The Auditory Aid Apparatus

Final report Engineering Design (4WBB0)

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Figure 1: The A.A.A. (Auditory Aid Apparatus) logo

Group no: 253	
Name	**Student ID**
Victoria Bogachenkova	1455109
Robin van Velzen	1431714
Stijn Plekkenpol	1440772
Angad Khurana	1460455
Anusha Ravishankar	1409018
Salah Hamed	1380508

1 Group effectiveness

All of the members of the group are from different majors which provided the team with a lot of different perspectives on the choice of the design goal and the selection of preliminary concepts. In general, most group members were very motivated and enthusiastic about learning new skills in order to use them in the implementation of the design and actuation of the project.

A few members were very interested in programming and development of the mechanical parts of the device. These members also had a bit of experience with setting up and controlling sensors and actuators with an Arduino. The students with an Electrical Engineering background have a basic knowledge of electronic circuits and diagrams, which proved to be very helpful in the development of the final product. Students with less technical knowledge were willing to learn and collaborate with those who were familiar with a certain field in order to improve their technical knowledge. Students with analytical skills planed to help with the collection and visualization of the experimental data.

The group consisted of students from different faculties from which two will be elaborated on. The first being an Electrical Engineering student. Since the device had to work autonomously, it was important to have some understanding of electrical circuits as well as knowledge about an Arduino. The Electrical Engineering student had good knowledge of this subject and was very eager to help others with it. The extra knowledge that was added to the group due to his expertise really helped the effectiveness to the group. Besides that, the willingness of the other students to help and learn more about the Arduino and electrical circuit assembly combined with the eagerness of the Electrical Engineering student to help them resulted in great group work.

The second major that played a very central role within our group was Industrial Design. Our group contained one Industrial Design student. The device that was in the end decided on by the group had to be an aesthetically pleasing device. This included an aesthetic logo for the device, as can be seen on the front page, a good-fitting casing to protect the electronics and some sketches and drawings of how the device was supposed to look like prior to assembly. Having a student who already had knowledge in these areas really helped the group during the process. The knowledge combined with the enthusiastic approach of other members of the group formed a very efficient combination.

During the design process many different skills of multiple members of the group were necessary to achieve the final design. Since the members of this group are from many different majors, most of them had a good input in the design process. Whilst some were better with programming and working with the Arduino, others were great at making design sketches and thinking of creative solutions to problems.

As stated before, students with less technical knowledge were very keen to learn more about this part of the design and realization process. The students who already had this technical knowledge helped them with their self-study assignments. This created a nice atmosphere within the group where everyone could learn new skills and apply them. Everyone worked on the different parts of the design and realization process, which led to new insights and creative solutions. When one group member was stuck on his/her assignment, another was happy to help him/her with their problems. This led to a high group effectiveness throughout the project.

During the intermediate presentation the group failed to completely explain the purpose of the device and what makes it new and innovative idea. This resulted in a grade which the group was not happy with. The next meeting a good discussion was held on what needed improvement and due helpful feedback from the tutor the team were back on track. This critical reflection on the intermediate presentation helped the team to get a better overview of the project. The group needed to be clearer about the exact purpose of the device. Critically thinking about the presentation as well as the idea behind it resulted in small adjustments within the design which made the device much better. The second improvement that needed to be made was within the video. The video did not come across as enthusiastic and professional, so for the final presentation, extra emphasis was put on that aspect. The critical reflection and mindset of the group resulted in these improvements which positively influenced the effectiveness of the group.

This project was also done during the COVID-19 pandemic, which resulted in an online-offline study environment. With one meeting online and one on-campus each week, it was tough to keep working efficiently. On-campus meetings seemed much more efficient and productive than online meetings. There was more interaction and it was easier to have discussions. This stimulated group efficiency and the effectiveness of the meetings. Due to a decrease in restrictions regarding the pandemic, the group was able to book rooms during the online meetings. This way it was possible to have an on-campus meeting whilst the tutor joined online, which also lead to a large increase in effectiveness of the team.

There were also some weaknesses within the group, which mainly focused on communication. One of the members was really quiet which sometimes meant that her ideas were not heard. This problem was dealt with by making sure that she was chairwoman more often, which both improved her self-confidence as well as boosted her contribution during the meetings. There were also three members of the team who were quite loud and liked their opinions and ideas to be heard. So in order to give everyone and equal chance to express his/hers ideas those members stayed more quiet than they would usually and tried to ask the quieter members of the group about their opinions. Even though the enthusiasm of most group members was very much appreciated some members spent way too much time perfecting their work, so in order to improve effectiveness and time management every got very specific Self Study Assignments and some of them even had a time limit. This meant that every group member knew how much was expected of him/her and once again improve the effectiveness of the team.

Figure 2: The group picture

Finally, as you can see from the picture the group improved on already existent skills and learn new ones within this project. Most members worked extremely well together and were able to deal with situation when one of the group members was not contributing as much as was expected of him, which lead to an improvement communication and team-working skills.

2 Design goal

Many different disabilities where considered when figuring out the design goal, such as visual impairment, auditory impairment and epilepsy. Besides that, old age was also thought of as a possible target group for the design. However, in the end it was decided that the best disability to focus on would be auditory impairment. All in all it was a very tough decision, because all group members were interested in developing tool in order to aid many different disabilities. To make sure that everyone agreed with the decision before the planning and implementation stages of the project began, there was a vote during one of the meetings in which the auditory impairment was a clear winner. Thus, an auditory impairment aid for in-house use was decided on as a design goal.

The team particularly wanted to focus on helping individuals with auditory impairments to perform in-house activities. This group often faces difficulties with hearing important sounds, such as a fire alarm and this might be detrimental to their health and safety. If they can't hear a fire-alarm, as well as other less important sounds such as people talking, next to them or to them, means that they are often unable or struggle to perform simple daily tasks. This makes their life less safe and less enjoyable compared to people without such a disability. The possible solutions to this impairment fitted best with the overall skills of the group: a good amount of programming knowledge, knowledge about Arduino and electronics, creative skills, elementary CAD knowledge but no knowledge about app-development at all.

According to the world health organization, around 466 million people are suffering from disabling hearing loss. By 2050 this number will rise to around 900 million people [1]. This makes auditory impairment one of the biggest disabilities in the world at the moment. There are already many different devices on the market dedicated to improving lives of people with an auditory disability. However, these devices are often aimed at enabling predictable daily tasks for people with an auditory impairment. These are for example: devices that alert the user when someone is at the door with the use of lamps [5], and devices that help people wake up in the morning with the use of vibrations [8].

However, when looking at the amount of people that suffer from an auditory impairment, we believe it is not enough to only assist these people with predictable, daily tasks but we should aim to improve their standard of living and help them perform unpredictable daily tasks. This can be done by creating aid devices that will allow them to do more complex tasks, which they would not be able to do these tasks normally. With the aid of our device they can do tasks such as detecting sound as well as the direction it is coming from. Extra care should be taken to help these people function well in unpredictable situations that are hard to detect, or solve with an auditory impairment.

Examples of unpredictable and sometimes dangerous situation are: in-house accidents of fellow residents, fire alarms going off, loud water-faucets being open for extended periods of time or someone calling out for help. These accidents are often indicated and recognized by a certain noise. The person who fell calls for help, the fire alarm makes a beeping noise and the faucet can also be heard by people without an auditory impairment. In all these cases the noise indicates that something is going on and enables people without an auditory impairment to take care of it as quickly as possible, which is often very important. A problem arises for deaf people, the late arrival to the scene of an in-house accident is often not a pretty sight. Taking all these factors into account, it was decided to aim this project at improving situational awareness of auditory impaired individuals that they are missing because of their disability.

The design goal is to fix the issue of lack of situational awareness of auditory impaired people. It is necessary for them to be able to know that something is going on in a house. Due to the fact that they cannot hear sounds the device has to have a certain translation of sound to some feedback which is apparent for auditory impaired people. This could be haptic feedback, feedback in the shape of light or another kind of feedback.

The feeling that this design goal could lead to a desirable and innovative product mostly stems from the idea that with this product a lot of people can be helped in a substantial amount without it being a huge burden to them. The product does not have to be big, intrusive or dangerous to fulfill its tasks. The hope is that such an accessory can be designed in a way that it is not only helpful, but also creative, practical and aesthetic to the user.

Besides this, the design should be multifunctional, which makes it even more innovative. The original design is innovative since it is the first device to help recognize and locate sounds to its users in unpredictable situations. Making the device multifunctional makes the A.A.A. even more versatile. Users can place the device on multiple parts of their body or even on a table or counter. This multifunctionaliy creates a device which can be used at any time and during any in-house task.

3 Functional design and solutions

The MoSCoW method in order to separate the different functional specifications according to their importance in the design is given below. With the use of the MoSCoW method the goals for the design were clearly defined and noted. There are 4 categories which all the technical specifications must be put under: must have's, should have's, could have's and won't have's.

The *must have's* of the design are:
The product must help people with a disability in their home and has to be within the size of $0.34 \times 0.23 \times 0.32 m^3$. The cost of production of the device must not exceed 70 euros. The device must work autonomously and/or interactively. It must also have some sort of sensors and actuators (buttons or other sensors). At least 4 special topics must be implemented in the design-process or the design itself.

The *should have's* of the design are:
The device has to be able to locate sound and indicate the direction of the sound by providing feedback.

The *could have's* of the design are:
The device could be lightweight and portable. It could differentiate certain sounds and give feedback to the user depending on the sound. The device could indicate loudness or frequency of recognised sounds with different vibrations. The device could have a battery life of at least 16 hours or it could be rechargeable. It could also be aesthetically pleasing for an average user. The device could be attached to different parts of clothing and body

parts

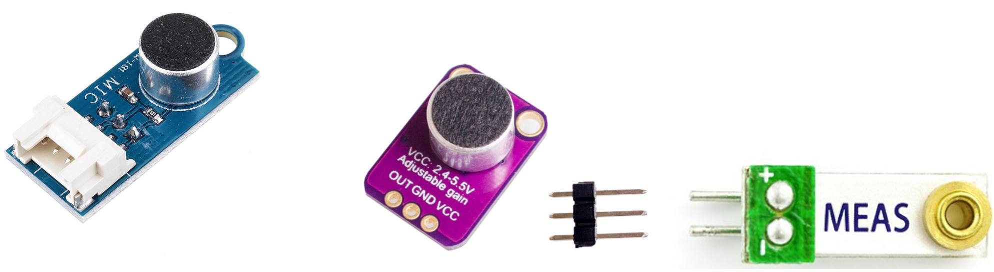
The *won't have's* of the design are:
The device won't be connected to an app or any other external hardware/software. The device won't be necessary when other people are around. The device won't be waterproof due to the electronics inside and it being to hard to build a waterproof casing. It will not consist of parts with a complete function (for example a complete ready-made motorized gripper).

Solution Encyclopedia

The main two goals of the design is to first recognize presence of sound and locate it and then the presence and location of sound should be indicated to the user. Different options on how to do that will be shown in this solution encyclopedia. These goals are also supported by the must have and should have features of the MoSCoW prioritisation and possible solutions are explored in this Solution Encyclopedia.

<u>Locating and recognizing sounds:</u>

- A wearable microphone/Volume sensor
- Stationary microphones (Volume sensor) throughout the house
- Multiple wearable microphones (Volume sensors), located on one small device.
- Multiple wearable microphones, located in different parts on the body, e.g in shoes, watches etc.
- Microphones which respond to different frequencies to recognize sound.
- Sound comes in waves, so we could use a device which senses these waves in the form of vibrations. It would look like a speaker, but work in the reverse way.
- The CIA and FBI use a technique which uses lasers to detect sound. The lasers get disturbed by the soundwaves and these distortions are converted into conversations [9].
- A vibration detector circuit can be used to detect sounds via vibrations [2].



(a) Microphone sensor (b) Microphone sensor (c) Piezo vibration detector

Figure 3: Different components for possible use

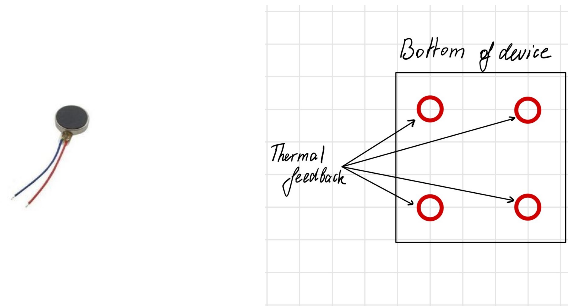
<u>Indicate sound to the user with the use of:</u>

- Different variants of LED's (LEDstrip, LED ring, pcb of LEDs, RGB LEDs or LED matrix) - this way the user will be able to see where the sound is coming from. The multiple versions of LEDs can be seen in Figure 4.
- Thermal feedback - this way the user will feel the heat and that will indicate to him/her that the device is able to detect sound coming from somewhere .
- Vibrotactile feedback - this way the person would be able to feel sound. So the sound waves would be transformed and the person would feel them thorough this feedback.

- Haptic feedback - this is buzzing of the device in order to alert the user that there is sound coming from somewhere. This type of feedback can be seen in Figure 26.
- Electrotactile feedback - small electrodes that would provide weak electric simulations to the skin in order to alert the user of sound. The layout would be similar to the layout of thermal feedback as shown in Figure 5b.

(a) LED (b) LED strip (c) LED ring (d) LED matrix (e) LED pcb

Figure 4: Different LED components



(a) Haptic motor (b) Thermal Feedback

Figure 5: Different types of feedback

4 Design concepts

The three concepts that we chose were based on ideas that would help deaf people to identify sounds around the house. This will increase their safety of living alone. The three concepts are described below.

A.A.A.

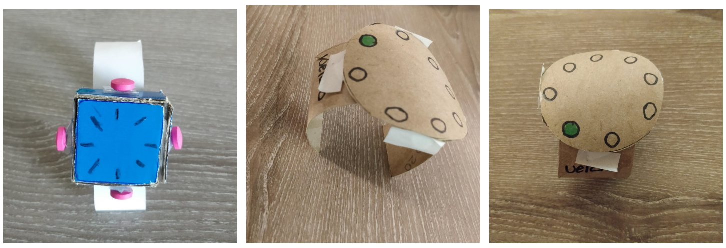
The first concept is called A.A.A (Auditory Aid Apparatus). The design is build with the purpose to guide the users towards certain sounds. This device contains sound sensors. The sounds detected by these sensors will be indicated to the user via LED lights. Depending on the loudness and direction of the sound, the LED lights will light up at a certain brightness and in a certain direction.

Possible design features:

- Haptic feedback as a secondary function to the LED in order to assure the users attention
- The LED's, in total 8 of them, used in order to be able to show the direction from where the sound is coming from, when possible
- Screen in the middle to indicate what sound it is for a specific set of sounds such as burglar and fire alarms
- Multiple sound detectors around the bracelet/band to detect the direction of sound

Possible ways to implement this design:

- Using a haptic sensor to give feedback to the user about presence of sound
- Using an Arduino in combination with all the other components to detect the direction of sound and give feedback
- Using separate LEDs to show the direction of the sound to the user by lighting up one LED which should indicate the direction of the sound.
- Using a LED ring to show the direction of the sound to the user, similar to the separte LEDs



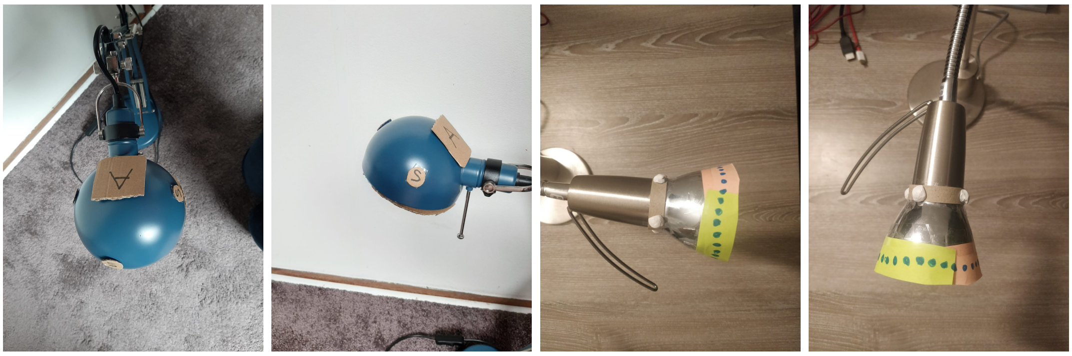
(a) (b) (c)

Figure 6: Multiple prototypes of the auditory assistance band.

There are many technical aspects to be considered when creating such a device. The number of microphones used to capture the sound which is place along the wristband. There are around 8 LED's used to show the direction of the light. At last there various components present on the Arduino board. Combining these components makes this a device which will be quite hard to realize.

Auditory assistance lamp

The second concept is called the auditory assistance lamp. This design is supposed to show the users which kind of sounds can be heard in the house. The lamp has a sound sensor implemented in it. This sensor detects the sounds and will then detect which wavelength it is. This will be translated into which sound it can be. An alarm has a different wavelength compared to a incoming phone call. The device will turn to a certain color, depending on which sound it recognizes.



(a) (b) (c) (d)

Figure 7: Multiple prototypes of the auditory assistance lamp. Where A stands for arduino and S stand for speaker/sensor in the prototype a-c. In the second prototype the white dots stand for sensors while the paper with blue dots are LEDs that will light up. The arduino would be built into the lamp in the second prototype

Possible design features:

- A RGB light. This makes the color distinction between different sounds very clear.
- A sound sensor, which does not only detect sounds but can also make distinctions between the frequency at which they occur and at what wavelength they are.

Possible ways to implement this design:

- Using a RGB light which is implemented in a standard lamp. This RGB light will switch off the standard light to replace it by a colored light.
- Using an Arduino in combination with all the other components to detect the wavelength and frequency at which the sound occurs.

This device does not have many different components so building the device should not be very complex. However, detecting the different frequencies and wavelengths of sounds will be quite hard. Especially coupling the detected sound with the correct color will be a hard task. So the coding behind this device will become complex.

Massaging feedback socks

The third concept is called massaging feedback socks. These are socks with vibrating motors on it. The socks also have lights and sounds sensor implemented in them. These sound sensor will detect sound, the motors will start vibrating (massaging) and at the same time the lights will go on in a certain color to indicate to the user which sound is detected.

(a) (b) (c) (d)

Figure 8: Multiple massaging assistance socks, where M stand for motor, S or SS stands for sound sensor. In the prototype in 8a,8b the arduino is built into the sock and is not shown.

Possible design features:

- Multiple RGB lights. These will make the color distinction between different sounds clear
- A sound sensor, which does not only detect sounds but can also make distinctions between the frequency at which they occur and at what wavelength they are
- Vibrating motors which will give haptic feedback to the user
- An Arduino which couples certain detected sounds to certain colors

Possible ways to implement this design:

- Using a RGB light which is implemented on the socks. This RGB light will turn on once the sound sensors detect certain sounds

- Using an Arduino in combination with all the other components to detect the wavelength and frequency at which the sound occurs
- Using vibrating motors to give haptic feedback to the user. This will feel like a massage
- A sound sensor, which does not only detect sounds but can also make distinctions between the frequency at which they occur and at what wavelength they are

This device will not be easy to build. Socks are very flexible and users want them to be comfortable. Implementing multiple vibrating motors, sound sensors, lights and an Arduino in them will be very hard. Especially since they still need to be flexible and comfortable.

Conclusion

All in all it seemed that if any of the above mentioned devices was chosen as the final device, it would be a challenge to implement. This suited the team very well as they were looking for a challenge. It was also very important that the team was interested in implementing an innovative device which would make the device harder to realise. The team was ready to take on the challenge of implementing such a device.

5 Final design concept

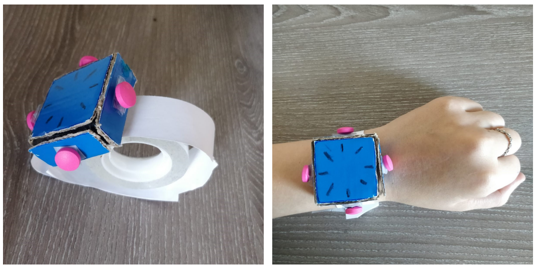
The aim of the project was to build a device that can aid someone with a disability in their home. The team focused on auditory impairment as a disability of people who live by themselves and would require to react to sounds like those individuals without an auditory impairment, as already discussed in Chapter 2. After multiple meetings and discussions focused on which design concept should be chosen as the final project goal, the team decided to go with the A.A.A.(sound assisting apparatus). This was the final decision because the preliminary design and ideas behind the A.A.A were the most challenging to build as well as the most innovative out of the three preliminary designs described in Chapter 4 and yet this idea still seemed feasible.

The functionality specifications of the MoSCoW prioritisation (Chapter 3) can be well implemented in this device. The idea is that this device will have convenient dimensions to be lightweight and portable. Besides that it is very convenient to wear in-house due to its weight and shape. The A.A.A. is also easily used on the wrist as well as other parts of the body, put in the pocket or even just placed on a table next to the user. The device would have a Velcro sticker attached to it and where you would like to attach it there should also be a Velcro patch. The haptic feedback and LED feedback is implemented in the device in a way that it is also in accordance with the MoSCoW list. This made the A.A.A. the best design to implement for a user with auditory impairment.

The design concept of the A.A.A. was previously discussed in Chapter 4. In this chapter we aim to show that the design is innovative, of challenging nature to produce and of user-friendly character. In order for a design to be innovative it has to be something that no-one else has thought of or put into practice before. Therefore, the team carried out extensive research to investigate if a product similar to the A.A.A. is on the market or not. None of the team members could find such a device on the market. Compared to the devices that have already been produced before, the A.A.A. is not only able to detect sound and the sound direction but also give haptic feedback to the user to draw their attention, signal that there is a sound and then with the use of an LED matrix show the direction from which the sound is coming from. Such a device requires knowledge of coding and implementing sound sensors, haptic feedback and coding in order for all the above described features to work. Therefore, the project is of challenging nature because even though some team members had some experience with Arduino, noone had ever used the Arduino Nano Every (which the team ended up using), implemented code for sound sensors or had any experince with haptic feedback with the use of a vibration motor. Therefore, the team viewed this is a challenging and interesting project that they were willing to take on.

At the beginning of the project all the team members got to know each other's strengths and weaknesses, as described in Chapter 1. From then on all the members wanted to work on their weaknesses as well as show and use their strengths during the project. The team was interested in choosing a challenging project idea which fits in with the groups strengths such as some previous experience with Arduino and circuit generation experience as well as some basic CAD design knowledge.

The team sympathises with people with auditory impairment and wanted to create a design that would be easy to use for everyone no matter their age or technical expertise. Hence, it was decided to be a wrist band with a simple on/off switch, haptic feedback and an LED matrix. The simplicity of the design made the device user-friendly. The definition of user-friendly is "easy for people who are not experts to use or understand" [3], according to the Oxford dictionary definition. The A.A.A. fits perfectly with this definition and therefore can be referred to as user-friendly.



(a) (b)

Figure 9: The prototype of the A.A.A.

After all the components were put together in a design sketch shown in Section 11.2 the team realised that a wristband design would no longer be feasible as the design would simply be too big to be put on the wrist. Therefore the multi-functionality of the design was used. The team agreed that the A.A.A. can be used on other parts of the body such as the upper arm, put in the pocket and put next to the user on the desk/table. The final design of the A.A.A. could be placed on the upper arm, in the pocket as well as simply right next to workstation of the user shown in Figure 17a, 17b and 17c and . Even after the design concept changed the, functional specifications and their prioritisation based on MoSCoW prioritisation system which were discussed in Chapter 3 still remained valid for the team's design as these specifications were closely considered when the different design placement ideas were developed.

6 Technical specification

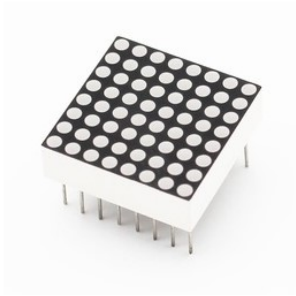
The A.A.A design was chosen as our final design. This device consists of multiple components, which will be clearly discussed in the following chapter. The table below shows all the components that where used in this device. It also shows their price, the production number and the manufacturer of the component.

Components	Price	Production number	Retailer/Manufacturer
Arduino Nano Every	12.50	ABX00028	Tinytronics
8 x 8 LED matrix	4.00	MAX7219LEDSMALL	Tinytronics
(4x) Audio Sensor	2.50	MAX4466MICMOD	Tinytronics
Lipo battery	6.50	LIPO800MAH	Tinytronics
Charging module	6.00	SEEED-106990290	SEEED
Vibration motor	2.50	SKU:002158	Tinytronics
3d printed casing (made in NX12)	5.00	Final design in appendix	Robin van Velzen
ON/OFF Switch	0.45	SWITCHS	Tinytronics
Velcro stickers	5.00		Praxis

To give more technical specifications of the components within the device, the following table is made. It consists of the different components, combined with some technical specifications and some outcomes of these technical specifications.

Component	Technical specification	Outcome
Arduino Nano Every	DC current per I/O	40mA
	DC Current V_{CC} and GND Pins	200mA
8X8 LED matrix	Required voltage	5V
	Current (when off)	2.6mA
	Current (when fully on)	67mA
Audio sensor	Voltage	2.4-5.5V
Vibration module	Current (continue)	60mA
	Current (startup)	90mA

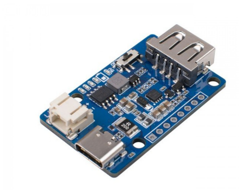
(a) Arduino Nano Every



(b) 8x8 LED matrix

(c) Audio sensor

(d) Lipo battery



(e) Charging module

(f) Vibration Motor

Figure 10: All the components of the A.A.A. device

The Arduino Nano every is the main component in this device. The Arduino needs to be able to provide enough current to the system in order to keep it running. An Arduino Nano can provide a maximum of 500mA of current to the system.(https://www.electricrcaircraftguy.com/2014/02/arduino-power-current-and-voltage.html) The different components require a certain amount of current themselves. This being:

- 2.6 mA for the 8x8 LED matrix (when off)
- 67 mA for the 8x8 LED matrix (when fully on)
- Sound sensors didn't have details about the currents but were measured to be negligible.
- 90 mA for startup vibration module
- 60 mA for continuing vibration module

This gives that a maximum total of 67mA + 90mA = 157mA is used. This is lower than the max limit of 500mA of the arduino Nano every.

The power source used in the device is a Li-Po accu. This Li-Po accu is used in this device since it has a very good operation time vs its size and weight. The dimensions of this battery are 48.5 x 34.5 x 5.5 mm. This makes the battery very thin, which is perfect for the device. The device has to fit on the arm of the user. Therefore it should not be to thick, so having a thin battery is very convenient.

The Li-Po accu is rechargeable. This is done with the Seeed Studio Lipo Rider Plus. This makes the use of this device much easier, since the user does not have to worry about buying new batteries. The Li-Po accu has a capacity of 800mAh. To calculate its lifetime, an approximation of its use has to be made. This device will be used daily by its user. For this approximation an estimation of 24 hours per day is made, and it senses noise above the set threshold for a total time of 1 hour per day. This results in 60mAh in stand-by mode and 157mAh in active mode. This would mean that the battery works for about 3.7 days.

The power within the system differs. Depending on whether the device is on or off. When the device is off, the circuit has a voltage of 5V and a current of 2.6mA. This results in a power of 13mW. When the device is on, the circuit has a voltage of 5V and a current of 157mA. This results in a power of 785mW.

According to the MoSCoW method our device had to consist of multiple different specifications. The device had to be a small and cheap device. This was taken into account when looking for different components. The group especially searched for cheap and small components. This can be seen with the Lipo battery. This battery is very small, yet not expensive and it works very well.

According the the MoSCoW method the device should have some way of locating and communicating sound to the user. This is achieved with the 4 Audio sensors and the LED-matrix. The LED-matrix was the best option since it shows arrows to the direction of the sound. This is a convenient way of communicating.

The MoSCoW method also states that the device could be multifunctional and that it could be lightweight and good-looking. These criteria are achieve by making a 3D-printed casing around the electronics. This creates a very neat product. Besides that, the device can be placed on the body, as well as on the table. It comes with Velcro and a band so it is possible to stick it to cloting, or to place it around the arm.

7 Detailing

The original idea when the design was created was to make the device portable. This idea was decided on because such a device is the most convenient but still manageable option for a product that should indicate visual information to a auditory impaired user.
For the detailing of this design all components were specifically selected with a few specifications in mind:

- They should be as small as possible
  Since the product will be carried with the user (originally as a wristwatch). All components have to be a small as possible, in order to prevent the device from becoming an unnecessary inconvenience for the user.
- They should be available for delivery
- They should be affordable, all of the components should be 70 euros all together
- They should give immediate feedback in order for the device to be responsive

In order to decide on which model of each component would be used a few preliminary tests had to be carried out. These are describe below.

Sound Sensor

The search for a suitable sound sensor module led to the discovery of a complete sound sensing module by the name of KY-038. It has 4 pins: Analog Output(A0) which gives the direct microphone signal as voltage value, VCC and GND pin for power and Digital Output (D0).The attached potentiometer could be used to configure an extreme value for the sensor. If the value exceeds the extreme value, D0 would send a high signal using the inbuilt comparator circuit. These outputs were exactly the desired outputs which were to be used to detect the loudness above the desired threshold and inform the user through visual feedback. However, in spite of the positive attributes of this module, it was discarded due to the following reasons

- The module was too big. Its dimensions were 3.5cm x 2cm x 1cm. Since the device(AAA) had to be compact, the use of this module was discarded.
- Setting the threshold manually using the potentiometer would be extremely tedious and inefficient.

Upon further exploration the MAX 4466 module was discovered. It is one of the most compact sound sensing modules available (2cm x 1cm x 0.5cm). It has three pins: VCC and GND for power and the OUT pin which gives the direct microphone signal as voltage value. The analog Output from the A0 pin can be easily used to extract the information about the amplitude of the sound. The threshold can also be easily set using the software by the use of IF statements. Due to all the reasons, this module was final choice for a sound sensor.

Micro-controller

One of the most readily available and easy-to-use micro-controllers present on the market are the Arduino microcontrollers. Thus, due to size restrictions and prior experience with Arduino micro-controllers, the team decided that a micro-controller from the Arduino family would be used. Amongst the various micro-controllers available, Arduino Nano Every was chosen. This was primarily due to the following reasons

- The compact nature (4.5cm x 1.8cm x 1cm)
- Even though Arduino Nano Every and Arduino Nano are of the same size, Arduino Nano Every is cheaper hence allowing more budget for other coponents.
- Clock speed of Arduino Nano Every is 20MHz which is much higher than that of Arduino Nano (16MHz).

Powering the device

Since the intention for the device was for it to be used very regularly, replaceable batteries or removable batteries did not seem like the best idea. This led to the option of adding a charging port into the device. The Arduino Nano Every also needed a 5V current to work properly, but the device required a battery that is optimal for the portable size of the device. The chosen LIPO800MAH battery only provided a 3,7 V current. A solution to this problem was to incorporate a module that could not only charge the battery via a USB-c port, but also amplify the current the battery provides to a higher voltage which enables the usage of this battery with the Arduino Nano Every. Eventually the module that was found and decided upon was the SEEED-106990290, this module has more functionalities than is necessary for the proposed task of voltage amplification, but it should fulfill its function well. To save space in the design, unnecessary parts of this module, like the USB-port were removed. For extra safety measures concerning the LIPO battery the course managers were contacted for extra information. After thinking thoroughly about which safety options were necessary next to the inbuilt safety measures of in the LIPO battery and the charging module, a fuse was added between the battery and the module.

Casing

When all the parts were put together the original idea of the device being a device located on the wrist, as decided previously, was no longer feasible. Although all parts were selected based on their small size, no other compromises for reduction in size could be made without seriously altering the functionality of the device. Due to this, the original idea of a wristband device was replaced by a design that is multi-functional. The A.A.A could be worn on the wrist if the user desired to do so, although for many people the device would be too large to wear on the wrist; not only would the haptic feedback not be felt anymore by users with a small wrist, the size of the device would also be uncomfortable for everyday in-house use. Though luckily there are other alternative; the device could also be placed on the upper arm, be in a pocket, or be placed next to a workstation where it is clearly visible to the user. Though the intention to keep the device as small as possible for user convenience was still kept through this change in placement. The process of the design of the casing can be found in the subsection 11.4.

Visual Feedback

One of the special functions of this device is the ability to locate the direction sound is coming from, as well as the ability to indicate this direction to the user. To accomplish this, a combination of four microphones with a LED-matrix is used.
A big part of creating these functionalities was coming up with a correct placement of the microphones, and code to compare the sound levels of the microphones and derive a direction from this. The team's solution was to continually measure the maximal and minimal values that the audio sensors supplied, for small periods of time (e.g 20 ms). Since the sound sensors give sinusoids as measurements, for each small interval the maximum amplitudes of the audio sensors can be compared, which is further explored in Chapter 8. These maximum amplitudes can give an indication, also addressed in Chapter 8, of where the sound is coming from, and code is written to indicate which of the 8 directions (North, Northeast, East, etc.) is the closest to the direction the sound is coming from.
To indicate these we had several options in mind directions to the user an arrow is drawn on the LED matrix to the direction the sound is coming from. Several designs were explored and are listed below

- Using 8 independent LEDs to indicate the direction. This idea was discarded as the design was very bulky and rudimentary.
- Using a 128 x 128 Oled I2C1 display by Adafruit. This dislay was extremely thin and compact (4.5cm x 3.4cm). However this was also discarded as the Arduino Nano Every was not powerful enough to process information at the desired rate and thus the display was very slow.
- Finally an Adafruit 8x8 The the LED matrix. Even though its a bit bigger (7.1cm x 7.1cm x 3.3cm) than the OLEd display, its compact enough to be used and the Arduino Nano can power it sufficiently.

Thus, finally the Adafruit 8x8 Led matrix was used.

Haptic Feedback

For haptic feedback, the Vibration DC Motor Module was used due to its compactness and the option to control the level of vibration through an analog signal as an input to it.

Device Algorithm

For the overall device an algorithm was constructed which were basically just steps or instructions that the device would follow to achieve the desired goal of sensing sound and provide visual feedback.

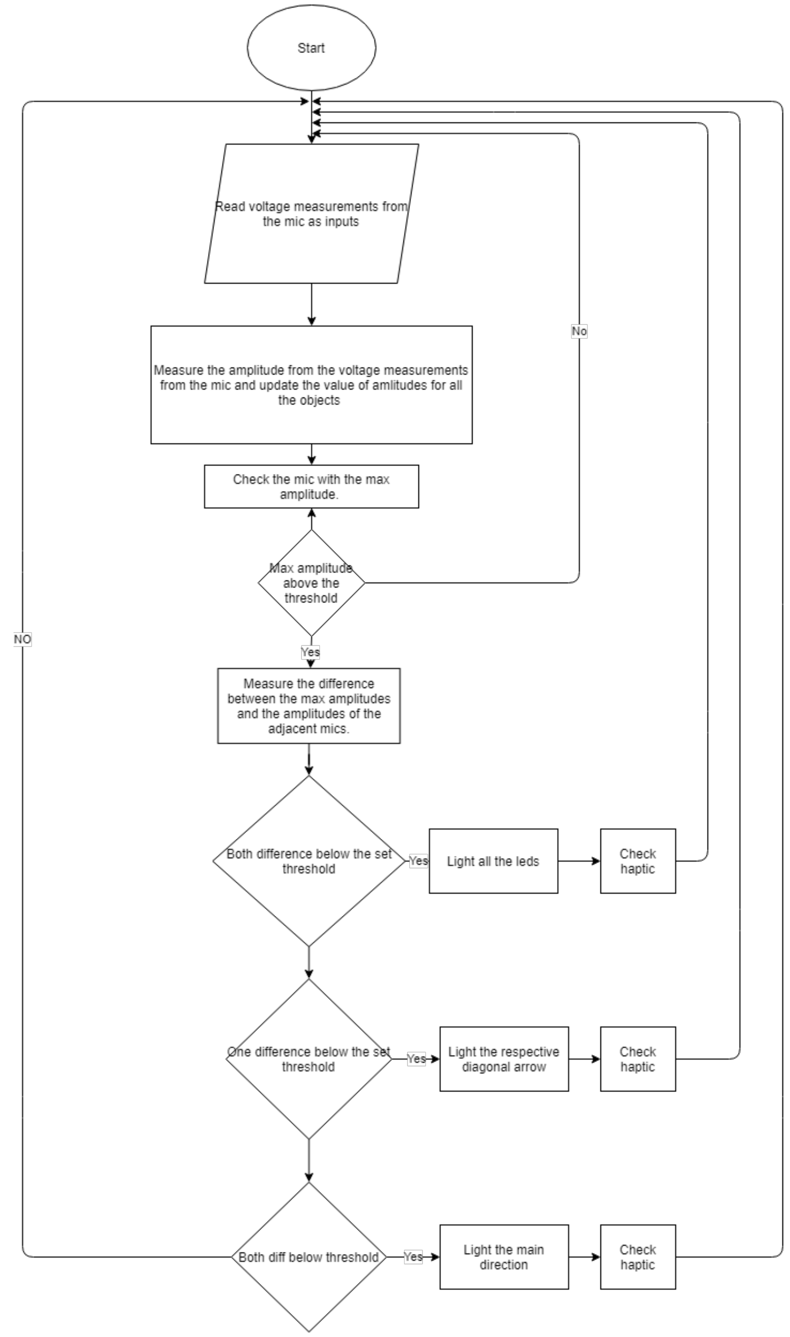


Figure 11: Flowchart for the algorithm behind the code

Final Overall Design

Another challenging step of the detailing process was figuring out the circuit for the whole device. For electrical efficiency, the team decided that only the LED-matrix and the audio sensors will be powered by the Arduino Nano Every, and the vibration motor would be directly powered by the LIPO battery. Powering the module in this manner is possible because the module for the vibration motor contains an in-build transistor.
The detailing process also included coming up with a way to fit all the electronics in a case, this led to a few sketches, and a few designs in NX12. The way these designs are created is further explored in the special topic

Chapter 11.4 . The Ultimate goals for the final casing were:

1. It should be as compact as possible
2. It should have a removable lid
3. It should promote the detection of sound by the microphones
4. It should have fitting holes for the charging port, the vibration motor, the on/off switch and the microphones.
5. A band should be attachable

In trying to fulfill these goals there were ideas for round and rectangular designs. There were ideas with and without possible solutions to improve the sound that is picked up by the microphones (these are further explored in Chapter 8).

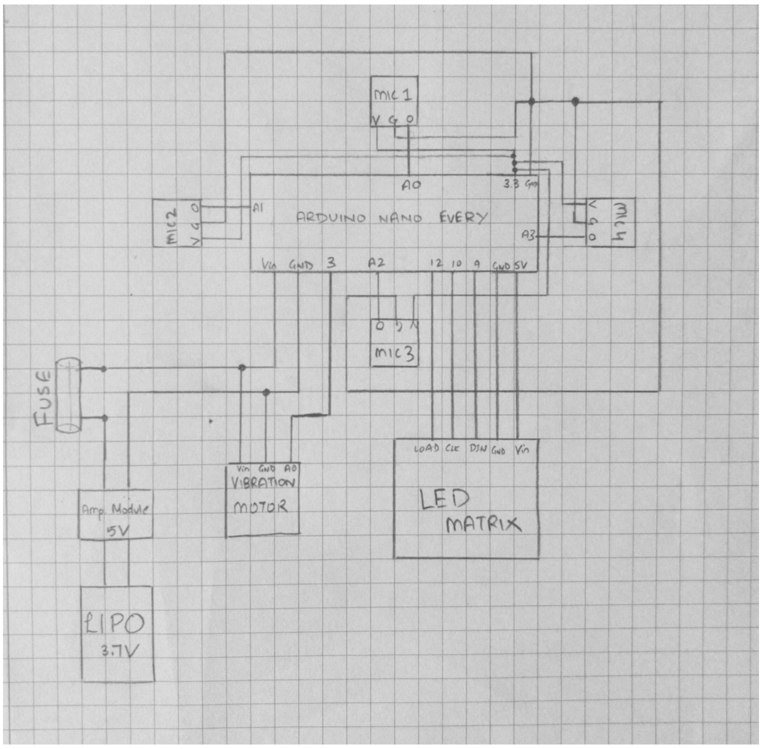


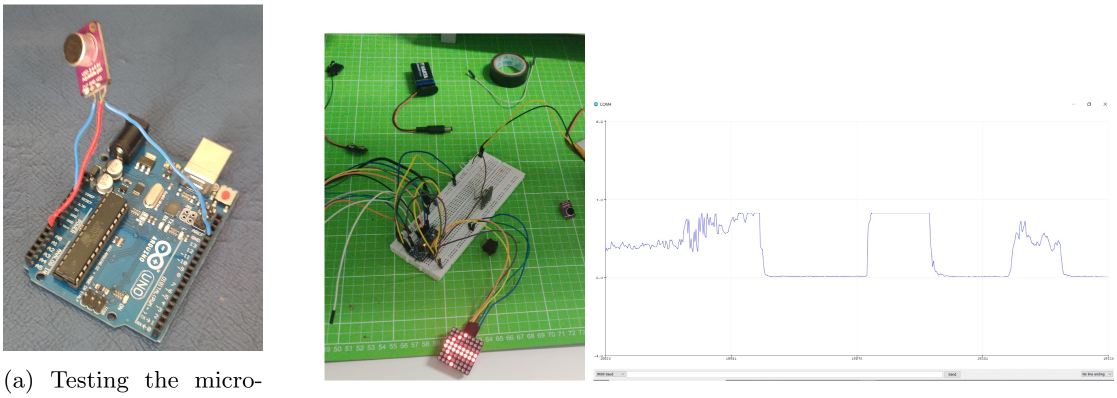
Figure 12: Block diagram showing the circuit and how all the parts are connected within it

8 Realization

In order to assemble the final system the team needed to carry out a few preliminary test to make sure that all components worked separately as well as tests to make sure that everything works when it is assembled.

At first, the team tested each individual component separately with the Arduino UNO to make sure that all the components were functional. The Arduino UNO was used at first because it is easier to use as it is bigger and sturdier. The team also had a lot of previous experience with the Arduino UNO, so it made the first testing stage more efficient. The components were successfully tested with the Arduino UNO.

After all the components were tested with the Arduino UNO, they were then tested with the Arduino Nano



(a) Testing the microphones detecting directions

(b) Testing the LED matrix

(c) Graph shows amplitude recorded by the microphones

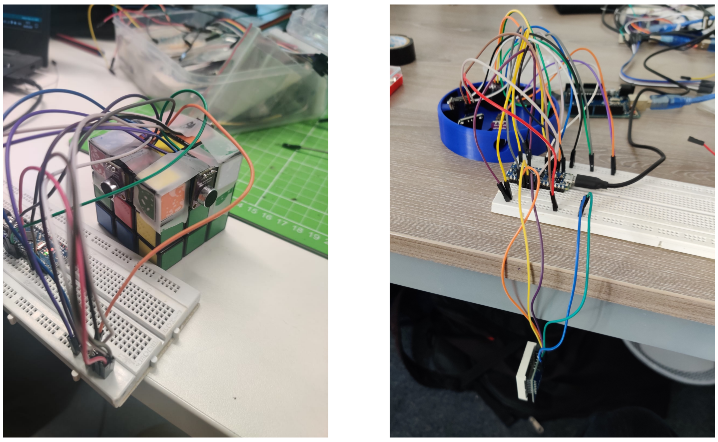
Figure 13: Multiple experiments that were carried out during the realisation stage

Every in order to make sure they were compatible with it and worked correctly. These tests included making sure that the input from the microphones was correctly recognised as well as making sure that the lamps on the LED matrix were bright enough and that the haptic feedback gave strong enough feedback in form of vibrations. All the tests with the Arduino UNO and Arduino Nano Every were carried out using a breadboard in order to hold all the components in place

Multiple casings were printed for testing. The first prototype that was printed had a circular shape and was used to test how the microphones work with the special tubes. After another look, the team decided that the circular casing would be wasting a lot of space, therefore the design was changed to be square/rectangular. The thickness and the height of the first design was also improved upon in order to make the device thinner, smaller and more portable. The designs are further explored in 11.4. Unfortunately, even with those changes the design was too big to fit on a wrist. This meant that the team needed to figure out another placement for the device.

With the casings the team also wanted to test if the tubes within the manufactured plastic casing would improve sound detection over no tubes at all . The initial hypothesis was that if tubes that would surround the microphones were inbuilt into the casing then sound detection would be better. The tests that were carried out with the tubes led to worse sound detection than without the tubes in the casing. The difference between the amplitudes detected by different microphones was less detectable with tubes in the casing than when there were no tubes in the casing. This led to the team discarding the tubes for the casing design. And the final design for the casing was made. The process of how the casing was designed and manufactured is further described in Chapter 11.4.

After the preliminary tests were carried out, the team needed to figure out the battery circuit in order to power the Arduino Nano Every as well as all the other components. At first, the Lipo battery was connected through the charging module straight to the Arduino Nano Every. The team assumed that all the components would get enough power from the power source of the Arduino. However, the vibration module did not work as well as expected and the vibrations given off were very weak. This problem was then resolved by changing the circuit. The vibration module was powered directly by the battery. This worked much better and meant that every component functioned at its full power.
When the final circuit was decided upon, all the pieces were put together to create the final prototype. First a piece of standard pcb, a little bit bigger than the Arduino Nano Every was measured and cut into shape in



(a) Testing the microphones detecting directions

(b) Final circuit on a breadboard

Figure 14: Multiple experiments that were carried out during the realisation stage

order to fit in the casing. Then the Arduino Nano Every was soldered onto this pcb. For ease of connecting all the other components later, three lanes were created on the pcb, one for GND, one for 3,3 V and one for 5V. The charging module was then modified by removing the usb-port, to reduce size. The Lipo battery and the charging port were not compatible, so they were also modified to make sure these two could be connected. The battery connection wires were connected to the charging modules plus and minus. However the battery was not yet connected to these connection wires and this was done to make the following steps safe. The charging modules GND header was connected to the GND header on the Arduino Nano Every, and the charging modules 5V header was connected to a switch, and after this to the Vin pin on the Arduino Nano Every. This way the Arduino Nano Every is only powered if the switch is turned on, while it is still possible to charge the device when it is turned off. A negative aspect of this is that the charging module itself will always be powered. This is negative because the battery will use charge even when the device is off. The next step was to solder the vibration motor with wires to the pcb, VCC to Vin, GND to GND and IN to pin 10. Then flexible wires were connected to the LED-matrix and the microphone modules so they would fit nicely into the final casing. The flexible wires of the LED-matrix were connected to the Arduino Nano Every through the pcb, to the 5V output, the GND output and pins 2, 3 and 4. All the microphones were connected to the GND lane, and the 3,3 V lane and they were connected to pins A0,A1,A3 and A5 on the Arduino Nano Every through the pcb respectivly, as shown in Figure 15 After this the battery was connected to the battery connection wires, and the final code was uploaded (1) to the Arduino Nano Every. When everything was tested (see 9). The components were all fitted in the casing, the LED matrix was connected to the lid with hot-glue, the casing lid was placed on top of the casing, and the casing was screwed shut with 4 simple flat head screws (2,5x10 mm) The group thought of a few

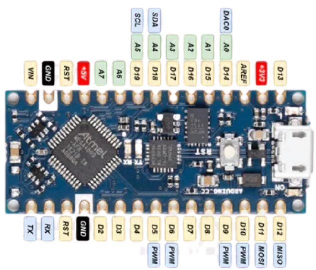
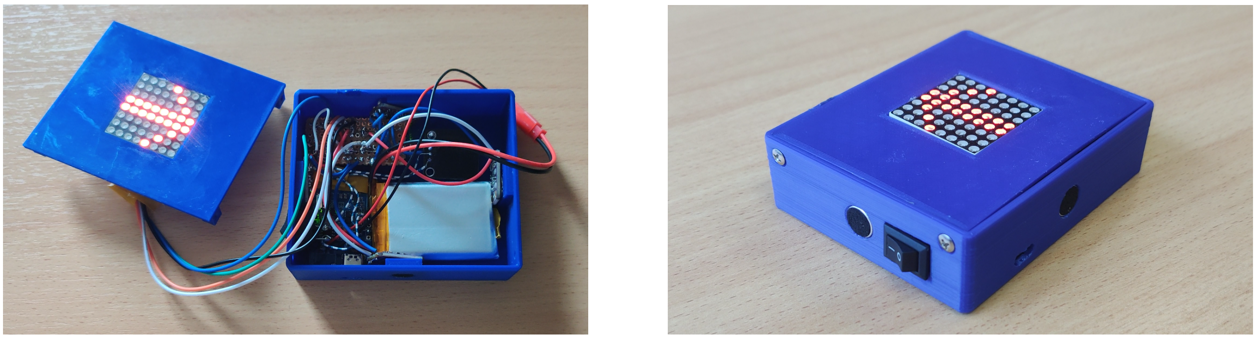


Figure 15: The diagram showing all the pins of the Arduino Nano Every

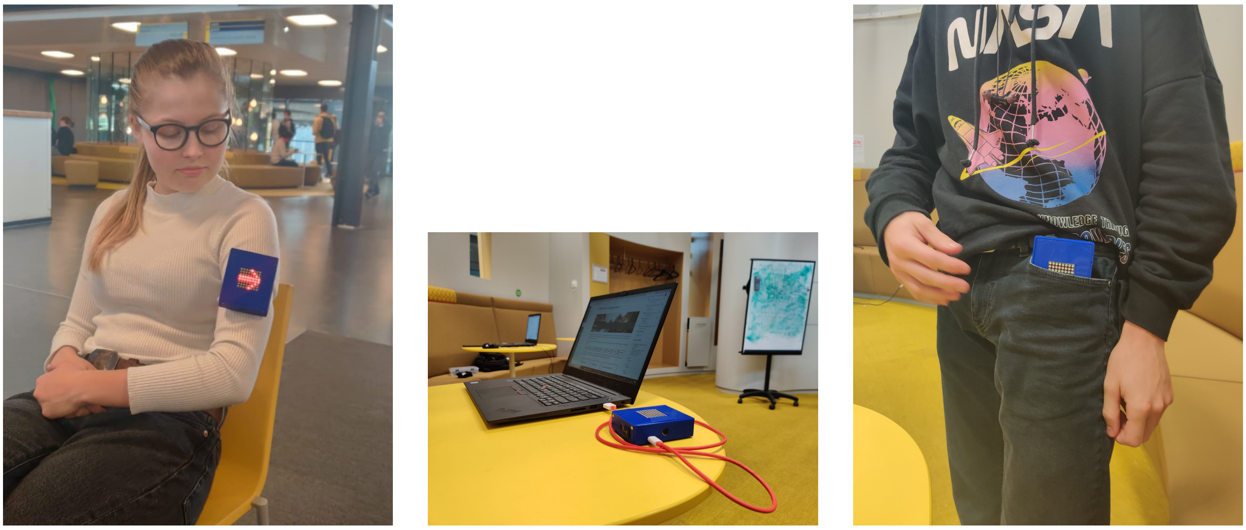
different new placements for the device. These differed from placement on the upper arm to a stationary device which can be placed on a table. Other possibilities were a placement on the upper arm or putting the A.A.A. in the pocket. These different placements all had their own advantages and disadvantages. For example, the pocket version made it harder for indoor use since users don't always have pockets to put the A.A.A. in. This is why we came to the conclusion that we want to make the A.A.A. multifunctional. Thus all the previously mentioned placements of the device were implemented.



(a) Final prototype with the lid off

(b) Final prototype with lid

Making the A.A.A. multifunctional makes sure that the A.A.A. can be used in many different situations. The user can place it on the table when they are working there. The user can also put it in their pocket whilst walking around the house. The A.A.A. can also be worn on any body part within reason by using the Velcro sticker that comes with the device. The Velcro sticker allows the user to stick the device on any piece of clothing that also has a Velcro sticker. It can also be worn around the upper arm thanks to the elastic band that can be sown onto the Velcro. The placement is flexible and depends on the user's preference.



(a) On the arm

(b) Placement at a work-space

(c) Placement in the pocket

Figure 17: Possible placements of the AAA

Explanation of the realization of the code

During the realization phase of the process, combining the components and making sure that they worked was the main priority. However, a code also needed to be written in order to make the device work as a whole. This paragraph will elaborate on that process, some major changes and improvements during the realization of the code and a small elaboration on the full code. The code itself can be seen in the Appendix (1).

The initial code was rudimentary. The A.A.A. device consists of many different components and to increase the chance of the device working successfully, these different components where first tested. To test this, many small pieces of code where written in order to test the workings of the different components. This code consisted of very basic loops and was solely created with the purpose to test all the singular components by themselves. Once every components was successfully tested the group proceeded to the next coding phase.

The first code that was written was for the sound sensors(microphones). The Analog Output(A0) of the microphones gives the direct microphone signal as a voltage value. The signal the module gives is in the form of a sinusoid, as the sound produced is sinusoidal in nature the voltage signal received is also a sinusoid. To get the loudness of the sound, the amplitude had to be detected, which was done by creating a function called 'getamplitude()' which does the following: within a defined sample time (a few ms) all the data is taken and analyzed. This is done by using if statements and loops. The maximum and minimum (Voltage) of the sound voltage signal were recorded for every single microphone. By calculating the difference between the maximum and minimum for each microphone, the amplitude within the set time-frame was determined. This process enables us to calculate the amplitude of the sound voltage signal, which is a representation of the loudness. Only if the amplitude is above a set threshold the device would be active. This enabled the device to ignore the low ambient level of noise.

The second part of the code was written for the LED matrix. The LED matrix should give the user visual feedback in the shape of arrows on where the detected sound is coming from. The LED matrix is a square formed by 8x8 LEDs. The size of the matrix is translated into the code with the use of a 2D array from 0 to 7. The code contains 8 manually programmed arrow shapes and each arrow points to a different directions depending on what the Arduino Nano Every instructs it to. The four standard direction (front back left right) all have their own basic function. This function states to which direction the arrow has to point without a necessary argument. Instead of making four different functions for the diagonals, in order to achieve computational ease a single function was defined called middle(int a,int b) which takes 2 integers as the arguments. The arguments are the Cartesian coordinates of the tip of the arrow in the direction it needs to be deployed. This can for example be (0,0), in this case the arrow points to the bottom left - the origin. The last function the LED matrix has is the 'lightall()' function. In case every microphone detects a very high volume, all the LED's will light up due to this function. This will be particularly helpful in scenarios like fire. The fire alarm is so loud that it will be sensed by all the four microphones as being above the threshold and thus the whole matrix will light up and will notify the user.
The team faced an issue with duration from which the lights remain on. Every time a sound was detected, the LED matrix responded very quickly, which was a good sign, however, the LED's almost instantly turned off. It could be possible for instance that someone falls and there is a loud noise for a brief moment of time but if the user misses to see the screen then he will not be notified.Thus To prevent the user missing any important information, the code was changed. This change made sure that the LED's would be on for at least 2 seconds after a sound is detected.refer to the code with explanatory comments in the appendix. This gives the user time to notice the light and look at the A.A.A. and react. The use of delay() (an Arduino function that halts the program at the given line for the specified milliseconds) for was avoided to achieve this as this would not allow the microphones to receive data while the program is halted using the delay. Thus the use of a global iterator variable was used for this purpose. For more details please refer to the code with explanatory comments in the appendix.The function maxamp() was constructed to measure and compare the amplitudes of noise being intercepted by various mics. Maxamp()'s algorithm then analyses these comparisons to decide which arrow should light up on the led matrix. This function then calls another function called ledmatrix() and provides it with the necesarry data as arguments. The ledmatrix() function then lights up the ledmatrix according to the arguments.

The last part of the code was written to control the vibration/haptic module. This module should start vibrating once sound above a certain threshold is detected. The initial idea was to let the vibration module vibrate as much as possible. However, this was very electrically expensive and due to lack of auditor insulation of the microphones from within, the vibration motor noise was also captured by the microphones which resulted in errors. Thus the haptic motor and the microphones could not stay on at the same time. Sufficient time for the haptic motor to stop even after the its power was cut was also to be given. Thus the use of delay() was employed. While it solved the issue mentioned above, while the delay() was active the microphones cold not receive data from the environment. After experimenting the optimal value of 750ms was decided for the delay() function. The haptic motor works using the function analogWrite() which inputs a mapped value of voltage(0-5V) from 0 to 255. To make the circuit even more electrically efficient the mid value of 127 was chosen as this value resulted in the desired level of vibration which could be felt properly thus providing more power would have been a waste and thus this value was chosen. The function haptic() was constructed to activate the haptic/vibration motor. This function caused the haptic motor to produce three pulses of sounds ('buzzes') with equal intervals in between and the delay pf 750 ms in the end. The haptic motor is active for a time of 1.75 second each time haptic() is called.

After all these different pieces of code were written and tested, they had to be put together. Initially, all the code was just added in the main loop but this made the code extremely difficult to understand and modify. Thus for making the code as clean and efficient as possible, classes were constructed. A class is a user-defined data type, which holds its own data members and member functions, which can be accessed and used by creating an instance of that class called objects. So a class called sensor was constructed with 2 attributes: an integer which was set to the pin value to which the given microphone was attached and a float number which was the amplitude of the sound being intercepted by that particular microphone at that instant. Four instances of this class (objects) were constructed one for each microphone. The overall algorithm of the code is illustrated in the flowchart below:

All of the electrical components for the device were bought in Tinytronics web-shop and delivered to the one of the team member's home. The Velcro stickers were bought in Praxis and the 3D-casing was printed on a 3D-printer which belongs to one of our teammates. The full Bill of material is given in Table 1. From this table, one can see that the total price of all the required components did not exceed the price limit of 70 and the total cost of required to build the A.A.A. is 44.45. Thus one of the main goals of the project, the budget as defined in MoSCoW, is satisfied.

Quantity	Components	Price	Production number	Retailer/Manufacturer
1	Arduino Nano Every	12.50	ABX00028	Tinytronics
1	8 x 8 LED matrix	4.00	MAX7219LEDSMALL	Tinytronics
4	Audio Sensor	2.50	MAX4466MICMOD	Tinytronics
1	Lipo battery	6.50	LIPO800MAH	Tinytronics
1	Charging module	6.00	SEEED-106990290	SEEED
1	Vibration motor	2.50	SKU:002158	Tinytronics
1	3D printed casing (made in NX12)	5.00	Final design in appendix	Robin van Velzen
1	ON/OFF Switch	0.45	SWITCHS	Tinytronics
1	Velcro stickers	5.00		Praxis
TOTAL	-	44.45	-	-

Table 1: The Bill of Material

9 Test plan and results

Once the final device was realised, after integration of all the sub-components, many tests were carried out to figure out the relation of the final device with the technical specifications

Experiment 1 - Directional Sensing in the horizontal plane

This experiment was carried out to check the directional sensing of the device for directions in the horizontal plane (North,East,West,South,Northeast,Southeast,Northwest,Southwest). Directional sensing implies the ability of the device to detect the sound and provide visuals to the user about the direction of the sound using the Led Matrix. Noise of a fixed volume from a fixed distance was produced at different angles with respect to the device and the frequency of correct responses were recorded. This was in consideration with the technical specification that the device must be able to sense sound and indicate the direction to the user (The should have in MoSCoW). The number of times the device was able to sense the direction correctly was recorded. A regression plot was created with the number of times sound produced on the x-axis and the number of times the device sensed correctly on the y-axis.The root mean squared error of the data points was calculated from the line (y=x) which shows the ideal situation where number of correct outcomes equals the number of tests. First the experiment was carried by producing sound from all the 8 directions and then was repeated for only the four main directions (North East West South). The noise was produced by a group member at a distance of about 1 metre from the device as shown in the figure below.

Results: The former experiment gave a Root Mean Squared Error (RMSE) of 5.0646 which is quite significant and the latter one gave 0.7071. This proves that while the main directions were sensed with almost no error, the sensing of the diagonal directions was not very accurate. In the 'Detailing' section 7, the algorithm shows that the diagonal arrows are deployed when the difference between the two adjacent microphones (between which the arrow needs to be deployed) is below a certain threshold. This threshold value was also tweaked a lot to minimise the error and the optimal value was found to be 0.3V

Experiment 2 - Sensing Sound from the top and bottom

This experiment was carried to analyse the device's performance to sound being produced from top and bottom of the device. This was in consideration with the technical specification that the device must be able to sense

(a) Experiment 1 (b) Experiment 2

Figure 18: Experiments 1 - Directional Sensing Experiment; Experiment 2 - Experiment with sound source at the top and bottom position.

sound and indicate the direction to the user (The should have in MoSCoW) The sound was produced using the sound generator app. A regression plot was made by plotting the number of tests on the x-axis and the number of correct outcomes on the y-axis. The root mean squared error of the data points was calculated from the line (y=x) which shows the ideal situation where number of correct outcomes equals the number of tests and the device and the phone (sound source) was held by a group member as shown in the figure below.

Results: The RMSE was a mere 1.1832 implying the the device was able to sense sound from these directions and notify the user using the visual feedback very effectively.

Experiment 3 - Setting the sensitivity threshold

In the 'Detailing section' 7, the algorithm was shown. It shows that the visual feedback was given only when sound above a given threshold is sensed by the microphones. This was imperative, otherwise the device will constantly give visual feedback as there is always a very low level of ambient sound. This threshold was to be set in such a way that the device is able to sense sound even at a significant distance. Thus, for the experiment a group member stood almost 9 metres away from the device and the values were tweaked until the optimal value was found. The picture of the group member with the device showing the right arrow is shown below.

Figure 19: Experiment to set the threshold

Results: The optimal value for the threshold above which the device should activate was found to be 1V and this threshold was set within the code

Experiment 4 - Haptic Feedback

This experiment was conducted to check the working of the haptic motor and was it strong enough to be felt through the casing. Sound was again generated using the sound generator app on the phone.

Results: The haptic feedback worked was activated above the set threshold of 3.25V and thus worked as expected. While the haptic feedback was on the arrows' directions did not change as expected as the sound sensors and the haptic feedback should not work at the same time as explained extensively in the 'Realization' section.8

Conclusion

These experiments were imperative to check for the overall functionality of the device. Carrying out these experiments enabled us to discover and set the optimal values of some important thresholds of the device to achieve the finest performance. It was also discovered that the diagonal directional sensing was not improving after a certain level and the level was not satisfactory. This could mean that probably something completely different has to be done at the hardware and/or software level.

10 Design evaluation

The design evaluation chapter will consist of a critical view of the design and realization phase, combined with a critical view on the final product. First, an evaluation of the design phase.

The concept phase went very well. The group made great progress with thinking of multiple different designs and coming up with good solutions for problems rising for each of the concepts. In the end the Auditory Aid Apparatus was chosen as the final design concept. This was mainly done because it seemed like the most innovative idea and the group figured it would be a good challenge combining all the technical components. The choice of the final design concept also went very well as each of the team members shared their opinion on which design concept should be chose and the reasoning behind it. Almost unanimously the A.A.A. was chosen.

The sound assisting apparatus was chosen because it was believed to be a helpful and aesthetically pleasing product, which could be worn by the user with pride, whilst also helping them with every day tasks. During the design phase it was quickly discovered that this device was going to be much bigger than previously envisioned, as already mentioned in previous chapters. The intended product was supposed to be the dimensions of a watch, with a possibility to be a little bit bigger. However, the final device was going to be much larger. The dimensions of all the components were measured and the first design sketch showed that the dimensions of the device were going to be 7 by 7 centimeters. This was not going to be convenient for a device on the users wrist.

This set-back forced the group to think of other possibilities for the concept placement and usage. Placing the sound assisting apparatus on the wrist was no longer an option. Since the device needed to be usable at all times, the group figured that the best solution to the dimensions problem was to make the device multi-functional. This meant that we would put more emphasis on different placements of this device on the body, as well as others such as in the pocket or on the table. This change within the design procedure was the most critical.

This new multi-functionality was provided in three ways. The device can be put in a stationary position, on a table for example. It can be charged during these times and the user can see it when he is working on his laptop. The device can also be placed in pockets. This is convenient during movements within the house. The LED-display is not visible then, but this is compensated by the vibration module. This starts vibrating and the user will be alerted to get the device out of his pocket to see the arrows. The device comes with Velcro. This gives the user the possibility to attach the device to any piece of clothing. It is also possible to attach the device to a Velcro patch with an elastic band in order for the device to be more fixed on one body part such as the upper arm.

In the end, the final product is not the same as the group envisioned it during the start of the project. However, even though there were some difficulties the team managed to come up with a final product that is a creative and innovative, which gives the users a much safer in-house life. Besides that, it is an even more creative product than initially envisioned. Looking back on the idea of a watch now it seems basic and similar to products that are already on the market, but the final product being multi-functional makes it is even more creative than the team previously imagined.

The group is very happy with the outcome of the final product. However, there are some things that can be improved on within the design. These improvements will be elaborated on in the following paragraphs.

The first improvement has to do with the microphones. The microphones that are used within this design are the MAX 4466 module was used. These microphones were specifically chosen due to their small dimensions. The maximum voltage signal that these microphones can output is equal to the voltage V0 supplied to it. Any sound with a corresponding voltage value higher than V0 is clipped to V0 and this sets a limit to the range of values the microphones can perceive. For our device, V0 was set to 3.3V after considering the maximum power supply of the arduino in mind.This limits the range of the loudness of sounds that the microphone can read. This could be improved by using a transistor amplification circuit to increase the value of V0 to consequently increase the range of loudness. Currently the device measures sound and most of the time is able to detect the general direction pretty well. However, sometimes when the space is very big or there is an echo in the room the microphones do not measure the sound precisely enough, which leads to not very accurate readings and arrows pointing in the wrong direction. In order to improve this one should look into the technical specifications and detailing phase of the design cycle more carefully and take into account the problems the team faced with the microphones and try to solve them on a theoretical level first prior to implementation.

The second improvement has to do with the coding of the device. During the realization and testing phase, it was discovered that the device works well and is pretty accurate. This can be said once the device measures low to average sound volumes. However, when the noise was too loud the haptic feedback would go off and then the sound that should be detected during the time that the haptic motor goes off would no longer be measured. The team could not figure out a way for this problem to be solved neither manually nor in the code.

The third improvement that can be made is an obvious one. The dimensions of the final product are 8 by 9, which makes the device quite large. In order to make it more user-friendly the device should be much smaller. This makes it easier for the user to carry around. It will be easier to put in their pockets, attach to their clothing and it could possibly be reduced to the size of a watch. This improvement has to be made within the preliminary design phase. Sketches have to be made which can result in a more optimal way of placing the components and eventually shrinking the size of the device. Another way to improve this would be getting rid of the wires or getting smaller wires in order for them to take up a lot less space. This would save space but would be harder to do as this would require a lot more soldering and possible mistake could lead to the electronics of the device being destroyed.

Another improvement that could be made is to do with the vibration motor and the sound it produced. Even though, as previously mentioned the microphones are not very sensitive, the vibration motor produced a sound which is then picked up by one of the microphones and leads to arrows points in the wrong direction. This could be theoretically solved by somehow insulating the vibration motor or possibly editing the code in a way that the microphones do not pick up sound from the vibration motor.

The final improvement that the team thought of was the to find a way to indicate the loudness of the sound that is detected by the microphones. At first, the team was planning on doing that by using different colours to indicate different volumes of sound. However, that was not possible as it could only be done with the LED screen which was not compatible with the other components of our device as previous discussed in Chapter 7. Therefore, the 8x8 LED matrix was chosen but it only has red LEDs and thus could not indicate volume of sound. The team decided that it would a very nice feature to have but was not plausible in combination with all the other components. Therefore, if this project was carried on the team would like to look into other LED devices to display different colours for different volumes of sound.

In conclusion, the final device that the team was able to produce works and is able to detect certain sounds and give feedback to the user. The team is very proud of the result that they were able to achieve but they also acknowledge that they were are a few possible improvements that could be made. These improvements should be both made during the detailing and realisation. A lot of the improvements were thought of and adjusted on the way but if there was more time the team believes that should have been put into the detailing phase of the project.

11 Special topics

The four special topics that were chosen to explore are:

1. Error analysis & curve fitting
2. Design sketching
3. Haptic preception
4. CAD design

These special topics allowed the team to further understand the workings of the device, adapt it and provide the best possible user experience. The team was divide into subgroups in order for each group to research one special topic in detail and the share their finding with the rest of the team. After the special topics were researched, certain changed were implemented in the device. These changes are described within each special topic.

11.1 Error analysis & curve fitting

This special topic was very important during the experimental stage of the design. With the help of multiple experiments and analysis of the data that was collected from the experiments the team was able to eliminate multiple errors and optimise the performance of the device.
In order to fully understand how error analysis is carried out, how to use Matlab for analysis of the data as well as getting familiar with statistics, two group members went through the material available on CANVAS, as well as some extra material provided on canvas and some research papers on error analysis. This research allowed them to further develop tests to check the functionality of the device and improve it.
There were three main experiments that the two members of the team, who were in charge of this special topic carried out:

- How well the microphones were sensing all the 8 directions of sound,
- How sensitive and reliable are the microphones,
- How well the microphones were sensing sound from top and bottom.

All these experiments were described in detail in Chapter 9.

Experiment 1

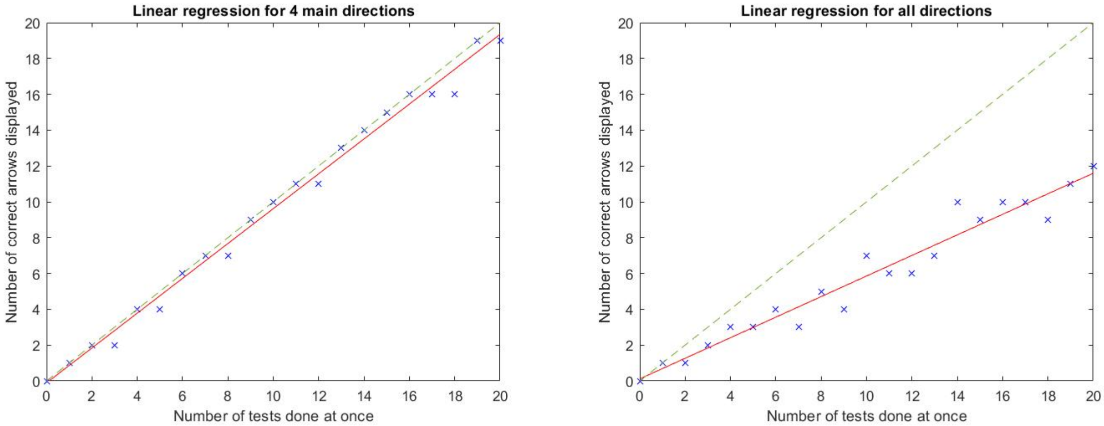
For the first experiment, the sound at a consistent volume was turned on in different locations around the room but in the 1 meter radius of the A.A.A. The distance of 1 metre was chosen because it was a good representation of real-life in-house scenarios and was also very experimentally convenient. The device was placed in the middle of the room and was meant to indicate with the arrows the direction from where the sound was coming from. There were two versions of this experiment:

- testing the 4 main directions (north, east, south and west)
- testing all the 8 directions(north,north-east,east,south-east,south,south-west,west,north-west)

The results were then recorded and analysed with help from the material provided. Below one can see two linear regression plots, one for each version of the experiment.

From the first graph the team concluded that the 4 main directions are detected almost perfectly. These are conclusions that the team came to because the linear regression line, which is plotted in red, is almost the same as the optimal linear regression plotted in green. The optimal linear regression shows what the results should be if all the microphones worked perfectly without any errors present and detected the direction of the sounds perfectly. The root mean square error from the optimal error regression line value was also calculated for the second experiment and it was a mere 0.7071.

From the second graph the team concluded that the diagonal arrows didn't work so well. This can be seen because even though all the directional arrows were tested some around half of them didn't work each time. Therefore, it can be seen that the optimal regression line is very different from the line of best fit for our data points. The root mean square error from the optimal error regression line value for this first experiment was 5.0646. This error is quite significant.



(a) First experiment (b) Second experiment

Figure 20: Linear regression graphs. The key for these graph: green dotted line shows optimal regression or line graph for the ideal case (number of correct outcomes = number of tests); red line shows the line of best fit of our data; our data is shown with blue crosses.

Experiment 2

For this experiment, the voltage output from the microphones was measured as a response to a constant sound level. The reason this experiment was conducted was due to the fact that the microphones themselves have a certain inherent tolerance (variability) concerning the voltage. Thus even to a sound with a constant level of loudness, the output voltage can be non constant (fluctuating). This could be either due to the inevitable errors that crawl in during the manufacturing of any electrical device. This can be a problem because a sound above the decided threshold could be intercepted as a voltage below the threshold due to the fluctuations and the device would not respond even though it should. This explains the importance of this experiment.

Two boxplots for the voltage measurements from the mics (a quantification/representation of the amplitude) were constructed as shown below. The first one corresponding a constant sound of 50 dB with a frequency of 440Hz and the second one for a sound of 60dB with the same frequency as the former case.

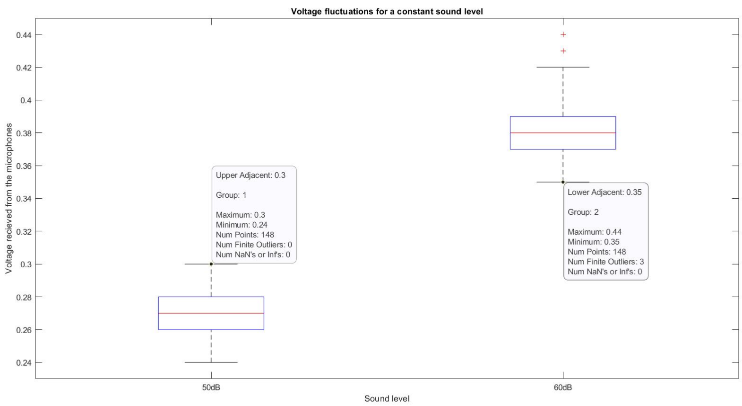


Figure 21: Boxplots for the voltage measurements. Left boxplot corresponding a constant sound of 50 dB with a frequency of 440Hz and the right boxplot corresponds to a sound of 60dB with the same frequency as the former case.

As shown in the graph the fluctuations are extremely less. The range of fluctuations corresponding to 50dB is just 0.06V and corresponding to 60dB is a mere 0.09V. Thus we can conclude that the microphones are reliable.

From these experiments it was concluded that the diagonal directional arrows didn't work as well as expected when there was only one source of sound. This meant that the team should either rewrite the code or have 8 microphone instead of 4. However experiment 2 proved that the sound sensors are extremely reliable. These

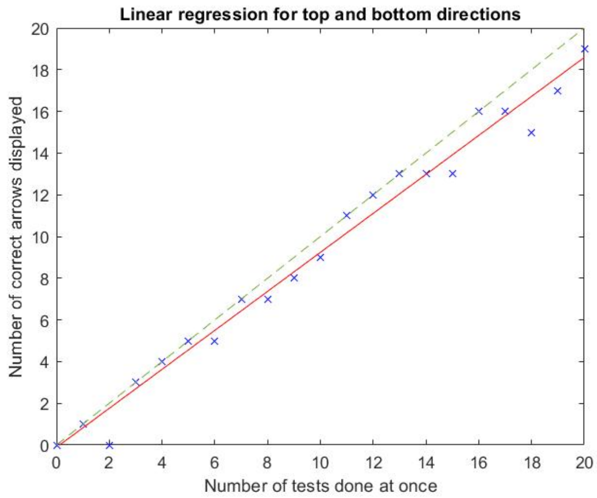


Figure 22: Linear regression graph. The key for these graph: green dotted line shows optimal regression or line graph for the ideal case (number of correct outcomes = number of tests); red line shows the line of best fit of our our data; our data is shown with blue crosses.

tests were done only towards the end of the project when the final product was already assembled so neither of those changes could be made. Hence, these errors are something the team put in the Chapter 10 of the report in order to acknowledge it as possible future improvements of the device.

Experiment 3

For this experiment, a consistent frequency and loudness of sound was turned on both above and below the device. During the experiment, the device was held at a consistent distance as shown in the Figure 19. This was done to make sure the readings were consistent. The details of this experiment are further explored in Chapter 9.
Above a linear regression plot can be seen (Figure 25c which shows the results of 20 experiments. From this graph we could conclude that the bottom and top directions were well detected. The optimal regression line is very similar to the line of best fit which in turn mean that the device senses the top and bottom directions very well. The root mean square error from the optimal error regression line value was also calculated for the third experiment and it was a mere 1.1832, which quite low and hence once again supports the argument that the device detects up and down directions well.

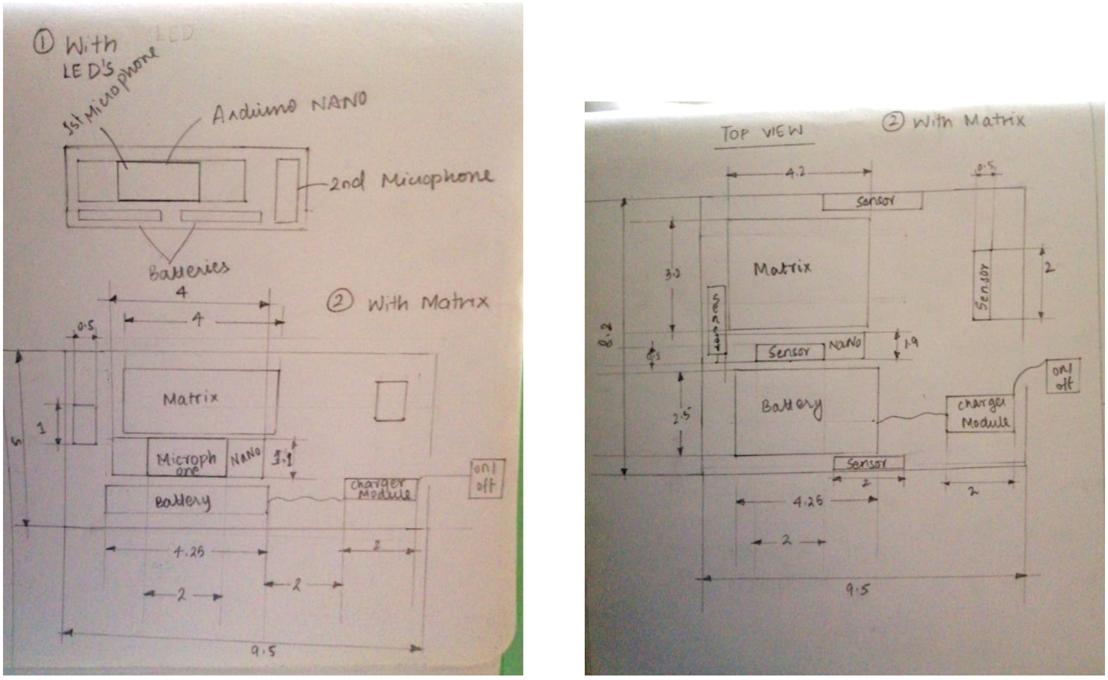
11.2 Design sketching

To begin the design of the prototype, it was necessary to sketch out a few designs. This was done to get an idea on how to fit all the electrical components and make a casing. This casing should not only protect any electrical mishaps from happening, but also provide a snug and comfortable fit for the user to carry out during any in-house activity.

At first, dimensions of each component which was given were noted down and sketched in different view to get a clear idea on how big the casing should be in dimensions. It was easier to draw a perspective drawing to get an idea on how the outline of the wristband would look. But with perspective drawing the dimensions of the components were not exact and there would always be a $\pm$ in dimensions.

To tackle this situation, several views of the casing with all the components placed in it were drawn. To get familiar with the technical sketching process, the modules on canvas were of great help. They made it easier to understand what different projections the sketch can be done in, such as 2-D or 3-D projections. With the help of these modules, different views such as front, top and side view of the design was drawn out. In addition to this, the course design sketching was followed. However, this course was not useful for a technical sketch since it was more focused on perspective drawing.

The design drawn out in 2-D projections helped to get the drawings done faster and to think ahead. Because the components turned out bigger than initially expected it was clear to see that even if the components were arranged compactly, the size of the casing would be large and would not be comfortable to wear. After a group meeting, it was decided that a round casing would not be the most feasible option. Various other designs were sketched out in which all the components would fit. Due to the continuous change in electrical components, the technical sketch kept changing and was not final for a long time. This gave the team room for a lot of sketching and iterations to take place, which could help fit all the components properly. Different shapes were explored and a few were sketched out.



(a) (b)

Figure 23: Technical Drawings for the final design, where all the measurements are in cm

To get an understanding on the users perception of the product, the modules under design sketching were studied. Specific focus was put on the study material base ond communicating and understanding product marketing. This is an essential part since it gives a final idea to the users on how the product will look as well as the functionalities it possesses to serve the users.

After this process, the device was sketched out in a very pleasing and visual sketch, which can be seen in Figure 24. This process was done in the end since such a sketch is only sketched out only after everything is finalized. Hence this process had to be done during week 7 as well as week 8 due to the last minute changes that happened in the design of the casing and changes of its dimensions.

Design sketching was done throughout the project at first to get an idea of how the final product would look like and after that to further improve on the design. The skills of design sketching were improved upon during this project and helped the team to decide on the final design of the A.A.A.

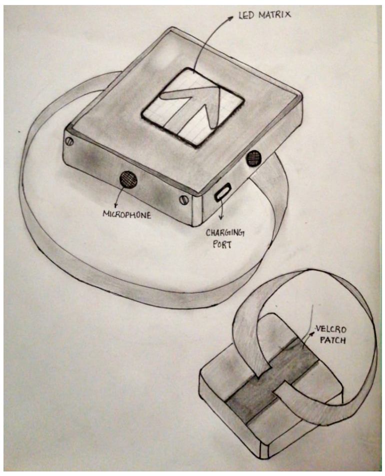
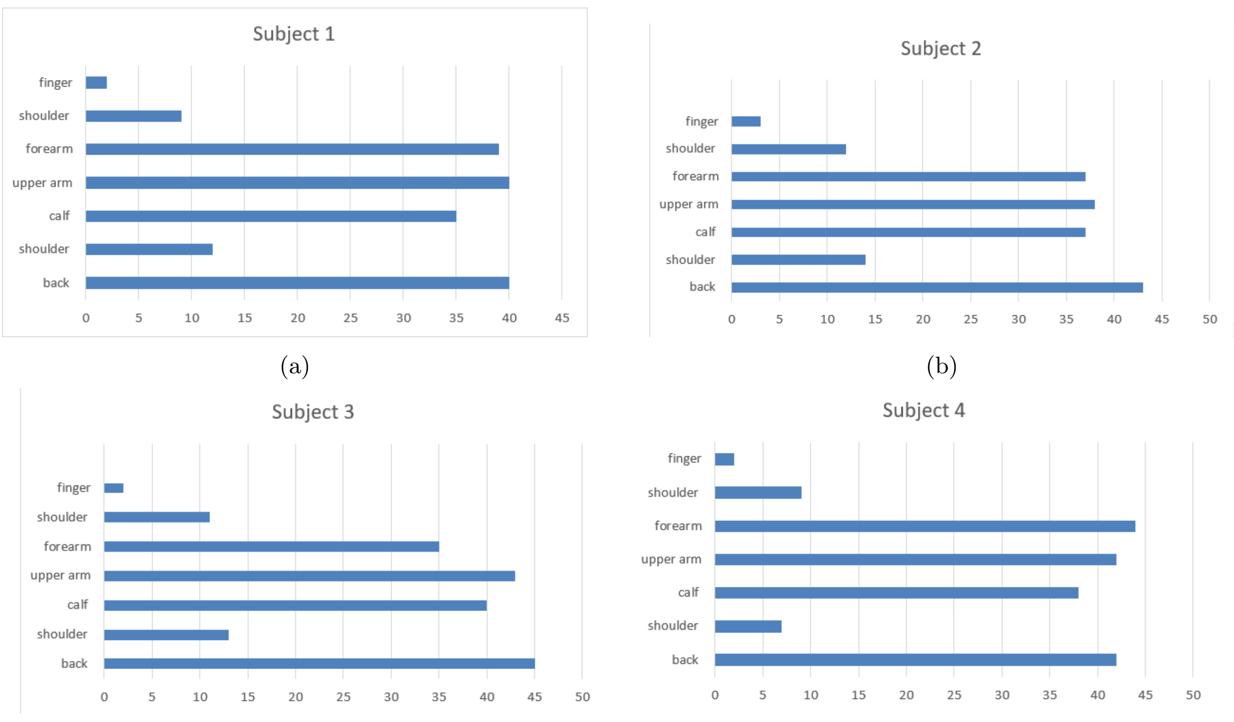


Figure 24: Final sketch of the device

11.3 Haptic perception

The haptic perception topic was very important during the design concept stage as well as realisation of the final product. The team wanted to figure out what was the optimal position of the device on our body and understand the reasoning behind it. In order to achieve this, material on Canvas was studied thoroughly as well as other research papers that were found on the internet. This research was started during the concept phase when the three prototypes were developed as was further elaborated on in Chapter 4.

At the very start of the team's research, it was found that haptic perception is often overpowered by vision [4]. It was also noted that people with an impaired sense experience heightening of other non-impaired senses [6]. In the case of auditory impaired individuals it is clear that vision is the sense that they use most and haptic perception is a bit less developed. Based on all the information that was already known to the team after preliminary research of the auditory impaired individuals during the concept stage, the team decided to carry out a bit more research into the topic before concluding anything. However, already at the beginning of the project it was clear that haptic perception will be present in the device but the extent to which it would used was still unknown. Visual feedback through the LED screen was decided to be the main way of communicating to the user which direction the sound is coming from. The team still needed to figure out how haptic feedback would be used.



(a) (b) (c) (d)

Figure 25: Graphs showing the results obtained from the experiments carried out on 4 different test subjects. The vertical axis of each graph shows the part of the body parts tested, while the horizontal axis shows the mean 2-point threshold measured in millimeters

In order to study the topic of haptic perception even more rigorously in-house experiments were conducted using the point localization and 2-point threshold principle in order to find out the most suitable place to wear the A.A.A.

Point localisation is the ability to locate a point on the skin that is being stimulated and the 2-point threshold is the distance between two stimuli at which both stimuli are felt as one. Conducting an experiment which involved point localisation was paramount in order to see if our results would match that of literature [7]. The results were also important because they would suggest onto which part of the body, if any at all the device should be placed on based on high sensitivity in that area.

The experiment that was carried out had 4 participants, 2 males, and 2 females each giving explicit consent on willingness to participate in the experiment. Each participant was told that a set of body parts (calf, back, shoulder, upper arm, forearm, palm, and finger) would be tested. All test participants were blindfolded and then chopsticks were pressed against each body part previously mentioned alternating between 1 chopstick and 2 chopsticks. The participants had to identify if they are being poked by 1 stick or 2. When 2 chopsticks were

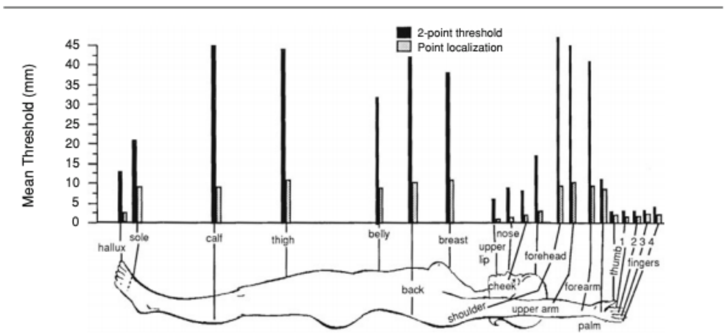


Figure 26: Haptic feedback graph from a "Haptic Percetion:A Turorial" [7], which shows which parts of the body are more sensitive based on their mean 2-point threshold shown in black and mean point localisation threshold, shown in grey.

used they had to be kept at a certain predefined distance. If a participant was almost always correct, when the two chopsticks were used, the distance between the chopsticks was decreased and vice versa (TU/e provided experiments on canvas, 2016).

The results of Figure 25 are closely linked to that of the results provided by scientific literature, shown in 26 with slight anomalies this which could be due to the design of the experiment in which a lot of the distances were not measured very precisely. Moreover, due to a smaller sample size it better to rely on the literature as a larger sample was taken for the experiments described in "Haptic Perception: A Tutorial" paper [7]. All in all, the results of the experiments that were carried out were insightful and allowed for a better design to be developed.

After all the above mentioned research was completed, it was concluded that different body parts are able to sense stimuli at different rates. This is likely due to the distribution of nerves and the overall structure of the skin. This realization allowed the team to optimize where the vibration should be felt and how effective these vibrations would be. Conclusively, the more sensitive the area of the body is, the more effective the haptic feedback function becomes. In theory, the haptic function should be an effective secondary function for the hearing impaired, but the scientific literature suggests that when vision is involved in perceiving the environment haptic sensing is a lot less effective in comparison to vision. Hence, this lead us to making the haptic motor secondary to the LED matrix in order to fit our target demographic.

11.4 CAD Design

To help throughout this sketching process and to produce the casing in a 3-D form, the CAD software NX-12 was used. The modules and tutorials given on Canvas were very helpful but also very complicated to fully understand for an amateur. Understanding of the concepts and all the functionalities was important to get started and was done in order to create a 3-D printed model. These topics took time to understand and required continuous revision.

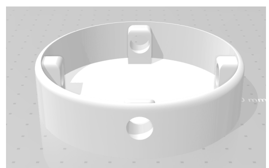
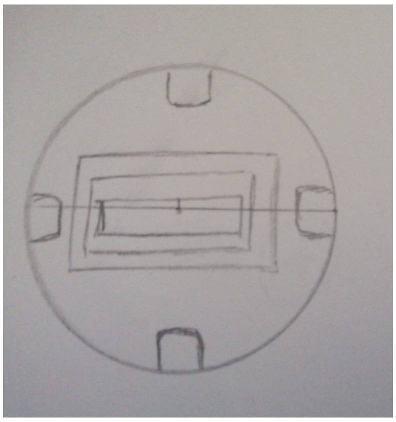


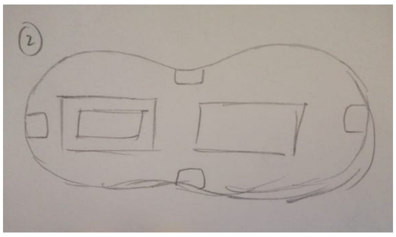
Figure 27: First CAD design

Further, it was decided to create a test casing in order to test how the microphone sensors can be fitted and which fitting would result in the sound being captured in the most optimal way for deriving the direction the sound came from. Experimentation with different shapes such as a rectangle, a square and a cylinder was done. Working on the test case helped to give a feel of the software and how to work around the options to achieve what is needed.
After discussion, it was decided to make a cylindrical test case to test and fit the microphones with the correct dimensions put in. After experimentation with different shapes, cylindrical seemed the most viable even though it was the biggest. The team wanted to see how the microphones and the electronics would fit and then further modify the case. Holes for the microphones were designed for the first case, which was used to fit them in easily and test the circuit. This was just a test design on which further iterations and work needs to be done to create a better casing which would be smaller and could still fit all the components inside with less space lost.

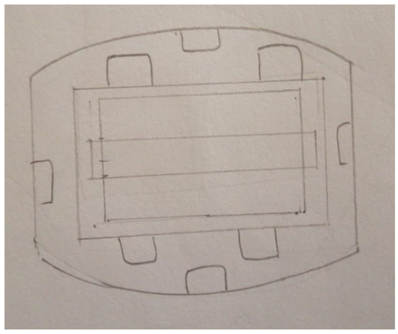
After the first casing was printed to test if the microphones would fit, further assembly of the circuit was done to make the circuit as compact as possible. After this, the positioning of each component was known and it



(a)



(b)



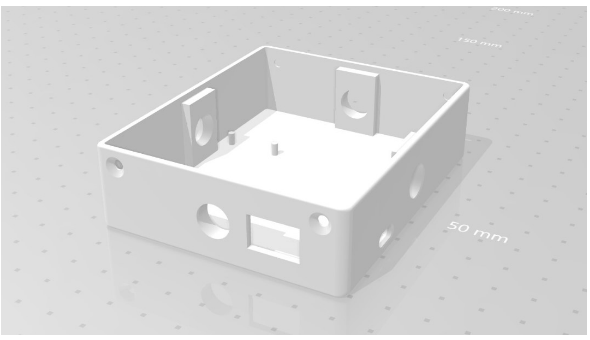
(c)

Figure 28: Sketches of different CAD designs. First CAD design is the most left one and the most recent is the most right one.

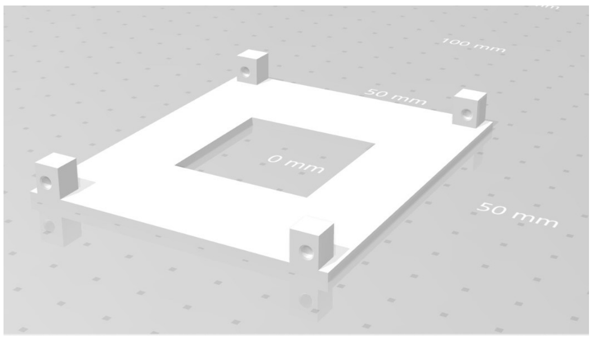
was easier to design the 2^{nd} casing. The 2^{nd} casing took more time than estimated since it consisted of quite a few extrusions and holes. There were holes for the microphones, the vibration motor, the on/off switch, and the USB port for the charging module. The printing of this case took more than 6 hours due to its complex and large design. After assembling the circuit into the casing, it was observed that some changes had to be made in the positioning of the holes since certain components of the circuit were not fitting in properly. To elaborate further on these changes, the dimensions of the on/off hole and how it was positioned had to be changed. Further,the screw holes were not aligned correctly which would not allow the lid to be screwed on top of the casing tightly. In addition to this the positioning of the USB port had to altered as well for better compactness of all components. These changes were implemented in the next CAD design.

After the final casing was printed, the assembled circuit was placed to test the fit inside the casing. The next step was to design and print the lid for the casing. The design for the lid went through several stages of design due to the faults in the design. These faults were dimensions of the blocks on which the screw holes would be for the lid was confusing to decipher and re-create exactly so they align, due to which it had to be corrected a few times. After the lid was designed the whole circuit was assembled inside and the lid was screwed on top of the main casing to secure it. The final casing CAD design can be seen in Figure 29a and 29b.

The process of CAD design took place mainly in the last 4 weeks of the project. At first, a lot of research was done and then, as described above, multiple prototypes were printed. This process of creating and modifying the design of the casing helped the team to get the final product to the smallest dimensions possible as well as making it look good. A lot of new skills were learnt about CAD design during the manufacturing stage of the project.



(a) The main body



(b) The lid of the casing

Figure 29: Final CAD design casing

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A Appendices

Final code

Listing 1: EngineeringDesign.ino

```
#include "LedControl.h"  /*including the necessary library for the LED Matrix*/
const int sampletime=50;
const int ledtime =500;/*The is the sampling time for which readings will be taken by the mics
    and processed to calculate the amplitude of the sound being received*/
const float threshold=0.3; /*This is the thresold for the difference between the max amplitudes
     and the amplitude of the adjacent mics*/
const float threshold2=1;/*This is the threshold below which the whole device is inactive*/
unsigned long int v=0; /*This is the global iterator which is used to set the aroows for nearly
     2 seconds even after the sound has stopped*/
LedControl lc=LedControl(2,4,3,1);
const int hapticpin =10 ;
class sensor{       /* a class which is basically like a custom data type has been initialised
    called sensor.*/
  public:
    int pin;          /*first attribute is an integer called pin which is the pin number to
    which a given microphone is attached*/
    float amplitude; /*second attribute is an floating point number called amplitude which is
    the amplitude of the sound that is being received by the microphone at any given instant
    its continuously updated in the main code as mentioned below*/

    sensor(int pin1, float amplitude1) { /*this is constructor initialisation that just makes
    the process of initialising an object (instance of a class) and setting the attributes
    extremely efficient*/
      pin =pin1;
      amplitude=amplitude1;
    }
};

sensor mic1(A3,0),mic2(A1,0),mic3(A0,0),mic4(A5,0); /* Initialising 4 objects one for each
    sonud sensor (mic) and setting the value of pin and the amplitude to the expected values.
    They are constructed as global variables to prevent any 'out of scope' issue*/

```

```
void setup() {

pinMode(mic1.pin,INPUT); /*Setting the pinModes to tell the arduino if a particular pin is being used as INPUT or OUTPUT*/
pinMode(mic2.pin,INPUT);
pinMode(mic3.pin,INPUT);
pinMode(mic4.pin,INPUT);
pinMode(hapticpin,OUTPUT);
lc.shutdown(0,false); /*This acts like a wake up call for the ledmatrix*/
lc.setIntensity(0,4); /*This sets the intensity of the LEDs on the matrix*/
lc.clearDisplay(0);  /*Clears the display*/
}


void getamplitude(sensor *mic1,sensor *mic2,sensor *mic3,sensor *mic4) /*This function is used to get the amplitude of the sound from each sensor*/
{
int i;
  unsigned long int millispresent=millis(); /*millis() function returns the number of milliseconds for which the code has been running*/
  float maxval1=1.65;  /*Initally all the maxvals and minvals are set to 1.65. This is because it was experimentally observed that when no sound was being received by the microphones the voltage output of the sensors was a steaady 1.65 (the average of the max (3.3V) and min (0 V)). Thus these values are initially set to 1.65*/

  float maxval2=1.65;
  float maxval3=1.65;
  float maxval4=1.65;
  float minval1=1.65;
  float minval2=1.65;
  float minval3=1.65;
  float minval4=1.65;
  unsigned long int x=millis();
  while(millispresent+sampletime>x)   /*This loop iterates for the sample time defined above and continuously takes readings*/
  {
    float a = analogRead(mic1->pin)*5.0/1023;
    float b = analogRead(mic2->pin)*5.0/1023;
    float c = analogRead(mic3->pin)*5.0/1023;
    float d = analogRead(mic4->pin)*5.0/1023;
    if(a>maxval1)                          /*Over a single sampletime the maxvals and minvals are calculated*/
    {
      maxval1=a;
    }
    if(a<minval1)
    {
      minval1=a;
    }
    if(b>maxval2)
    {
      maxval2=b;
    }
    if(b<minval2)
    {
      minval2=b;
    }
    if(c>maxval3)
    {
      maxval3=c;
    }
    if(c<minval3)
    {
      minval3=c;
    }
    if(d>maxval4)
    {
      maxval4=d;
    }
    if(d<minval4)
    {
      minval4=d;
    }
     x=millis();
```

```
  }

  mic1->amplitude=maxval1-minval1;     /*The amplitude is updated using the pointers for all the
     4 objects*/
  mic2->amplitude=maxval2-minval2;
  mic3->amplitude=maxval3-minval3;
  mic4->amplitude=maxval4-minval4;
}

void front()    /*This produces an arrow on the LED matrix facing forward*/
{
  lc.clearDisplay(0);
  int i,j,k;
  for(j=0;j<8;j++)
  {
    lc.setLed(0,3,j,true);
    lc.setLed(0,4,j,true);
  }
   j=4;
   k=6;
  for(i=0;i<3;i++)
  {
      lc.setLed(0,i,j,true);
      lc.setLed(0,i+5,k,true);
      j++;
      k--;
  }
}

void left()  /*This produces an arrow on the LED matrix facing left*/
{
  lc.clearDisplay(0);
 int i,j,k;
  for(j=0;j<8;j++)
  {
    lc.setLed(0,j,3,true);
    lc.setLed(0,j,4,true);
  }
   j=4;
   k=3;
  for(i=0;i<4;i++)
  {
      lc.setLed(0,i,j,true);
      lc.setLed(0,i,k,true);
      j++;
      k--;
  }
}

void right()  /*This produces an arrow on the LED matrix facing right*/
{
  lc.clearDisplay(0);
int i,j,k;
  for(j=0;j<8;j++)
  {
    lc.setLed(0,j,3,true);
    lc.setLed(0,j,4,true);
  }
   j=7;
   k=0;
  for(i=4;i<8;i++)
  {
      lc.setLed(0,i,j,true);
      lc.setLed(0,i,k,true);
      j--;
      k++;
  }
}

void back()  /*This produces an arrow on the LED matrix facing backward*/
{
  lc.clearDisplay(0);
 int i,j,k;
  for(j=0;j<8;j++)
```

```
  {
    lc.setLed(0,3,j,true);
    lc.setLed(0,4,j,true);
  }
   i=3;
   k=4;
  for(j=0;j<5;j++)
  {
      lc.setLed(0,i,j,true);
      lc.setLed(0,k,j,true);
      i--;
      k++;
  }
}
/*The function below is used to produce an arrow in any of the intermediate positions. This function takes in two arguments (i,j) which are the coordinates of the of the tip of the arrow. So for instance if an arow needs to be constructed pointing diagonally to the right the function call will be as follows: middle(7,7) (not 8 beacuse the indices start from 0 and not 1 so since there are eight LEDs in each row and column, the indices range from 0 to 7)*/
void middle(int i,int j)
{
  lc.clearDisplay(0);
  int a,b;
  if((i==0&&j==0)||(i==7&&j==7))
  {
    for(a=0;a<8;a++)
    {
      lc.setLed(0,a,a,true);
    }
    if(i==0)
    {
      for(b=0;b<4;b++)
      {
        lc.setLed(0,i,b,true);
      }
      for(a=0;a<4;a++)
      {
        lc.setLed(0,a,0,true);
      }
    }
     else
    {
      for(b=4;b<8;b++)
      {
        lc.setLed(0,7,b,true);
      }
      for(a=4;a<8;a++)
      {
        lc.setLed(0,a,7,true);
      }
    }
  }
  else
  {
     if(i==0)
    {
      for(i=0;i<4;i++)
      {
        lc.setLed(0,i,7,true);
      }
      for(b=7;b>3;b--)
      {
        lc.setLed(0,0,b,true);
      }
    }
     else
    {
      for(b=3;b>=0;b--)
      {
        lc.setLed(0,7,b,true);
      }
      for(a=4;a<8;a++)
      {
```

```
          lc.setLed(0,a,0,true);
        }
      }
      b=7;
      for(a=0;a<8;a++)
      {
        lc.setLed(0,a,b,true);
        b--;
      }
    }
}

void lightall() /*light everything*/
{
      lc.clearDisplay(0);
    int i=0,j=0;
    for(i=0;i<8;i++)
    {
      for(j=0;j<8;j++)
      {
        lc.setLed(0,i,j,true);
      }
    }
}

void ledmatrix(sensor *main,sensor*after,sensor*before,int a,int b, int c ,int d) /*This the function responsible to deploy the respetive arrows*/
{
  float diff1 = main->amplitude-after->amplitude;
  float diff2 = main->amplitude-before->amplitude;
  if(diff1<threshold &&diff2 <threshold)
  {
   lightall();
  }
  else if(diff1<threshold&&diff2>threshold)
  {
      middle(a,b);
   }
  else if(diff1>threshold&&diff2<threshold)
  {
      middle(c,d);
   }
  else
  {
   if(main==&mic1)
   {
      front();
   }
   if(main==&mic2)
   {
      left();
   }
   if(main==&mic3)
   {
      back();
   }
   if(main==&mic4)
   {
      right();
   }
   }
}

void haptic() /*This function produced three pulses of buzzes*/
{
    analogWrite(hapticpin,127);
    delay(400);
    analogWrite(hapticpin,0);
    delay(100);
    analogWrite(hapticpin,127);
    delay(400);
    analogWrite(hapticpin,0);
    delay(100);
    analogWrite(hapticpin,127);
```

```
  delay(400);
  analogWrite(hapticpin,0);
  delay(750);
}

void maxamp(sensor *mic1,sensor *mic2,sensor *mic3,sensor *mic4) /*To find the mics with the
    max amplitudes and get the differnece of the maxamp and the amplitude of the adjacent mics
    */
{
  sensor *arr[4]={mic1,mic2,mic3,mic4};
  int i;
  sensor *j;
  j=arr[0];
  float maxamp=arr[0]->amplitude;
  for(i=1;i<4;i++)
  {
    if(arr[i]->amplitude>maxamp)
    {
      j=arr[i];
      maxamp=arr[i]->amplitude;
    }
  }
if(j->amplitude>threshold2)
{
if(j==mic1)
{
 ledmatrix(j,mic2,mic4,0,7,7,7);
}
if(j==mic2)
{
 ledmatrix(j,mic3,mic1,0,0,0,7);
}
if(j==mic3)
{
 ledmatrix(j,mic4,mic2,7,0,0,0);
}
if(j==mic4)
{
 ledmatrix(j,mic1,mic3,7,7,7,0);
}
v=0;
lightall();
v=0;
}
if(j->amplitude>3.25)
{
 haptic();
}
else
{
 v++;
}
if(v==40)
{
  lc.clearDisplay(0);
  analogWrite(hapticpin,0);
  v=0;
}
}

void loop() {

getamplitude(&mic1,&mic2,&mic3,&mic4);
maxamp(&mic1,&mic2,&mic3,&mic4);

}
```