Support input using a braille keyboard [**partially achieved**]

  Unfortunately it proved impossible to source braille key caps through a university approved supplier. After some attempts at 3D printing them ourselves, it proved too difficult due to the size of braille.

- Have buttons which are easy to find without sight [**unachieved**]

  Due to focusing on more pressing design issues, we ran out of time to implement this. This is currently in progress for industry day.

- Have an external attachable camera mount. [**partially achieved**]

  We are yet to design a way to mount the camera in a way that is fully accessible to the users of our product, so we decided it was better not to mount it until then.

- Accurately display the braille output using 10 braille cells. [**partially achieved**]

  After our discussion with Elizabeth McCann (McCann, 2024), we realised that the speed with which words are displayed is very important, in order to to reduce the motor's latency we decided to experiment with lesser number of Braille cells (5 in this case), we are still testing this (refer to appendix).

1.2. Coordination of progress

We coordinated our work towards these goals primarily through the use of GitHub issues and GitHub projects, as together these allow us to specify start and finish dates for each task, as well as assigning them to individuals so we know who is responsible for getting a particular task done.

To ensure quality of code we decided upon a policy of implementing changes in branches and submitting pull requests for other members of the team to review and approve.[1]

Additionally, we introduced Github Actions[2] for continuous integration (CI). This process consists of triggering linting [3] and testing of the software upon every commit. We opted for *Ruff*[4] for linting due to its speed, extensive checks and its seamless integration with other tools. For writing unit tests, we utilised*Pytest* [5]. Lastly to piece all these components together with Github Actions, *Nox*[6] orchestrates everything effortlessly. We regret not producing a CI workflow earlier as it became an indispensable tool in producing more robust and readable software.

Whenever integration between the hardware and software was required, work on this was primarily done by the hardware and software leaders, while other members of the teams carried on with developing other parts of the system. This was made possible through the use of different branches on GitHub, enabling changes to sub-components to be made without risk of breaking ongoing integration work.

1.3. Allocation of time

The following is a summary of the areas of the project worked on by each team member, and the estimated total time each person has spent so far on the project.

Ol project management, budgeting, preparing for user testing, user needs and marketing/deployment research, software component integration and debugging, industry day poster, manufacturing and assembling hardware (200 hours total).

[1] Text duplicated from our previous report is printed in blue.
[2] https://docs.github.com/en/actions
[3] the process of analysing code for potential errors, bugs or stylistic inconsistencies.
[4] https://docs.astral.sh/ruff/
[5] https://docs.pytest.org/en/8.0.x/
[6] https://nox.thea.codes/en/stable/index.html

Nikodem software planning and management, speech-to-text, text-to-braille, mobile app, software component integration, software-hardware integration, user needs research, graphics and design for demos (200 hours total).

Florian market research, text-to-speech, flashcard mode [7] (76 hours total).

Poppy software-hardware integration, code for translation into braille, setting up data tables for contracted braille translation, research, static analysis and continuous integration (178 hours total).

Nikita Raspberry Pi setup, speech-to-text, text-to-braille, camera setup, image text recognition implementation, software integration, software testing, report writing, user needs research (180 hours total).

Souparna hardware planning and management, braille display engineering, CAD designing of the new rail system, error correction design, motor circuit design and integration, PCB design and soldering, hardware-software integration, manufacturing and assembly of hardware components (210 hours total).

Daniel braille display prototyping and testing, CAD modelling of 3D printed components and casing, motor mounting, developmental render of product, animation of render for demo (185 hours total).

Ripley braille display development and prototyping, construction of sliding rail, motor mounting, user test planning, construction of scissor lift, assembly of gear mount, full system integration (180 hours total).

Balint motor calibration and integration, quantitative test planning, quantitative testing, 3D modelling, manufacturing and assembly of hardware, hardware-software integration, prototyping, quantitative research (180 hours total).

1.4. Budget and technician time

We have spent £199 of our £300 manufacturing and purchasing budget, as detailed in Table 1. In addition to this, we have used 6 hours and 37 minutes of our 10 hour technician time allowance, as detailed in Table 2.

[7] This is a work in progress planned for industry day.

Item	Cost
1/2 sheet of 5.5mm plywood for old box	£10.27
1/7 sheet of 3mm plywood for old box	£2.38
880g PLA for plastic box	£22.00
100g PLA for braille wheels	£2.50
45g PLA for rod housing	£1.13
30g PLA for scissor lift	£1.00
11g PLA for motor mount	£0.27
47g PLA for rail attachments	£1.75
10g PLA for pulley wheels	£0.25
100g PLA for old gears	£2.50
1/4 sheet 5mm clear acrylic for lid	£6.50
1/8 sheet 3mm clear acrylic for gears	£2.63
1/20 single sided PCB blank	£0.75
135cm of 5mm aluminium round bar	£9.45
2x large stepper motor	£52.30
Telescopic poles for camera mount	£14.32
Raspberry Pi 5	£69
TOTAL	£199

Table 1. Breakdown of how we spent our allocated budget.

Item	Technician time
Laser cutting old box 1	0:30
Laser cutting old box 2	0:30
Laser cutting for lid	0:17
Laser cutting for gears	0:20
3D printing plastic box	1:00
3D printing for braille wheels	0:30
3D printing for rod housing	0:15
3D printing for scissor lift	0:15
3D printing for motor mount	0:15
3D printing for rail attachments	0:15
3D printing for pulley wheels	0:15
3D printing for old gears	0:30
Unsuccessful 3d printing	0:15
Cutting of aluminium rods	0:15
Drilling out gear holes	0:15
PCB manufacturing	0:30
Repairs for Raspberry Pi	0:30
TOTAL	6:37

Table 2. Breakdown of technician time allowance use.

1.5. Reflection

While we developed BraillEd with enthusiasm and no small effort, it was always an ambitious project. We aimed to plan for potential issues before they arose yet we still encountered difficulties in multiple areas, each which took their fair share of effort to account for.

One main issue we had was with timing, we as a team underestimated the amount of time that processes out of our control would take. This included manufacturing, such as 3D printing and laser cutting, and getting ethics approval in order to do user testing for our robot. Time constrictions meant we had to "crunch" close to the demo when materials became available and when issues arose in manufacturing meant we had little time to come up with another solution.

Although we did well to plan what we intended to do in regards to the development of the robot there are things one cannot plan for. Issues in the construction of the robot such as dynamic issues with moving parts or execution of motors and size constraints no matching our plan meant we often had to change our plan several times in development. We tried to stick faithfully to the original plan but whenever these issues arose we were often scrambling to get another plan before deadline was reached.

Despite unforeseen issues in development we were still pleased at our approach to this project, and in reflection did many things well. BraillEd is not the first braille support robot in SDP but ours is functionally better in multiple ways. Compared to other projects our system makes use of more letters increasing device usability. Our robot also can use contracted and uncontracted braille[8]. meaning it take the braille learning journey further. Additionally we have tried to target more functions than the other teams by succeeding in having both speech and visual text translators on our robot.

The systems used to make BraillEd are mostly unique, no other project has created a braille robot the way we have which we are proud of, we had to come up with our own system to combat the increased size of letters and it paid of. We also used custom braille tables in our software for are translating as well which is unique to our team.

We are very proud of the software we have developed, incorporating all the input methods in a way which can be controlled by the users using the buttons. It includes translation to contracted braille, image processing and speech recognition, as well as software to split the text into pages and control the motors.

We were also pleased to be able to meet with a relevant academic (see subsection 4.2) who helped us refine our image of what the robot can do and which market to target; this really helped us in development before demo 3 as it gave insight as to where the demand in the market is, allowing us to know what to supply.

2. Quantitative analysis and testing

2.1. Braille display testing

Testing of the braille display hardware itself is divided into 2 domains that focus on the repeatable accuracy of crucial components and the durability of the components following prolonged and continuous use respectively to allow us to determine exact points of failure within our multi-faceted system.

[8]Uncontracted braille has a one-to-one mapping from letters to braille characters, and generally learned first. Contracted braille adds contractions for commonly used words and letter sequences (Royal National Institute of Blind People, a).

2.1.1. Display Accuracy Testing

The outcomes of this test showcases the reliability of the BraillEd. The accuracy is crucially important as the alternative may lead to the user learning incorrect Braille representations.

Half Cell Testing The criteria for a successful half-cell test involves the correct display of every character on a single braille wheel (half-cell) in the correct order, with the requirement of resetting the wheel to blank between each character. This ensures our display actuating motor is well-calibrated and accurate in both directions. The outcome of the test Table 9 indicates that our system is accurate enough to be used a learning device for a single character or guaranteed the correct operation of the rail and lift system. Hence this part of the system works well.

Full Cell Testing In this test we carry out the half cell test but this time setting and resetting each half-cell in the first cell to one state and then moving on to the other half cell, until all the states are tested. The outcome of the test reveals only a 40% accuracy indicating that the rail system doe not work as intended (since this test depends on the combination of the half-cell test and the rail system, and the half-cell test passed as described above, the error must be with the rail). Hence, our robot cannot accurately set an entire letter for it to be used for learning and this issue needs to be prioritised.

Multi-Cell & Random Word Testing In this test we carry out the half cell test, but this time setting and resetting each cell to one state and then moving on to the next half cell, until all the states/cells are tested. Further, sometimes, random words were selected to be displayed. The outcome of the test reveals that BraillEd was unable to pass any test case, indicating a major flaw in the way the lift mechanism is calibrated, as it does not allow efficient meshing of gears. Combined with the inaccuracy of the rail (revealed from the previous test) which is still part of this test, it led to a situation where it was impossible to achieve the millimeter precision required by our design to function. As a result, we have planned several changes to our project plan to improve its accuracy (Appendix G).

The tests above exhaustively measure the performance of different systems in the Braille Display and their interactions between themselves, the tests are robust and are an accurate representation of the types of moment that the motors would have to perform regularly. However, there may be a possibility of missing some edge cases, so it is important to have mitigation strategies in place involving the use of an optical encoder to physically measure the state of each cell in the case of an error.

Test Name	Component Tested	Pass Count	Success Rate
Half-Cell	Cell Actuator Motor	5/5	100%
Full-Cell	Inter-Cell rail and all of the above	2/5	40%
Multi-Cell	Intra-Cell rail and all of the above	0/5	0%
Full-Display	Lift Mehcanism and all of the above	0/5	0%
Random-Word	All of the above	0/5	0%

Table 3. Results for each system's accuracy test

Repeat	Pass	Average time (seconds)	Reason for failure
1	√	0.87	—
2	√	0.87	—
3	√	0.87	—
4	√	0.87	—
5	√	0.87	—

Table 4. Half-cell accuracy testing result

2.1.2. Display Durability Testing

The durability of the system was measured by operating each of the 3 systems (the rail, the lift, the cell actuator), independently for 2 minutes, moving it from its initial position to its final position and back. The results of the test as per Table 6 indicated no issues, further we also shook the product vigorously while operating the device, the device passed all the tests. This means that the electronics and motors are mechanically sound and our design is durable and mechanical operates without failure.

The tests were elaborate enough to cover cases of extended use and travelling with the product, however these tests can be improved by also considering waterproofing and dropping the product.

2.1.3. Latency Testing

Latency of a refreshable braille display is an important feature that determines its usability, however since there is no other device in the market focused on aiding to teach braille and no other commercial product using the same technology as us, we were forced to set our own standards. We have decided on an appropriate time limit of 1 second per braille wheel, or 20 seconds for the entire display to finish the display operation and present the information to the reader. Exceeding these limits would mean for an impractical use case scenario.

As per Table 4 and Table 5, we fulfilled one of the time limit requirements, since we are able to set a single braille wheel in 0.87 seconds on average. However, further tests revealed that the current rail and carriage mechanism adds enough time for even the full-cell accuracy test to not fulfill our time limit criteria, taking 2.3 seconds on average.

2.2. Speech recognition

We employ VOSK[9], an open-source audio speech recognition (ASR) toolkit, chosen for its lightweight design, ideal for platforms like Raspberry Pi, and its offline capability. In a recent study (Whetten et al., 2023), VOSK exhibited higher Word Error Rates (WERs) [10] compared to some models. However, the study noted that despite higher WERs, VOSK showed low Error Output (EO), making it a promising candidate for speech-driven systems requiring high accuracy, low latency, and minimal error output, such as in "robotic platforms". This context underscores VOSK's suitability for BrailleEd which after all is a robotic device. Nevertheless, a longer project duration might prompt exploration of other local ASR models, such as DeepSpeech (DS), an open-source model by Mozilla, which performed better in the study. Its repository also suggests suitability for Raspberry Pis, providing an alternative worth considering.

2.3. Text-to-Speech

We utilise pyttsx3[11] for the text-to-speech functionality. This feature is of utmost importance as it provides auditory feedback to the user, aiding in learning how to touch type around a keyboard. Latency, defined as the time taken to process text or letters into audio output, is crucial to ensure that users do not experience delays in receiving the necessary feedback. We conducted tests 100 times to ensure conclusive results. On average, the processing time for text to be spoken was 0.56 seconds. Although the latency may

[9] https://alphacephei.com/vosk/

[10] Word Error Rate is defined as the total number of editing operations (insertion [I], deletion [D] or substitutions[S]) divided by the total number of words

$$WER = \frac{S + I + D}{N}$$

WER provides insight into the accuracy of the ASR system, with lower values indicating better performance

[11] https://pypi.org/project/pyttsx3/

Test	Pass	Time (seconds)	Reason for failure
1	√	2.3	—
2	√	2.3	—
3	×	—	Display actuator gear misalignment
4	×	—	Display actuator gear misalignment
5	×	—	Display actuator gear misalignment

Table 5. Full-cell accuracy testing result

Test (durability)	Runtime (minutes)	Pass	Time of failure
Half-cell	2:00	√	—
Rail	2:00	√	—
Lift	2:00	√	—

Table 6. Results for each systems durability test

raise some concerns, it's important to consider that this tool primarily serves as an aid for blind individuals to touch type. Experienced touch typists, who are likely to type faster, would not rely heavily on this feature.

3. Budget

The cost of producing our final prototype amounts to £251.41, as detailed in Table 7. Much of this cost was taken up by 3D printing and laser cutting components that could be commercially produced for a lot less using techniques such as injection moulding. Furthermore, we can get better rates on some of the parts by ordering for them in bulk.Table 8 provides a more detailed breakdown of the cost of manufacturing for our final marketable product.

Based on the calculated manufacturing cost of £213.86 per unit , we are aiming to launch our final product for £279. Based on this price, and our deployment strategy for year 1, we are expecting to make a loss of £10,000 due to the inclusion of one time setup costs, labour costs, etc. However we will make up from it from year 3 onwards given we meet our target sales of 200 units in year 1, 300 units in year 2 and 500 units in year 3.

A more detailed breakdown of our commercialisation plan to launch the product and the balance sheets, deployment and investment strategy can be found in the appendices in Appendix H.

Item	Cost
880g PLA for housing	£22.00
100g PLA for braille wheels	£2.50
45g PLA for rod housing	£1.13
30g PLA for scissor lift	£1.00
11g PLA for motor mount	£0.27
47g PLA for rail attachments	£1.75
10g PLA for pulley wheels	£0.25
1/4 sheet 5mm clear acrylic for lid	£6.50
1/8 sheet 3mm clear acrylic for gears	£2.63
52cm of 5mm aluminium round bar	£3.64
80cm of 20mm aluminium struts for rail	£5.02
2x large stepper motor	£52.30
Telescopic poles for camera mount	£14.32
Raspberry Pi 5	£69.00
Motor drivers	£5.00
Miscellaneous wires and electronics	£5.00
Miscellaneous fixings and fittings	£10.00
Mouse and keyboard	£15.00
Camera	£20.00
Microphone	£5.20
Speaker	£8.80
A few pieces of lego	£0.10
TOTAL	£251.41

Table 7. The actual cost of our final prototype.

Item	Cost
Acrylic Based Casing (LasAcryl Ltd, 2024)	£0.35
3D printed braille wheels	£2.50
Injection Mould 3d Printed polymer (setup)	£100
Rod housing	£3.13
Scissor lift	£1.30
Motor mount	£0.42
Rail attachments	£3.75
Pulley wheels	£0.25
Acrylic lid (LasAcryl Ltd, 2024)	£0.20
Acrylic for gears	£0.03
Aluminium round bar	£4.84
Aluminium struts for rail	£6.02
2x large stepper motor	£40.15
Camera mount	£14.32
Raspberry Pi 5	£69.00
Motor drivers	£3.00
Miscellaneous wires and electronics	£5.00
Miscellaneous fixings and fittings	£10.00
Mouse and keyboard	£15.00
Camera	£20.00
Microphone	£4.20
Speaker	£9.80
Time of flight sensor for error correction	£0.60
TOTAL (excl set up)	£213.86

Table 8. The estimated cost of items for our marketable product.

4. Miscellaneous

4.1. User Research

Due to the nature of our product being designed for a highly specific group with unique needs, it was essential to identify what issues our users can experience in order to plan the user experience around them. This user research highlighted a severe lack of support for blind and visually impaired individuals both in the UK and globally, with education on braille being a key hindrance to a person's education and creating challenges in later employment. Further compounding this issue are delays in diagnosis and support for visually impaired people, and a decline in teachers skilled in braille due to funding cuts. We designed BraillEd with the aim to address these issues, offering an affordable system to aid in braille learning, and promoting independence and a higher quality of life through learning and reading. Further details of this research are provided in Appendix D.

4.2. Meeting with Relevant Academic

A meeting was conducted with Elizabeth McCann (McCann, 2024), who is a Teaching Fellow of Visual Impairment at the Moray House School of Education and Sport, to discuss BraillEd's user needs and to direct the focus of the project accordingly.

She provided us with some extremely valuable feedback and pointers, including advising us to expand our target audience from the narrow primary school market. As someone with experience teaching braille, she also gave us the insight that braille learners need daily practise to avoid losing the necessary sensitivity in their fingertips. This supports BraillEd's use case of independent braille practise in the learner's time off.

Further details of our meeting with McCann are provided as Appendix E.

4.3. Visualisation

Appendix A provides a photograph of BraillEd as we presented it at the final demo.

Furthermore, a developmental render of the robot was made during the process to visualise the end product and synchronise creation goal with group members. The render proved a useful reference source for how the robot was intended to look and function. However, due to reliability problems changes have since been made to the design and further changes will be made before industry day. The labelled render is provided as Appendix B, which also gives a brief explanation of each component.

4.4. Custom Pi Hat PCB

To provide a product that is cheap and durable, we designed a custom Raspberry Pi Hat PCB that rests on top of the Pi, and encompasses the entire electronics of our system, it was designed with serviceability in mind, as it consists of connectors that allows easy replacement of damaged/ faulty motors and other electronic components, while ensuring that the product is classroom proof. The designs of the PCB are provided in Appendix C.

A. Product Photograph

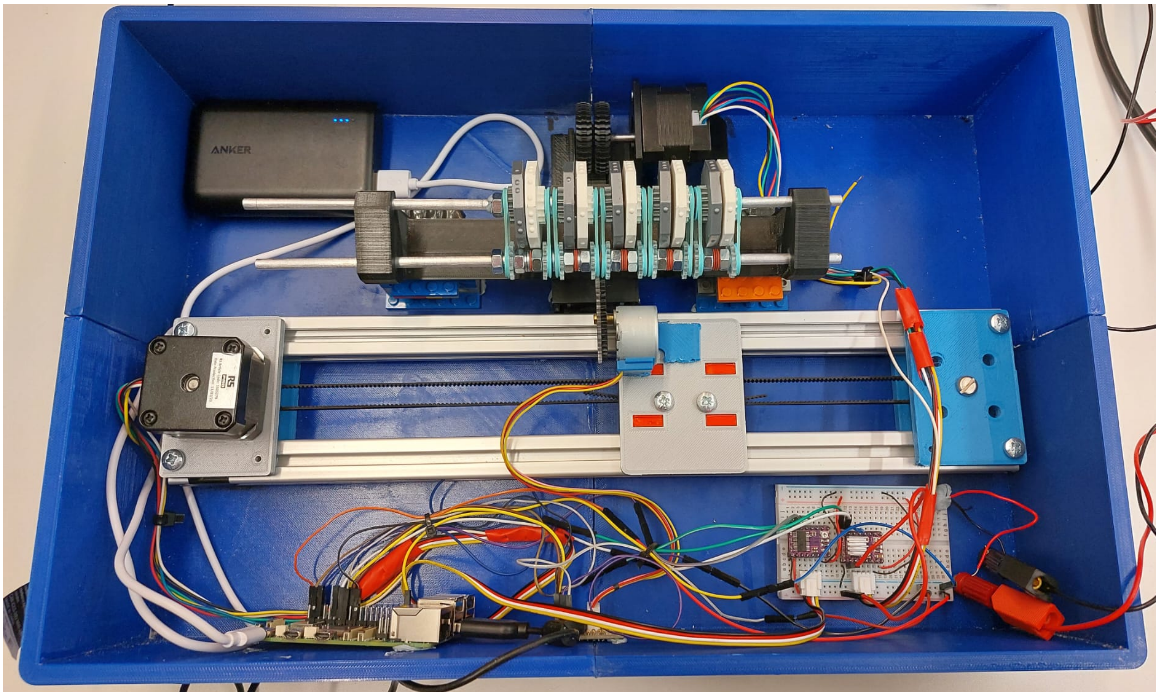

Figure 1. A photograph of BraillEd as we presented it at the final demo.

B. Developmental Render

Figure 2 and Figure 3 show the developmental render we produced. The components shown are:

Braille Display The display consists of 20 octagon pieces, each representing a half cell of braille. Rotation of these can display any braille character.

Rail This rail contains a belt which controls the position of the carriage. This was moved using a stepper motor (not visualised), to allow for more precise movement.

Carriage This sits in the rail, sliding to line up with the gears. It was envisioned to have two motors to spin an entire braille cell at a time, but during development this was reduced to one motor for space reasons.

Raspberry Pi 5 : Depicted here inside a Pi case, the Raspberry Pi holds all the software, responsible for braille translation, speech and image recognition, and keeping track of the motor positions.

Breadboard The breadboard represents the electronic circuit, containing the motor drivers and supplying them with control signals from the Pi as well as power from a battery pack or external power supply.

Power Supply A battery pack or external power source is required to supply power to the system.

Scissor Lift The scissor lift is intended to serve a dual purpose. Firstly, it lifts the display slightly up to disconnect it from the motor gear, allowing it to reposition to the next gear. Secondly, it pushes the braille octagons through the slot in the lid to allow the user to read the braille.

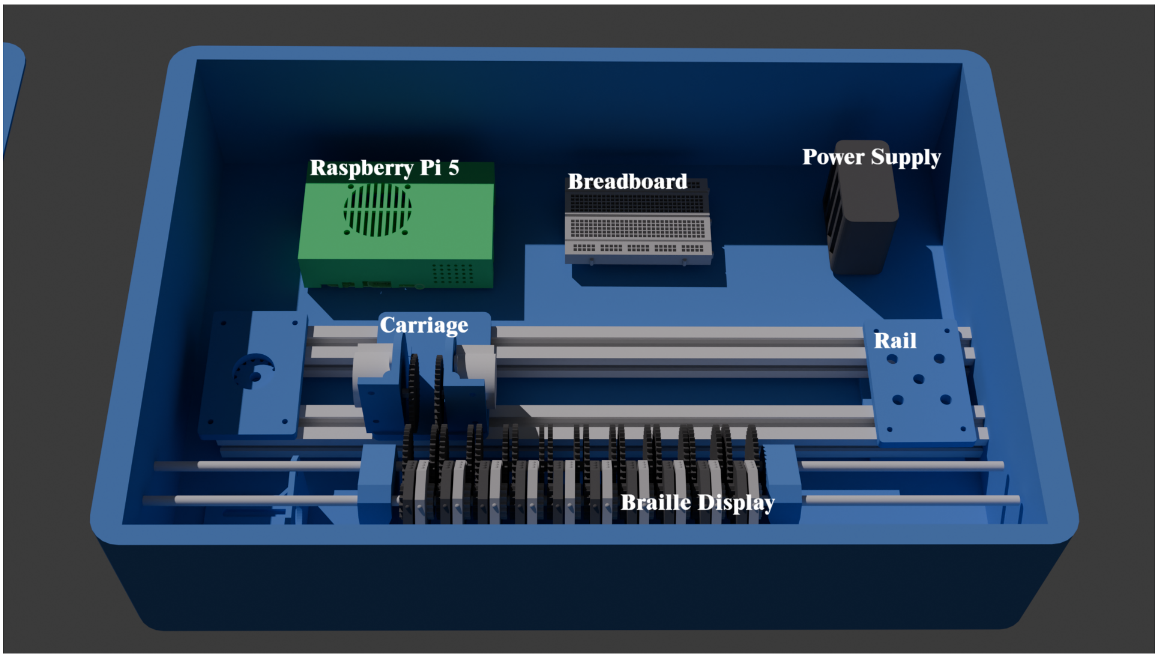

Figure 2. Front View of Render

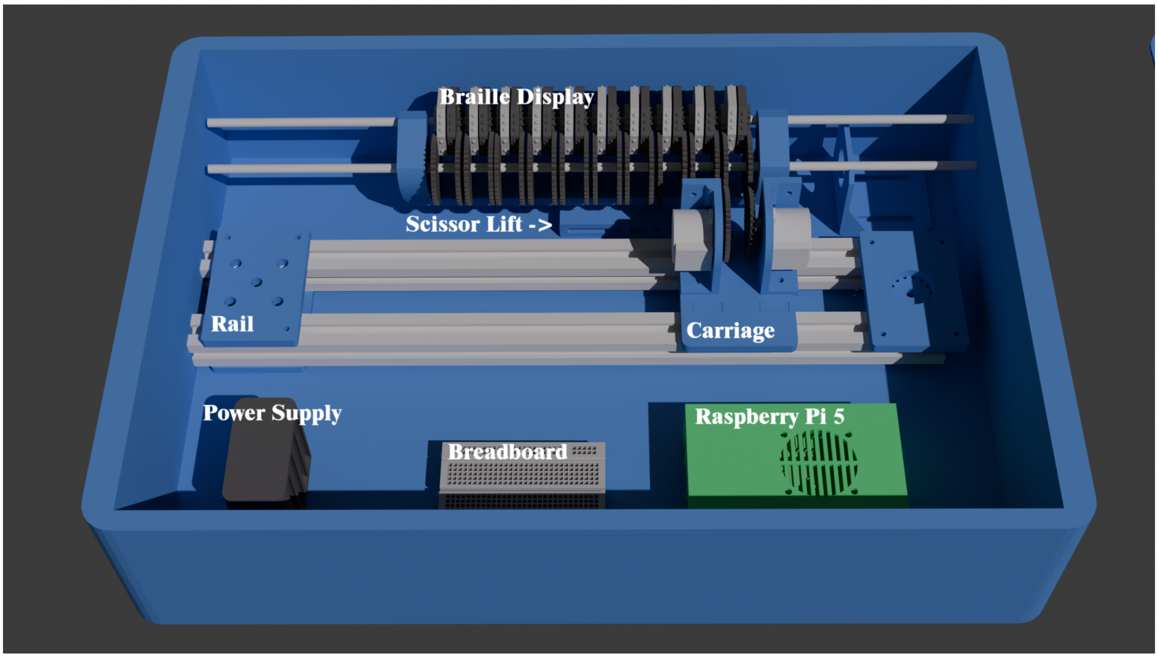

Figure 3. Back View of Render

C. PCB Design

Figure 4 and Figure 5 show the PCB design.

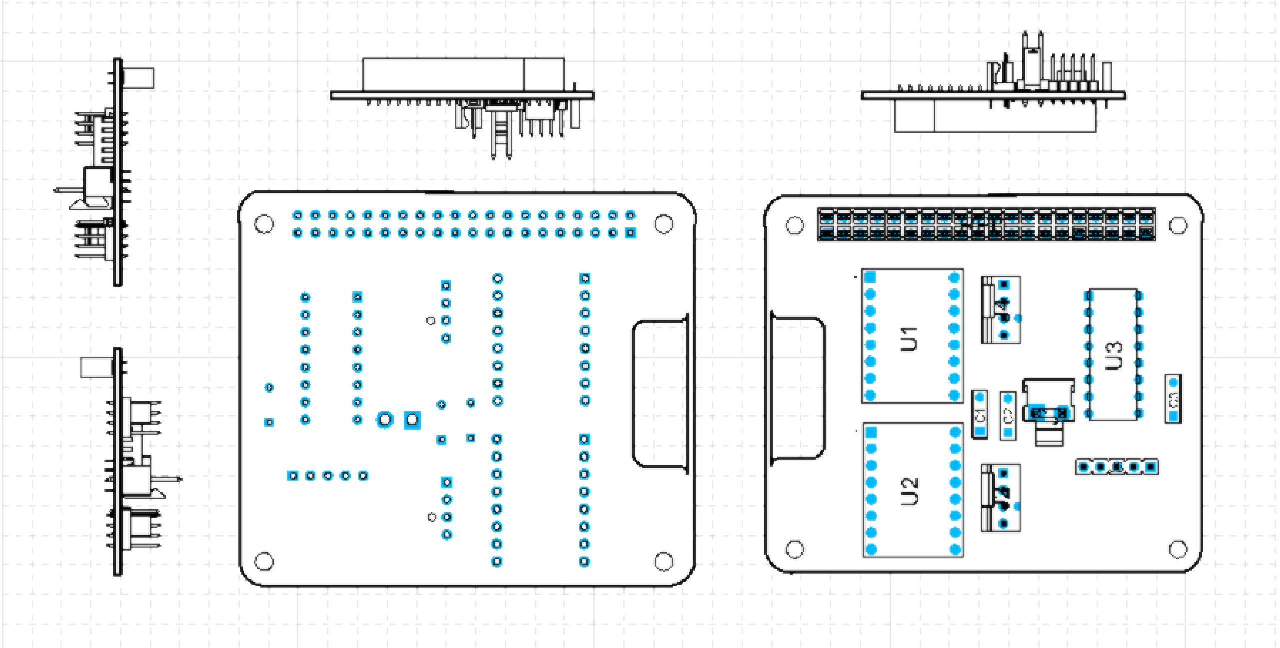

Figure 4. Engineering Sketch of custom Pi hat

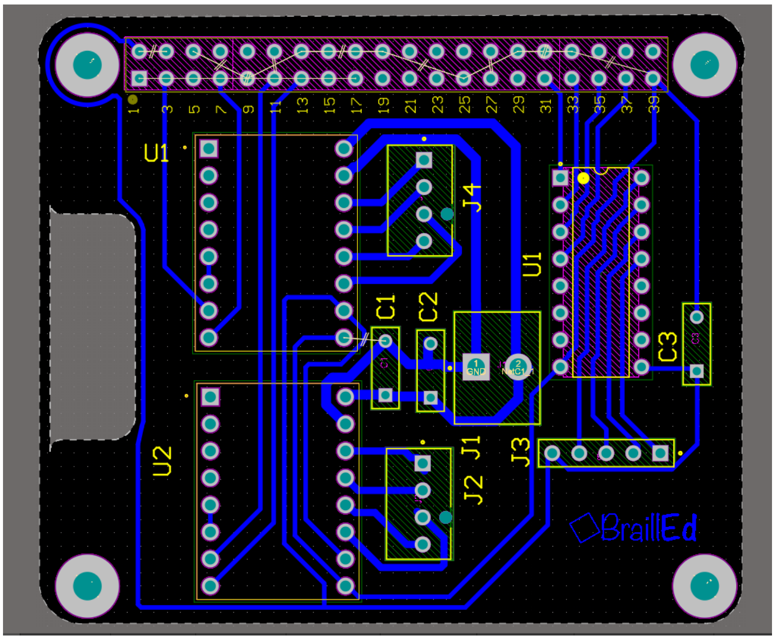

Figure 5. Design of PCB housing all the electronics

D. User Research

User research was conducted to understand the users' needs and identify potential problems we wanted to solve using BraillEd. Through this, it was learnt that there is a lack of education and support for the 40 million people across the world, 340,000 people across the UK and 34,500 people across Scotland (NHS, 2024) who are blind and visually impaired (VI). Despite braille being a vital form of learning for blind people, 93% of them do not know braille. 85% of blind children attend mainstream schools out of which 60% drop out of school, leading to an unemployment rate of 70%. (BrailleWorks, 2022). Recent reports from the Guardian show that at least a quarter of English councils take a year or longer to provide support to people with a new visual impairment diagnosis. 31% of blind and VI pupils are still waiting for rehabilitation services after a diagnosis (Weale, 2019) (Weaver, 2024). Additionally, the work force of teachers supporting school students with braille transcription is declining (View, 2024). Funding cuts by schools are taking a toll on the quality of life and BraillEd aims to solve this as it is affordable, and instils independence and higher life satisfaction for learning and reading.

In Scotland, various councils, including South Lanarkshire (SLC) and North Lanarkshire (NLC), maintain dedicated Visual Impairment Services (VIS) tailored specifically for educational purposes. These services notably play a crucial role in supporting visually impaired pupils, with SLC alone reporting to be supporting over 300 students (Uddingston Grammar). The interconnectedness among these services is also a desirable situation that BrailleEd can leverage to ultimately help every visually impaired person achieve their potential. More specifically, VISs tend to liaise with adjoining councils to share resources and best practices.The concept of the 'network effect', widely recognised in economics, perfectly encapsulates this phenomenon. As BrailleEd's assistive product gains adoption within one council, its value and benefits extend beyond, thus catalysing organic growth through word of mouth and recommendations. We also hope that by offering our solution at a significantly lower price point compared to solutions in the market (a tenfold difference!) will also serve as a decisive factor in the widespread adoption of our product.

To get an idea on how the user base looks across the UK, The Royal National Institute of Blind People (RNIB) offers a valuable tool providing insights into the blind and partially sighted population across the UK (Royal National Institute of Blind People, b) Each country within the UK—England, Scotland, Wales, and Northern Ireland—has its respective briefing report, detailing various statistics including estimates of individuals living with sight loss and age brackets. However, a discrepancy arises in Scotland's report, where the estimated number of individuals with sight loss is unexpectedly lower than the registered number, unlike the other three countries. Moreover, Scotland's data seems to halt after 2010, while the other countries continue to provide updated figures from 2021 onwards.

Therefore for Scotland we have decided to use a report by the Times Educational Supplement (Craig, 2023) in 2023 which outlines that 5000 pupils have a sight loss in Scotland. England, Wales and Northern Ireland estimate that 24,450, 1280 and 890 individuals aged 0-17 years are living with a sight loss respectively. Therefore we can estimate that there is a potential user base of 30000 individuals in the UK. Additionally, it further demonstrates the existence of a viable market for such a device. This outcome is unsurprising considering the presence of similar products in the market, albeit at higher price points. However, our thorough analysis confirms the rationale behind targeting this audience, given the significant number of potential users.

E. Meeting with Relevant Academic

A meeting was conducted with Elizabeth McCann (McCann, 2024), who is a Teaching Fellow of Visual Impairment at the Moray House School of Education and Sport, to discuss BraillEd's user needs and to direct the focus of the project accordingly.

While BraillEd's original user focus was on primary schools, McCann encouraged us to widen our audience, as she felt our product to be more useful for adults and youth who became blind at a later point in their lives. She mentioned that adults would be more familiar with technology and that it is also preferred for younger children to learn braille and literature on paper. Therefore, we shifted our target audience based on this extremely helpful feedback.

She also endorsed the idea of auditory feedback for the keyboard, which confirms the usefulness of our text-to-speech feature.

She additionally emphasised the importance of bringing the braille cells closer so they are read as a single word rather than separate characters, and ensuring the braille cells are of the standardised size. Neither of these were possible in our prototype due to the precision limitations of 3D printing, but we believe that we could meet these requirements in a commercially produced product.

McCann mentioned a braille device called Canute by Bristol Braille[12] which is a multi line braille display relying on pins, however it is very expensive and does not feature an image recognition feature like BraillEd. She suggested that BraillEd can be marketed as a more affordable braille device, which could be of particular benefit to people in the Global South.

She also saw potential in us introducing braille to people with degenerative vision conditions, who would like to learn braille before they lose their sight.

McCann told us of the importance of practising braille daily to avoid the loss of the required fingertip sensitivity. This highlights another benefit of BraillEd – allowing braille learners to expand their learning beyond their direct teaching sessions to practise their learning on their days off.

She also mentioned that many blind and partially sighted people use mobile phones through the use of voiceover features. This motivated us to move with our idea to integrate BraillEd with a mobile application for text recognition supported by voiceovers.[13]

[12] https://bristolbraille.org/

[13] While the mobile app was briefly showcased in the final demo to demonstrate the image recognition, we hope to continue development for industry day.

F. Flowcharts

This appendix consists of diagrams to explain the operation of some of BraillEd's use cases. Figure 6 demonstrates the operation of the camera input, while Figure 6 demonstrates that of the speech recognition.

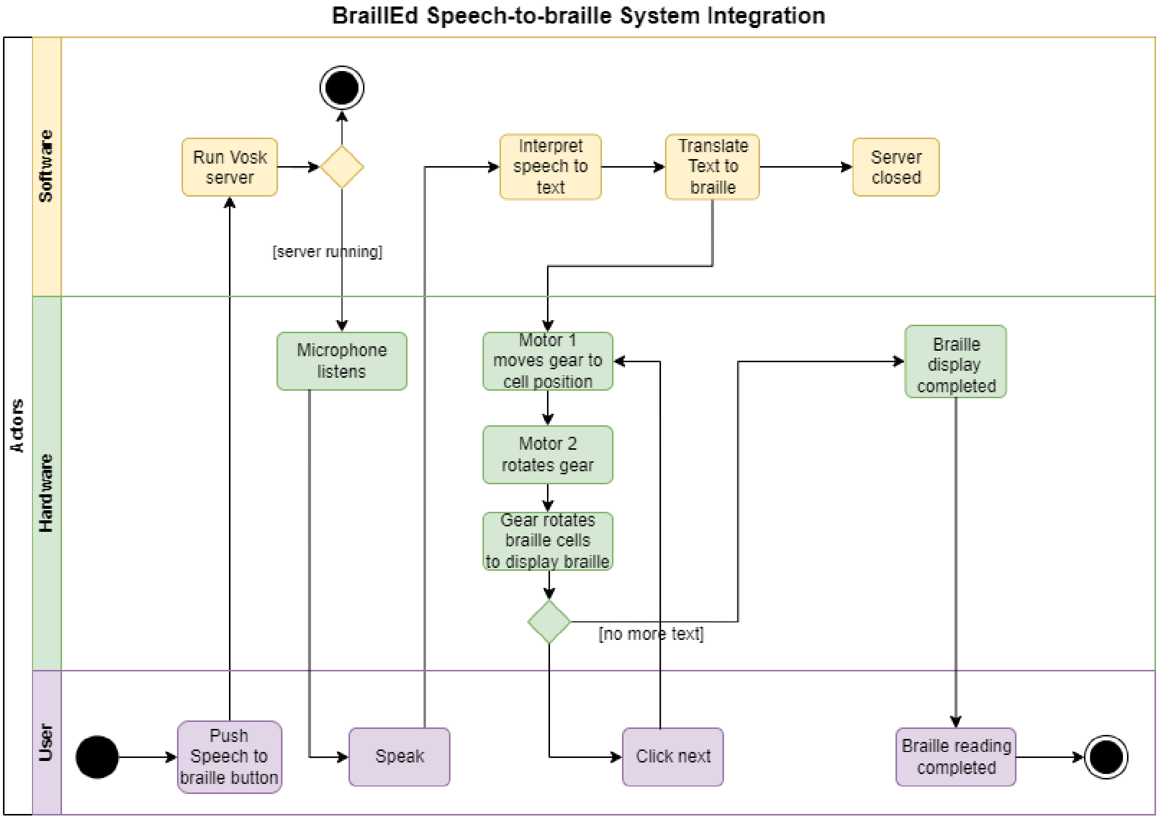

Figure 6. Flowchart for speech to braille translation

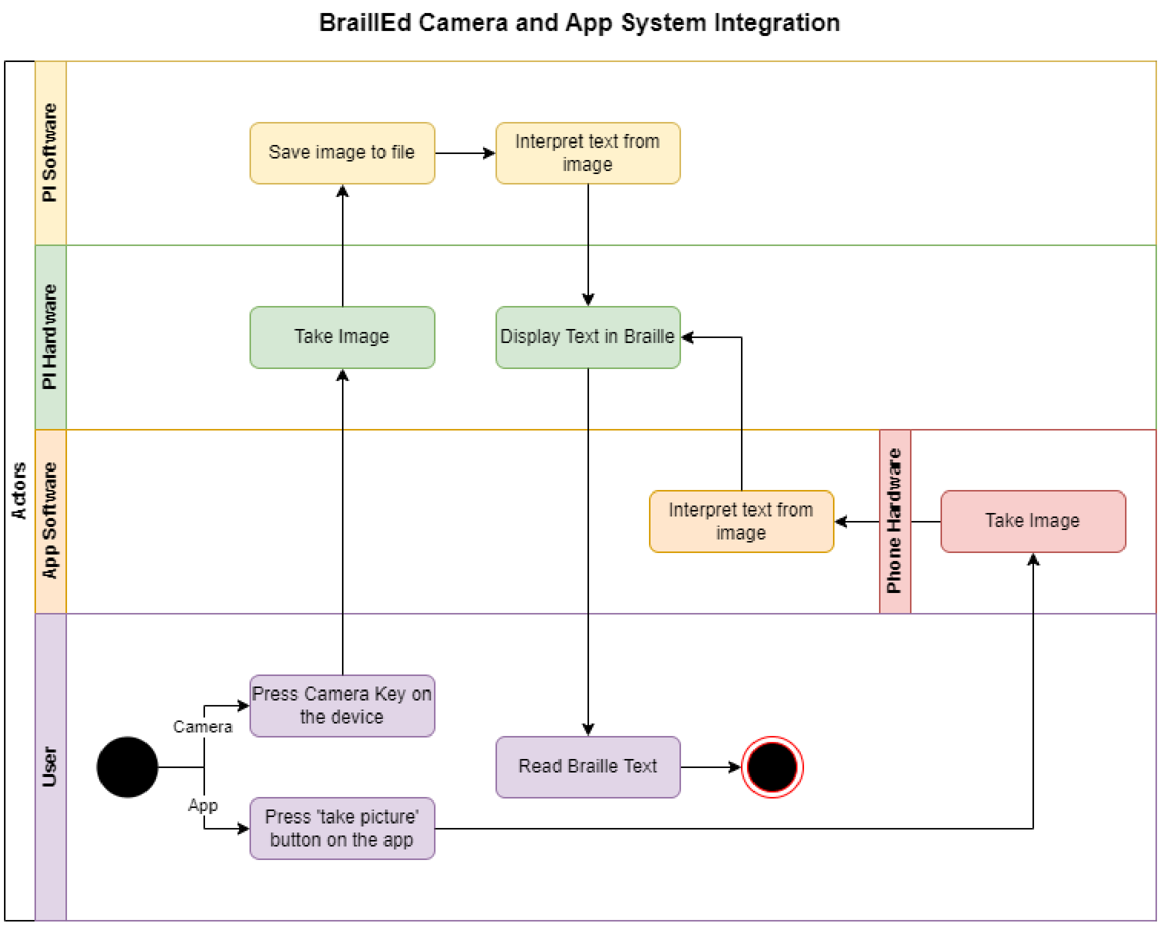

Figure 7. Flowchart for printed text to braille translation

G. Quantitative Analysis

Test	Pass	Time (seconds)	Reason for failure
1	×	—	Display actuator gear misalignment
2	×	—	Display actuator gear misalignment
3	×	—	Display actuator gear misalignment
4	×	—	Display actuator gear misalignment
5	×	—	Display actuator gear misalignment

Table 9. Multi-cell accuracy testing result

Test	Pass	Time (seconds)	Reason for failure
1	×	—	Gear misalignment & lift failure
2	×	—	Gear misalignment & lift failure
3	×	—	Gear misalignment & lift failure
4	×	—	Gear misalignment & lift failure
5	×	—	Gear misalignment & lift failure

Table 10. Full-display accuracy testing result

This appendix section talks about a brief tabular summary of our quantitative results and then the decisions taken towards the development of our product after analysing the quantitative results.

In Brief, Results from the testing show several flaws in the design and implementation of the display system. Firstly, several accuracy tests failed to meet our standards because of the carriage's inability to reach the millimeter precision level required to mesh the actuating gear with the display's gears. Significant lateral play was observed in both the actuating gear and the carriage to which the actuator motor was mounted. Eliminating this movement would provide an increase in our ability to match gears when changing target cells. This could be achieved with a more precise carriage design, one that is secured into grooves. Additionally, finer actuation of the motor which controls the carriage through micro-stepping would eliminate unwanted movement from the carriage. The current link between the display's gears and the braille cells also produces unwanted errors due to the belt's low friction on the pulley wheel. One straightforward solution would be to corrugate the pulley wheels so that a toothed belt can be fitted which is less likely to slip. Additionally, our bracket which houses the components of the braille display doesn't allow for the 2 rods, holding the display's gears and the braille cells respectively, to be moved away from each other, which means we cannot dynamically tighten the belt link between them.

Lastly, the lift mechanism proved to be too stiff at times, such that the motor had difficulty engaging the scissor arms from the bottom position. This issue showed during the accuracy testing, but was absent during the durability testing, which was conducted the day before. Incomplete extension of the lift meant that the actuator gear travelling on the carriage sometimes collided with the display gears or the lift platform itself during accuracy tests. A better solution would have used less frictional materials for the lift components and improved the power transfer from the motor shaft to the lift slider so that less torque would still be able to lift the mechanism.

H. Finance

BrailED Profit & Loss Plan			
FORECAST PROFIT AND LOSS ACCOUNT	VAT REG:- YES		
	YEAR 1	**YEAR 2**	**YEAR 3**
Opening Stock in year	0	0	0
Material Purchases	5071.5	7571.5	10143
Component Purchase	3388	6688	6776
Direct Employment Costs	7,200	7,200	7200
Insurance	1000	1000	1400
Rent & Manufacturing	3000	3200	3300
Repairs & Maintenance	500	750	570
Advertising & Promotion	150	350	350
Travel & Subsistence	480	700	700
Other Expenditure	1,200	1,200	1,200
Interest - Loan/H P	900	900	900
Other Finances Charges	0	0	0
Depreciation - Assets	900	1800	2,817
Selling Price Per Unit	279	279	289
Total Target Sales	200	300	500
Turn over	55800	83700	144500
Cost of Sale	42600	63900	106500
Net Profit / Losss	-10589.5	-11838.5	14748

Figure 8. Profit Loss Chart for 3 years

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