1 Introduction

According to the NHS, there were almost 2 million people living with sight loss in the UK in 2018, from which around 360,000 were registered as blind or partially sighted [1]. Technology has advanced a lot in the last few years, and now due to COVID-19, almost everything has moved to an online environment. For blind people, one way of knowing what is in their screen is through a screen reader, which is a software that automatically reads out text. JAWS is one of the most popular ones, and it costs $90 per month or $1200 for a professional license [2]. This particular screen reader allows you to navigate throughout the page by using the “tab” key. But you cannot control what it is going to read next. This can be a problem for web pages, as the order of reading depends on how they are structured (columns and rows) and may not be intuitive to the user. Documents with multiple columns can also be problematic.

Another popular screen reader is NVDA[3]. This is an open-source software, only available for PCs running Microsoft Windows 7 and later. It contains multiple shortcut commands for easier access for the user [4]. Alternatively, it can read out the text that the mouse is currently pointing at, without the need of clicking any button. Nevertheless, a vision impaired user will not know where their mouse is pointing, which again, can cause difficulties.

The main aim of this project is to create a desktop haptic interface that is connected to the computer via USB, to give feedback to a vision impaired user about the position of the mouse or cursor relative to the webpage or document. This will help blind or vision impaired individuals to navigate and understand documents more effectively when using a screen reader. Knowing one’s location in a webpage or document is often achieved for sighted people with a scroll bar on the side of a window. This system is like a two-dimensional scroll bar that uses touch to communicate with vision impaired people. In such a way, it will provide a sensation that is always available, without interfering with the audio output of the screen reader. The interface will be first implemented in PDF documents and then extended to web pages.

The project itself is divided into two parts: design and fabrication of the interface; and modify the source code of the screen reader, in this case NVDA, to communicate with the system. Solid Works was used as the CAD software as many models of components such as Arduino’s and motors are widely available online. This will save a considerably amount of time while designing. As for the screen reader used, NVDA was the best choice as it is open source, and it is written in python, and so, easy to ‘hack’.

2 Background

2.1 Visual Impairement

Visual impairment is a term used to describe any kind of vision loss. Most people experience vision loss after birth, but babies can be born with congenital blindness [5]. Globally, around 80% of the visually impaired people are aged 50 or older (203 million people in the world) [6]. In the UK, a person can be registered as visually impaired, and get some help from social services to remain independent (e.g. get help with cleaning and cooking) [1]. The sight status will be assessed through the Snellen test for visual acuity conducted by an ophthalmologist, who will decide if the person can be certified as severely sight impaired (blind), or sight impaired (partially sighted). The results from this test are expressed as a fraction of two numbers. For example, a result of 6 / 60 means that the user is able to see at 6 metres what someone with standard vision can see at 60 metres [7].

2.2 Technological Aid for VI Persons

As technology has been evolving over the years, the human being had progressively relied on it. This is especially true during this pandemic, where people had to work from home, and students had to learn remotely. For a person with standard vision, this may not have presented a big challenge, but for severe sight impaired users, the fact of staying in front of a screen without knowing what is on it, may have been difficult. Writing in a computer with a screen reader without misspelling a word is possible, as it will read out every letter separately. Nevertheless, the user may need to reduce their typing speed to allow it enough time to finish saying each letter. Alternative input options to the computer includes using a high contrast keyboard for partially sighted users or braille display keyboards [8]. Voice control is also available in computer with Cortana (windows) and VoiceOver (MACOSX).

All the technological aid mentioned above, are inputs to the computer, but this project focuses on output/feedback from it. Nowadays, all mobile phone devices have integrated screen readers, “TalkBack” in android, and “VoiceOver” in iOS [9] [10]. It allows visually impaired users to interact with their device using touch and auditory feedback. Every time a new app or option is focused, the phone will vibrate and read out loud the text. To enter an app, the user just needs to double tap anywhere on the screen. The user can also use two fingers to scroll through the screen. Both screen readers start up a full tutorial of the gestures when activated for the first time. This makes it easier for new users to familiarize themselves with the user interface.

2.3 Haptic Feedback

Visually impaired people are used to perceiving the world through touch and sound. The ability of echolocation in some users demonstrate the stronger auditory sensitivity compared to an able-bodied person. Echolocation uses echoes and sound waves to determine the position of an object [11]. Nonetheless, it is undesired to mix sounds with the output of the screen reader. Thus, the interface in this project will rely only in touch. A lack of sight does lead to a better sense of touch. However, this sensitivity will also depend on the time from which the person has been blind (a VI person from birth will have a better sense of touch than a person blind at 20 years) [11]. A common way to perceive what is around them through touch is by the use of a white cane. When navigating and there is an obstacle on their way, their cane will collide with the obstacle, providing a haptic sensation to let the user know that something is in there.

Haptic feedback enhances user experience through the sense of touch, which includes both tactile and force. Touch is part of the somatosensory system which comprises sensations about temperature, pain, and movement of a person's own body in space among others [12]. The most common type of haptic feedback is vibration. Vibration of mobile phone can happen at any time when getting alerts or notifications from any app. It is easier for the VI users to navigate in a phone compared to a computer because the tactile screen of the phone allows them to explore the limits of the device, while getting auditory and haptic feedback. In fact, phone interfaces are simpler than computer interfaces mainly due to a smaller screen size.

2.3.1 Vibrotactile Haptics

Vibrotactile feedback relies on vibration to transmit a specific message. Salazar et al. have shown that a vibrotactile device attached to the wrist can be used to provide guidance in human navigation. The number of actuators used was six, so to cover every direction (0 to 360 degrees), "virtual" cues were created by the combination of 2 actuators. This is known as the Phantom Sensation illusion. For example, if actuator 1 is at 0 degrees and actuator 2 is at 60 degrees. Any angle in between them can be express by the combination of both motors [13]. If the direction we want to communicate is closer to 60 degrees, then the vibration from actuator 2 will be stronger than from actuator 1. For this project purpose, the interface could be made cube or cylinder shaped, and use a similar principle. It will vibrate when the mouse has been deviated from the centre of the screen, the greater the deviation, the stronger the vibration. Yet, feeling constant vibrations in hand can distract the user from the primary task.

2.3.2 Skin Stretch Haptics

Skin stretch haptics can be an effective mean of communication to provide direction, magnitude, and frequency information directly [14]. The fingertip is the most sensitive part for this purpose. However, the same accuracies for identifying motion were achieved if the distance of the stimulus was increased by 6 [15]. This type of haptic have 2 degrees if freedom: direction (x and y-axis) and velocity. In [16], longer skin stretches and faster movement lead to higher accuracies when communicating the direction of motion on the fingertip. One of its advantages is that it can be made relatively small. Nevertheless, for this project, the whole screen will need to be mapped to the interface. Given the interface is small, a change on the position of the mouse will correspond to a small-scale skin stretch. This is not practical, as the user may not be able to identify the position of the mouse unless it goes from one corner of the screen to another one. Making the interface larger (i.e. 5cm*5cm), may impose an uncomfortable hand position for the user, especially when used for long periods of time. Thus, this type is not suitable.

2.3.3 Shape Changing Haptics

Shape-changing haptics can alter its size and shape to provide guidance or directional cues as in [17]. In this application, the interface can move in the x and y directions to provide feedback related to the mouse or cursor position. It will be placed near the computer for easy access to the user. The initial idea is to have a similar design to the animotus/haptic sandwich as in [18] (see implementation plan for more details).

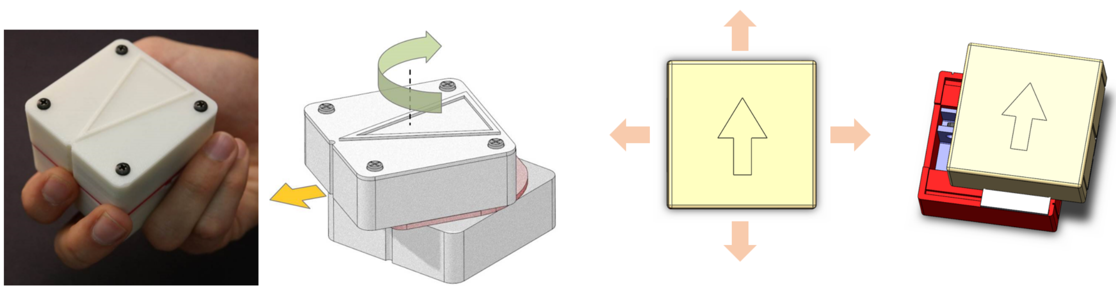
2.4 Interview with a VI person

To get a better insight into the interaction between a VI person and a computer using screen readers, an interview was carried out. The interviewee was a 32-year male, who has been visually impaired since he was 2 years-old. The user has been using screen readers for 7 or 8 years approximately, and now uses NVDA (same as this project) because is free and open source. The user said: *"I don't really use the mouse because there is no enough guidelines, so if you tried it in NVDA obviously the pitch is helpful because it makes some noises"*. He also emphasized: *"the mouse is the last resource I use"*. He also found more interesting obtaining feedback related with the position of the mouse rather than the position of the cursor. Based on his feedback the system will be adapted to let the user change between these two modes. The VI person also found useful touch feedback: *"when you touch an icon or when something happens. You are able to get some extra information"* and suggested to add vibrotactile feedback when changing between windows.

3 Implementation Plan

The initial idea of the project was to extract the cursor position as the screen reader reads the text out loud. However, as mentioned before, the VI individual interviewed found more interesting to track the position of the mouse instead. Thus, the device designed during this project may be able to switch between the 2 modes. The mouse tracker implementation was tested with 4 LEDs (top, down, left, and right) at the beginning of the project. The position was extracted from the NVDA source code and sent to the Arduino via serial communication. For the embedded system, an Arduino Nano v33 BLE was used. This device includes Bluetooth, but it may not be convenient of a VI person to connect the interface to the computer, given the difficulty of locating Bluetooth – settings without visual feedback. In addition, Bluetooth may have some connectivity problems, requiring the user to reconnect the device; the data may be received with a greater delay compared to USB connection making the haptic device to display the wrong position.

The actuators chosen were HiTec HS-82MG servo motors. Its rotation angle ranges from 0 to 180 degrees, making it more precise for this application compared to stepper motors. It provides a better initial position and easier to control it, only need to write the desired angle in the Arduino code. Furthermore, this motor uses metal gears, giving a high-power torque which can be beneficial in terms of the sustainability of the device. The actuators will be powered from an external source rather than the USB cable. This way, we can ensure the current and voltage (with a voltage regulator) going into the motor is sufficient, and it does not exceed the limits for correct operation. For the batteries, the main option is to use lithium-ion batteries as they can be small enough to fit into the interface.



(a) Animotus Design [18]   **(b)** My design

Figure 1: Comparison of designs between this project and the Animotus

From late November onwards, the main focus was on the CAD design of the interface. As mentioned earlier, the CAD design will be very similar to the Animotus design, a cube where the bottom part is fixed, and the top part is extendable to indicate the direction of the cursor. In this case, the top and bottom of this device will move linearly, unlike the Animotus, whose top half rotated. The approximate dimensions for the device are 66x66x45mm.

The device developed during this project can be grasped from either the bottom or the top part. There are lateral grooves in the top and right sides of the device to indicate the rest position and help the user understand how much the top half device has moved with respect to the bottom half device. The middle grooves are 1mm thicker to be able to differentiate them from the side ones. Additionally, the arrow on the top indicates the front part of the device.

3.1 Mechanical Structure

The motion within the device is controlled using a linear rack and a 20-tooth spur gear attached to each motor. This will convert the output of the rotational actuators to a linear motion. The bottom actuator handles the horizontal movement, whereas the top actuator manages the vertical movement. The outer diameter of the gears was greater than the thickness of the motor. Thus, a step-up plate was needed in the top half motor to avoid collision between the gear and the middle plate. To avoid complications during printing, it was decided to place a rack in the top half device rather than placing both racks in the middle part. This also allows the motor to be secured in the middle part via bolts, nuts, and the servo holder, which releases some pressure on the motor as now it only needs to move the top case.

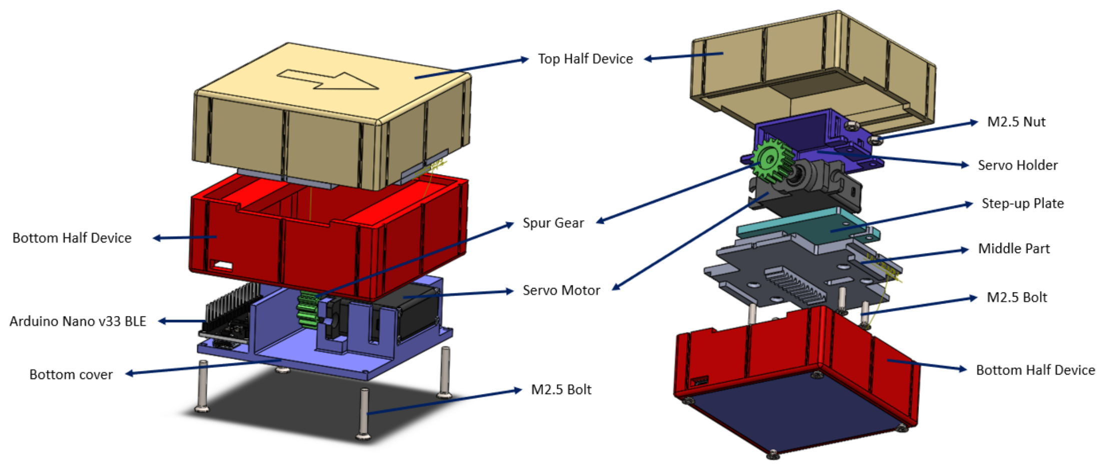


Figure 2: Detailed structure of the haptic device

The dynamic movement of the device is guided by some protruding parts within the middle part and cave in parts in the top and bottom halves. This sets the motion of the device to the desired direction (x-axis for the bottom part, and y-axis for the top part), and prevents the middle part from exceeding the limits. Currently, the maximum displacement is 7mm top and bottom, and 12mm left and right. Since around 2010, most of the laptop screens use a 16:9 ratio display [19]. Therefore, it is desirable for the haptic device to have a higher mobility in the x-direction compared to the y-direction for a higher accuracy in direction 'cues'. The surface of the middle plate needs to be completely flat for correct operation. However, M2.5 bolts are needed to secure the top motor. Hence, the head of the bolts need to be extruded into the plate.

3.2 Future plans

The next steps involve 3D printing the interface, and fix errors, or factors that were not thought of during the design step. The most critical and easy to go wrong, is the fitting of the 3D-printed linear rack, and the gears ordered for the actuators. Even a small mismatch could make the top part and bottom part to be misaligned in the rest state. Another important factor to look at closely, is the mechanical motion between parts. Printing inaccuracies could lead to misfitting of the driving segments from the middle part and the top/bottom parts. This could take 2-3 weeks, depending on the printing speed of the 3D printing.

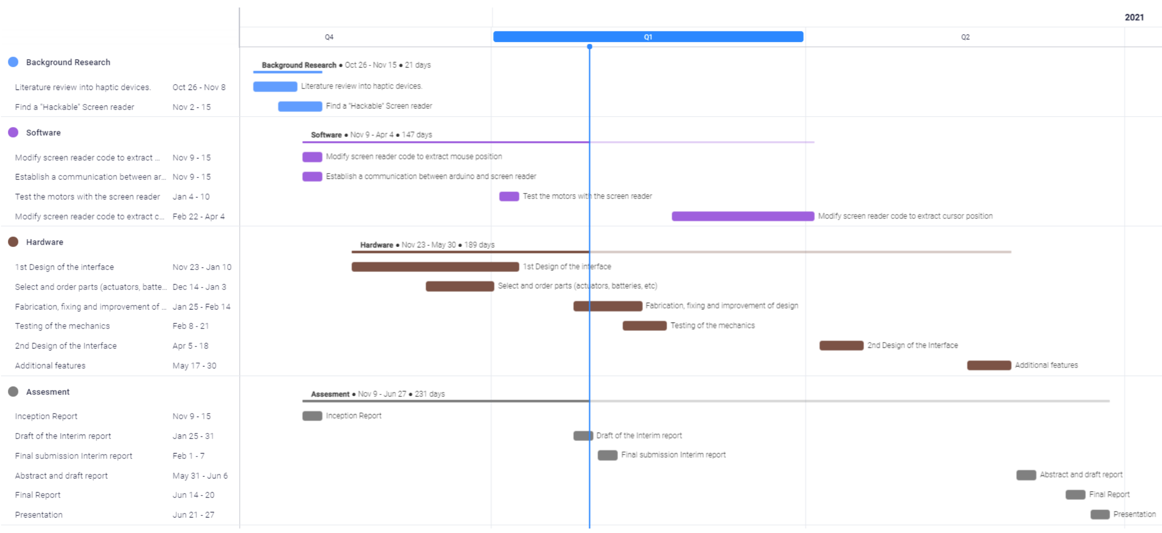


Figure 3: Gantt Chart

From late February to April, the code of NVDA will be explored and modified to try to extract the coordinates of the cursor as the screen reader reads out the text. This will be a time-consuming activity and requires high programming skills. The NVDA source code currently contains more than 20 python files. Before making changes to the code, a further understanding of the code is needed, and need find where it is performing this task. The interface may require further changes to allow the user switch between these two modes.

From mid-May to the end of the month, some additional features can be integrated to the interface. During the interview with the VI individual, he mentioned: “It will also be very handy to add vibration when changing a window. There are lots of times where I try to do something, and then realize I am not in the correct program”. The rest of the time will be focused on improving the final report and make slight changes to the design and code if required.

4 Evaluation plan

Since this device has been design for VI people, if COVID restrictions allow, the system will be evaluated with human participant test, ideally VI individuals. An alternative solution would be testing with sighted people who are blindfolded. Nevertheless, this may not be optimal as the way sighted people interact with the computer is not the same as VI individuals, especially congenitally blind individuals. In some cases, VI users may have had some previous experience in interacting with a computer before losing some or all their vision. This will allow them to have an ambiguous picture about the content in their screen.

The tests could consist in asking the participant to execute a task in the computer: going to a specific window, asking for the relative position of the mouse, or describing the structure of a webpage. The user will control the mouse themselves and try to complete the task with help of the haptic device. There will be some additional questions about their thoughts of the device, differences of what they expected and what they actually found, and possible improvements to make it more user friendly.

In the case that current COVID restrictions continue, we are currently discussing the potential of remote testing of the system. This could involve sending the device and a blindfold by post to potential (sighted) study participants, who would install and run our bespoke testing software on their own computer. The test can be carried on through teams or zoom so that the participant can share their screen while performing the test, allowing a better understanding on the struggles of the user. Another option is to tell the user to film themselves when testing the device.

5 Ethical, Legal and Safety Plan

If future COVID restrictions permit, evaluation of this system will be completed via human participant tests. Therefore, we will apply for ethical approval for the study from Imperial College London's Ethics board. Informed consent will then be obtained from the participants.

According to the research integrity provided by the University of Cambridge [20], this includes:

- Respecting Autonomy: Sufficient information will be provided to the individual before deciding upon participation and will have the right to withdraw at any time. Protection to personal data will be addressed by rigorous and appropriate procedures of confidentiality and anonymisation.
- Maximising Benefit: all the tests are carefully chosen to ensure quality and obtain useful results. In this case, the combination of the successfulness of the task and the actual feelings of the user are the best feedback.
- Minimising harm: In this case, participants may include VI, which can be considered part of the vulnerable community. The tests will be kept short to avoid fatigue on users.
- Being fair: the research can contain VI participants and participants with standard vision to further understand and compare the human-computer interaction between the different groups. This can help improve the interface, and therefore none of the groups or individuals will be unfairly discriminated.

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