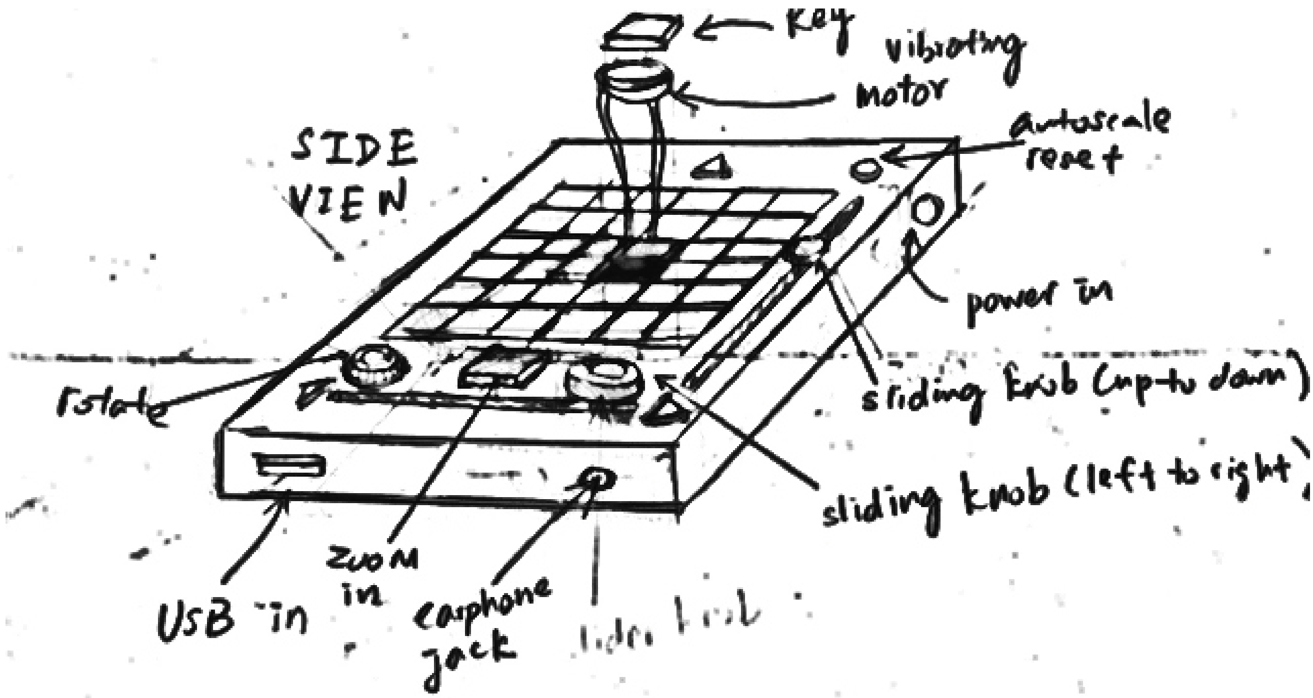
Visual Access for Blind People

ELEC95012 – EEE2 Electronics Design Project
Department of Electrical & Electronic Engineering, Imperial College London
Real Page Count: 12 Pages



Preliminary Report

Team 7 EEE 2019 (365-team7eee@groups.imperial.ac.uk)
Kevin Xia, Umut Ekinci, Lukas Baliunas, Arman Fidanoglu, Alp Atakav
Issa Bqain, Pavan Gill, Omar Inuwa

Supervisor: **Dr. Thomas J. W. Clarke**

Contents

Editorial Note

Sections 1 to 5 span pages 3 to 14 (inclusive) give a total real page count of 12 thus meeting the deemed page limit of this assessment.

We would like to offer our special thanks to Dr. T. Clarke for his continued support and to the RNIB, Enfield Vision Group and Lindon Lodge School for the time they gave during our interviews with them regarding this report.

I: Problem and Design Summary

1.1 Summary of Selected Problem

Today, visually impaired people often suffer from limited employment and education prospects due to their inability to independently learn non-verbal information that normally requires sight, including both images (e.g. graphs, charts, drawings) and characters (Braille text, alphabet).

Starting from young, the lack of access to visual based subjects (such as STEM & Economics) in schools have led to a high dropout rate (up to 50% in the United States) among blind students [1] [2], with many lacking the tools and support required to keep up with their peers when it comes to visualization of diagrams and graphs. Literacy rates blind among children have also dropped to an unprecedented low of 12% with many not having access to blind schools and not being able to afford a device that would help them learn Braille independently.

For adults, jobs in several fields where graphs, charts, and schematics are widely used, (e.g. accountancy, economics, and engineering) are out of reach/ prohibitively difficult for the blind. This has contributed to high unemployment rates among them, with only 27% [3] of visually impaired people of working age in the UK being in employment and 39% [4] expressing great difficulty in making ends meet. Even in their everyday lives, basic needs like viewing stock charts, maps and statistics to independently understand and navigate the world around them are often near impossible feats.

As a result, they are generally unable to fulfil their true potential in society and often find it difficult to make a living, or even survive independently. It was also estimated that there are 285 million visually impaired people worldwide, with 90% living in developing countries. [1] The number is also set to increase as the population ages, indicating a huge demand for an affordable solution.

This project therefore aims to develop an electronic device that grants blind people access to everyday visual information, allowing them to independently interpret, learn and possibly even create graphics. The aim is to improve their education and employment prospects and access while enriching their daily lives. This is mainly done through converting the 2D graphical information through software before expressing it in a tangible form easily interpreted by the blind through hardware.

1.2 Direct User Research

Several Institutes were contacted to make an informed decision on the chosen concept. The advice gained was also used to develop our existing proposals to make them more relevant to our end consumer. Our first interview was with the RNIB from which Kevin Xia conducted. Relevant information on statistics of unemployment, main devices used, and the main issues blind people face were covered.

The second interview was carried out with the Enfield Vision Association for the Blind and Visually Impaired [5] from which Kevin Xia and Umut Ekinci conducted. A 20-minute phone interview was carried out and the main problems the committee and the members faced were given. One interesting note was that Braille was deemed as not very popular and the advent of the accessibility option in modern day smart phones dominated the use of technology within the Blind community. Apps such as TapTapGo [6] were mentioned and their daily use.

Finally, a 25-minute interview was carried out with the Linden Lodge School for the Blind and Visually Impaired. We were lucky enough to talk to Ms. Leony whom was a qualified teacher for the blind. She gave her insight onto the main problems that were faced within the student community. We asked for feedback on some of our existing ideas such as an affordable Braille Display (Solution 5) and Visual Strip display. While both were well received, the visual strip idea was the most requested idea as it would fill the issue surrounding the education of blind people regarding mathematics. The interviewee said it would be most beneficial to the students to understand visual content more so than the Braille idea.

As you read through this report, you will see segments referring to these interviews taken at these institutes and what was learned during the interviews and how they influenced some of our decisions regarding the proposals.

II: Design Criteria

2.1 Performance

For this product to aid the visually impaired, the key role our device needs to fulfil is its effectiveness in enabling blind people to interpret visual information. Performance can hence be defined as follows:

⇒ **Effectiveness:** The device should act as an effective learning tool, leading to significant improvements in the test scores of blind students in visual based subjects, and enable blind users to carry out other visual based tasks e.g. analysis of data, identification of graphical trends, much more quickly and accurately.

⇒ **Resolution:** The images themselves also need to be expressed in as much detail and accuracy as possible, with minimal ambiguity while retaining most properties of the original images (e.g. size, shape, colour, textures) to properly relay the right information across without causing any confusion.

⇒ **Versatility:** The quantity and range of visual information (from mathematical graphs, characters, to colourful charts and images) that can be expressed through our device also needs to be as large as possible in order to cater to a larger range of blind audiences from different age groups and backgrounds. It should also synergize well with other tools used by blind people (e.g. text to speech)

⇒ **Functionality:** Technically, it also needs to meet basic functional requirements and operate as fast as most modern-day devices, with minimal lag time and excellent synchronization and compatibility with everyday electronic devices and their respective operating systems.

2.2 Quality and Reliability

The device is intended to be used in educational and work environments. As the device may be exposed to wear and tear due to repeated use, it will need to withstand these as well as small shocks caused by daily use of such devices. More specifically, it needs to withstand repeated mild hand movements along with light shocks from drops. However, it is not expected to be able to survive heavy shock loading and impact. It should also ideally be able to function reliably and consistently, e.g. give the same correct display, synchronise well, when placed under any condition at any time in any position e.g. when tilted, upside down etc.

2.3 Shelf Life

The product is not expected to be completely waterproof or dustproof but should be able to endure moderate amounts of ambient dust and moisture to have an expected shelf life of around 2 years, which is the minimum guarantee for most similar electronic products on the market.

2.4 Target Product Cost

In our case, a typical customer would be a visually impaired student or blind person living in poverty with enough allowance to purchase a home laptop costing from 200 pounds upwards, hence an estimated fair product cost is around 200 to 1000 pounds. Any development cost outside of this range would be too expensive for most of our target audience.

2.5 Size

The device is designed for visually impaired students and this would require it to easily fit into a standard laptop bag for everyday use in school settings [7] It should also be small enough to be held and felt with only two hands, as such we decided to take the Apple iPad as a reference. Therefore, the approximate size of the device is 250.6 mm x 174.1 mm x 7.5 mm (height, width, depth).

2.6 Weight

Similarly, for it to be portable it cannot weigh too much. Again, taking reference from Apple iPad, which has a weight of 0.483kg and from braille readers [8], which have a weight range from 0.317kg to 1.18kg, we aim to limit the weight of our product to 0.5kg, which is both within the weight range of existing visual aid technologies [9] (i.e. braille reader) and is close to the weight range of an Apple iPad.

2.7 Ergonomics

The device needs to be built around blind people's perception of the world, in order to suit their needs and make it as easy to use and convenient for them as possible, optimizing usage experience. [10] The design should be thoroughly researched and conceived based on feedback from blind organizations and people, with all potential shortcomings (e.g. incorrect view of images from different orientations) accounted for. It should preferably look simple and elegant, without any excessive complexity beyond its basic functions, and can be easily set up and operated independently by blind people or the general public without prior training.

2.8 Safety

The concept should not pose any risk of injury during operation or malfunction, especially when certain hazards are not immediately visible to the target blind audience. More specifically, the product must not have any sharp edges, overheat, draw excessive current or have exposed moving parts that might cause harm to the user when in constant close contact. (e.g. when feeling across the device)

2.9 Time-scale

Given the limited time of 2 months for development, the concept also needs to be simple and feasible enough to allow at least a functioning prototype/proof of concept to be developed within the timeframe.

III: High Level Design Proposals

Overview of Proposals

Each proposal mainly consists of the general description of the mode of operation, followed by the hardware and software implementation of the concept. All 5 solutions will require a microcontroller in order to multiplex the various signals to the correct actuators, which by default is the Arduino Uno. (why Arduino Uno), and are coupled with similar front end text-to-speech software on computers that serves as a virtual guide for independent learning. This is followed by a feasibility and cost evaluation based on the implementation described.

3.1 Solution 1 - Dynamic Pixels

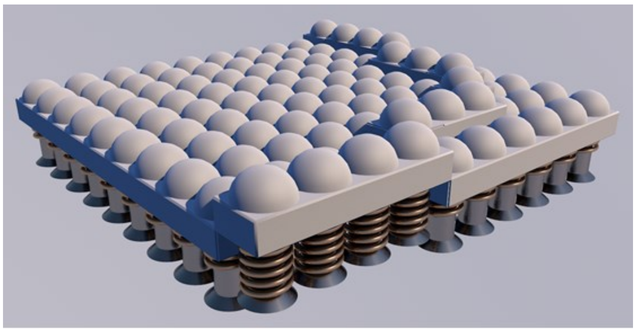


Figure 1 Computer Generated Simulation (credits Arman Fidanoglu)

A tablet-sized device with "dynamic pixels" that can move up or down to form a two-dimensional image can be developed to enable the blind user to directly feel the image through across the screen. Various shapes and graphs can be displayed in the form of raised pixels, with the resolution being determined by the number of pixels, with the 10x10 version shown above offering enough resolution for most basic shapes and graphs. The device also allows for zooming in by pressing the target pixel. Converted images are first uploaded onto the device via a companion app, and once they are stored in the device's memory, the device should be usable as a standalone tablet.

3.11 Software Implementation

The system will receive input by a companion application what will run on a personal computer, smartphone or tablet. The app will have several features, including a settings menu, connection options (Wi-Fi or Bluetooth and USB) and an option to send uploaded images to the device. Since the images sent to the device need to be in a format that can be interpreted by it, the app will process uploaded image files (two-dimensional graphs/charts) before transferring them to the device.

Image files are arrays of colours (a number representing RGBA for each pixel). The application will first convert the input image into monochrome. It will then consider the array as a sampled function (every sample of which can take a value from 0 to 255) and differentiate it, revealing the image's contours. The differentiated image will then go through a correction process, where each pixel above a certain darkness threshold will be converted to black, whereas those below this threshold will be converted to white. This process will result in a binary bitstream, or an array of binary digits containing the simplified image.

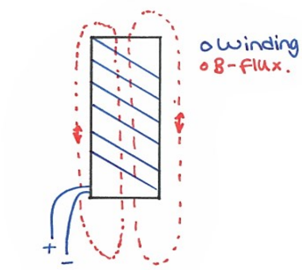


Figure 2 Solenoid Element describing static magnetic flux

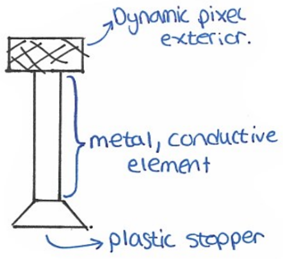


Figure 3 Actuation Element that will be placed inside solenoid

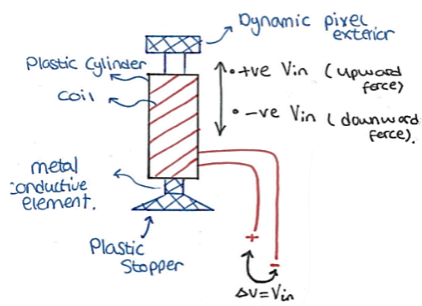


Figure 4 Combined Result

3.12 Hardware Implementation

After the image array is received by the device, it will be downscaled to match the number of pixels on the display, which will be an $n \times m$ grid. Each 1 and 0 in the array will be encoded using an analogue comparator into high (+VCC) and low (-VCC) voltages and read by their corresponding pixels. Each of the dynamic pixels will be implemented using electromagnetic solid-state actuators. As seen in figures 1, 2 and 3, a small cylindrical solenoid will produce magnetic flux upon current passing through it. If now the pixel is attached to a conductive rod and placed inside the solenoid, it will move upwards when positive voltage is applied to the setup [11]. If instead a negative voltage is applied, the pixel will move back down.

3.13 Feasibility and Cost Analysis

Item	Cost
Copper solenoids (Reel)	GBP 5.27 for 10m [12]
Metal rods (iron bar nails)	GBP 49.90 for 160 pieces [13]
Arduino Uno	GBP 34 [14]
Comparators and Op-Amps	GBP 33 (300 units total) [15]
Total	GBP 122.17

Since solenoids are often cheap and small, the overall cost is still well within budget.

Although such an idea has never been realised, the technology exists and is used in many sectors, e.g. old typewriters, and hence it can be realised given the right guidance.

Solenoids also do draw massive current in order to produce a strong enough magnetic field, meaning that there are risks associated with overheating, along with massive power consumption.
Scaling up the resolution of such a device could also be a major challenge, given that each pixel needs to contain a solenoid which cannot be nearly as small as a modern pixel. Additionally, as the resolution increases, the cost will also increase at a quadratic rate.

3.2 Solution 2 - Vibrating Keys

The vibrating keys idea is a haptic device mainly consisting of a grid of flat keys like that of a laptop, with the image expressed in the form of vibrating keys at different locations, which can then be sensed by the blind user through touch. The magnitude of the vibrations indicates the thickness of the outlines, therefore essentially creating a tactile image, and the tempo, speed of the vibrations can also be varied as well to display different properties of the image.

The image can also be shifted from left to right and from up to down using the sliding knobs at the sides, with the location of the vibrating keys changing along with the image, until the knob is moved out of bounds of the image, where no keys will vibrate.

If the displayed image resolution is too low, the user can align the part of the image that needs to be zoomed into at the centre of the grid using the sliding knobs, (with the four distinct central keys protruding outwards from the board for easy location and alignment), before pressing the zoom button to zoom in. The vibrations will now correspond to the zoomed in part of the image.

The image can also be rotated to different angles by using the rotation knobs. The three triangles at the top and sides mark out the orientation of the device, ensuring the image is viewed from the correct angle. There is also an auto scale reset button which enables instant reset and zoom out back to the full image.

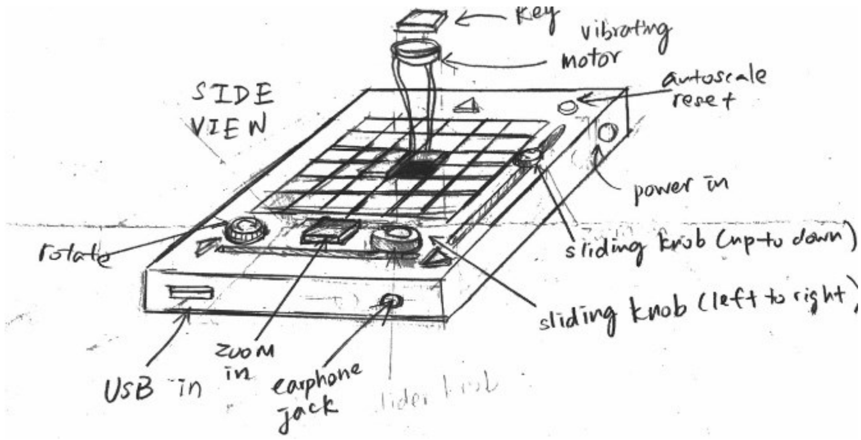


Figure 5 Artist Sketch of Proposed device

3.2.1 Software Implementation

There will be two software parts – a user friendly computer program for uploading specific graphs to the device and the microcontroller code, which controls the device. The computer program will have a list of mathematical functions with different parameters, that can be selected and uploaded to the device.

The microcontroller code will have to take inputs from the buttons and adjust the vibrating motors accordingly. Each function vibrating parts will be in a stored in memory (as a 2D array), in a similar way as the previous implementation of the moving pixels and after some movement of the display, specific microcontroller outputs will go through a multiplexer that will control the dc current through each of the motors to vary the magnitude/tempo of vibrations.

3.2.2 Hardware Implementation

For vibrations, vibration DC motors can be attached to each key on the device as shown above. The keys are secured at the bottom using a larger fixed frame, with gaps between each key at the top to isolate the vibrations. (shown above) The motors mainly operate through unstable rotation, with one side larger than the other creating an uneven torque that causes vibration. Changing the current also controls the frequency/magnitude of vibration. Each key and motor are identified by a unit x-y coordinate system and linked together to form a larger circuit system with a single power supply. The mechanical sensors by the side will also sense inputs from the user when pressed and send the correct signals to the microcontroller for the displays to be adjusted.

3.2.3 Feasibility and Cost Analysis

The key advantage offered by this context is the minimal displacement of moving parts, allowing for instant transition between different patterns, with the vibration of the keys starting and stopping instantaneously on command.

The key difficulty however is to isolate the vibrations of each key, and to ensure that the keys vibrate freely while remaining secured to the device after repeated usage. There will likely also be significant gaps between keys to fully isolate the vibrations, care also needs to be taken to make the device reliable and waterproof. Due to their similar mode of operations, the device also suffers from similar scalability issues as the dynamic pixels concept.

Item	**Cost**
Motors	GBP 1.92 – a piece [16]
Keys (full set)	GBP 7.60 [17]
Arduino Uno	GBP 20 [14]
Total estimated cost (5x5 display)	GBP 75.60

The overall cost is low and well within budget as only cheap vibration disc motors are used as actuators, with no excessive moving parts involved.

3.3 Solution 3 - Magnetic Stylus

The drawing guide consists of a robotic guide capable of motion in two dimensions (Similar to a computer numerical control (CNC) machine in 3D printers) as shown in figure 6. The blind user first places a stylus with a magnetic tip on the white board. On the other side of the board, the two axes of the machine guide the pen using a magnet to draw an image (figure 6), hence teaching the user about different kinds of graphs of shapes through hands on practical means.

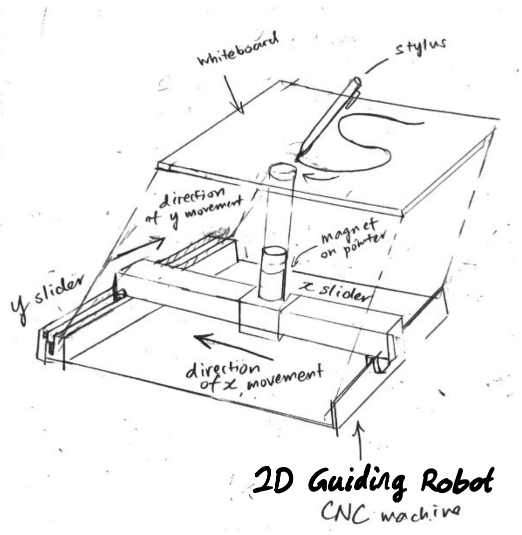


Figure 6 Proposed Sketch for Device

3.3.1 Software Implementation

The device will have a companion PC application which, when input a function, uses the public API [18] of Desmos, which is an online graphing calculator program, to retrieve values of that function at predefined x-values. It will then store the values in a two-dimensional array:

$$A = [[x1, y1],[x2,y2,],[x3,y3,],\ldots]$$

This array will then be sent to the device, which will decode this information and use it to move the x- and y- conveyors. The companion application will be written using Java and will require a Wi-Fi connection to work. This is for two reasons:

⇒ It will rely Desmos' online API to operate,
⇒ It will connect to the device via Wi-Fi.

The resolution and number of x-values that will be used by the application to retrieve information from the API will be adjustable and the user will be able to change this in the settings menu.

3.3.2 Hardware Implementation

After obtaining the X and Y values for the graph at multiple points to be able to describe it, we will then use this information in conjunction with a CNC machine. The pointer of a CNC-like machine will hold the magnet which will be used to guide the stylus pen to represent the graphical information to the user. The pointer of the CNC machine be varying based on 2 axes for x and y. the pointer will be freely available to move across the x axis and in order to alter the y axis, the frame used for the x axis will move vertically and this will be able to map data for 2D information.

This could face some issues when it comes to discontinuous curves where the transition between the beginning and end might fault the user into thinking that movement is part of the curve, which is overcome by using a buzzer which would sound when there is a discontinuity. Strong neodymium magnets will also be used to secure the pen to the board while enabling horizontal movement.

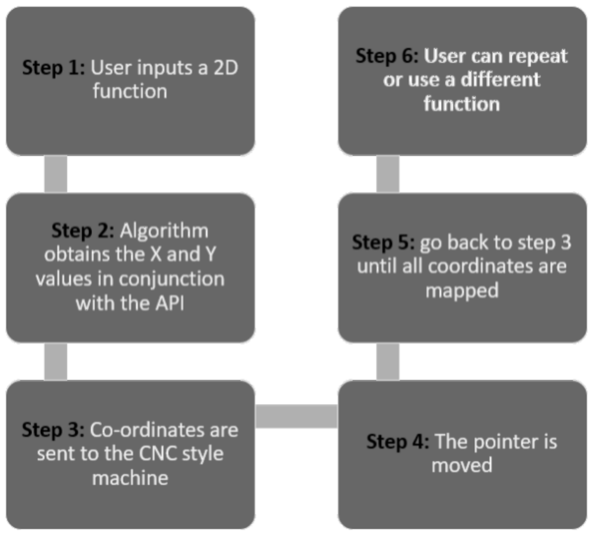


Figure 7 Simplified Flowchart of operation

Finally, this would allow the magnet to move from one coordinate to another until all the information has been displayed.

3.3.3 Feasibility and Cost Analysis

Component	Cost
2 axis CNC machines	GBP 150 [19]
Software development costs	GBP 0 (All resources available in the department)
Casing and stylus pen – 3D printed	GBP 8 [20]
Neodymium Magnets	GBP 20 [21]
Total cost:	GBP 178

The idea of drawing an image (waveform) on a tablet by using a 2D CNC machine has never been implemented but the general idea had been used in many sectors e.g. 3D printing, and it can therefore be built with enough guidance.

However, since the device uses the idea of "a pen" for the hardware part, it would get harder to produce a display as the images get complicated (with loops and jumps). Secondly, CNC machines aren't cheap so this implementation of hardware would cause a significant increase in the cost of the whole device. The biggest difficulty we will face regarding the hardware is integrating this into a small enough case as these usually require a large volume. Since we only have 2-axis, the limitation will be due to the width of the device and since the x axis is within the y axis frame, this would reduce it significantly.

3.4 Solution 4 - Vertical Sliding Display

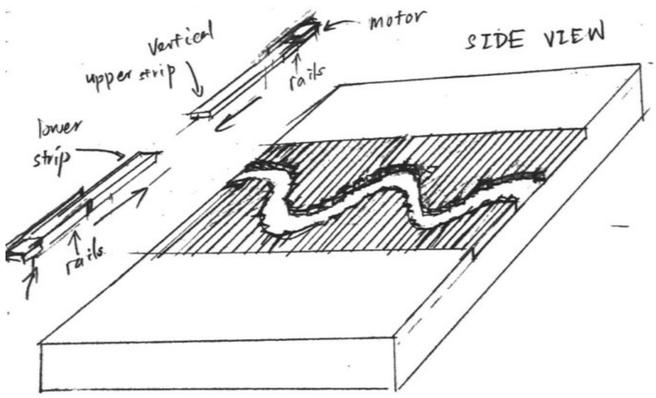


Figure 9 Artist Impression of Device

The next device seeks to effectively overcome the inevitable resolution problems faced by the other ideas, allowing blind users to access all kinds of mathematical graphs and charts (e.g. function curves, data, stock charts) with minimal distortion.

It consists of two rows of vertical metallic strips on top of a flat board as shown below. The gap between the two rows forms a hollow cavity in the middle that can be sensed through touch.

In its default state as shown, only a horizontal line is "displayed", with each upper and lower vertical strip being equidistant from each other.

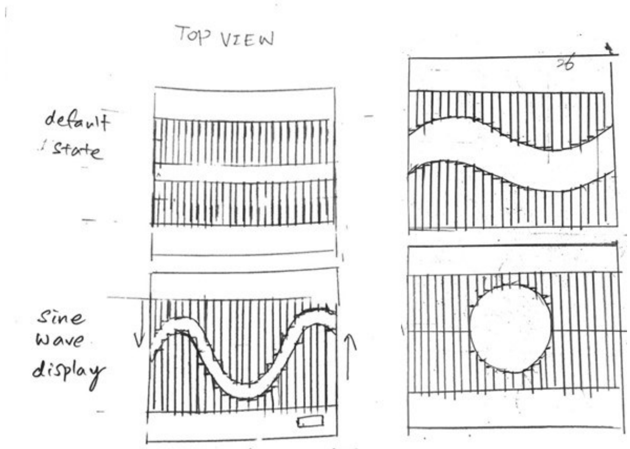


Figure 8 Top view demonstrations of mechanism

To display a graph (e.g. sine wave), the vertical metallic strips, which are operated by motors and concealed in a casing, slide up or down across the board, "extending" and "contracting" to their respective lengths such that the gap between the rows form a tactile image of a sine wave that can be touched as shown in the bottom left:

The key distinguishing factor of this design is that the line thickness of the sinewave can be increased by increasing the gap as shown above on the top right, reducing the staircase-like "quantisation error" introduced by the edges of the strips. This enables a large range of curves to be accurately represented. Zooming into the sinewave as a result will also not lead to loss in resolution. Basic shapes without outlines like circles and squares can also be represented as shown in the bottom right:

The rest of the features including the zoom in display and left, and right control is like the previous vibrating display concept, with the user zooming in only after aligning that target in the centre. Text to speech technology along with front end software is also used to teach the blind user what function each graph corresponds to, and read the more precise values of the graphs at the locations they specify through zooming in.

3.4.1 Software

For software, the key challenge is to convert a graph into displacement signals for the microcontroller. This can be done through a technique like analogue to digital conversion/sampling, with each strip representing a "sample". The graph is sliced up into vertical strips with the height of each strip corresponding to the value of the curve at that point. The higher the number of strips, or the smaller the part of the curve represented, the higher the resolution and the smaller the quantisation error. This would give the desired positions in y coordinates for the lower row of vertical strips, with the bottom of the display being defined as the y=0 point. The previous position (current position of the strip) will then be subtracted away from the new position as computed above to get the actual displacement of the strip (negative values indicate downward displacement; positive values indicate upward displacement).

The displacement for the upper strips is then easily determined by: position of upper strips = total length of board – line thickness – position of lower strips, with the displacement similarly calculated from previous values. Magnified/shifted images will also employ the same techniques. The values are then sent to the microcontroller for execution.

3.4.2 Hardware

Each strip is powered by a rotary motor on the underside of the strip. The motor is fitted with a gear acting as a small "wheel" that moves along a gear track. The motor converts current into rotary motion, the gears convert rotary motion into linear motion, with the displacement of the strip controlled by how long the motor is turned on for when rotating at a uniform speed. The displacement signals are sent by the microcontroller to each strip. The key difficulty is ensuring that the strips move smoothly and are synchronised properly while remaining secured when no signal is sent. To produce an image of significant resolution, around 30 strips of 1cm width would be required, each strip will have its own gear track (placed either on top or below the strip) and surrounded by rails to prevent the strips from interfering with one another. Rollers can also be added to keep the strips level. Two manual rotation adjusted clamps can also be placed across the row of strips at the very top and bottom to apply pressure to the rails and fix the strips when the user is interpreting the graph.

3.4.3 Feasibility and Cost Analysis

Sliding and rolling mechanisms are commonly applied in many everyday appliances and constructions (e.g. sliding doors, conveyor belts, CNC machines) in many different forms and hence there will be multiple feasible ways to implement this idea. The key difficulty is the alignment and synchronization of the vertical strips. rotation and stopping of motors, with differences in acceleration and deceleration could lead to errors that might be especially visible for graphs with thin lines, and the error needs to be considered and calibrated during testing.

The gears also need to be at optimal distance from the track to "bite" onto the gears and enable quick responsive linear motion of the strips while not being too close such that they get stuck or cause uneven/inconsistent movement. The vertical strips also need to be locked into place while the graph is being read and should not slide on their own with slight tilting.

Item	Cost
Motors	GBP 1.47- apiece [22]
Metal strips x 100	GBP 48.09 [23]
Gears x10	GBP 4 [24]
Gear tracks x10	GBP 4
Adjustable Clamps	GBP 15 [25]
Total estimated cost (30 strip display)	GBP 140.8

In terms of product cost, the main component would be the rotary motors which can be purchased for less than a pound per piece. The cost similarly also goes up with resolution, but at a linear rate since strips only need to be added in one direction. Even for a highly detailed 30 strip implementation as shown in the table above, the overestimated cost is still well within budget.

3.5 Solution 5 – Customizable Braille Display

The next problem seeks to tackle the same problem through a different approach: by addressing characters (which are visual information) instead of graphs.

In the last 40 years, Braille literacy among school-aged blind children in the United States has decreased from nearly 50% to 12%. [2]

Part of the reason is that learning Braille takes too much time, because it requires multiple repetitions of different words, but also another person's feedback on the word that is being read. This product aims to tackle this problem by providing a portable and customizable education device.

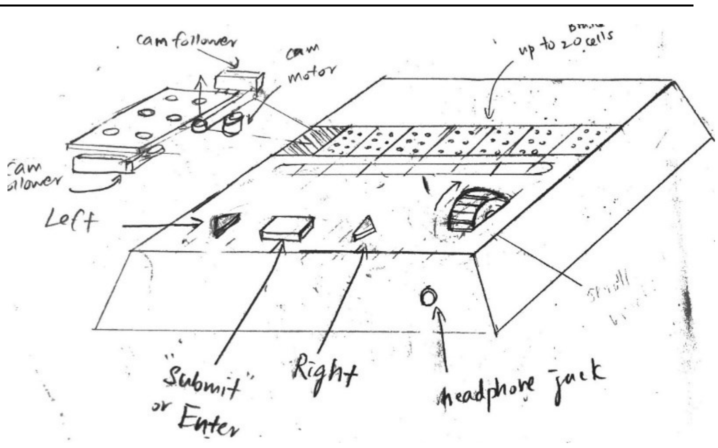


Figure 10 Artist Impression of Device

The purpose of the device is to replace current use of tactile alphabet cards and repetitive reading with a secondary person's input. The product will have the possibility of having different educational programs, dictionaries and tests uploaded to it with different ways of using the button inputs, audio output and the memory.

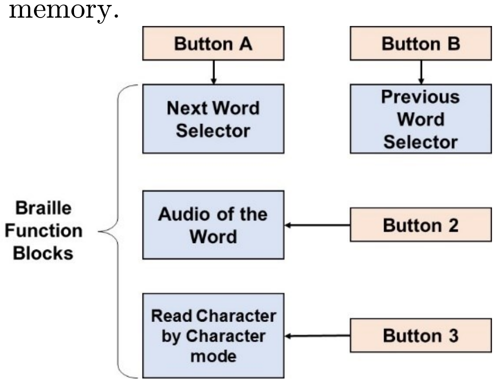


Figure 11 Flowchart of Block System for Software

3.5.1 Software

The software implementation is divided into two parts: dedicated program and microcontroller. The dedicated computer software will provide the user with the interface for uploading default scripts or making their own. Each script is created using "blocks" and can make use of memory (lists of words), buttons and audio.

For instance, let us take the sentence: Frequency Response Analysis. This can be spread into 3 words such as [FREQUENCY] [RESPONSE] [ANALYSIS]. Each word will then be outputted onto the device to be read by the user.

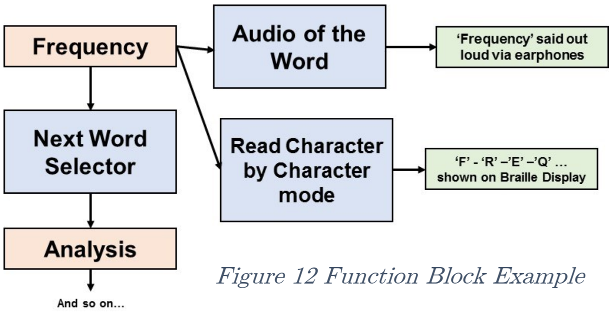


Figure 12 Function Block Example

The UI will have a panel with different block functions, such as "Next word", "Previous word", "Word audio", etc.; default word lists (formatted .txt files can also be uploaded); button blocks. Connecting function blocks with button blocks will create the required relationship and the function will be activated on the button event.

The other part of software is the microcontroller, which will set up the relationships described by the computer software, as well as include the logic for displaying each Braille symbol.

3.5.2 Hardware

The hardware mechanism in this system is very modular. Each Braille cell will be made using 6 stepper motors which will utilise a 'cam' mechanism. These will in-turn exert a force onto a plastic tab which will elevate the element of a braille cell. There will be 6 motors for the 6 elements in each Braille cell. Each cell will be connected to an encoder IC which will enable a serial input from a microcontroller to control which element moves up and down, like how a 7 -segment display is utilised in software.

Figure 13 ' Cam' mechanism example. Yellow parts indicating elements. Image is Creative Commons (Wikimedia) [33]

3.5.3 Feasibility and Cost Analysis

Item	Cost
Mini Stepper Motors	GBP 33.64 (for 100 total units) [26]
3D Printed Cam Mechanism	GBP 30 (for total 3kg of material) [20]
Soft-touch buttons	GBP 4.45 (10 Sets) [27]
Analogue Digital Decoder Chipset (for speaker)	GBP 5.76 [28]
Speaker	GBP 7.18 [29]
Total estimated cost	GBP 81.03

As seen above in the costs table, this device is certainly achievable from a cost prospective. However, particularly with this proposal, getting the electromechanical mechanism to work will be difficult. As the Braille standard has specific width and heights for the elements [10], the internal component such as the motors must be very small. As a result, making the mechanism reliable and portable enough will be a challenge. The device has also got many rivals which it would need to compete with in order to make it sell well. The next comparable product on the market is the Orbit Reader [30] which retails for GBP 599 (VAT). This idea would be feasible, but the team will need to overcome the initial barrier with miniaturizing the mechanism.

IV: Selected Proposal and Next Steps

4.1 Comparison and Performance Evaluation of Proposals

Performance:

Among the displays (vibration, dynamic pixels, sliding), in terms of resolution, the vertical sliding display is the only concept that offers significantly higher adjustable resolution through changing the gaps between the strips, while the dynamic and vibrating versions have fixed resolution and are often unable to represent minute details in images even after magnification without significant upscaling.

Even though it loses out to the dynamic pixel and vibration display in terms of versatility, as it is limited by only projecting graphs with an outline, its overall utility is maximized by how well the graphs are displayed. Within the field of graphs, the sliding vertical display also offers much more versatility in terms of the types of graphs displayed, with almost any kind of line graph (including curves, sharp edges and discontinuities) being displayed with minimal distortion.

Relaying accurate information about graphs with minimal ambiguity would be much more useful for the blind as they could reliably use them for different applications (e.g. learning about all kinds of functions) compared to low resolution images formed by the dynamic pixel's proposal.

On top of that, in most scenarios, graphs are also sufficient to represent much of the critical information blind people need but cannot access (e.g. stock charts and statistics), and could potentially enable previously inaccessible activities (investing in stocks, reading and understanding scientific papers and news independently) to be accessible for the blind, while images and objects can still be touched by the blind in everyday life, with only their two dimensional versions being more abstract to visualize. Modern day apps like TapTapSee [6] already allow blind people to independently understand various images by narration.

For the magnetic stylus concept, which does technically offer much higher resolution than any of the displays when the image is drawn, enables the blind person to understand various images and curves. However, it still does not completely bridge the gap in enabling the blind person to understand the image drawn. The image is still drawn on a flat surface that cannot be easily sensed, making it a very effective tool for a different purpose of creating graphics instead of visualizing them.

For the Braille Learner, which does directly appeal to conventional ways of learning information, making it by default an effective learning tool, it does not have the same utility and versatility as the other ideas. From interviews with blind people modern day text to speech technology have made it much easier for blind people to read, and cheaper versions of Braille Learners are also commonplace on the market.

On the other hand, from similar first-hand interviews sources, currently 98% [3] of all images must be described verbally and there are no products currently available on the market which would blind people to visualize images. Specialist schools for the visually impaired have also expressed notable interest in a device that could help their students learn about graphs on their own. [31] This would imply that devices that display graphics have a much bigger marginal impact on the lives of blind people in terms of both employment and educational than the Braille Learner and are therefore much more effective.

In terms of basic functionality, all five ideas are very similar and are all very compatible with other modern-day devices and can operate with minimal lag time, with the vibrating display being the fastest device due to minimal moving parts. Therefore, when it comes to performance, the sliding display is the overall winner.

Target Cost

Given a similar budget of 450 pounds, vertical strips proposal prevails since the resolution/performance only scales linearly with cost, with twice the number of strips in each row leading to half the error. For the dynamic pixels and vibrating keys, the fact that they must be arranged in a square means that new rows and columns must be added in order to reduce the error along both axis by a similar amount.

The Braille Learner also scales linearly in cost, with each additional character providing additional functionality to the device (with longer lines of text displayed), but at a higher rate than the sliding display. Though the magnetic stylus concept is technically a fixed cost with minimal change by scaling, the fixed costs of building a CNC machine with multiple moving precise parts are extremely high by default, while the other ideas mostly involve cheap motors/solenoids costing less than a pound each as actuators.

Ergonomics

Ergonomics wise, there is marginal difference between the various displays, with the Braille learner by default being the most usable since similar devices are already commonly used by the blind. However, from interviews with blind schools, it was discovered that blind students similarly use tactile images to learn graphs and diagrams, have a solid grasp of coordinate systems, angles, and orientations. Hence, they will very likely also be able to adapt well to the new display concepts (which also makes use of tactile sensing and coordinates) after some practice.

Safety

All the products contain moving and exposed parts to some extent, which could meet water or hands, with the Braille Reader being the safest due to it having the least components exposed and the dynamic pixels posing the largest safety risk due to the large currents and overheating required to produce the magnetic field.

Timescale

Some of the more novel concepts like the dynamic pixels and sliding display would require more time to test and finalise compared to the concepts with existing implementations like the magnetic stylus and Braille display. However, the relative complexity can always be reduced to adjust to the allowed time scale, and smaller scale versions can almost certainly be built within the 2-month time frame.

Life in service

The difference in durability of the concepts is similarly determined by the number of moving and exposed parts. Devices like the dynamic and vibrating pixels are more vulnerable to environment conditions like water, dust and dirt due to exposed gaps between moving parts, and repeated frequent motion will also wear the devices out in the long run.

Size and Weight

All 5 concepts are of similar size and weight and are made up of similar components, with the exception being the magnetic stylus as the CNC machine introduces heavy moving parts with constantly shifting centre of gravity which makes it much more unwieldy than the rest.

4.2 Selected Concept and Next Steps

	Dynamic Pixels	**Vibrating Keys**	**Magnetic Stylus**	**Vertical Sliding Display**	**Braille Learner**
Performance	1	2	4	5	3
Life in service	2	3	1	4	5
Ergonomics	3	2	1	5	4
Quality and Reliability	1	3	2	5	4
Safety	1	4	2	3	5
Timescale	1	3	2	5	4
Target Cost	1	2	3	5	4
Size	2	3	1	4	5
Weight	2	3	1	4	5
Total	14	25	17	40	39

Figure 14 Matrix Evaluation Table

As evaluated quantitatively above in the design matrix based on each PDS element, the sliding display has the highest score overall. Even though the Braille reader is beaten by a close margin, the criteria where it scores highest in, namely performance and cost, are more critical than the rest. Therefore, from the above evaluation, the sliding display is our chosen idea mainly due to its performance and cost factors, while not presenting any notable disadvantages in the rest of the criteria.

4.3 Next Steps and Timeline

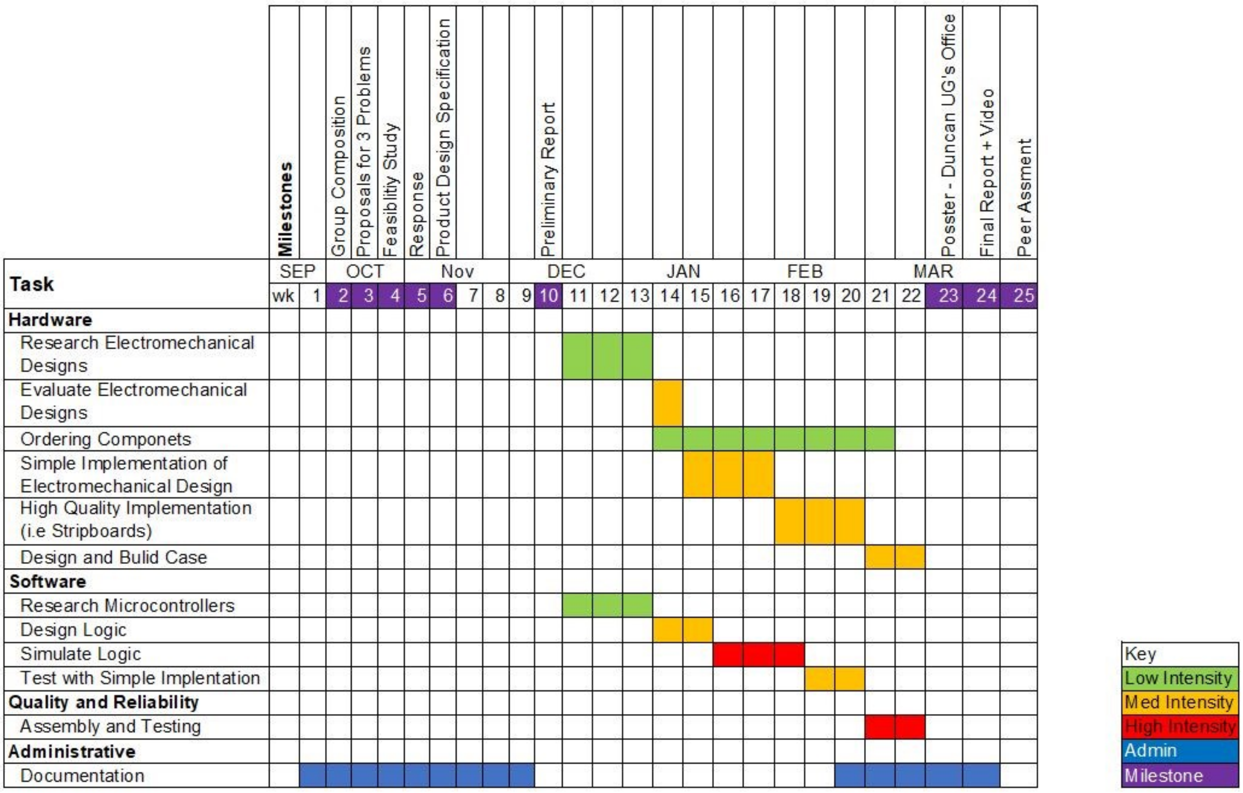
On this section, we will detail our next actions in order to finalise and start building the chosen concept. We will start of with a general week-based plan which is seen below.

Detailed Timeline (stated weeks starting in the Spring term)

Week 1-2	Start ordering the components and start developing graphing software (Designing Logic)
Week 3-4	Assemble basic mechanical units (Simple Implementation).
Week 5-6	Electrical System Design and Microcontroller programming Mass produce and construct basic mechanical units once proof of concept is verified
Week 7-8	Combined testing/calibration of electrical and mechanical units
Week 9-10	Develop front end text to speech software and library of functions
Week 11	Final testing and troubleshooting for the demonstration Set up the demonstration and perform live demos in blind schools

Gantt Chart

Below is our Gantt Chart showing a more specific visual representation of the groups plan to complete this project in the given time frame.



The team would be split into two sub-teams, hardware and software. The software team will work on the logic implementation of the electromechanical system and programming the device. The hardware team will work on conceptualising and implementing the electromechanical system. Both teams will work together to ensure its reliability and document the entire process. The sequence of events is shown in the Gantt chart above. Each colour on the Gantt chart represents either the type of work or intensity of the period; Red (high intensity), Orange (med intensity), Green (low intensity), Blue(documentation) and Purple (Milestones).

Regular meetings will be held with most members of the meetings; scheduled every Friday from 10:00 to 11:30.

- Online 'Informal' Meetings will also be held on Google Hangouts
- Progress of each sub group and announcements made on Slack
- Informal Communications maintained via WhatsApp
- Formal Milestone communications made via Mailing list.

V: References

5.1 In this section, the references cited in the above document will be referenced below:

[1] National Federation of the Blind (NFB), “Blind Statistics regarding Education Levels,” January 2019. [Online]. Available: https://www.nfb.org/resources/blindness-statistics.

[2] W. H. Organisation, “Global Data on Visual Impairment 2010,” 1 December 2011. [Online]. Available: https://www.who.int/blindness/publications/globaldata/en/.

[3] R. S. Person, “Phone Call,” in *Phone Call*, London, 2019.

[4] R. N. I. o. t. B. U. (RNIB), “Key Information and Statistics on Sight loss in the UK,” 1 February 2018. [Online]. Available: https://www.rnib.org.uk/professionals/knowledge-and-research-hub/key-information-and-statistics.

[5] “Enfield Vision,” [Online]. Available: https://www.enfieldvision.org.uk/. [Accessed 2019 December 2019].

[6] TapTapSee App, “TapTapSee Application,” [Online]. Available: https://taptapseeapp.com/. [Accessed 12 December 2019].

[7] T3 Group, “Best Student Laptops,” [Online]. Available: https://www.t3.com/news/best-student-laptops . [Accessed 12 December 2019].

[8] L. U. G. Department, “Blindness and Visual Impairment,” [Online]. Available: https://www.loc.gov/nls/resources/blindness-and-vision-impairment/devices-aids/braille-displays-notetakers/ .

[9] ICT Pulse Com, “Laptops versus Tablets,” [Online]. Available: https://www.ict-pulse.com/2011/06/laptops-versus-tablets-which-one-is-better/ . [Accessed 12 December 2019].

[10] U. A. o. A. Formats, “Braille Standard Dimentions,” [Online]. Available: https://www.ukaaf.org/wp-content/uploads/BrailleStandardDimensionsFinal.pdf . [Accessed 2019 December 2019].

[11] H. D. Stolting, “Acuators,” in *Electromagnetic Acuator*, Springer-Link, pp. 85 - 153.

[12] eBay Marketplace, “Reel of Copper Wire Round Solid Bare,” [Online]. Available: https://www.ebay.co.uk/itm/Reel-of-Copper-Wire-Round-Solid-Bare-DIY-Jewellery-Making-Size-0-3mm-3-0mm-Multi/193195697313?var=493384590481&hash=item2cfb5c64a1:m:mK˙MUTW4DyqK0CUdzOyXpAQ. [Accessed 2019 December 2019].

[13] eBay Online, “Hand Forged Iron Rose Head Nail,” [Online]. Available: https://www.ebay.co.uk/itm/Hand-Forged-Iron-Rose-Head-Nail-Wrought-Iron-Handmade-Forged-Nails-35mm-65mm/152125056497?hash=item236b5c25f1:m:m6m-GhLG6FztTUJVH8kNJbg. [Accessed 12 December 2019].

[14] Amazon Online, “ARDUNIO UNO REV 3 A000066,” [Online]. Available: https://www.amazon.co.uk/Arduino-A000066-ARDUINO-UNO-REV3/dp/B008GRTSV6. [Accessed 12 December 2019].

[15] AliExpress Online, “LM358 LM358P DIP-8 Operational Amplifiers,” [Online]. Available: https://www.aliexpress.com/item/32866681748.html?spm=a2g0o.productlist.0.0.21204993eNWFDt&algo˙pvid=11c03dad-d07c-4af6-863f-ff217204e9c5&algo˙expid=11c03dad-d07c-4af6-863f-ff217204e9c5-0&btsid=604f037a-0d11-48da-8993-02e72c827a3f&ws˙ab˙test=searchweb0˙0,s. [Accessed 12 December 2019].

[16] Amazon Market Place, “DC 3V 70mA 12000RPM Mobile Phone Coin Flat Vibrating Vibration Motor,” [Online]. Available: https://www.amazon.co.uk/12000RPM-Mobile-Phone-Vibrating-Vibration/dp/B00GN67918/ref=asc˙df˙B00GN67918/?tag=googshopuk-21&linkCode=df0&hvadid=231965104222&hvpos=1o1&hvnetw=g&hvrand=5939163559879112034&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvl. [Accessed 12 December 2019].

[17] Amazon Marketplace, “Keyboard Key Caps,” [Online]. Available: https://www.amazon.com/slp/keyboard-key-caps/voy86phoejf298o.

[18] Desmos LLC, “Desmos API v1.3 Use,” DESMOS, [Online]. Available: https://www.desmos.com/api/v1.3/docs/index.html. [Accessed 12 December 2019].

[19] e. Online, “CNC 2 Axis Digital Readout Scale DRO,” [Online]. Available: https://www.ebay.co.uk/itm/CNC-2-Axis-Digital-Readout-Scale-DRO-Linear-Machine-For-Mill-Lathe-

BRIDGEPORT/112564658870?epid=2178358442&hash=item1a356062b6:g:kbAAAOSwA3dYIDDZ. [Accessed 12 December 2019].

[20] eBay Marketplace, "3D Printer Filament 1.75mm PLA 1kg FDM Up, Leapfrog," [Online]. Available: https://www.ebay.co.uk/itm/3D-Printer-Filament-1-75mm-PLA-1kg-FDM-Up-Leapfrog/332354463830?hash=item4d61dea856:m:mTLOM-1sSyvMd5˙UnOsAIaQ. [Accessed 12 December 2019].

[21] e. Online, "Neodymium Magnets Rare Earth Disk Ring Super Strong Craft Various Strengths," [Online]. Available: https://www.ebay.co.uk/itm/Neodymium-Magnets-Rare-Earth-Disk-Ring-Super-Strong-Craft-Various-Strengths/351416155240?hash=item51d208fc68:m:mKF1zsLYdQ9m2MJvZ2rQANQ. [Accessed 12 December 2019].

[22] RS Electronics, "DC Motor System," [Online]. Available: https://uk.rs-online.com/web/p/dc-motors/2389692. [Accessed 12 December 2019].

[23] RAE Service, "Metal Sheet Strips (100 Units)," [Online]. Available: https://www.raeservice.com/product/sheet-metal-strips/. [Accessed 12 December 2019].

[24] Rapid Electroncis, "Gear Rack System for Device," [Online]. Available: https://www.rapidonline.com/RVFM-Gear-Rack-Pack-of-10-37-0246?IncVat=1&pdg=pla-294357559827:kwd-294357559827:cmp-757438067:adg-44804851896:crv-207912323492:pid-37-0246:dev-c&gclid=CjwKCAiAxMLvBRBNEiwAKhr-nKMzoi12JCh8urq9TyUBUahFOnS6ILB22yfF-PPYbLKrSXE-QCh. [Accessed 12 December 2019].

[25] BHP Photo Group, "Black Table Clamp (Adjustable)," [Online]. Available: https://www.bhphotovideo.com/c/product/534714-REG/K˙M˙23700˙500˙55˙237B˙Table˙Clamp˙Black.html. [Accessed 12 December 2019].

[26] AliExpress, "3-5v Dc 2 Phase 4 Wire Dia 8mm Dc Stepper Motor," [Online]. Available: https://www.aliexpress.com/item/32908973633.html?spm=a2g0o.productlist.0.0.6fa86ae40ckq7Y&algo˙pvid=ad152970-bbdd-454c-b8ea-24c9dbcc5aa5&algo˙expid=ad152970-bbdd-454c-b8ea-24c9dbcc5aa5-3&btsid=d3246d3e-b127-45c5-9723-d4b96ab6e680&ws˙ab˙test=searchweb0˙0,s. [Accessed 12 December 2019].

[27] eBay Market Place, "Miniature SPST Momentary Push Button," [Online]. Available: https://www.ebay.co.uk/itm/Miniature-SPST-Momentary-Push-Button-Switch-Push-To-Make-UK-Stock/123891494048?hash=item1cd8822ca0:m:m-Lfn-dpGHpMXTYd03Gjxgg. [Accessed 12 December 2019].

[28] eBay Market Place, "TDA1543 Dual 16-bit DAC Chip DIP-8," [Online]. Available: https://www.ebay.co.uk/itm/10pcs-TDA1543-Dual-16-bit-DAC-Chip-DIP-8-NEW-GOOD-QUALITY/171907258962?hash=item2806789a52:g:MB8AAOSwq7JT4trs. [Accessed 12 December 2019].

[29] eBay Marketplace, "Mini Audio TV Speaker Driver 8 Ohm 10W," [Online]. Available: https://www.ebay.co.uk/itm/Mini-Audio-TV-Speaker-Driver-8-Ohm-10W-Loudspeaker-DIY-Sound-Computer-Speaker/184062435476?hash=item2adaf9e094:g:CUkAAOSwo49d4k-t. [Accessed 12 December 2019].

[30] RNIB UK, "ORBIT READER 2," [Online]. Available: https://shop.rnib.org.uk/orbit.html. [Accessed 1 December 2019].

[31] L. L. School, "Phone Interview," UK, 2019.

[32] Cool Components, "Electromagnetic Holding Force variants," [Online]. Available: https://coolcomponents.co.uk/products/5v-electromagnet-5-kg-holding-force-p25-20?variant=13205204631613&currency=GBP&gclid=EAIaIQobChMIj5HrnZqm5gIVArTtCh3YPwOrEAQYAyABEgJ0KPD˙BwE. [Accessed 12 December 2019].

[33] "Camshaft animation. Animierte Nockenwelle. Own work, 20th July 2006, Borowski," Wikimedia Commons, [Online]. Available: https://commons.wikimedia.org/wiki/File:Nockenwelle˙ani.gif. [Accessed 12 December 2019].

VI: Diagrams & Appendices

Additional Copies and Omitted Figures and Texts

Solution 1:

Reduced complexity, Bit-to-Row (Buffer) Encoding: An alternative way to reduce the complexity would be to multiplex and include a buffer. That is, assuming again we have n x n, then we can represent the vertical axis through $\log_2 n$ bits, using the same bit stream, we can also represent the same for the horizontal axis by holding the first result in a buffer. Although this is not done in real-time, this method will not affect the performance by a large amount due to the high speed of digital logic which can be easily implemented with an onboard FPGA system.

The incoming signals then can be intercepted by a digital bitstream that is stored on on-board programmable ROM.

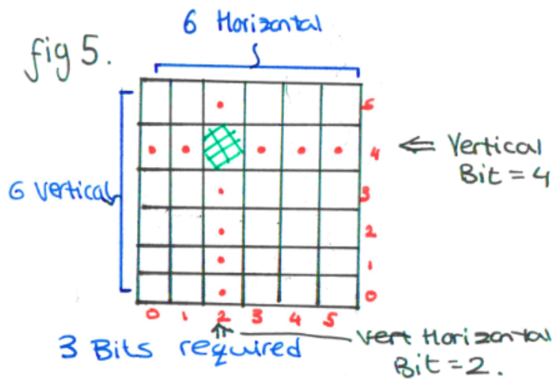


Figure 15 Bit-to-Row Encoding

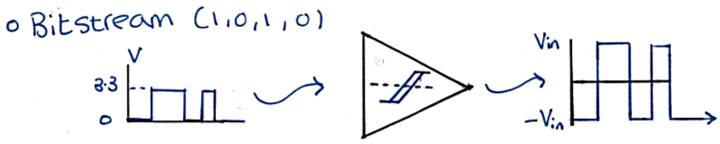


Figure 17 Bitstream Encoding Visual Aid

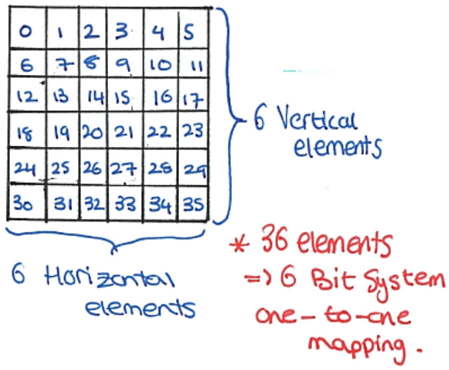


Figure 16 Simple Bit-to Symbol Encoding

Solution 2:

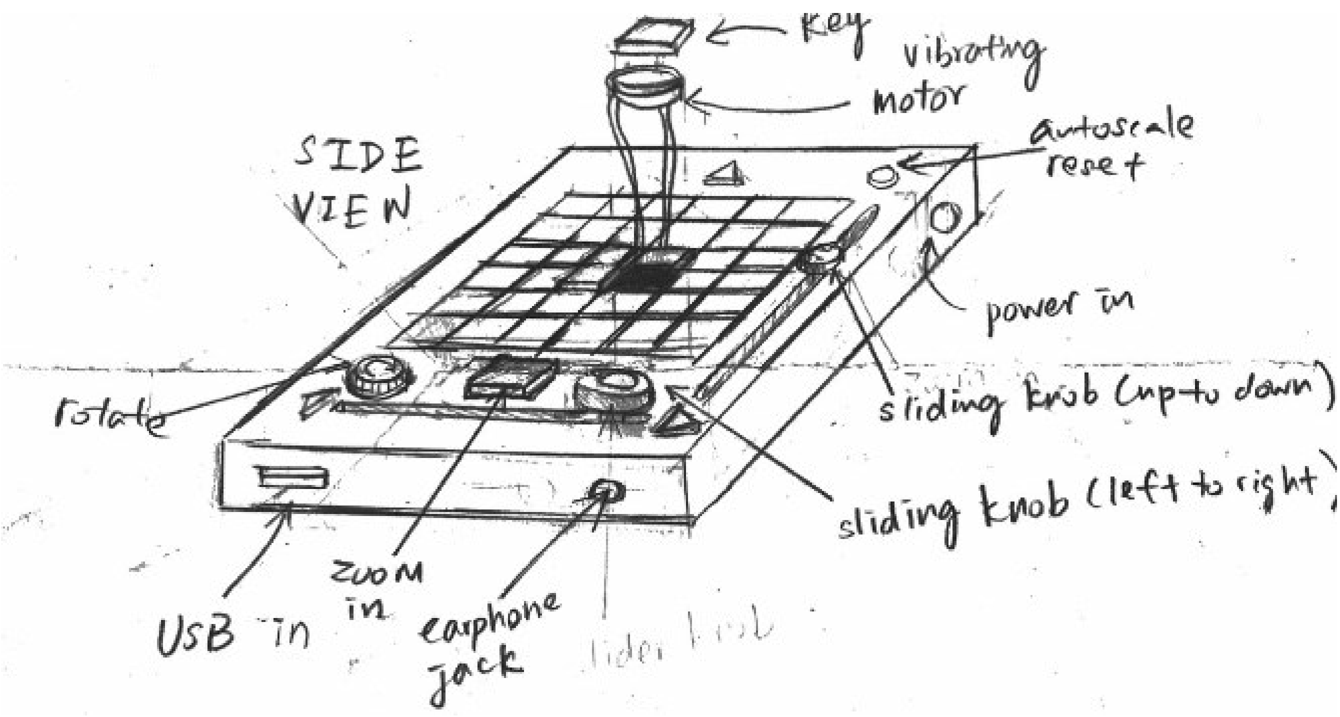


Figure 18 Artist Sketch of Proposed device

Solution 3:

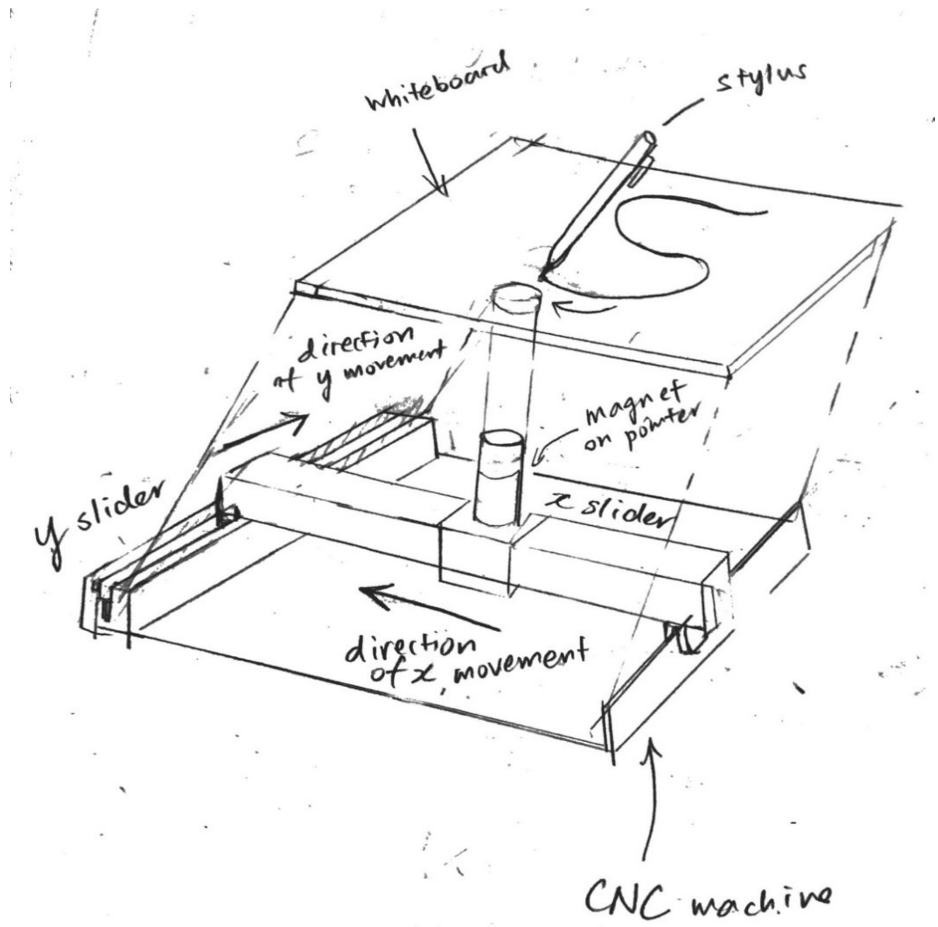


Figure 19 Proposed Sketch for Device

Solution 4:

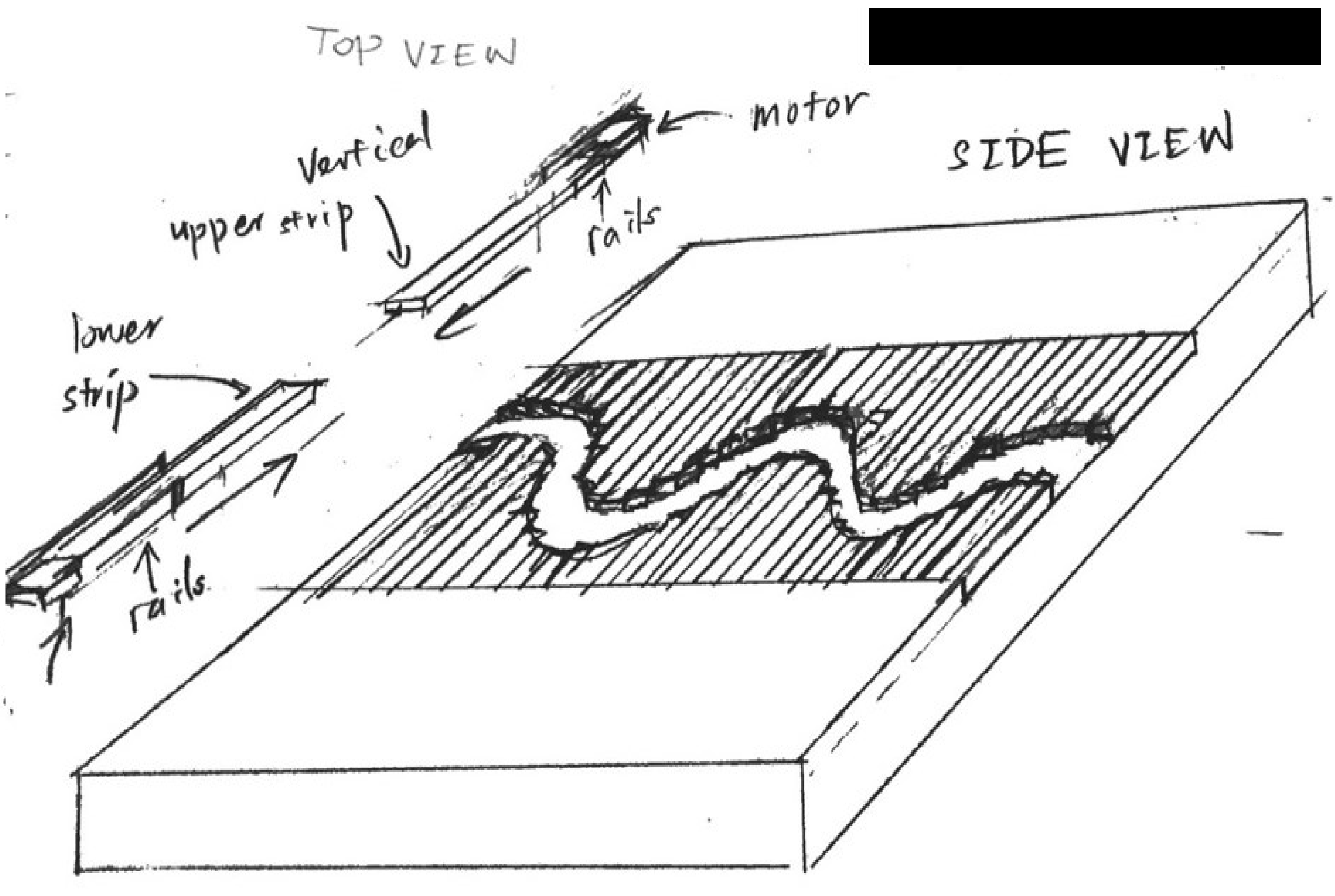
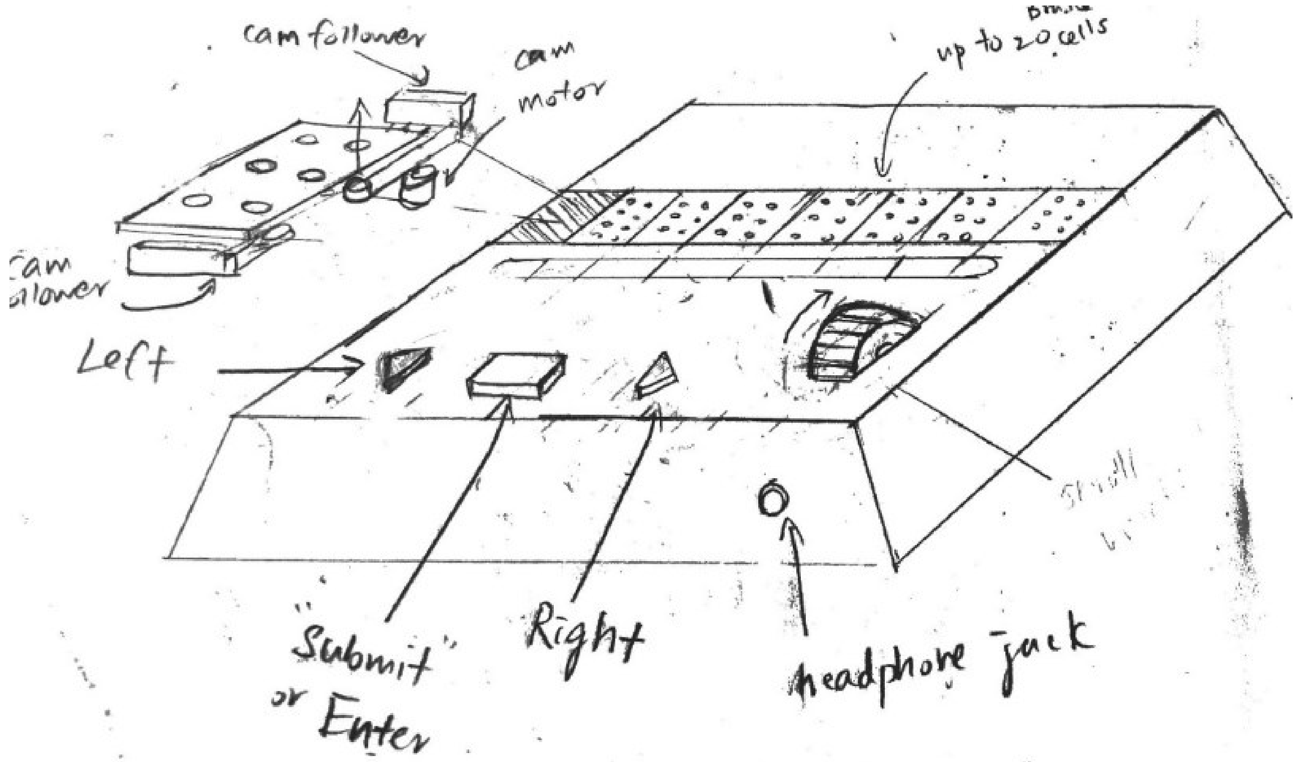


Figure 20 Artist Impression of Solution

Solution 5:


cam follower
cam motor
up to 20 cells
cam follower
Left
"Submit" or Enter
Right
headphone jack