Imperial College London

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EE2 Project: Group 16
Allowing People to Hear Colours

Final Report 2016

SonoChrome
Symphony of colours

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Abstract

Colour Vision Deficiency (CVD) is caused by a number of colour-perceiving cones in the eye being out of alignment, and is an optical condition that affects 8% of men and 0.5% of women in the world. Approximately 40% of sufferers are unaware of their condition, whilst 60% experience many problems in daily life. There are currently only a handful of products and services created specifically to assist colour blind people in their daily lives, all of which are either still under development or beyond the affordable limit of the average person.

Based on this situation, the SonoChrome was first conceived to be an affordable wearable with the specification to capture the user's field of vision, process the colours contained within, and generate an audio output of single discernible frequencies. With further research conducted into the technical aspects and market reception, it has evolved from its initial concept to an actual device with an array of features. The prototype runs on a Raspberry Pi, powered by a typical power bank. Images are captured using the Raspberry pi camera module and fed into the processor. The prototype possesses two modes of operation, catering to people who require knowledge of the location of specific colours, and those who want to know what colour lies in front of them. Audio output can also be customized from single frequencies to a series of sounds or a short melody, accessed via the in-built 3.5mm audio jack of the Pi.

The aim of the Project is to enhance the visual experience of colours for people suffering from colour vision deficiency through sound, thereby improving their aesthetic quality of life and increasing personal safety and awareness of their surroundings.

Introduction

This Final Report includes information on the design and development process of the SonoChrome, the organization of the Project as a whole, and motivations behind various decisions made which have advanced the Project to what is now presentable.

Colour Blindness

Colour Vision Deficiency (henceforth referred to as 'colour blindness'), is an optical condition that affects 8% of men and 0.5% of women in the world. Approximately 40% of sufferers are unaware of their condition, whilst 60% experience many problems in daily life[13].

Colour blindness is caused by a number of colour-perceiving cones in the eye being out of alignment. The majority of cases is heredity, although the condition can also be acquired as a consequence of age, environmental factors, and chronic diseases such as Alzheimer's disease, diabetes and multiple sclerosis[12].

There are many types of colour blindness but the most prevalent form is commonly known as 'red/green colour blindness', and these people face difficulty in distinguishing between red, green, brown and orange. They may also confuse blue and purple hues. In extremely rare cases, a person may suffer from full colour blindness[13].

The Project

The Team recognizes the potential dangers that colour blind people face in their daily lives. While it may simply be a headache to be unable to match clothes, the inability to distinguish between red and green on the busy streets with traffic could be life-threatening[20]. Thus the Team decided to carry out this Project with the aim to enhance the visual experience of colours for people suffering from colour blindness, improve their aesthetic quality of life, and increase personal safety and awareness of their surroundings.

In the TED talk 'I Listen to Colours'[23] speaker Neil Harbisson explains how he was born into a world of strictly black-and-white, devoid of colour. With the help of a cyberneticist, he designed a prosthetic device named the 'eyeborg' that converts colour into audible frequencies. It deeply changed his perception and his interaction with his surroundings, opening up a new world for him. This served as the inspiration for the Team behind the SonoChrome.

The Project aims to develop a personal portable wearable device that transposes all colours in the user's field of vision to sound in real-time. Observing the scale and duration of the Project, the Team decided that only one prototype would be built, allowing more time to refine the single device. Furthermore, within the defined period six months, a complex algorithm able to sample and process all colours and their blending in a user's field of vision was deemed too challenging, and as a result it was decided to only sample the colour roughly in the middle of the user's field of vision. This downscaling was imposed to make the Project manageable and able to produce results at this initial stage. Building upon the research and prototype development carried out in Autumn Term, the initial prototype was further improved in Spring Term. Extended market research was conducted reaching out to both colour blind and people with regular vision to gauge overall reaction and user needs for such a device.

Regarding competition, currently in existence there are plenty of colour naming mobile applications, but only two similar services that are wearables dedicated to colour blind welfare: the above mentioned 'eyeborg', and Enchroma[16]. Due to the difference in nature of these products and the SonoChrome (such as user interface, colour experience approach, cost), the Team believes that the SonoChrome is on par with these other devices and can provide a unique, perhaps even desired, user experience (refer to section on *Market Research I: The Fundamentals* and *Appendix C: Market Research*).

Market Research I: The Fundamentals

Market Research makes up a significant part since the Project is centred on a socio-economic context. In this section, findings from research conducted on colour blind user needs and information related to various aspects of the Project is shown. *Market Research I: The Fundamentals,* is as important to the Project as its name implies, serving as the basis of information on which further developments and decisions were carried out. In all surveys carried out for the Project, the same 116 individuals were approached to ensure consistency in samples. 11.2% were colour blind; the top three age ranges of respondents were 45-54, 19-24, and 18 or younger; 51% were male and 49% were female. Full market research findings can be found in *Appendix C: Market Research.*

User reception towards the concept of the Project

A market survey was released to the public to gauge user reception towards the concept of the project. In the survey, respondents were first given a brief summary of colour blindness, the purpose of the Project, and what it aims to deliver. Then they were asked to rate the idea of representing sound as colour.

With reference to the survey results in *figure 1*, the average rating is 6.27, indicating users are unsure about the concept but slightly tending towards feeling positive. Taking into consideration all scores above 5, that is, 6-9, this group forms a majority 62% of responses. Hence it can be concluded that there is a positive inclination towards the idea of representing sound as colour.

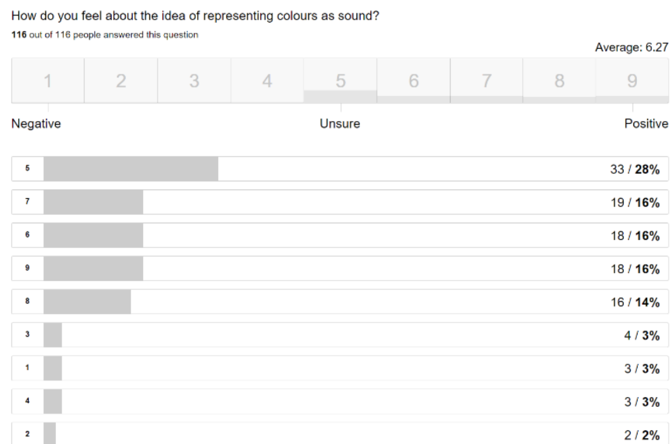


Figure 1: Survey results on the idea of representing colours as sound

Needs of the users

Following on from the previous question of the survey, respondents were asked in which situations they felt the need to differentiate between colours. The responses are summarized in no particular order of importance as follows:

- Buying things/shopping
- Matching clothes
- Traffic situations, both pedestrian and driving
- Conditions of food or materials
- Cooking
- Viewing videos, images, graphics, games
- During work, education, and trying to understand something that uses colour to convey information
- Graphic design, architecture, art, visual and design work
- Medical purposes such as sorting medication

The above situations largely agree with those stated by Ms Albany-Ward, founder of Colour Blind Awareness UK, whose response can be found in parts *K1, K2a, K2b, K6* and *K9* of the transcript attached in *Appendix C: Market Research.*

Reception and preferences towards wearable devices

Due to the SonoChrome being planned as a wearable device, it was necessary to determine the current status and public reception towards this class of technology in order to realize whether the proposal is justified or needs revision.

In the past year there has been increasing popular support for wearable technology. In 2013, Apple sold two million smart watches; in 2014, 3.3 million fitness trackers were sold; and last year in June, Google Glass sold out within a day at USD$1500 each[9]. Wearable technology is starting to become a bigger part of our society.

According to a survey[34] conducted by PricewaterhouseCoopers (PwC) to explore the positive and negative impacts of wearable tech, a huge percentage of people suggested that wearable tech should be subtle and attract as little attention as possible. This strongly correlates to the psychology of colour blind people presented by Ms Albany-Ward, seen in parts *K3* and *K4* of the transcript attached in *Appendix C: Market Research*. From the PwC survey, up to 82% of the people are concerned about wearables invading their privacy, and 52% are afraid wearables would turn people into robots and make everyone look ridiculous. Wearable tech might not be widely understood now, but as big brands such as Apple or Google launch new wearable products, it should be more widespread and accepted by society. The survey concluded that if the adoption rate of wearable tech parallels that of tablets, in two years' time owning a wearable device will be equivalent to owning tablets or smart phones.

Analysis shows that technology in the wearable category is ripe with opportunities to deliver to its users, hence the Project can move forward as a wearable device.

Competition for the SonoChrome

Competition for the SonoChrome was investigated in an attempt to understand what it would take to bring the SonoChrome onto the playing field.

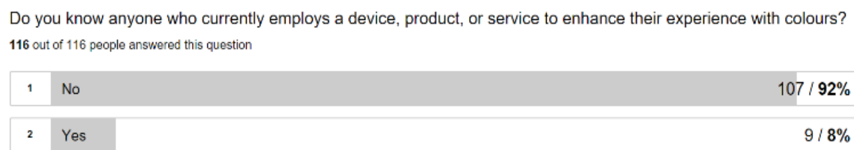


Figure 2: Survey results on extent of use of colour blind assistive devices

In the same market survey for the Project, respondents were asked whether they knew anyone who used a product or service to enhance their experience with colours. 92% answered no. This falls in line with the information provided by Ms Albany-Ward in part *K12* of the transcript attached in *Appendix C: Market Research*, where she mentions regarding competition how half the problem is that colour blind people are unaware of these products, and the other half of the problem is colour blind people being unaware that they have this condition.

Previously mentioned in the Introduction section, the 'eyeborg' serves not only as the inspiration for the SonoChrome, but also a main competitor. Currently, only one unit has been produced, and the device is surgically implanted into the user's head. This is the main obstacle against widespread implementation of the 'eyeborg' as the approach is reasonably invasive and costly.

The widely publicized Enchroma[16] glasses is another main competitor. However, it only caters to those who have abnormal functionality of the green cone. The Enchroma shifts light in the green spectrum to a frequency which the user can detect with their eye. This detected colour may not be the 'true' colour that people without colour blindness see, thus they would not fully experience colours the same way that fully sighted people do. The Enchroma glasses retail at USD$349-$469 depending on the model, which is not a small sum. Glasses using the same technology as the Enchroma, like the Oxy-Iso, Chromogen, Colourmax and other colour correcting glasses, are also used in the medical field by doctors and nurses to locate miniscule wounds[29].

Other competitive products that exist in the market include mobile phone applications that name colour, or computer applications that shift colour on an RGB screen[19].

Using affordable components and a system that allows colour perception in a synesthetic manner, the SonoChrome lets users experience the full range of colours using a sensory organ that they possess high utility of without altering reality.

SonoChrome Integration Scheme

The integration of the SonoChrome into the daily lives of the user would be a gradual process starting with audio output as distinct individual frequencies, providing users time to associate tones with colours, slowly working towards more complex sounds to cover a wider range of colours. This was suggested by Ms Albany-Ward with reference to her experience at her organization and a personal story, which can be found in parts *K8* and *K9* of the transcript attached in *Appendix C: Market Research.* She explains the need for gradual increase in sound complexity to not overwhelm users at the beginning.

Design Criteria

To specify limitations and provide a solution specifically suited to this problem, design criteria were at first identified through the following means:

1. Initial research on colour blind people and user needs (from previous section *Market Research I* and *Appendix C)*
2. Problem Definition Statement (*Appendix B*):
- A method which provides the essential missing information in a way that is easy to interpret
- The device should translate colours within the user's field of vision into sound in real time
- The sense of hearing is very well developed in humans and audio technology is cheaper and more advanced than technologies related to other senses
- Since there are no easily applicable ways to emulate the spatial resolution of eyesight with hearing, the device should only be intended to translate colours from a very small region of the total field of view
3. Product Design Specification (*Appendix A*)

Consequently, the following main criteria were selected from the Product Design Specification for future reference:

Performance

The device should
- Capture the view in front of the user
- Process the colours and their blending of the captured image
- Output a sound configured by the user (single frequencies, tones, melodies, etc)
- Process each consecutive visual input within 1 second to roughly mimic real-time
- Keep sound output consistent for the same colour under different lighting conditions if the user wishes to hear the colour of an object under white-light (base reference) conditions

Quality and Reliability

The device should
- Produce audio output discernible to the user, so red would sound different than green for example. Thus, the frequency resolution should be bigger than or equal to 3.6 Hz[31]
- Be able to produce a sound with frequency tolerance margin of ± 3.6 Hz
- Keep sound output consistent for the same colour under different lighting conditions if the user wishes to hear the colour of an object under white-light (base reference) conditions
- Be able to consistently, continuously, and consecutively take pictures while turned on and process them

Aesthetics, Appearance and Finish

The device is a wearable, so it will be very visible on the user when functioning. Hence, its appearance is rather important in determining whether a target customer will choose to employ it to hear colours.
The device must
- Be non-invasive as a wearable
- Look simple but elegant
- Be subtle and should not draw too much attention to the user
- Be small enough so that the user can integrate it into their everyday life

Maintenance

- The device should either be able to be recharged daily, or have its power source replaced when depleted.
- Regular maintenance should not be necessary. All parts are easily accessible as the device case protects all components and is removable. Only maintenance required is cleaning the camera lens when it gets dirty

Safety

- There must be no exposed wiring or shortages that could cause electric shocks or potential fires
- None of the components should pose a risk to safety or obstruct the user's vision and hearing

Concept Designs

Design 1: Arm Mount

The device is designed to be worn on the arm, right above the wrist, fastened using the straps. The full design sketch can be found in *Appendix D: Concept Designs*. Dimensions: 5cm x 10cm, thickness less than 1cm.

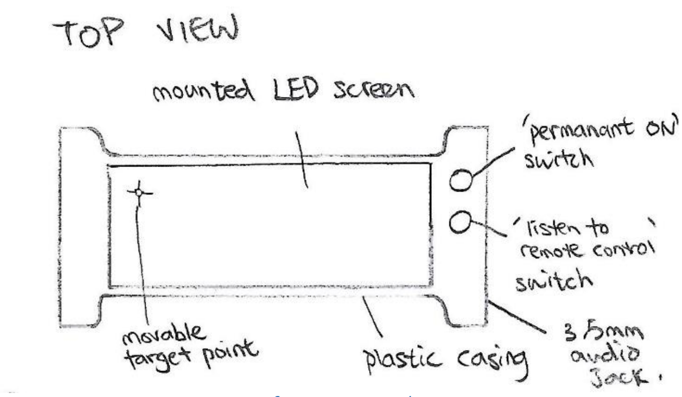


Figure 3: Top view of Arm Mount design

The LED Screen:

A captured image can be displayed on the LED screen, and while the camera is on, the most recent image will be displayed. There will be an option to 'pause' sampling to stop refreshing the visual input from the camera, focusing on one image only. Using the arrow buttons on the remote control, the target point on the screen can be moved. To hear the colour at the point, press the 'play sound' button. The remote control can be inserted (docked) into the injection moulded polymer casing of the device.

For the sound output, two methods are available:

1. Plug in headphones using the 3.5mm audio jack
2. Link Bluetooth headphones to the device, which will have an in-built Bluetooth connector

To further enhance the colour experience of users, the concept of brainwaves can be adopted into the design. Colours can also affect the atmosphere or mood around a person, so to reflect that in the device, different sampled colours will lead to respective binaural wave sound outputs. These binaural waves have an effect on people, such as calming down, being more energetic, feeling 'anger', and even inducing sleep.

Design 2: Head Mount

The head mount is designed such that it can be attached to any pair of glasses with small straps to firmly secure it in place. The processing unit and power supply would be stored in the rectangular case whilst the camera would lie on a ball joint to adjust the aim and field of vision, giving the user higher flexibility over the image desired to be sampled. To hear the sound output, the user can plug in headphones to the bottom of the device.

The dimensions for the case are 10cm x 8cm, with the thickness not exceeding 4cm, and 3cm x 3cm x 1cm for the camera

The primary disadvantage of this design is its size, since even a small weight can make the glasses tilt towards one side.

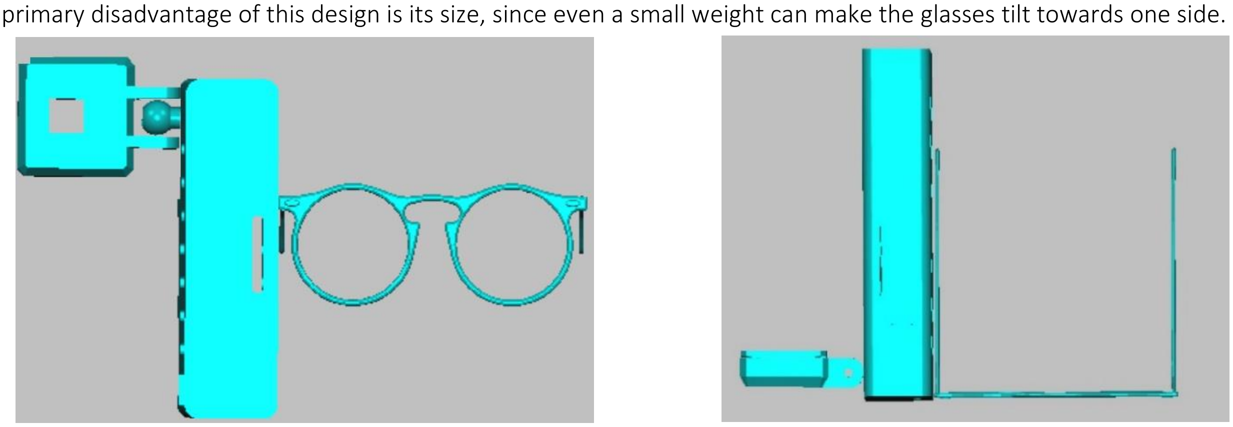


Figure 4: 3D models of the Head mount; Left: Font view; Right: Top view

Design 3: Neck Mount

The device will be attached to a lanyard so that it can be conveniently worn by the user, with it hanging from the neck.

When it is necessary to learn the colour of some object, the user can take the device in his hands and point it at the desired object with the assistance of the crosshairs. When ready, a button on the side of the device can be pressed which would trigger the device to take picture and tell the colour of the object that fits into the crosshairs.

Optionally, a 7 segment LCD display can be attached to the case of the device which would display the colour in text.

To hear the audio output, the user can simply plug their headphones into the 3.5mm jack located at the side.

The processor and power supply are placed inside the protective casing, and is rechargeable, hence removing the need to open the case. This decreases risk of contamination by foreign substances and makes the device more rigorous.

The dimensions for the case are 10cm x 8cm, and less than 2cm thick. The crosshairs would add around 2-3cm to the length.

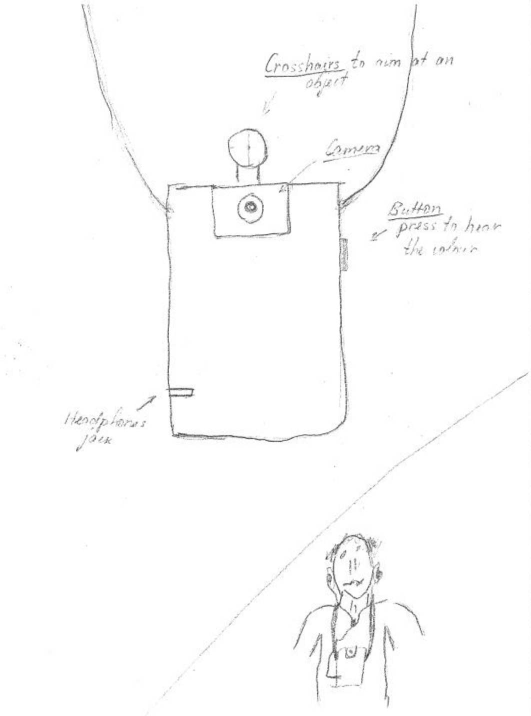


Figure 5: Neck Mount; Up: Close up front view; Down: Shown being worn by user

Design 4: Wrist Mount

This device would be worn on the wrist of the user with a rubber wristband to secure itself, with the case parallel to, and the camera standing perpendicular to the user's arm.

The rectangular case would contain the processing unit and a rechargeable power supply. The camera would be attached on top of the case for the user to point at the object that they wish to hear the colour of. There would be an LCD display on top of the case to display colour information to the user, such as the name of the colour or shades, and possibly the degree of ambient light. Additionally, the audio can be accessed by plugging in headphones into the jack located at the side of the device.

The suggested dimensions for the case are 10cm x 8cm, with a thickness less than 2cm. For the camera, it would be 3cm x 3cm x 1cm. The wristband should be of adjustable length, to accommodate for the varying physical builds of users.

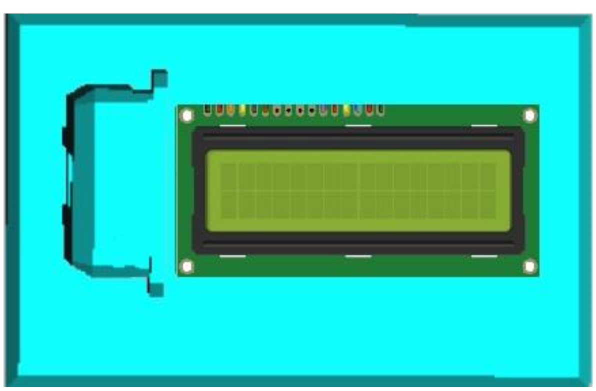
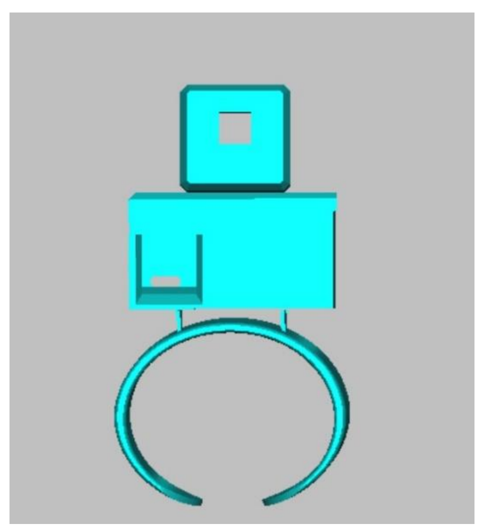


Figure 6: 3D models of Wrist Mount;
Up: Top view showing integrated LCD display
Right: Front view showing wristband fastener



Concept Selection

Criteria \ Designs		Arm Mount		Head Mount		Neck Mount		Wrist Mount	
Name	Weight	Score	Total	Score	Total	Score	Total	Score	Total
Fundamental Criteria									
Performance	9	9	81	8	72	8	72	8	72
		Camera built in Real time sampling Additional Bluetooth audio LED screen user interface		Camera included Real time sampling Earphones audio		Camera included Real time sampling Earphones audio		Camera included Real time sampling Earphones audio	
Quality and Reliability	8	9	72	7	56	8	64	8	64
		Discernible audio Consistent function Additional colour hearing options		Discernible audio Consistent function		Discernible audio Consistent function 7-seg LCD indicator		Discernible audio Consistent function 7-seg LCD indicator	
Aesthetics and Finish	10	10	100	5	50	8	80	6	60
		Sleek and compact design Compactly wrap on arm Easily accessed Does not restrict user movements		Integrate onto glasses as external attachment Bulky Not subtle		Hangs on neck Semi-subtle Does not restrict user movements too much		Less obvious than Head Mount Bulky Interferes with user movements	
Maintenance	3	5	15	5	15	8	24	6	18
		LED screen and camera need cleaning Hard to repair screen Recharge daily Replace remote batteries		Camera more exposed and needs cleaning Recharge daily Replace glasses straps when broken		Camera built in, less susceptible to dirt Recharge daily		Camera more exposed and needs cleaning Recharge daily	
Safety	6	9	54	5	30	6	36	7	42
		No exposed wires No protruding parts that invade on user's vision/mobility		No exposed wires Box on one side of glasses will tilt them May block some field of vision		No exposed wires The strap around neck MAY pose safety risk		No exposed wires Worn on wrist so does not affect user's vision, but some mobility	
Initial User Feedback Criteria									
Size and weight are all within FAA Guidelines									
Size	6	9	54	7	42	8	48	6	36
		Very compact Wraps around arm		Camera protrudes out		Basically a box shape		Camera protrudes out Wrist strap adds size	
Weight	6	7	42	6	36	7	42	5	30
		Thin design Light components		Heavier processor Weigh on head		Compact box		Heavier processor Torque against wrist	
Cost	6	4	24	7	42	7	42	5	30
		Expensive to get high-end components		Components are reasonably priced		Components are reasonably priced		Same as Head and Neck, but wristband incl	
Base Weighted Total/540			**442**		**343**		**408**		**352**
Survey Results	8	7.8	62.4	0	0	2.2	17.6	0	0
		Arm and Neck Mount had highest scores, thus were released in a public survey for user reception.							
Net Weighted Total/600			**504.4**		**343**		**425.6**		**352**
Practicality Criteria									
Feasibility	-		30%		90%		60%		75%
			Outside cost and reach		Readily available parts		LCD is main concern		Between Head /Neck
Overall Score /600			151.32		308.70		255.36		264.00

Figure 7: Complete updated concept selection matrix

Selection Criteria and Project Scope Limitations

In the Criteria Matrix *(figure 7)*, each criterion was given a weight from 1 to 10 in accordance with their importance to the device. The 4 concept designs were then allocated a mark from 1 to 10 for each criterion based on how well they would fulfil them if constructed as described.

The fundamental criteria are the 5 aspects identified from the *Design Criteria* section. On top of that, from *Market Research I*, it is clear that users put attention onto the physical characteristics and affordability of the device, hence the criteria of 'size', 'weight', and 'cost' (consumer cost) were added. This would form the base of the Criteria Matrix, with scores allocated in line with the ideal final design the Team holds as their vision.

The two highest scoring designs were released in a public survey to determine user reception. The results are shown below in *figure 8* of *Market Research II: User Reception to Concept* Designs. User feedback was given a weight of 8 to reflect the importance their opinions had on the Project. However, since most respondents were unlikely to be technically well-versed, the weight was limited to below that of 'Aesthetics and Finish' and 'Performance'. As 78% of respondents voted for the Arm Mount, it was given a score of 7.8. Similarly, the Neck Mount was given a score of 2.2 based on the 24% of remaining votes.

The Team wanted to first see how each design performed under scrutiny by the Team as well as the public (potential users), giving an idea of overall expectations and direction towards the ideal device. In practicality, due to the Project having a defined budget of £50 and timeframe of 6 months (October 2015 to March 2016), it was decided that only one prototype could be developed. Resource and expertise constraints also limited the lengths that the Project could develop to. As a result, a final percentage was imposed: 'feasibility', referring to whether the design could be researched on and developed under these limits, using present resources, and the ease of building a functioning prototype to act as a proof of concept of this Project.

After comparing the overall score, the Head Mount was selected for development as the prototype. The Team would like to note here that while this design was selected at this stage, it was largely due to constraints of the Project's scope. The scores for each design up to the 'feasibility' criteria, that is, the 'Net Weighted Total' reflects better the direction the Team would have taken (regarding aesthetics, function, and quality of the device, as opposed to the specific design) if they were provided with more time and resources. Further details can be found in the *Future Work* section, documenting the *Ideal Future Device*.

Market Research II: User Reception towards Concept Designs

Upon obtaining the 'Base Weighted Total', a market survey was released to the public to gauge user reception towards the Arm Mount and Neck Mount. In the survey, respondents were first given a brief summary of the Project, individual explanations on each design with supporting sketches (the same sketches as included in the *Concept Designs* section of this report), and finally asked to select the concept design that appealed to them more.

As with the other surveys, the same 116 individuals were approached to ensure consistency in samples, where 11.2% were colour blind. With reference to the survey results in *figure 8,* 78% of respondents selected the Arm Mount, and 22% selected the Neck Mount. It is worth noting the significant difference between the selection result of the two designs (56%) and that of their 'Base Weighted Total' (7.7%), hence increasing the need to incorporate user reception into the selection criteria.

Figure 8: Survey results on user reception towards Arm Mount and Neck Mount

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Concept Development

This section first provides comparisons and analysis into implementation options for each internal module following a design pipeline going from image input, microprocessor, audio output, and finally power supply. With a feasible and cost effective method selected for each module, the assembly of the initial prototype is detailed. Based on further research and feedback from potential users in Spring Term, improvements to the prototype and their respective testing processes are explained.

Module 1: Image Input

The primary concern in image processing is deciding what technology to use to capture colour. Phototransistors and cameras are compared in the table below *figure 9*:

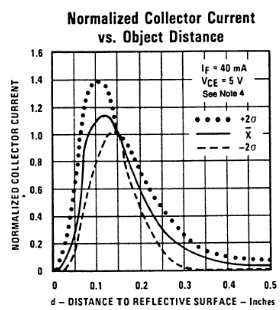
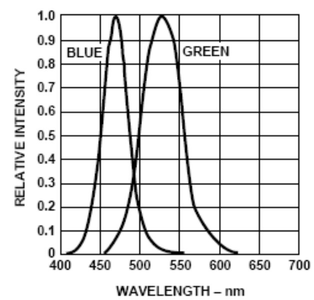
Image Input	
Advantages	Disadvantages
Phototransistor – SFH203[32]	
Figure 9a: Graph of normalized collector current against object distance 	 *Figure 9b: Graph of relative intensity current against wavelength*
- Easiest sensor to implement - Readily available and affordable (~£1)	- Can only detect colour if sensor is near the object (~0.12 inch), as seen in *figure 9a* - Slight angle shift can distort readings - Wavelength of colours overlap (blue 400-550nm and green 450-600nm, as seen in *figure 9b*), thus sensor may not be accurate - Ambient light affects sensor readings, calibration before every sample would be required
Camera	
Raspberry Pi Camera[35]	
- Recognizes 7 different colours - Can track 100 items concurrently at 50fps - 5 megapixel fixed focus, resolution up to 1080p - Reports data in useful/simple interfaces such as (UART/SPI/I2C/simple digital or analogue output) - Recognizes colours and location of objects - Very fast; can detect object in motion - Programmed to detect colour codes - Can detect angles	- May be hard to find because it is new to the market - Difficult to program
Arduino Camera OV7670[2]	
- Low operating voltage (3.3V-5V) - Simple interface (I2C) - Noise reduction and defect correction - Support image scaling	- Difficult to program - Sampling sped is only 30fps - Small resolution of 0.3 Megapixels

Figure 9: Table comparing phototransistor SFH203, the Raspberry Pi Camera, and the Arduino Camera OV7670 as the image input method

The choice to utilize a camera over a phototransistor was made, since a phototransistor severely lacks the precision and rigour to fulfil the design requirements, and the Project has enough resources to obtain and operate a camera.

The Arduino Camera OV7670 can be bought for £8[1], but a camera shield would be needed to connect it to the Arduino for an added £22[2]. Additionally, due to the limited RAM of an Arduino, an SD card would be needed to store images.

The Raspberry Pi camera module also costs £8[36], but can be directly attached to a Raspberry Pi board without additional circuitry. It also samples images faster and at a higher resolution.

After weighing the advantages and disadvantages of both cameras from the table in *figure 9* and their respective requirements for implementation, the Raspberry Pi Camera was selected for the purpose of capturing visual input.

Module 2: Processor

A unit is required to process the visual input in the form of a picture/video to then output an audio signal. The Raspberry Pi and Arduino processor families were selected for comparison.

An obvious candidate for the task would be an Arduino Uno microcontroller as it can be connected to a camera and sound module (like a piezoelectric speaker). However, this unit would not be self-contained and would require a breadboard for the various connections between modules.

As seen in *figure 10* below, for similar specifications, the Raspberry Pi, which is a computer the size of a credit card, is small enough to meet the design specifications and offers much more. It clocks roughly 44 times faster than the Arduino Uno and also possesses in-built input/output for video and audio formats. The Raspberry Pi includes a camera connector and a 3.5mm audio jack so it is effectively plug-and-play with an appropriate camera module and headphones. Furthermore, there is a lot of support and documentation for the Raspberry Pi, with widely available libraries to interface with the camera module or headphones.

Following on from the Image Input selection to use the Raspberry Pi Camera, and reinforced by the above points, the decision to adopt the Raspberry Pi (any model) was only natural.

Processors		Raspberry Pi Model A+[35]	Arduino Uno[5]
Target Price	/ £	15.50	13.25
Memory (RAM)	/ Bytes	256M + in-built SD Card	2k
Input Voltage	/ V	4.75-5.25	5-12
Size	/ mm^3	65x56.5x10	68.6x53.4x15
Weight	/ g	23	25
Clock Speed	/ MHz	700	16

Figure 10: Table comparing the Raspberry Pi Model A+ and the Arduino Uno as the processor

Module 3: Audio Output

The third aspect of the design requires an audio output generated from the output signal from the Raspberry Pi. There are two shortlisted methods which fully take advantage of the in-built 3.5mm audio jack of the Raspberry Pi: air conduction and bone conduction. The analysis of both methods is detailed in *figure 11*. Further information and supporting diagrams can be found in *Appendix F: Technology Research*.

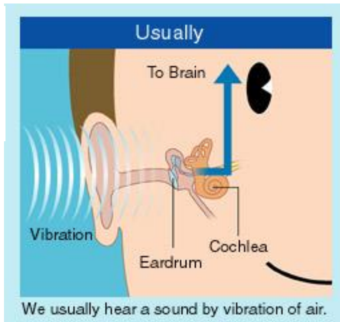
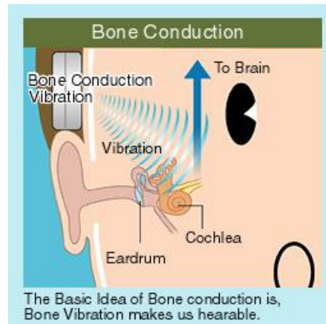
Audio Output	Air Conduction	Bone Conduction
Methodology[21]	*Figure 11a: Diagram illustrating Air conduction*  Air conduction refers to the transmission of sound waves through air and into the ear. This is the 'normal' way humans hear sound from their surroundings.	 *Figure 11b: Diagram illustrating Bone conduction* Bone conduction bypasses the eardrums and sends vibrations through the skull to allow the person to 'hear' a sound. Only the user can hear the output sound.
Power consumption	Headphones typically require 10-20mW output power, mostly around 12mW.[7]	1W using the small motor as described in the 'Feasible Implementation for Project' below.
Output Frequency Range (Humans: 20Hz-20kHz)	Up to 4kHz. From the frequency response of a typical headphone, the amplitude starts rolling off at around 4KHz, meaning the sound output would not be an accurate reproduction of the tone beyond this range[25].	Up to 95 kHz[14]. Although outside the human audible range, these frequencies add to the listening experience to people, the same way bass (less than 20Hz) is experienced as pulses against the chest
Typical Implementation	Regular headphones and earphones commonly found on the market which are compatible with the standard 3.5mm audio jack.	Bone conduction headphones have been commercially produced. Prices begin at around £30 and averaging at around £65[18].
Feasible Implementation for Project (both methods utilize the 3.5mm audio jack of the Raspberry Pi)	The user most likely owns headphones or earphones. Simply plug them into the 3.5mm audio jack of the Raspberry Pi, driven by the relevant code.	Using an old functioning earphone, a piezoelectric disc and a small motor, bone conduction can be implemented, albeit to limited quality. The impedance of the device will also be higher than low-impedance headphones, so more voltage will be required to achieve a similar sound output. [26 41]

Figure 11: Table comparing air conduction and bone conduction as the module for audio output

Implementing bone conduction is absolutely possible, but utilizing the feasible method within the scope of this Project would result in more power drawn despite the method not being very high quality, user-friendly nor appealing. Hence, for the development of the prototype at this stage, air conduction was selected.

Module 4: Power Supply

The components for the other three modules have been selected, forming a good idea of the overall power requirements of the device. The Raspberry Pi requires a constant voltage of 4.75-5.25V and a current of 1A. There are several ways in which power can be generated and supplied, with the analysis shown in *figure 12* in the following page.

Zero-mercury batteries are inefficient and highly susceptible to environmental factors. Piezoelectric crystals are currently not commercially available, their implementation is highly invasive and advised against. The output ratings for solar panels with sizes relevant to the scale of the device are insufficient, and also have poor efficiency.

Power banks are very common and inexpensive. They allow users to store and withdraw electrical energy anytime. Their output ratings compared to the other three methods are perfect for the Raspberry Pi. Although heat from power banks may be a small issue as the device is in close contact with the user, they satisfy the design requirements and hence was selected.

Power Supply	Methodology	Feasibility and Limitations	Output Ratings
Power Banks[8]	A portable device that can supply power using stored energy in its built-in batteries, either Lithium-ion or Lithium-Polymer cells. Usually recharged with a USB.	Efficiency differs based on cell type, the estimated efficiency for most power banks is 70-80%. They can hold charge for 3-6 months with minimal loss. However, environmental factors such as temperature fluctuation can shorten its lifespan or cause it to discharge. Continuous use may cause it to heat up.	V: 5V I: 1.1-2A
Photovoltaic Solar Cells	Solar cells absorb photon energy from the sun and converts it directly into electricity by the photovoltaic effect. Mostly constructed using wafer-based crystalline silicon cells.	Cells of different sizes are currently widely available on the market and generally inexpensive. They are rechargeable, but only work outdoors when there is sunlight. Also, efficiency is only 14%.[30]	Small panels[42]: V: 3-20V I: 20-230mA
Piezoelectric Crystals[44]	Power can be harvested from the user's heartbeat or the footsteps using these crystals. By squeezing the crystal, charges in it are forced out of balance, creating a potential difference across the 'squeeze'.	Requires medical implants. This technology is not commercially available and is still being developed. It is also not cost effective relative to using simple batteries.	V: 8V
Zero-mercury Batteries[15]	Generates power through the oxidization of zinc with air. It has a high energy density and can store more energy per unit weight compared to other small batteries.	It has a lower power because of the high internal resistance which supplies a much smaller current. It is sensitive to high temperatures, unsuitable in humid climates.	V: 1.64V I: 200-620mA

Figure 12: Table comparing power banks, photovoltaic solar cells, piezoelectric crystals, and zero-mercury batteries as the power supply

Prototype Assembly

Based on the concept design of the Head Mount and the selected technological modules, an initial prototype was constructed using a premade case for the Raspberry Pi[45]. All casing components were 3D–printed at the Imperial College Advanced Hackspace.

A card-sized power bank whose dimensions matched those of the case and is approximately 7mm thick was connected to the micro USB port of the Pi as its power supply via the blue cable seen in *figure 13*. Currently, the power bank is attached to the device using rubber bands, but a realistic approach would be to expand the case to include the power supply inside.

To secure the camera a drill-press was used to make a hole in the case to fit the ball-mount. Audio output can be accessed by plugging any pair of headphones into the 3.5mm jack of the Raspberry Pi. The connections are pictured in *Figure 13*. Additionally, a cost breakdown is provided in *figure 14*.

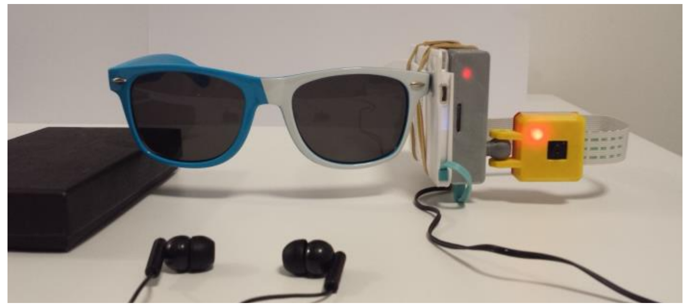


Figure 13: The initial prototype; Up: Front view; Down: Back view

Component	Price (£)
Raspberry Pi Model A+[35]	15.5
Raspberry Pi camera[36]	8
2000mAh Power Bank[3]	8.99
Total	32.49

Figure 14: Table showing cost breakdown of the prototype

Processing Algorithm and Code

The processing code was written in Python. The full code is attached in *Appendix E: Microprocessor Code*. A flowchart describing the function of the code is shown in *figure 15.*

The Raspberry Pi starts by taking a series of pictures. There are two modes of operation: sampling the colour at the middle of the image, or locating a specific colour within the image (having it split into nine square regions). The first mode of operation averages the colour in a defined middle region, whereas the second mode locates all pixels with colour close to the specified one and calculates an average of their coordinates. A third-party library (Webcolors) is used to map the RGB value to a standard colour name. The resulting text is then passed onto another third-party library (Espeak) for text-to-speech synthesis giving the colour name or square location as the audio output through the 3.5mm jack. At the moment, association of a colour to a frequency in Hz is done manually by the programmer, but a possible improvement would be to automatically translate RGB values to frequencies.

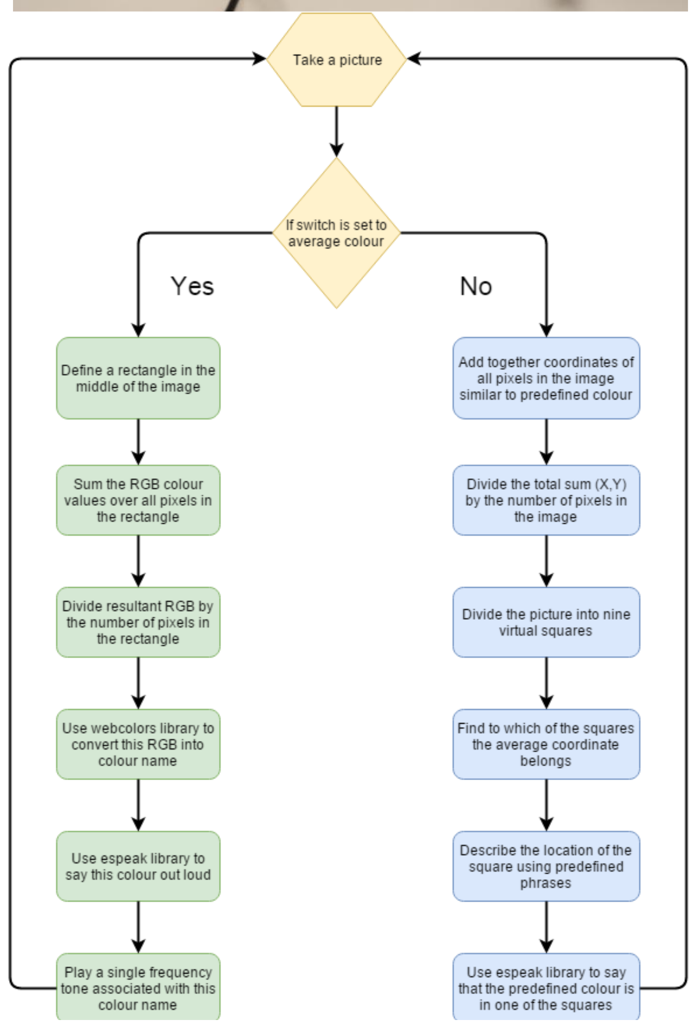


Figure 15: Flowchart describing the process of the Python code

Market Research III: User Reception towards Prototype

After the initial prototype was constructed, a demonstration video[39] of its function was created in Spring Term, and a market survey was released to the public to gauge user reception towards this prototype. In the survey, respondents were first given a brief summary of the Project, a short introduction to the prototype, and asked to watch the demonstration video. They were then prompted with the question seen in *figure 16* and asked whether they had further comments.

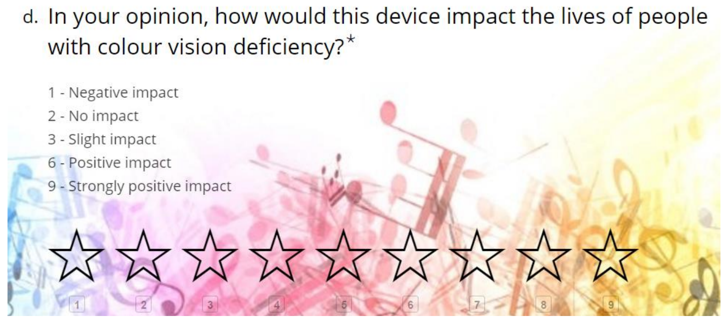


Figure 16: Survey question on user reception towards the prototype

As with the other surveys, the same 116 individuals were approached to ensure consistency in samples, where 11.2% were colour blind. With reference to the survey results in *figure 17*, zero respondents deemed the device to have a negative impact on the lives of colour blind people while 3% deemed it to have no impact. The highest selected rating was 6 stars – positive impact, at 28%. Summing the percentage of responses above 6 stars collects 67% of respondents, hence it can be concluded that a majority of respondents believe this prototype would have a positive impact on the lives of colour blind people.

<u>A summary of comments and suggestions toward improvements of device:</u>

- Add resistance to environmental factors such as rain
- Add capabilities to sample colour under different lighting conditions
- Increase the ability to differentiate between similar colour shades and scenes with high density of different colours
- Increase the range of options for audio output
- Ensure the device has a long battery life (i.e. 'Life in Service' defined in *Appendix A: Product Design Specification*)
- Make it more visually appealing, less bulky and use a size suitable for portable daily activities
- Develop an app for mobile or tablet devices to pair with the device
- Increase sampling speed to accommodate fast-changing scenes, such as videos

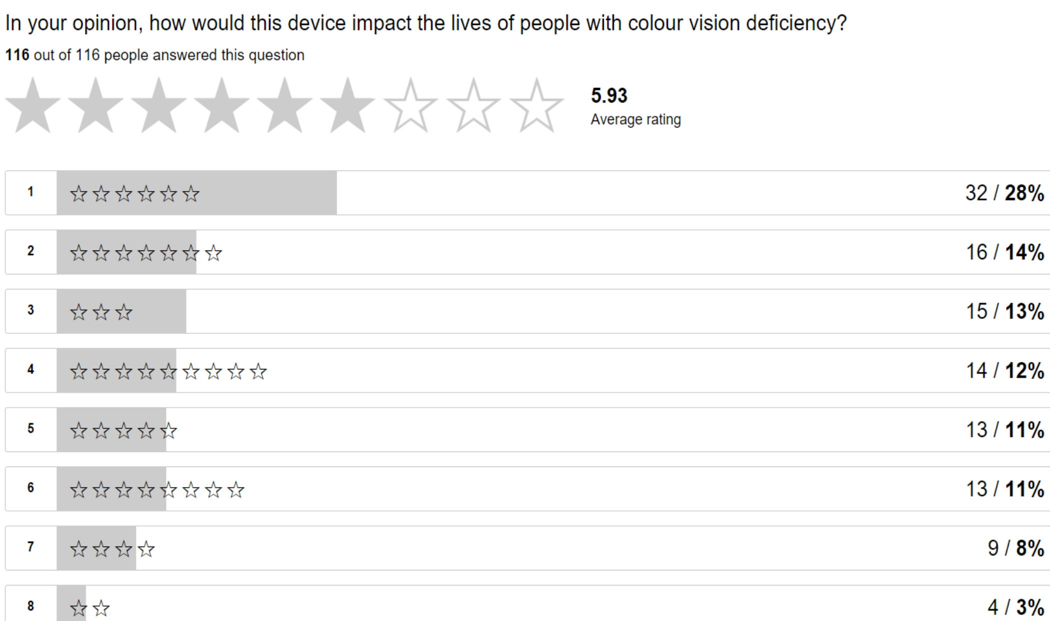


Figure 17: Survey results on user reception towards the prototype

Prototype Improvement and Testing

Taking into account the user feedback from *Market Research II: User Reception towards Prototype,* some improvements that proved to be possible at this stage were implemented, with the remaining documented for *Future Work – Ideal Future Device.*

Ambient Light Issues and Solution (sampling colour under different lighting conditions)

Although the Raspberry Pi camera has a full HD resolution of 1080p, a number of non-ideal factors influence the performance of the device. Most noticeably, low ambient light tend to give colours in the grey/black spectrum. Since the brightness and direction of natural light is not adjustable, the prototype has to adjust for it instead to produce a picture that ressembles its real-world counterpart. To account for this, the camera is set to increase brightness and change the exposure mode from **auto** to **nightpreview** when it detects that most pixels in the image are grey/black (indicating night or a low light environment).

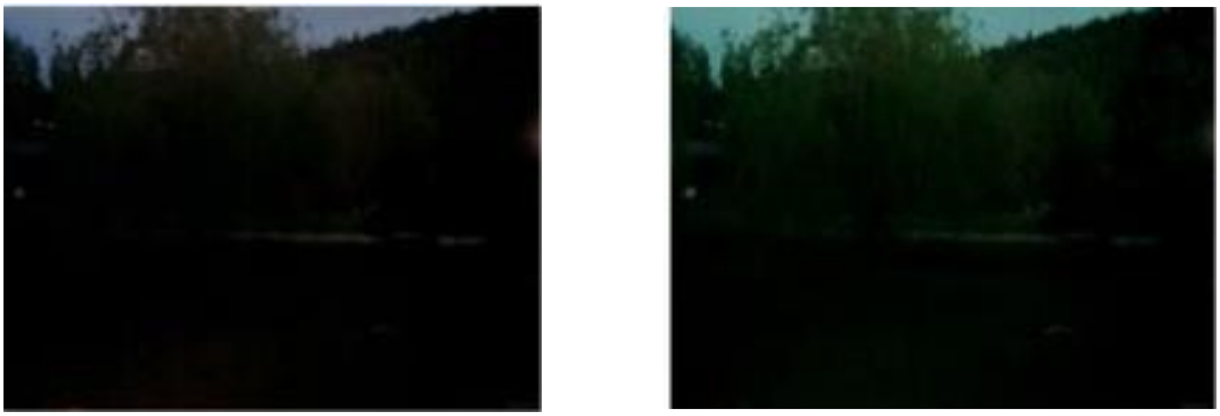


Figure 18: Camera image capture at default settings;
Left: Auto exposure mode with brightness=0; Right: Nightpreview exposure mode with brightness=25

Dual Mode Functionality

A second operating mode was included into the prototype in Spring Term. The device now has two distinct modes: it can either tell the colour of the object in the middle of the picture or the user can specify which colour to look for in the image. To change between these 2 modes, a switch was added between the supply voltage of 3.3V or 5V (pins 1, 2 or 4) and any single GPIO pin of the Raspberry Pi, diagram shown in *figure 19*.

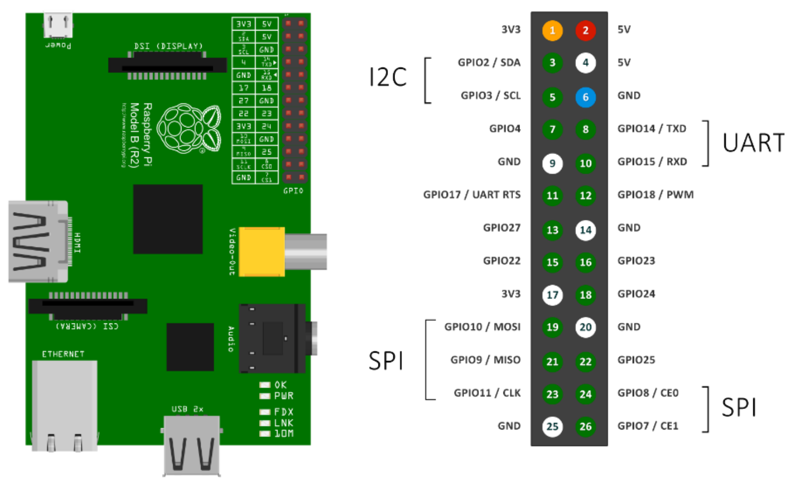


Figure 19: Raspberry Pi diagrams; Left: Top view; Right: Pin assignments

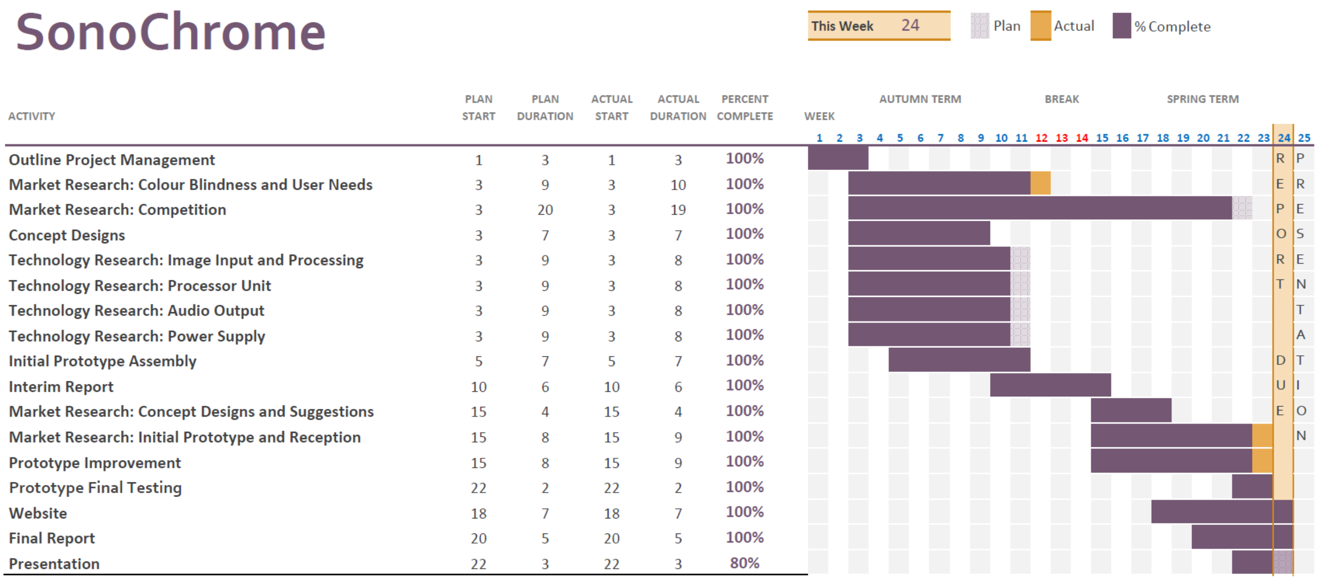
Colour Range and Increased Audio Output

The audio output can be made more accurate by increasing the number of colours available. For example the HTML4 standard which includes 16 colours is currently being used, but the Webcolors library contains the CSS3 standard in which 147 colours are included. One drawback of including more colours is redundancy, since the difference between 'light blue' and 'dark blue' may not be very useful to the user. This can be implemented in junction with the Scheme documented in *Market Research I: The Fundamentals – SonoChrome Integration Scheme,* which plans to gradually introduce the user to more complex shades and sounds of colours, increasing the level when they feel comfortable, starting with the primary colours (red, green and blue).

Project Management

To ensure successful completion of the project, an outline of the work to be done was created at the beginning of the term. This allowed for more flexibility with deadlines as they were accounted for in the beginning. Occasionally, plans had to be shifted a week forwards or backwards to accommodate new research findings, developments in the prototype, and user completion of market surveys.

Gantt Chart



ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Outline Project Management	1	3	1	3	100%
Market Research: Colour Blindness and User Needs	3	9	3	10	100%
Market Research: Competition	3	20	3	19	100%
Concept Designs	3	7	3	7	100%
Technology Research: Image Input and Processing	3	9	3	8	100%
Technology Research: Processor Unit	3	9	3	8	100%
Technology Research: Audio Output	3	9	3	8	100%
Technology Research: Power Supply	3	9	3	8	100%
Initial Prototype Assembly	5	7	5	7	100%
Interim Report	10	6	10	6	100%
Market Research: Concept Designs and Suggestions	15	4	15	4	100%
Market Research: Initial Prototype and Reception	15	8	15	9	100%
Prototype Improvement	15	8	15	9	100%
Prototype Final Testing	22	2	22	2	100%
Website	18	7	18	7	100%
Final Report	20	5	20	5	100%
Presentation	22	3	22	3	80%

Figure 20: Full Gantt Chart detailing work schedule plans from Autumn Term 2015 to Spring Term 2016

Division of Sub-teams

The project had two main fields of importance: technological development and market research. Hence, while all Team members would engage in project outlining, concept design and selection, and modular technological research, it was decided early on that the Team should be split into two to engage in the more in-depth tasks of prototype development and market research. The Sub-teams are as follows:

Sub-teams	Technological Research and Development Team	Business Outreach and Market Research Team
Members	Paulo Iswanto Nikita Karandejs Stefan Karolcik Tomas Pulmann	Anselm Au Sharlyn Doshi Prima Ongvises
Tasks	- Outlining the purpose and function of the device, creating designs and 3D models - Developing, testing and debugging of the prototype - Liaising with the Project Supervisor when faced with a complicated obstacle - Incorporating user suggestions obtained from the Market Research Team into the design if deemed reasonable or feasible	- Research on colour blindness as a condition and the needs of the target customer, ensure whole Team has sufficient understanding on the issue - Connecting with relevant external organizations for support - Conducting surveys, analyzing results, relaying useful findings to the R&D Team - Creating the prototype demonstration video

Figure 21: Division of Technological and Market Research Sub-teams

Work Packages and Modular Research

Aside from the defined tasks in the above-stated sub-teams, further work packages were defined to orient research and specify which deliverables were required from each team member. They are listed in the following *(figures 22 and 23)*:

Work Package	Project Management
Objectives	Define outlines for future work and overall group structure
Members	Paulo Iswanto, Stefan Karolcik, Tomas Pullman
Tasks	- Establish protocols for red flag personnel issues - Define aims and milestones
Deliverables	- List of possible issues that may arise and how to cope with them - Formulation of the project aim and its key dates

Work Package	Image Input and Processing
Objectives	Determine best way to take a picture and process the image
Members	Stefan Karolcik, Tomas Pullman
Tasks	- Research performance of different cameras - Determine optimal way to process image(s) to extract pixel colour - information
Deliverables	- Comparison of different cameras - High- and low-level implementation of image processing

Work Package	Audio Output
Objectives	Determine best way to output audio
Members	Anselm Au, Sharlyn Doshi
Tasks	- Research performance of different audio output methods and devices - Test quality of output in terms of precision and quality
Deliverables	- Comparison of various audio devices - Report of quality of sound of various devices

Work Package	Power Supply
Objectives	Determine which standalone power supplies would best fit the design criteria
Members	Sharlyn Doshi, Prima Ongvises
Tasks	- Research components required in the design - Determine a suitable power supply according to the design - requirements
Deliverables	- Comparison of different types of technology available to power the design - Compatibility and sustainability analysis of these methods

Work Package	Processing Unit and Power Supply
Objectives	Determine which processing unit would best fit design needs
Members	Paulo Iswanto, Nikita Karandejs
Tasks	- Research different microcontrollers and development boards - Determine a suitable power supply according to the processing unit's requirements
Deliverables	- Comparison of different processing units - Compatibility analysis of processing unit with other components of the design - Comparison of different power supplies according to design requirements

Figure 22: Work packages for Project Management, Image Input and Processing, Audio Output, Power Supply, and Processing Unit

Work Package	Website
Objectives	Create a website to provide detailed information about the project and SonoChrome, increasing its reach and presence
Members	Main: Stefan Karolcik(host, webmaster), Tomas Pullman Support: Anselm Au, Sharlyn Doshi, Paulo Iswanto, Nikita Karandejs, Prima Ongvises,
Tasks	- Set-up a website in the allocated space on the Imperial College Network - Design the website to include relevant information and maintain user-friendliness
Deliverables	A complete and functioning website: http://intranet.ee.ic.ac.uk/stefan.karolcik14/yr2proj/default.html

*screenshots of the website can be found in *Appendix G: Project Website*

Figure 23: Work package for the website

Online Collaboration Platform

The online project platform Trello was adopted to act as an online file storage and collaboration platform accessible by all members. This platform was selected due to its simplicity and extensive functionality in user interface, and a generous cloud storage limit. *Figure 24* shows a screenshot of the Trello page and its functionalities.

Trello mainly utilizes the concept of 'cards', which can be attached to 'card lists' such as "Final Report" and "Resources" as seen below. 'Cards' have many functions, including containing checklists, file attachments, due dates, and adding members to them. Thus, work can be sorted into checklists and to-do 'cards' and team members are assigned to them with a due date.

Changes to or completion of any card are logged in the 'Activity' column, hence it introduces transparency and peer monitoring to tasks carried out by members. This directly serves as positive motivation for members to perform better. The 'Activity' column is located on the right in *figure 24*, and was scrolled down to present a point that best reflected its function (showing as many records of team members' activity in one page as possible.)

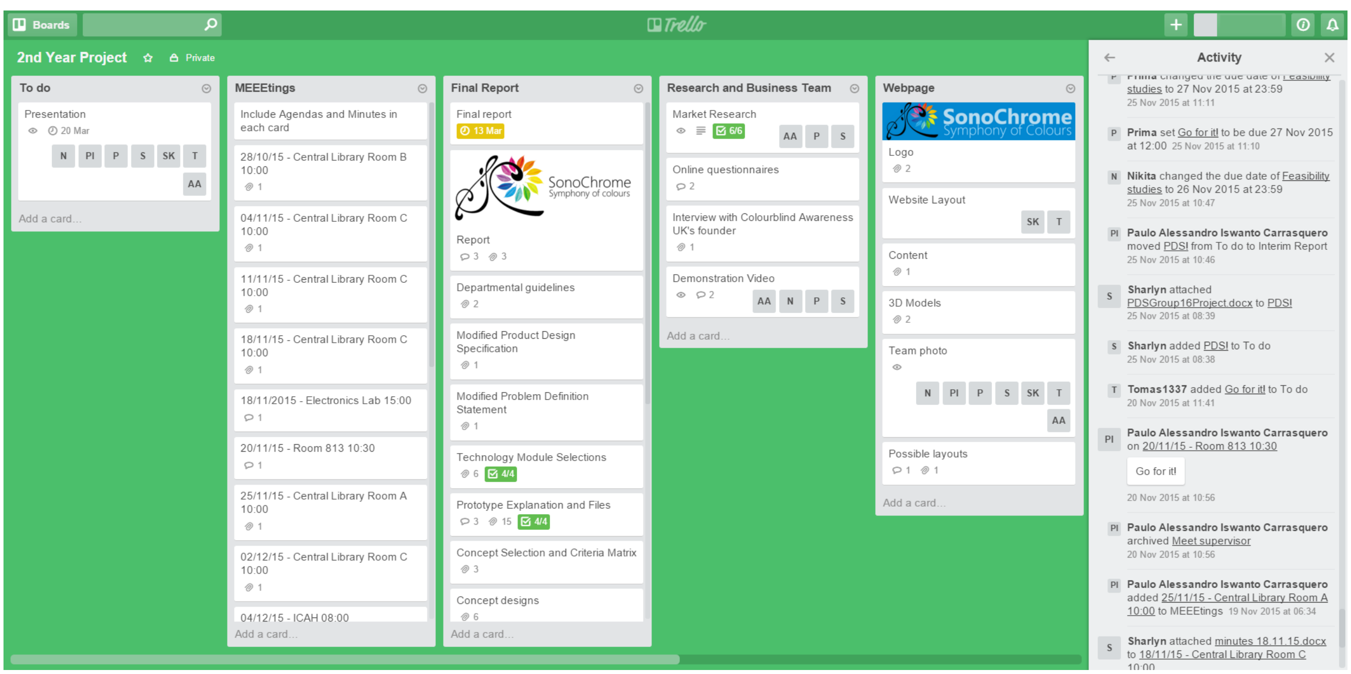


Figure 24: Screenshot of online collaboration platform Trello

Future Work

The prototype at this stage mostly meets the design criteria as specified in the section *Design Criteria*. In terms of performance, it can capture the view in front of the user, process the colours in the image within roughly one second, and output an audio tone selected by the user. Ambient light has also been taken into account. For quality and reliability, it is able to consistently capture images, and produce audio discernible to the user. Regarding aesthetics, while it is generally non-invasive, its appearance should be revised to increase subtlety, as many user response indicate discreetness as an important factor. Maintenance is kept minimal as required: the case protects internal components and the device needs to be recharged daily. Safety is assured since there are no exposed wires, although the device may tilt the glasses to one side. Furthermore, the user is able to operate the device with one hand, or none at all, since it is head mounted, and would not significantly interfere with the user's daily tasks (refer to *Appendix A: Product Design Specification – Ergonomics).*

In the future, assuming the design remains that of the current prototype, 3D printed cases could be mass produced and the Raspberry Pi could be programmed before manual assembly of the device. The cases are made from PLA (polylactic acid), a biodegradable thermos-plastic that is environmentally friendly and safe to use, hence only electronic components need to be separately processed in disposal. To make the device more compact, the Raspberry Pi could be replaced and microprocessors looked into, although this incurs a higher cost as seen in *Concept Development – Image Input and Processing*.

Ideal Future Device

<u>Aesthetics and Physical Design:</u>

The ideal device would be light and compact, maximizing user comfort. A possible concept design as seen in *figure 25* consists of a small aluminium strip, curved visor glass with an integrated transparent display, bone conduction modules to rest between the temple and ear of the user, and an adjustable band at the back side, which could house additional components.

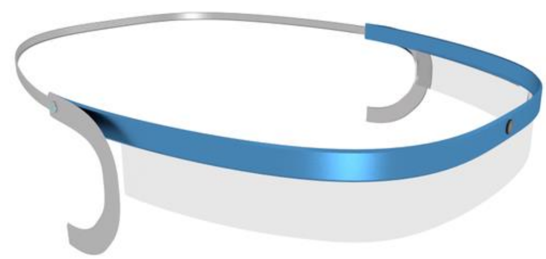


Figure 25: 3D model concept design of ideal final device

<u>Image Input and Software Processing:</u>

While the current prototype only focuses on a small region of the entire image, the improved version could execute image recognition algorithms in order to prioritize important objects, such as traffic lights. A viewfinder displayed on the device's visor display would indicate which region is currently being processed. The camera sensor would also use a lower resolution to utilize larger pixels instead, as these are able to collect more light. A resolution such as VGA (640x480) should offer enough compromise between the previously mentioned parameters while providing enough definition to allow for image recognition – an MIT study[46] has shown that even resolutions as low as 32x32 pixels are sufficient for humans to recognize images. Furthermore, eye-gaze tracking could be investigated to pinpoint specific regions to sample for colour. This can be implemented using the Raspberry Pi with some extra coding and testing[40]. Latest image recognition algorithms exhibit superhuman performance[43], and although these currently run on desktop-class GPU's, the future work of the Team would definitely feature research into the best compromise for this device.

<u>Hardware:</u>

For future improvements it would be natural to search for the best components available within the class of wearable technology. Modern chipsets provide enough computing power at very low power consumption. For example, the Samsung Gear S2 is a smart watch that utilizes an Exynos 3250 system-on-chip with an ARM-based Dual Core CPU clocked at 1 GHz, a Mali 400MP2 GPU, 512 MB of RAM, and an Image Signal Processor capable of 3 MP at 30 frames per second[37], rivalling the Raspberry Pi at a much smaller size. Moreover, semiconductor manufacturers such as TSMC have announced the start of production using a 10 nm process this year[24], which will provide additional performance improvements for future devices.

Audio Output:

The final device would ideally use bone conduction transducers to provide audio output. It is important to note that even when sound is transmitted through bone conduction, the user would still clearly hear all surrounding noise normally through air conduction. This significantly decreases the invasiveness of the device and dangers associated with wearing headphones for long periods of time. Some of the challenges associated with bone conduction arise from the fact that the energy delivered varies greatly with exact positioning of the device[9], potentially distorting the output signal. However, there are some commercial devices that show the viability of such technology, for example Google Glass[22]. Future research should be carried out to determine how to provide consistently good performance for a wide variety of users. An interesting use of audio would be to induce emotions in the user using binaural waves, closely mimicking the fashion in which colour also affects the mood of people perceiving them. For example, red is would be associated with anger, and white/blue is associated with calmness.

Power:

The most popular power supply in consumer electronics is lithium-ion batteries, which is what the improved device would use, since dramatic improvements in consumer-ready battery technology do not occur in short timescales. The batteries exhibit a desirable combination of high capacity, low price and the ability to recharge over several hundreds of cycles[38] in their lifetime.

Mobile Application and Extra Features:

The improved device would come paired with a mobile or tablet application for further analysis of colours and a more robust user interface. This would pave the way to incorporating more features and possible collaborations with other colour vision assistants such as the Coloradd[11] colour symbol code design, or existing technology focusing on related fields such as health monitoring or map navigation.

Conclusion

This Final Report provided information on colour blindness, the motivation for the SonoChrome, its design and development process, the organization of the Project as a whole, and explanations behind various decisions made which have advanced the Project to what has been presented.

Colour Vision Deficiency is a condition that affects 8% of men and 0.5% of women in the world. Approximately 40% of sufferers are unaware of their condition, whilst 60% experience many problems in daily life. Thus the Team decided to carry out this Project to develop a personal portable wearable device that transposes all colours in the user's field of vision to sound in real-time. The aim of the Project was to enhance the visual experience of colours for people suffering from colour blindness, improve their aesthetic quality of life, and increase personal safety and awareness of their surroundings. Reinforced with background research, opinions and feedback gathered from market surveys, and a discussion with the founder of Colour Blind Awareness UK, the Project was brought from four initial concept designs to the selection of implementation methods of four technological modules, and finally the assembly and improvement of the Prototype.

Through working on this Project, all team members have gained a deeper appreciation for the application of technology in socio-economic contexts, aiming to improve the lives of different groups of people each with unique situations and needs.

Acknowledgements

The Team would like to express their gratitude to Ms Kathryn Albany-Ward and her organization, Colour Blind Awareness UK, who supported the Team with their knowledge and experience working with colour blind people. The conversation with Ms Albany-Ward provided the team with great insight into the psychology and needs of colour blind people, and invaluable suggestions for new angles of development for the Project. Market surveys were distributed through their social media channels, reaching many potential users. The survey results proved to be very useful each and every time.

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(Vancouver style referencing adopted)

Appendix A: Product Design Specification

Performance

The device should

- Capture the view in front of the user
- Process the colours and their blending of the captured image
- Output a sound configured by the user (single frequencies, tones, melodies, etc)
- Process each consecutive visual input within 1 second to roughly mimic real-time
- Keep sound output consistent for the same colour under different lighting conditions if the user wishes to hear the colour of an object under white-light (base reference) conditions

Environment

The device would be worn by the user while carrying out various activities, ranging from work in less active office and urban environments to more extreme activities in outdoor or rural areas. Hence, the device

- Must not be affected by dirt, salt water, insects or weather conditions like rain or snow
- Must be able to withstand human-habitable environmental conditions, specifically temperatures between -10 and 45 degrees Celsius, altitudes (sea level at 0) between 0 and 4000, and humidity between 20% and 95%
- Must be able to function under constant turbulence and shaking (user riding a bike on an uneven road, running, etc)
- Should function under different lighting conditions and take ambient light into account when needed

Life in Service

The device acts as a sensory assistant to the user, so it should have a long service life, at least 2 years being used all day every day of the week

Maintenance

- The device should either be able to be recharged, or have its power source replaced when depleted. For recharging, the timeframe is daily
- Regular maintenance should not be necessary. All parts are easily accessible as the device case protects all components and is removable. Only maintenance required is cleaning the camera lens when it gets dirty

Target Product Cost

The price will not exceed £50, which is the project budget. Furthermore, current estimates put this figure closer to £25-30

Shipping

The product can be transported by any means and does not require extremely special treatment as it is small, except that it has to be handled with care since some components are fragile

Packing

The packaging should protect the camera lens from any external or invasive particles by placing it in a separate small bag

Quantity

Production will be limited to a single prototype within the scope of this project

Manufacturing Facility

The prototype will be built using the facilities offered by the Department of Electrical and Electronic Engineering, Robotics Society, and Advanced Hackspace at Imperial College London

Competition

For detailed information, please refer to *Market Research I: The Fundamentals – Competition for the SonoChrome* and *Appendix C: Market Research*

- 'Eyeborgs' are body modifications that are osseo-integrated to allow its user to hear colour. Thus, eyeborgs are treated as body parts. As the technology is still being piloted[17], they are donated at no cost in small numbers to blind and colour blind communities.
- Mobile applications exist that identify the colour at the centre of the camera/screen and displays its name on the screen. However, none of them currently provide the option to output as sound.
- Enchroma are eyeglasses with custom-made lenses which shift the perceived wavelength of a colour to compensate for colour blindness due to misaligned cones in the eye. This lets the user view the true colour of an object. However, it only works for people who have partial/slight colour blindness, as opposed to full colour blindness. The market price is at USD $349-$469 for different models[16].

Customer

People suffering from any degree of colour vision deficiency. By extension the product could also be used by the blind or anyone wanting to interact differently with their surroundings.

Size

The FAA (Federal Aviation Administration) has design standards based on the average human's limitations. The size limit is 100 mm high, 255 mm long and 125 mm wide[49].

Weight

The FAA (Federal Aviation Administration) has design standards based on the average human's limitations. The weight limit is 2.3 kg and the user should be able to operate the product with one hand. For this device, the weight should be below 1 kg[49].

Materials

Cannot be defined at present

Product Life Span

Cannot be defined at present

Standards and Specifications

The device will be designed following American standards set by the FAA[49] as this is the only organization to have set wide standards for head mounts.

Aesthetics, Appearance and Finish

The device is a wearable, so it will be very visible on the user when functioning. Hence, its appearance is rather important in determining whether a target customer will choose to employ it to hear colours.

The device must

- Be non-invasive as a wearable

The device should

- Look simple but elegant
- Be subtle and should not draw too much attention to the user
- Be small enough so that the user can integrate it into their everyday life

Ergonomics

- The user must be able to comfortably operate the device with one hand
- The device should not disturb the user in everyday life tasks
- The device should be non-invasive and not obstruct the user's vision or hearing

Quality and Reliability

The device should

- Produce audio output discernible to the user, so red would sound different than green for example. Thus, the frequency resolution should be bigger than or equal to 3.6 Hz[31]
- Be able to produce a sound with frequency tolerance margin of ± 3.6 Hz
- Keep sound output consistent for the same colour under different lighting conditions if the user wishes to hear the colour of an object under white-light (base reference) conditions
- Be able to consistently, continuously, and consecutively take pictures while turned on and process them

Shelf Life (storage)

N/A

Testing

After production, the device should be tested in normal usage conditions and checked against the performance specification.

Processes

N/A

Time Scale

The project will run from September 2015 to March 2016.

Safety

- There must be no exposed wiring or shortages that could cause electric shocks or potential fires.
- None of the components should pose a risk to safety or obstruct the user's vision and hearing

Company Constraints

N/A

Patents, Literature and Product Data

N/A

Market Constraints

For further market constraints, please refer to *Market Research I: The Fundamentals* and *Appendix C: Market Research* to see the preferences and opinions of potential users. A few main points are listed her:

- A discreet device
- Good aesthetic appearance
- Retail price between £36.5-76.5
- Fast and accurate response of device

Legal

N/A

Political and Social Implications

N/A

Installation

Regarding the prototype, it will be attached to one of the sides of a pair of eyeglasses, hence the user would need one

Documentation

All code used should be open source and provided with the device so users can tailor the product to suit their individual tastes if they wish to.

Disposal

No component of the product is susceptible of causing environmental damage. The modular nature of the design allows for individual components to be recycled at disposal.

Appendix B: Problem Definition Statement

Need Statement:

It is estimated that around 8% of male and 0.5% of female population is affected by some form of colour blindness. Approximately 40% of sufferers are unaware of their condition, whilst 60% experience many problems in daily life[13]. The Team recognizes the potential dangers that colour blind people face in their daily lives. While it may simply be a headache to be unable to match clothes, the inability to distinguish between red and green on the busy streets with traffic, colour-coded medication, and foods (potential allergic reaction) could be life-threatening[20].

Goal Statement:

A successful answer to the need statement would be to provide an alternative way in which colour blind people can experience or perceive the colour information required, effectively eliminating or at least alleviating the problems associated with this condition without heavily invading or negatively impacting the everyday life of the user.

User Requirements:

From a user's point of view, the solution to their problem would be a method which provides the essential missing information in a way that is easy to interpret. Fundamentally, there are two pieces of information needed to describe each point in an image - its position and colour. Leaving out either of the two leaves the user with incomplete or nonsensical information, therefore the user would expect the solution to provide both quantities in a way that makes sense to them.

Constraints:

The first two constraints faced are the limits of current technology and a very tight budget. An ideal solution would allow the colour blind person to perceive the colours with their sight, but since this technology is rather advanced, exclusive, and expensive, the exploitation of other senses should be investigated to produce a more affordable solution. Therefore, the physical limits of the chosen alternative sense also act as constraints. Due to each sense having its unique strengths and weaknesses, translating from one sense to another is going to be imperfect.

Functions:

The device is going to serve one function, to translate colours within the user's field of vision into sound in real time. The sense of hearing is very well developed in humans and audio technology is cheaper and more advanced than technologies related to other senses. Ears are able to perceive a wide range of sound frequencies, which is why translating colours to sound will allow the user to distinguish between colours with high precision. Since there are no easily applicable ways to emulate the spatial resolution of eyesight with hearing, the device should only be intended to translate colours from a very small region of the total field of view.

Appendix C: Market Research

Surveys

Two series of market surveys were created and released to public, one used to ask general questions or gauge user reception towards a certain topic, the other including relatively more technical questions. It was noted that most respondents are unlikely to be technically well-versed, hence the general series of surveys was pushed forward further and more publicized. Typeform was used as the platform to host all surveys.

For simplicity, the two series were each gathered into individual surveys for easy access from this report. The links are as follows:

General Series: https://acs1.typeform.com/to/JWqiZe

Technical Series: https://acs1.typeform.com/to/YfLmY1

In total, the general series of surveys attracted 116 responses, and was used as the basis for user-related research findings. Respondents who opted to tell us their occupation show a huge variety of backgrounds, including but not limited to: Marketing and finance, investment banking, audit, editorial, management and technical consultancy, engineering advisor, design, creative media, academia, architecture, fitness instructor, secretary, sales manager, trading, student, and housewife.

Diagrams showing respondent demographic not included in the main body of the Report are attached as follows:

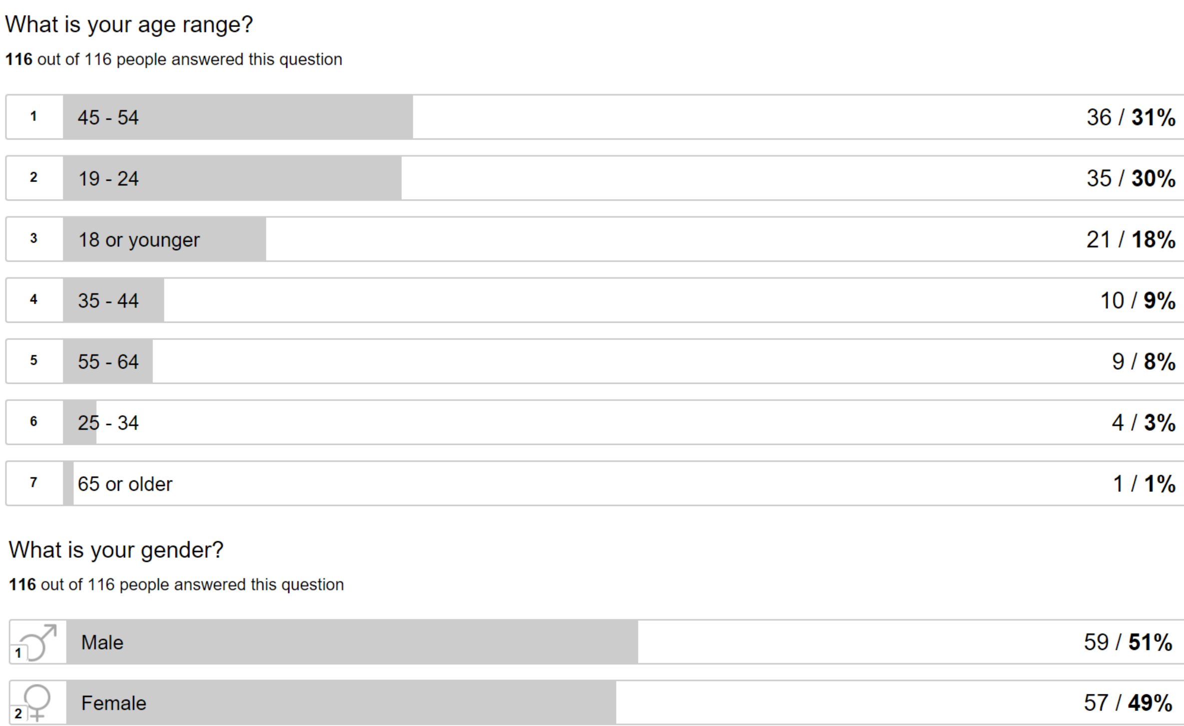

Figure 26: Survey responses showing age range and gender of respondents

The most important figure to note is that 11.2% of respondents are colour blind, which is higher than the 8% figure for the world. Since this device is mainly targeted at colour blind people but also open to the general public, this response rate is marginally acceptable.

Finally, respondents were also asked to give their opinion on the optimal price for the device in GBP (£). Excluding two extreme data of £800 and £1000, the average response was £76.47. 24% of responses were at £100 or above, so if the average was taken for the other 76% of responses under £100, the optimal price is at £36.5. This figure draws reasonably close to the Team's initial estimate of 25-30, and well within the Project budget of 50. It should be noted that the acceptable retail price range for the device is £36.5-76.5.

How visual entertainment accommodates the needs of colour blind people

Visual entertainment is a big part of everyday life, helping people communicate, understand perceptual processes, or even relax after a long day. However, what a lot of people find entertaining: watching TV shows, movies, playing games, can be frustrating for the colour blind. Gaming has always been an issue for the colour blind. Unlike watching movies, gaming requires reflex and analysis skills. For example, colour blind people have trouble differentiating between orange enemies and green squad members. Or something as simple as matching colours in Tetris.

Gaming industries are paying close attention to this issue. Over the past year, there have been more and more big name games that are starting to introduce colour-blind modes, such as Battlefield 4, Borderlands 2, and Sim City[5].

Lynsey Graham, a famous game designer at Sega is pushing for games to be colour-blind accessible as standard[5]. He claims that instead of adding in a colour-blind mode, all game designers should design games with it in mind from the outset. On the other hand, people are also questioning if there is actually a market, or if colour blind people have already written off games as an entertainment medium.

Daltonize[47] is an open source resource mainly for designers and teachers to get information about colour blindness. It also provides an algorithm for converting images or even real time videos for the colour blind. This algorithm improves the appearance of TV without disturbing the colour balance, for example, helping viewers differentiate between sports teams. Users could also turn on this algorithm while using a computer. Web-pages, videos and still images would automatically be rendered for the colour blind. Images can be processed before printing, important documents such as public safety, maps or technical instructions can be made more legible for the colour blind. Although this algorithm may seem very attractive, it still lacks the ability to render colour of objects or scenery in real life.

Competition

Previously mentioned in the *Introduction* section, the 'eyeborg' serves not only as the inspiration for the SonoChrome, but also a main competitor. Currently, only one unit has been produced, and the device is surgically implanted into the user's head. This is the main obstacle against widespread implementation of the 'eyeborg' as the approach is reasonably invasive and costly. By investigating other products currently in the market that assist the colour blind, the SonoChrome can be made to target a larger consumer base.

The widely publicized Enchroma[16] glasses is another main competitor. However, it does not cater to those who only see in grey scale, but only those who have abnormal functionality of the green cone. For those who have deuteranomaly, which is a reduced sensitivity to green light and also one of the most common forms of colour blindness, the Enchroma shifts light in the green spectrum to a frequency to that which the user can detect. This detected colour may not be the 'true' colour that trichromatic people, i.e. those without colour deficiencies, see, thus they do not fully experience colours the same way that fully sighted people do. The Enchroma glasses retail at USD$349-$469 depending on the model, which is not a small sum. Despite this, colour blind people have gotten quite excited about Enchroma, showing their enthusiasm towards products that help them with their condition. By perceiving colours in a synesthetic manner, the user of the SonoChrome is able to experience all colours without altering the reality of the colours, using a sensory organ that they possess full utility of.

Glasses using the same technology as the Enchroma, like the Oxy-Iso, Chromogen, Colourmax and other colour correcting glasses, are also used in the medical field by doctors and nurses. The lenses are used to identify veins and 'amplify trauma and bruising'[29] that may have otherwise been missed through regular vision. Regardless, designing the SonoChrome to have medical functions may not be a current purpose; it could be a potential feature that is added in the future.

Other competitive products that exist in the market include mobile phone applications, namely; Colorblind Helper, HueVue: Colorblind Tools, Colorblind Helper, Kolorami, iSpectrum Color Blind Assistant, and ColorBlind Assistant just to name a few. Most of these applications achieve what is commonly known as 'Colour Naming'. Therefore, they "name a colour from an image or live picture" [19] that the user points the mobile device to. These applications do either one of two things; they either fragment the images into sections of colour so the user knows where in the image each colour is, or they work similarly to the colour correcting glasses in that they shift the frequency of the colours to that of which the user can differentiate as illustrated in *figure 27*[27].

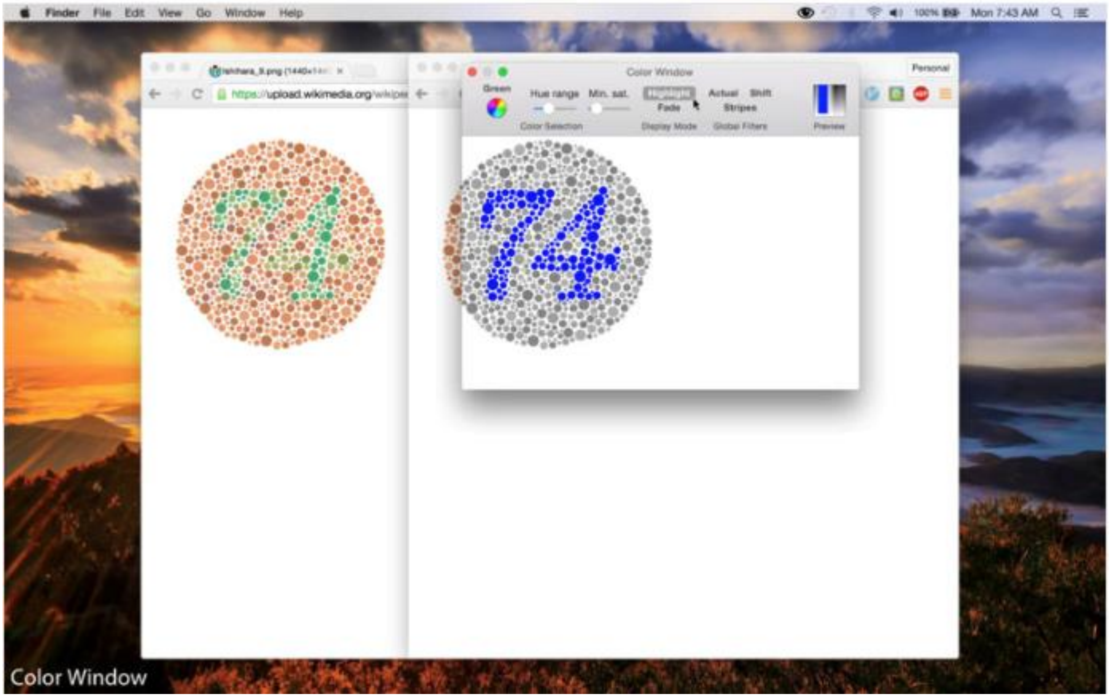

Figure 27: Screenshot showing the function of the Colour Blind Pal application

As mentioned before, the SonoChrome will be designed to translate colours to tones or sounds that the user can fully experience and immerse themselves into, being able to feel the same pleasures that other able eyed people feel when they look at colours.

By aiming to create an easy, hands free device that does not require an expensive phone to store applications with limited features, or glasses with special lenses that readjust the colours, the SonoChrome will engage users using the other senses. Other devices in the market currently do not use multiple senses to define colours, instead they simply aid the user in translating or manipulating them.

Preferences of general public when it comes to wearables and portable devices

For a long time, wearable technology has been little more than an intriguing concept. However, in the past year there has been increasing popular support. In 2013, Apple sold two million smart watches; in 2014, 3.3 million fitness trackers were sold; and last year in June, Google Glass sold out within a day at USD$1500 each[10]. Wearable technology is starting to become a bigger part of our society.

PricewaterhouseCoopers (PwC), the largest professional service firm specializing in industry-focused assurance and consulting, launched a survey with the aim to explore the positive and negative impacts of wearable technology[34].

According to PwC's survey, a huge percentage of people suggested that wearable technology should be subtle and attract as little attention as possible. Up to 82% of the people are concerned about wearable technology invading their privacy, hurting their ability to relate to other humans. While 52% are afraid wearable technology would turn people into robots and make everyone look ridiculous[34].

Steve Mann, or also known as the 'father of wearable computing', was attacked in Paris by three men fearful of the Eyetap Digital Eye Glass he was wearing[28]. This proves that to some extent people who utilize wearable tech might be seen as outcasts. Wearable tech might not be widely understood now, but as big brands such as Apple or Google launch new wearable products, it should be more widespread and accepted by society. From the survey, if the adoption rate of wearable technology parallels that of tablets, in two years' time owning a wearable device will be equivalent to owning tablets or smart phones. In a few years' time, owning a wearable device could potentially be fashionable[34].

Technology in the wearable category is ripe with opportunities to deliver to its users.

Transcript of Conversation with Ms Kathryn Albany-Ward

Transcript of the main content of the Skype conversation held between the Team and Ms Kathryn Albany-Ward, Founder of Colour Blind Awareness UK, at 14:30 on the 9th of March 2016. Exact wordings are slightly edited for clarity.

Key
T: The Team
K: Ms Kathryn Albany-Ward

T1: In which situations do you feel the need to differentiate or determine between particular colours?

K1: In everyday situations, when you're on the internet trying to access information, shopping, watching TV. People hardly take into account the needs of colour blind people, so there's hardly anything out there designed to suit their needs. Therefore colour blind people would miss out on a lot of information, and may not even be aware that they missed out on it.

T2: What would you deem as the biggest problem colour blind people face?

K2a: Challenges of colour blindness starts at school, when you can't access colour information that teachers or textbooks or online teaching software try to get across. If you don't understand things from a small age at school, there is a high chance you misunderstand things you're being taught and it becomes a faulty foundation for learning. You can guess what you're being taught, because you're not entirely sure, and once you guess wrong you continue to believe that's true for many years. So education is the most important thing to get right in the beginning. You will also always be learning throughout life, so if you can't access information because of colour blindness, that would pose the biggest problem.

K2b: Most children are going through their primary education and no one even knows they're colour blind. It could also affect grades of exams in higher education because these students are entitled to support but being undiagnosed, they are not receiving them. It is a widespread problem which was not the case even 10 years ago when children were screened for colour blindness but they are not anymore in the UK. The screenings were removed based on evidence from a study conducted in 1958 (when everything was black and white, did not even have colour television or wide use of the internet) which said that children who were colour blind did not have significantly worse outcomes compared to other students when they left school and went into career. However that is obviously completely different now.

T3: So how do colour blind people usually approach or overcome obstacles in their daily lives due to their condition?

K3: Colour blind people who are aware of their situation sort of learn coping strategies to approach their condition. They try different ways to find out information which does not rely on colour. So they will look at numbers, labels, codes, shapes...different ways of identifying information. They continue adapting and adopting different strategies as they go on in life. They also get more adept as guessing what colour something might be, because they've seen that particular shade in different circumstances, and through experience they will know that when they see that shade, it is most likely this colour, but they don't always get it right. They make mistakes, but they try not to because they want to avoid people thinking they're hopeless...they've been embarrassed about it all throughout their lives. So they will go to extraordinary lengths to make sure others don't know they're colour blind, because they're concerned that it might affect their career or social relationships. They tend to copy what other people do or ask colour questions in such a way that they find out the answer without the person they're interrogating necessarily finding out the purpose of the question.

T4: How do you feel about the idea of representing colours as sound?

K4: Interesting, but I think the problem colour blind people would have with that is other people will hear it as well, and draw attention to them. So if it was a sound that could be transmitted through headphones, I think it would be a good idea. They don't like to accept in any way that they are disabled and they don't like to draw attention to themselves. For example, there are devices out there that name colours and I've seen them in use, but they're not very good, actually, because they're not very accurate. You put the little machine on, say, a piece of clothing in a shop, and it will say 'dark yellow' or whatever the colour is. But it says it out in a loud way, and if you're trying to know the colour of something, you don't want other people knowing that. So it depends how you are planning how that sound is transmitted with earphones.

T5: We are planning to have the sound transmitted through earphones to provide a more personal experience.

K5: Also as I'm sure you're aware, it's been tried in the case with Neil Harbisson, who has got an antenna on his head. I know it works well with him, but I don't know how much effort he has had to put in to recognize those different wavelengths of sound and relate them to colour. So I guess also how successful your device would be would come down to how useful colour blind people think it would be compare to how much effort they would need to put in to understand those sounds instantly.

T6: So contrasting to the device you mentioned just now that says the name of the colour out loud, how useful would it be to see the name of a colour instead of experiencing it? It is like telling them what a colour is called without attaching much of a meaning to it.

K6: Yes...but they can't get the meaning of it because they can't experience it anyway. What they've learnt overtime is how society uses this colour. They know if something is red it means stop. So if they hear your sound for red and get used to the meaning of stop, they will see that as an alert, where for the rest of us if we see red we would think 'oh we just need to pay more attention to what is going on here'. It's important to transfer information in a way that they would use, to have the same effect as reading the name. It can be very useful for them, even though they don't actually experience the colour, they know how people in society behave around those colours. So it's still useful. Going back to the example of choosing clothes, you want to know that you're not going to look silly by wearing colours that clash in terms of how people with normal colour vision would see you. You might wear something and think it looks fine, but by the same token, you won't want to wear it if you don't know whether everyone else thinks it looks fine. So you want to know what colours things are, even if you don't actually experience those colours. If sound allows you to understand what colour something is, it is just another tool that you would use to help interpret the world around you without being able to experience it properly.

T7: So there is quite some social pressure around needing to know colours...

K7: Yes, absolutely yes.

T8: In terms of hearing colours, would it be more useful to hear singled out colours only, for example, only two tones for red and green? Or a more all-round experience of being to hear a 'symphony' of colours that you see in the scene in front of you, but still being able to discern the red and green as useful/needed information?

K8: I think you need to be careful initially that you don't overwhelm people too much with information. What Colour Blind Awareness UK does is that we sell 3 different sets of Crayola colour crayons. We start off with the set of 12 for the younger children, and they learn red, yellow, green, blue, the basic colours, because that's what they're learning at school, so the crayons are labelled simply as 'red', 'yellow', 'green', 'blue'. Then there's the next stage when children are a bit more aware of the ranges of colour, say, 3 different shades of red, so it goes up to a set of 24 colour crayons and there are slightly different names for colour, for example pink is called 'salmon pink' and 'dark pink'. The third stage is a set of 36 crayons. So like this, I think you have to lead your customer through the system so they build up their own understanding through time.

T9: Ah, so it's a gradual learning process.

K9: Yes, for example in the third set of crayons, there's mahogany. My son is severely colour blind and I just read an article about a colour blind person who was sorting out his rubbish for recycling and he didn't know which bin to put out for the bin man when it was recycling day because he couldn't tell the difference between the brown and green. One day I was driving past some bins that people have put out and said to my son 'can you tell the difference between the colours of those bins?' I know what colours he sees, I know exactly how he sees the world because I can simulate it, and I know he can't see brown from some shades of green. But because he has got his 36 crayon set, and he just learnt those and was just using them, he said to me that the brown was mahogany. And you know, it was exactly the same shade of brown as the mahogany on his crayons as I checked when I got back home and I was so shocked. He managed to learn that difference in shade by practice. That's what people would have to do with your sounds. They would have to learn how sounds are as they relate to colours by practice. So you wouldn't give them the '36' right away because they'd find it too overwhelming, but would need to start with the '12'.

T10: So we can slowly introduce the sounds to them, and they can increase their audio experience to the next stage when they feel that they are ready and comfortable.

K10: Exactly. Oh, have you seen the Coloradd code?

T11: No, we can't say we have.

K11: You might want to take a look at it. It's sort of what you're talking about, only in code form. It's developed in Portugal by a Portuguese designer, and he has assigned different shapes to different colours. So the way that he's designed red is a triangle in a certain position, and yellow is a slash. So orange is red plus yellow, which is that particular triangle plus a slash. The way that it all connects together is quite intuitive. That starts off with the core colours and adds a bit more information to make you aware if something is dark orange or light orange. It might be worth taking a look at that to see how colours build up because you could use the same kind of idea with your sounds.

T12: Regarding competition, do colour blind people usually use devices to approach their condition or do they find that they cope just as well through their own means and strategies developed by experience? How common would it be for a colour blind person to be using such a device?

K12: I don't think that you necessarily do. They're not aware of them, that's half the problem. The first problem you've got is people don't know they're colour blind, nor what kind of colour blindness, and quite often they think they're managing quite well even though they face all sorts of problems. They don't actually see themselves as disabled in any way and they don't search for ways to make their lives easier. So when new technology comes out, and they find out about it, like the Enchroma glasses which I'm sure you've heard of, they get quite excited about those glasses but the problem is that they don't work for everybody. There are various apps on smartphones that identify colours and colour blind people use those, but they tend to do it in a discreet way so that other people aren't aware that they're making use of them. The glasses are quite a big step forward in terms of colour blind people psychology because the glasses are out there, big, bold, and bright. People will see you wearing them so automatically it would draw attention to the fact that you're colour blind, which may in turn attract all sorts of questioning and put you on the spot and colour blind people don't like that. They tend to just muddle along...so what you're proposing to do would have to be discreet, something on their mobile phone or an Apple Watch that they could use without anyone else knowing. Otherwise if it were a wearable, it would depend on how small it was. I think colour blind people would be much more likely to use it under those circumstances because they don't use anything else. As a group of people, I can't point you to anything that all colour blind people use, or find useful, because that's not the case.

T13: Would you have a vision or preference of how the device would be like?

K13: Well I guess it could be something like an earpiece, because what you're proposing is using sound. You can get tiny, tiny, hearing aids nowadays that people can't tell you're wearing. That would probably be the best thing because you would look like you weren't relying on any technology to get about your daily life.

Appendix D: Concept Designs

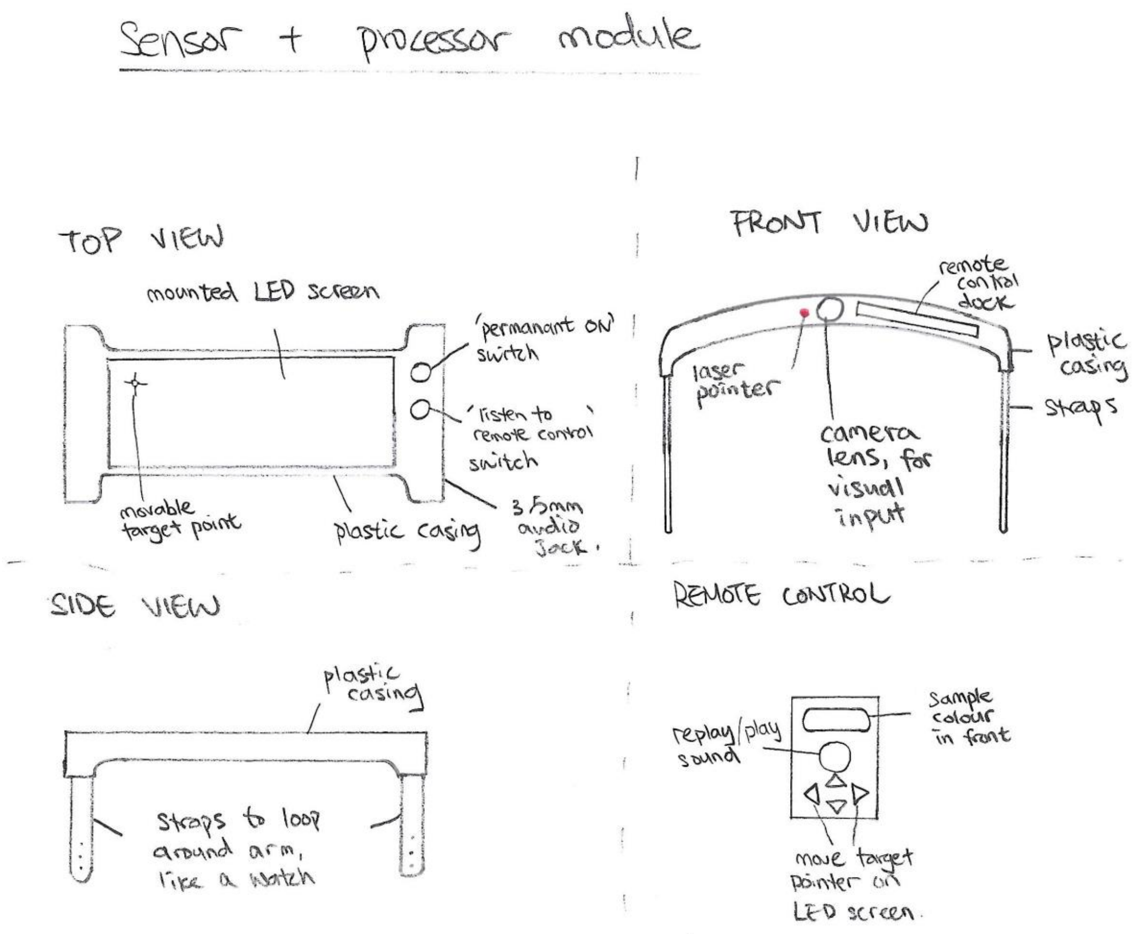

Figure 28: Full sketch of the Arm Mount concept design

The LED Screen:

A captured image can be displayed on the LED screen, and while the camera is on, the most recent image will be displayed. There will be an option to 'pause' sampling to stop refreshing the visual input from the camera, focusing on one image only. Using the arrow buttons on the remote control, the target point on the screen can be moved. To hear the colour at the point, press the 'play sound' button. The remote control can be inserted (docked) into the injection moulded polymer casing of the device.

For the sound output, two methods are available:

1. Plug in headphones using the 3.5mm audio jack
2. Link Bluetooth headphones to the device, which will have an in-built Bluetooth connector

To further enhance the colour experience of users, the concept of brainwaves can be adopted into the design. Colours can also affect the atmosphere or mood around a person, so to reflect that in the device, different sampled colours will lead to respective binaural wave sound outputs. These binaural waves have an effect on people, such as calming down, being more energetic, feeling 'anger', and even inducing sleep.

Appendix E: Microprocessor Code

```
from subprocess import call
from time import sleep
import math, cmath
import os

from PIL import Image

from picamera import PiCamera
import RPi.GPIO as GPIO

from webcolors import html4_hex_to_names, hex_to_rgb, rgb_to_name


# Set up pins so that can use switch.
def init_pins(button_pin):
    GPIO.setmode(GPIO.BCM)
    GPIO.setwarnings(False)
    GPIO.setup(button_pin, GPIO.IN, GPIO.PUD_UP)


# Compares given colur to every known colour in html4.
# This is done by choosing the colour that has
# the smallest sum of squared differences in RGB.
def closest_colour_name(RGB):
    min_colours = {}
    for key, name in html4_hex_to_names.items():
        r_c, g_c, b_c = hex_to_rgb(key)
        rd = (r_c - RGB[0]) ** 2
        gd = (g_c - RGB[1]) ** 2
        bd = (b_c - RGB[2]) ** 2
        min_colours[rd + gd + bd] = name

    return min_colours[min(min_colours.keys())]


# Returns the exact description of the colour
def get_colour_name(RGB):
    try:
        actual_name = rgb_to_name((RGB[0], RGB[1], RGB[2]), 'html4')
    except ValueError:
        actual_name = 'Unkown'

    closest_name = closest_colour(RGB)

    return str(actual_name), str(closest_name)
```

```python
# Computes the average colour value in the rectangle in the middle.
# Size of the rectangle is defined by the size_ratio.
def get_average_colour(image_name, size_ratio=0.1):
    img = Image.open(image_name)
    cropped_pic = []
    R, G, B = (0,0,0)

    # Here we get the coordinates of the rectangle
    # in the centre of the picture.
    image_width, image_height = img.size
    rect_width = int(image_width * size_ratio)
    rect_height = int(image_height * size_ratio)

    rect_left_x = int(0.5*(image_width - rect_width))
    rect_top_y = int(0.5*(image_height - rect_height))
    rect_right_x = rect_left_x + rect_width
    rect_bottom_y = rect_top_y + rect_height

    # Now every pixel data from the rectangle is stored in a list.
    img = img.load()
    for x in xrange(rect_left_x, rect_right_x+1):
        for y in xrange(rect_top_y, rect_bottom_y+1):
            cropped_pic.append(img[x, y])

    # Calculate the average value of each color component in the rectangle.
    for r, g, b in cropped_pic:
        R += r
        G += g
        B += b

    R //= rect_width*rect_height
    G //= rect_width*rect_height
    B //= rect_width*rect_height

    return (R, G, B)


# Take several pictures, average the colour of the rectangle from each.
def average_colour_from_image(image_file_name, camera, n=3):
    average_colour = [0,0,0]

    for i in xrange(n):
        camera.capture(image_file_name)
        avg_col = get_average_colour(image_file_name)
        for i in xrange(3):
            average_colour[i] += avg_col[i]


    return [x//n for x in average_colour]
```

```python
# Test whether x satisfies a <= x <= b.
def in_range(x, a, b):
    return x in xrange(a, b+1)


# Tests whether the given pixel has colour similar to target_colour.
def is_similar(pixel, target_colour):
    max_val = 0xff
    R, G, B = target_colour
    r, g, b = pixel
    # Experimentally determined value that works as desired.
    K = 0.15

    for c, C in zip(pixel, target_colour):
        if not in_range(c, int(C-K*max_val), int(C+K*max_val)):
            return False
    return True


# Compute the average position of certain colour in the image.
# It also includes colours that appear similar, to handle noise better.
def avg_pos(img_name, target_colour):
    img = Image.open(img_name)
    width, height = img.size
    img = img.load()

    total_x = 0
    total_y = 0
    n = 0
    for x in xrange(width):
        for y in xrange(height):
            pixel_colour = img[x, y]
            if is_similar(pixel_colour, target_colour):
                total_y += y
                total_x += x
                n += 1

    return (total_x // n, total_y // n)
```

```python
# Returns a string describing the location of the colour blob.
# Position is in one of 9 squares into which the image is virtually divided
def describe_coord(x, y, res):
    w, h = res

    directions = [['top left corner', 'upwards', 'top right corner'],
                  ['left', 'middle', 'right'],
                  ['bottom left corner', 'downwards', 'bottom right corner']]
    dx = x - w/2
    dy = h/2 - y

    xi = int(x / (w/3))
    yi = int(y / (h/3))

    return directions[yi][xi]


# Produce sound from given text.
def speak(text, speed=80):
    call(['espeak', '-ven+f3', '-s', str(speed), text, '2>/dev/null'])


# Plays a tune of some frequency that has been associated with a colour.
# To play a tune need to use 'omxplayer'. We call it using shell.
def play_tune(colour_name, duration=1):
    colours_map = {'aqua': '300.mp3', 'black': '400.mp3', 'blue': '500.mp3',
                   'fuchsia': '600.mp3', 'green': '700.mp3', 'grey': '800.mp3',
                   'lime': '900.mp3', 'maroon':'1000.mp3', 'navy':'1100.mp3',
                   'olive':'1200.mp3', 'purple':'1300.mp3', 'red':'1400.mp3',
                   'silver':'1500.mp3', 'teal':'1600.mp3', 'white':'1700.mp3',
                   'yellow':'1800.mp3'}

    if duration > 0:
        seek_pos = '00:00:0'.join([str(10-duration)])
    else:
        return

    play_cmd = ' '.join(['omxplayer -l', seek_pos, '-o local'])

    try:
        os.system(' '.join([play_cmd, colours_map[colour]]))
        return 0
    except:
        return 1
```

```
# Main routine where the device is initialised
def main():
    resolution = (1280, 720)
    button_pin = 14
    image_file_name = 'img0.jpg'

    unknown_colour = 'red'

    init_pins(14)
    unknown_colour_name = unicode(unknown_colour)
    uknown_colour_RGB = str(webcolors.name_to_hex(unknown_colour_name))

    camera = PiCamera()
    camera.resolution = resolution

    while True:
        # Tell the average colour of the middle of the picture.
        # If the switched to "average mode", the default mode.
        # Output of 'True' means the button is not pressed.
        if GPIO.input(button_pin) is True:
            average_RGB = average_colour_from_image(image_file_name, camera, 1)
            actual_colour, closest_colour = get_colour_name(average_RGB)
            speak(closest_colour)
            play_tune(closest_colour)

        # Tell where the specified colour is.
        else:
            x, y = avg_pos(image_file_name, unknown_colour)
            position = describe_coord(x, y, resolution)
            speak(' '.join([colour_name, position]))

        # Pause after processing an image.
        sleep(2)


main()
```

Appendix F: Technology Research

Technology Research: Audio Output

The third aspect of the design requires a sound output, taking the output signal from the Raspberry Pi. The in-built 3.5mm audio jack in the Pi will be fully taken advantage of. Two methods of implementation have been shortlisted, which prove to be the most realistic solutions to this module.

1. Air conduction
2. Bone conduction

A brief explanation on how people hear sound:

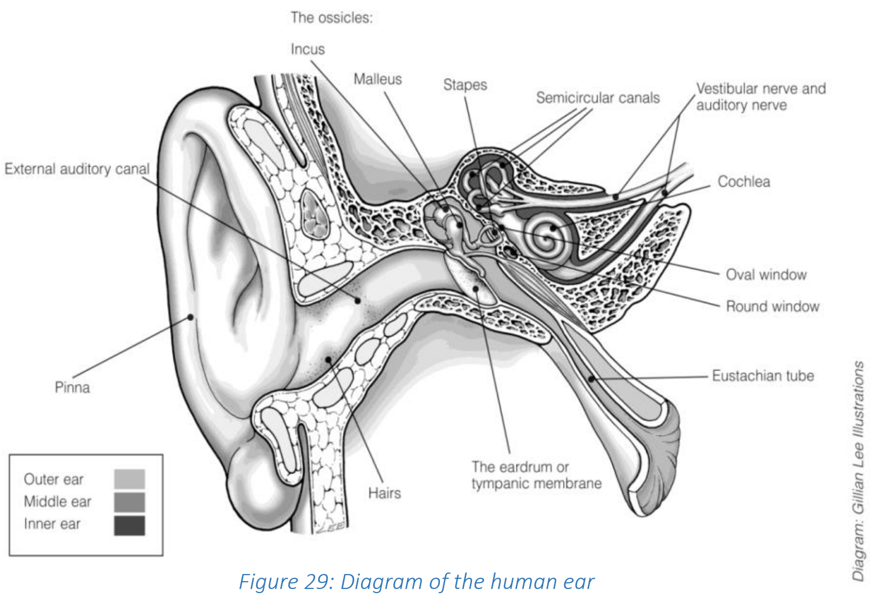

Figure 29: Diagram of the human ear

The outer ear consists of the auditory canal and eardrum. Sound travels through the ear canal, strikes the eardrum and causes it to vibrate.

The middle ear is behind the eardrum that contains three connected bones called ossicles. Vibrations from the eardrum cause the ossicles to vibrate which sets fluid in motion in the inner ear.

Movement of the fluid in the inner ear, or cochlea, causes movement in tiny structures called hair cells, which sends electric signals up the auditory nerve to the brain.

The brain then interprets these electrical signals as what is heard as 'sound'.

The hearing range for humans is around 20Hz-20kHz.

Air Conduction

Air conduction refers to the transmission of sound waves through the air and into the ear. This is the 'normal' way that humans hear sound from their surroundings.

Figure 30: Diagram illustrating air conduction[21]

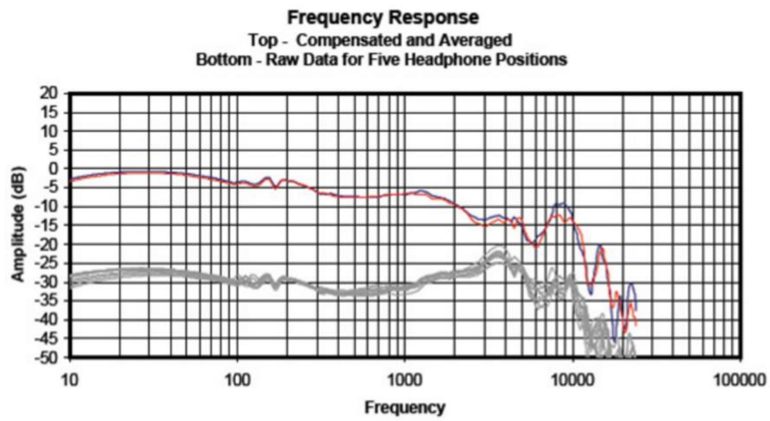

Figure 31: Frequency response plots for the NAD VISO HP50 headphone[25]

This method of sound transmission has been thoroughly investigated all around the world, as observed from the prevalent usage of earphones and headphones among the populace.

For the design, using earphones or headphones would be more suitable if air conduction was utilized, instead of loudspeakers, due to the personalized nature of the device. Standard earphones can be plugged into the 3.5mm audio jack of the Raspberry Pi to output sound.

Air Conduction Analysis

Headphone jacks typically provide 10-20 mW output power, mostly around 12mW[7], but depend on the load/headphone impedance at specific frequencies and operating levels. Low-impedance headphones range from 16-32 ohms and high-impedance headphones range from 100-600 ohms

Figure 31 shows the frequency response of a typical headphone. It is seen that the amplitude starts rolling off at around 4kHz, meaning the sound output would not be an accurate reproduction of the tone. A detailed explanation of this can be found at http://www.innerfidelity.com/content/headphone-measurements-explained-frequency-response-part-one#lJrM6HS6wexf02Ee.97.

Bone Conduction

Bone conduction is a relatively newer technology developed during the 1970s. It bypasses the eardrums and sends vibrations through the skull to allow the person to 'hear' a sound. A bone conduction device simulates the role of an eardrum, creating vibrations that can be directly received by the cochlea. No sound waves are detected outside the device, that is, people standing around the wearer will not hear the sound output.

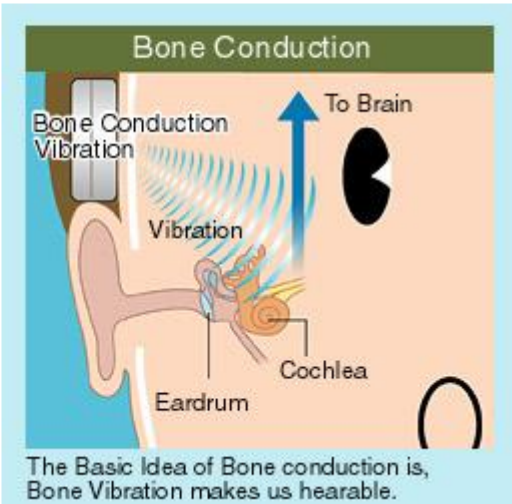

Figure 32: Diagram illustrating bone conduction[21]

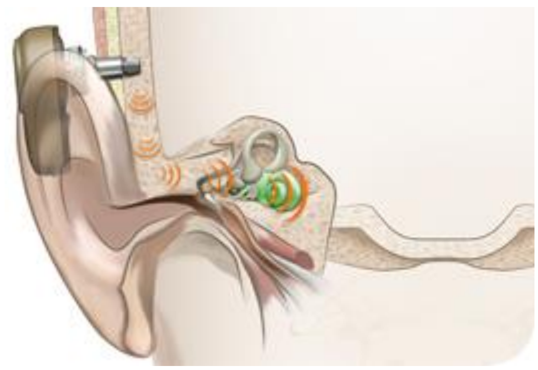

Figure 33: Permanent bone conduction implant[33]

The primitive method of implementing bone conduction involves screwing a small titanium implant into the skull right behind the ear, and hooking on a sound processor, as shown in *figure 33*.

Such a method is highly intrusive and infeasible, but thankfully new methods have been developed that simply require a device to be placed against the skull. The closer to the ear, the more accurate the sound. Bone conduction headphones have been commercially produced, however prices begin at around £30 and averaging at around £65[18]

Bone Conduction Analysis

Figure 35 shows that the lowest threshold (i.e., maximum sensitivity) for all three conditions occurred at around 1200Hz. At frequencies below or above these frequency values, greater intensity is required to detect the sound output by the cochlea, meaning it imposes more stress to the bones. From these findings, frequencies from 570-1850Hz should be attenuated, and frequencies at the high and low ends should be amplified[48].

Compared to air conduction, bone conduction may facilitate sensitivity to sounds in even higher frequency ranges, possibly up to 95 kHz[14]. Although outside the human audible range, these frequencies play a role in giving an overall listening experience to people, the same way bass (less than 20Hz) is experienced as pulses or 'being hit in the chest'.

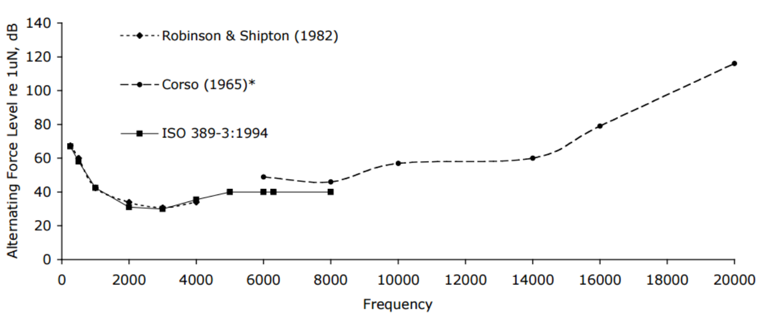

Figure 34: Some bone-conduction thresholds as reported in the literature

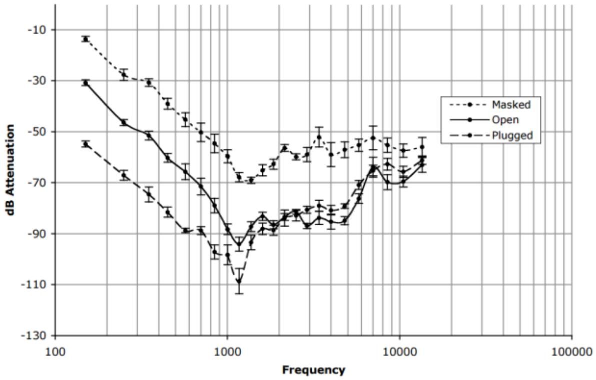

Figure 35: Threshold of audibility with bone conduction headphones under conditions of Masked, Open, and Plugged ears

Simple Implementation of Bone Conduction

Due to the relatively high prices of commercial bone conduction headphones, a simpler solution should be investigated. Using readily available and minimal components, such as an old functioning headphone, piezoelectric disc and a small motor, such a device can be produced, albeit to limited quality. The impedance of the device will also be higher than low-impedance headphones, so more voltage will be required to achieve a similar effect or sound output. Small motors usually require 1W or above to drive them. Note that this method also uses the 3.5mm audio jack on the Raspberry Pi, and is worth investigating.

Videos for reference:

1. Bone Conduction Headphones, https://www.youtube.com/watch?v=cdQo1RZ0QYc
2. STEMbite Bone Conduction Speakers, https://www.youtube.com/watch?v=I--euRwR75U

Conclusion

Both air conduction and bone conduction are feasible to implement at this scale, from a technological standpoint. High quality bone conduction devices can produce better sound experience compared to high quality headphones, but it is a matter of monetary cost. The simple bone conduction solution, despite the trade-off of sound quality, is a very fascinating idea to investigate. Power ratings are still comparable at this stage, as it highly depends on the exact device models and method of implementation adopted.

Potential Extended Applications

On top of generating a sound, both air conduction and bone conduction devices can be slightly tuned to act as hearing aids. There could be an option to turn on this function, helping people who have hearing difficulties as well.

Appendix G: Project Website

This section includes screenshots taken from the Project website.

Figure 36: Screenshots of the Project website;

Up: Home page, at http://intranet.ee.ic.ac.uk/stefan.karolcik14/yr2proj/default.html

Down: Mission page, at http://intranet.ee.ic.ac.uk/stefan.karolcik14/yr2proj/mission.html

Figure 37: Screenshots of the Project website;

Up: Technology page, at http://intranet.ee.ic.ac.uk/stefan.karolcik14/yr2proj/tech.html

Down: Prototype page, at http://intranet.ee.ic.ac.uk/stefan.karolcik14/yr2proj/prototype.html

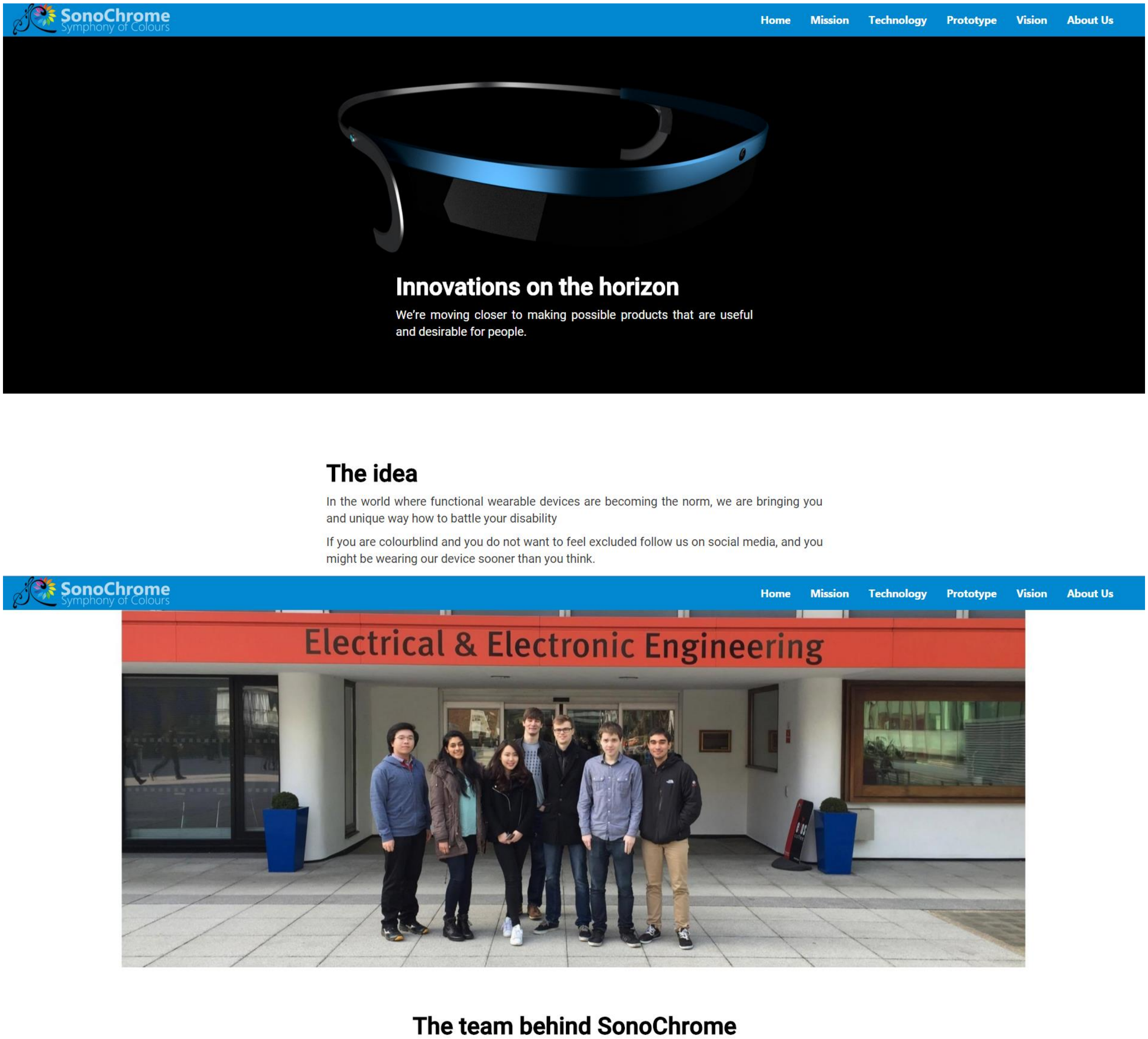

Figure 38: Screenshots of the Project website;
Up: Vision page, at http://intranet.ee.ic.ac.uk/stefan.karolcik14/yr2proj/vision.html
Down: About Us page, at http://intranet.ee.ic.ac.uk/stefan.karolcik14/yr2proj/about.html