HomeVoice

Final report Engineering Design (4WBB0)

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1 Group effectiveness

Team 254 consists of a group of very different people, all with different backgrounds and majors. While this difference might have caused trouble in other groups, it was exactly what made this group so effective. During the first meeting we all thought the same thing: the combination of this team and its majors is exactly what you need to build a dream team for an engineering design project. We had an industrial engineer, a data scientist, an electrical engineer, an industrial designer, a biomedical engineer and an applied physicist . With the different nuances in skills that each major provides combined with the individual skills of the group members we were able to work together like a well oiled machine.

Over the span of this course, the qualities which were useful for that phase of the project alternated a lot. Some people are more compatible with the conceiving phase of a design, while others shined more during the technical phase of the project in a later stage. To make the best use of these strengths and to compensate for the weaknesses of the group, we divided the tasks so that everyone was able to do an equal amount of work, like doing some tasks that need to be done or looking up things that help in the design process or supporting the group member who has the biggest strength in that part of the project.

As a group we quickly created an atmosphere where everyone felt confident to speak their mind. This greatly affected the discussions as everyone could contribute and let us in on his own unique insights. Due to this comfortable and safe environment we inhibited the bazooka effect during brainstorm sessions. That is to shoot ideas down, point out every flaw right after the idea is mentioned. The lack of this effect greatly improved our brainstorm sessions. The industrial engineer of our group had taken multiple courses regarding innovation with emphasis on the fuzzy front end of innovation. His experience lead us to think deeper about the preliminary concepts. At first ideas did not need to be feasible, since it is good to let as much out and let others possible take minor parts of your idea to come up with their own. Throughout the project we kept this comfortable and open atmosphere.

However, this comfortable atmosphere did not mean that the group members were not encouraged with challenging each others' ideas, as designs were often fleshed out on the spot, which made the flaws apparent. This made us deeply think about the concept and made for a well thought out plan which deterred us from encountering major issues later in the project.

Figure 1: Photo of group 254

The industrial designer of the group really provided the last push in fleshing the concepts out by making multiple designs for different concepts and making new adjustments as the concept changed and needed new specifications. This greatly contributed to the group's motivation to work on the project, because looking at a 3D design instead of just talking about it made the discussions much less abstract and helped with envisioning the functionalities.

It also helped on getting everyone on the same page regarding what the actual device will be and, of course, what will it look like.

A minor drawback of the previously stated open atmosphere was that it often created a lack of structure. We were prone to trail off and discuss other points that were not yet on the agenda and, as a result, we did not have enough time to discuss everything that we wanted.

After about 1 to 2 weeks we overcame this drawback by keeping in touch with each other outside of the meetings. This meant that we could finish our discourses and have a solid understanding of where we stood and what needed to be done. Furthermore, some group members came together before the actual meeting. During these pre-meetings a multitude of more minor subjects would be discussed. This led to the meetings gaining more structure, since we would trail off less.

As previously stated, our biggest weakness was a lack of structure. This was partly due to the fact that it was not quite clear for us at the beginning how the project would unfold. We slowly gained this grasp in the first two weeks, but by then we were already behind according to the canvas schedule. Due to this lagging behind we partly lost sight of the canvas planning specifics with its objectives. We went our own way and decided what to do according to our own minds. For the project as a whole this worked quite well, though for the midterm presentation there were some surprises. We had to, for example, rank our functionalities according to the MoSCoW method. Having figured out ourselves that we needed to write these functionalities it was a small adjustment to rank them according to the MoSCoW method. Similar surprises were equally trivial and we overcame these challenges fine, but in hindsight we should have been better prepared for them. The week before the intermediate deadline we should had let the canvas page guide us more.

As briefly mentioned before, letting go of the canvas planning also led to a strength. We thoroughly discussed where we stood and what needed to be done to achieve the end goal, providing a device that would satisfy our design goal. In this way, we already looked ahead instead of just following the weekly canvas planning. We had a clear birds eye view of each step that needed to be completed. After gaining this overview we set out to work, by delegating tasks accompanied with deadlines for each task. Everyone was involved in the project and knew what everybody was doing.

This leads into our next strength: (online) communication. In the beginning of the project communication outside of the meetings was minimal, but after a few weeks there was a steady increase in communication outside of the meetings.

In the last few weeks we encountered some hiccoughs. After the intermediate presentation we were ahead of schedule and thought ourselves to be in fine shape. This mindset lured us into a false sense of security. Now we needed to work on the physical device and this meant that is was made much more difficult to work in parallel. First, we needed to find out what parts were needed, thereafter they needed to be bought, assembled, coded, put into the frame and finally tested in order to make a few adjustments. We should had foreseen that this serial working would prove to be challenging, but due to us being ahead on schedule before we managed.

After the intermediate presentation we needed to figure out what the exact parts of the device should be, and then buy and assemble them together. This is where our electrical engineer was of great use as his skills and experience meant that he could make the circuit and the actual physical and functional parts of the device. This was of course of tremendous value to the group, as were the data scientist and the applied physicist which together made the code that gave the device its function. Is was challenging at first but they managed it.

2 Design goal

Deafness and hearing loss is a problem that many people have to deal with in their lives. According to research, about 15-26% of people are affected by hearing loss. For this design, we want to focus on individuals with profound deafness, with onset before language has been established. This group exists of about 0.07% of the population. This might not seem like a lot, but in the end, it comes down to a large group of people.

The purpose of this design is to make deaf people feel more comfortable and make them more aware in their own homes. Like most other people, deaf people also spend a considerable amount of time at home. We think home as a place where everyone should feel safe and pleasant.

As for our group, we chose deafness as an impairment because it is a relatively common problem. Some of our group members have people close to them who are deaf or whose hearing capabilities have deteriorated over the years. Furthermore, there were some individual concerns from group members that hard hearing at an early age may also come due to the extent of loud noises that people get exposed to on a regular basis, which represented an additional reason to think about this group of people in particular. It also helped us to put ourselves in the shoes of deaf people, which made us more motivated to help and think of better solutions.

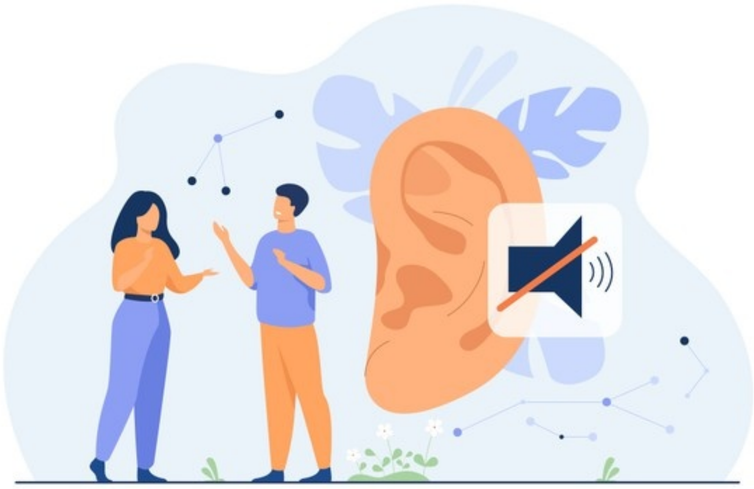

Figure 2: Picture from `www.freepik.com`

Extensive research on the subject has been done by all of the group members and it was found that there are not a lot of aides for deaf people which help them with multiple functions. For example, there are aides that help alert deaf people in case of a fire or an alarm clock which is designed to wake up deaf people through light or vibrations.

That is another reason why we thought there should be an aid that helps deaf people gain some more general awareness, helping them throughout the day. We want deaf people to feel more included and aware of their surroundings. To this end we wanted to mitigate the effect that hearing loss causes. This would be done by turning sound into visual aides, to which a deaf person could react. These visual aides would convey information to the deaf person. Namely, that there is something that makes a sound and might require the attention of the deaf person, think about a microwave or a doorbell. A key aspect of this is the direction of where the sound is coming from, otherwise it is not clear where the attention of the deaf person is needed and would therefore make the device less adequate. To pass on more information, the visual aides come in multiple colors. These could indicate the strength of the sound and thus possibly the importance of getting the deaf person's attention, the color scale will be instinctive and therefore easy to use for everyone.

Multiple members of our team know family members with impaired hearing. When visiting them in their own house, it is easy to notice that the person does not feel included in the group or the conversation. Not being able to properly hear what is being discussed in the room makes the person with impaired hearing practically give up on trying to be involved in the conversation, which is sad to notice as the goal of the visit is to be with that person in most cases. This comes to show that it was not difficult for our team to relate to the problems people with bad or no hearing at all might face.

According to studies [2], living with deafness can take a huge toll on people's mental strength. Whether you are born deaf or get it at a later stage of your life. Being deaf can make people feel quite powerless or left out in certain situations. It turns out that deaf people generally score higher on mental problems like depression, paranoia, insomnia and interpersonal sensitivity than the general population. Causes for this could be factors like having a difficult time communicating with people, having a lower self-esteem and for people who have grown deaf over the years, it might be difficult to accept their hearing loss. It is harder for deaf people to get any help with these problems, due to communication issues. As well as it might cause difficulties for the diagnosis of deaf people, because sometimes a verbal commentary is necessary, like for example the diagnosis of schizophrenia. Deafness is also associated with large heterogeneity in emotional, cognitive and social development. This is mainly caused by the problems that deaf people face. Examples are that education comes with many difficulties for deaf people, as well as the attitude of society towards deaf people which might cause them to feel left out. On top of that there are not a lot of people who know sign language and can therefore hardly communicate with deaf people.

However, deaf people are not alone. In the past few years deaf people are starting to develop a certain group strength. The deaf community begins to take more action in defining that they do not want to be seen as a handicapped group, but more like members of non-dominant cultural and linguistic groups. Through the use of sign language, they are able to have a strong sense of group solidarity [4].

This all comes to show that the life of deaf people is not at all easy, and that is all the more reason why we wanted to assist this group by creating our device. To help them as much as possible we did not want to help them with a specific activity, but we want to make an innovative design that can help them throughout the whole day with all kinds of problems. We wanted them to feel more included in everyday life. A device like this could cause a lot of joy for deaf people. We are convinced that our team is up for the task as we have multiple strengths that can realize this design and make it a desirable product for deaf people.

3 Functional design and solutions

Some functions are crucial in making the aid useful to the users. Without these, the aid would provide little to no use to deaf people. As such, these crucial functions fall under the category of "must haves".

The first step in giving function to the device is making it able to detect sound and detect the different directions where the sound comes from. This, in part, can be done by using:

- Multiple sound sensors

Furthermore, the device must be able to deliver a noticeable response to the user. This response should, to some extent, be related to the intensity of the sound so that extra information can be conveyed. All this means that a user should be easily aware whether the aid is notifying the user and, to a minimal extent, know what the nature of the sound is. It should be the equivalent of someone calling your name. Possible solutions for this function are:

- Light indication
- Very low frequency sound (bass)
- Large Movements
- Color changing
- On body vibration

Only notifying the user that there is a sound is inadequate, as it may cause unnecessary panic and stress. The aid must also be able to communicate the direction of the sound. In this way the user would know where he/she should turn their attention to. This could be achieved by;

- Having multiple light sources
- Having multiple vibration sources
- A pointer (e.g. arrow)
- The change of color

Moreover, there are also some functions that will really help this device to be more useful and help a deaf person to gain more awareness of their surrounding, all of them falling in the category of "should haves".

An aid that is hard to use, uncomfortable or ugly will lead to the user finding the aid less attractive and thus would result in less usage time. This would not be ideal and, therefore, the aid should be user friendly. User-friendliness could be achieved by;

- The aid being aesthetically pleasing
- The aid having a long lifetime
- Being compact
- Intuitive usage and signal processing
- Being comfortable (if it is a wearable device)
- Noticeable response intensity adjustment
- Being operational 24/7

- Being autonomous
- Requiring little to no maintenance

Some functions are ideal for the device but, because of their complexity or prices, are not likely to be added into the final project. All of those ideas are grouped in a “could haves” section.

Being able to integrate more at home technology will lead to greater utility and ease of use. To this extent connectivity of the aid to other devices could be achieved via:

- Bluetooth connection
- Wired connection

Further features or non-necessary functions could almost always be added to a device. These extra functions do not contribute to the main function of the device, but could still prove useful to the users. The solutions to these miscellaneous functions could be;

- A clock
- Being portable

Other features could always be added to the aid, but some won’t make the cut. These are solutions to features that the aid won’t have;

- A screen
- Customized settings

Summarizing, the aid will be placed in a room or worn by the user. It will detect sound and also the direction of where it is coming from. Thereafter it will notify the user that a sound was made and to some extent the loudness of the sound. After this distinct notification the user could turn their attention to the sound direction. Making them more aware of their surroundings and hopefully letting them feel more included.

4 Design concepts

There are many ways to get the attention of ordinary people. One could wave at them, tap their shoulder or call out their name. However, this is not the case for all people as notifying a deaf person requires more effort and creativeness. To overcome this problem, several design concepts were considered for the aid in the initial phase.

4.1 Bass based aid

When thinking about ways to alert a deaf person, the main senses that are worth triggering are sight and touch, as taste and smell would not be feasible and would probably make the user feel uncomfortable.

One of the ideas proposed during one of the early brainstorming sessions was to trigger the deaf person’s sense of touch by having a speaker produce a bass. This bass would need to be able to reach the user and make them feel that the speaker is producing these vibrations.

This design can be realised in a couple of different manners. There could be a stationary device on a table for example, this device will have multiple sound sensors that can measure the direction and intensity of the sounds in the environment. This aid can then have a speaker installed with it that produces the vibrations. The design could also have multiple speakers connected to it that can be placed in the room. An advantage of using multiple speakers will be that the aid could also indicate the direction of the sound. However, a disadvantage is, of course, the budget and the feasibility of having multiple speakers that are connected.

In the end, the general disadvantages of this aid convinced our group to not choose to go through with this project. It is not feasible to work with the vibrations and making them strong enough for larger distances would prove almost impossible. On top of that, this design might not be too comfortable for the users as they are being overwhelmed by vibrations relatively often throughout the day.

4.2 Wearable aid

To reach the goal of the project, the group initially thought of an aid that would be used as a wearable by the deaf person. The concept would have been easy to understand: the user would wear a couple of sound sensors somewhere on the body. Those sound sensors would be connected to a wearable item, which would give off vibrations to notify the user of any sound nearby. This design would have been useful for the deaf person to use throughout the day, staying at home as well as going out of the house, as it would have been always in contact with them.

Of course, there are multiple designs that allow for the implementation this idea. First, the sound sensors would need to be placed somewhere they can clearly measure sounds, such as next to the ears, in the form of earbuds, headphones or anything similar. Other places that could work are the wrists, with a design similar to a bracelet or a watch. Lastly, a belt could also work for sound sensors to be installed upon. However, it might be inconvenient in some situations as, for instance, during the winter when people are wearing warmer clothes. In that case, the sensors might be covered up too easily and become redundant. The same problem also applies to the bracelet and the watch.

The second part of this design would be the item that should notify the user of any nearby sounds through vibrations. For this, it is important that the emitter is in direct contact to the user, as the user needs to feel the vibrations in order to interact with the device. This could be, practically, anywhere on the body (e.g. a bracelet around the wrist or ankle, a belt, a necklace or even a kind of vest that can be worn underneath the clothing). The number of designs possible for this aid are equal to the number of combinations of the sound sensor location and the vibrating system location. In the end, the design which was thought to be the best was the earpiece for sound measurement. These earpieces would then be connected to a belt, where the rest of the system would be placed, including the battery, the Arduino, the vibrating motors and the rest of the components.

However, the problem with this design would be the wires which are required to connect the earpieces with the belt. This would not be, of course, comfortable for the user as they will have limited mobility, nor will it make for an elegant design. Moreover, this would not have been an isolated problem for this design only as the aid would have to store a lot of components in order to work, so the only option is to install those components on a larger wearable that cannot be placed in the ears or the wrist. As an effect, the aid would have to be wired between two devices. Because of all of these drawbacks, the ideas was scraped.

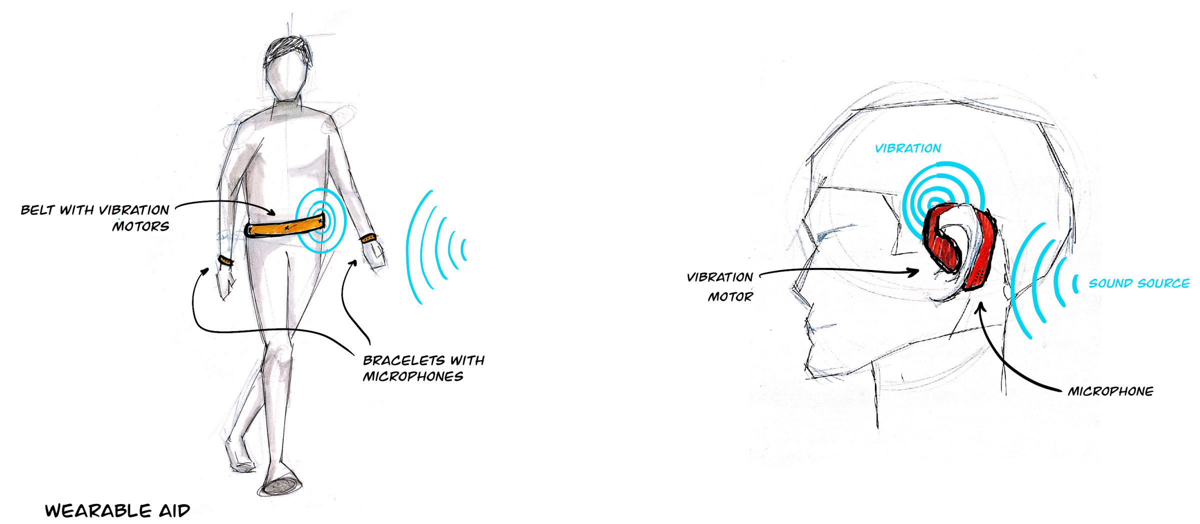

Figure 3: Early designs of the wearable aid for deaf people

4.3 Stationary aid

Before the group chose the idea that became the final design, other prototypes were evaluated as well. One device, for example, records sound from around itself by using several sound sensor and then gives a signal to the user by showing the direction of this sound with an RGB LED strip. In addition to that, it also indicates the intensity of the sound by changing the color with an intuitive colour scale.

One of the designs we evaluated was a skeleton-like structure in the shape of a puck which would then be wrapped in plastic or rubber. The LED-ring would be placed inside this package and would then light up the entire aid, which would result in a signal that can be seen from every side of the aid independent of where the user may look from. However, because of the wrapping, this design would be prone to damage as the outside plastic would have to be thin and, as such, would provide little to no protection.

The group also considered making an entirely 3D printed shell that would have four directions on the top of the device. Each direction would have a scale for the sound intensity with LED-rings underneath, the scale looking similar to a WiFi icon. This would then intuitively indicate the sound intensity by extending the reach of the light when the volume of the sound increases. The user will then be able to easily see the direction and intensity of the sound. However, although this device would be easy to read when the scale and light is visible, it would become more difficult whenever the deaf person looks at the device from further away, it being the main reason why the design was not chosen. Moreover, it would also require more LED strips, which would be difficult to obtain considering our budget.

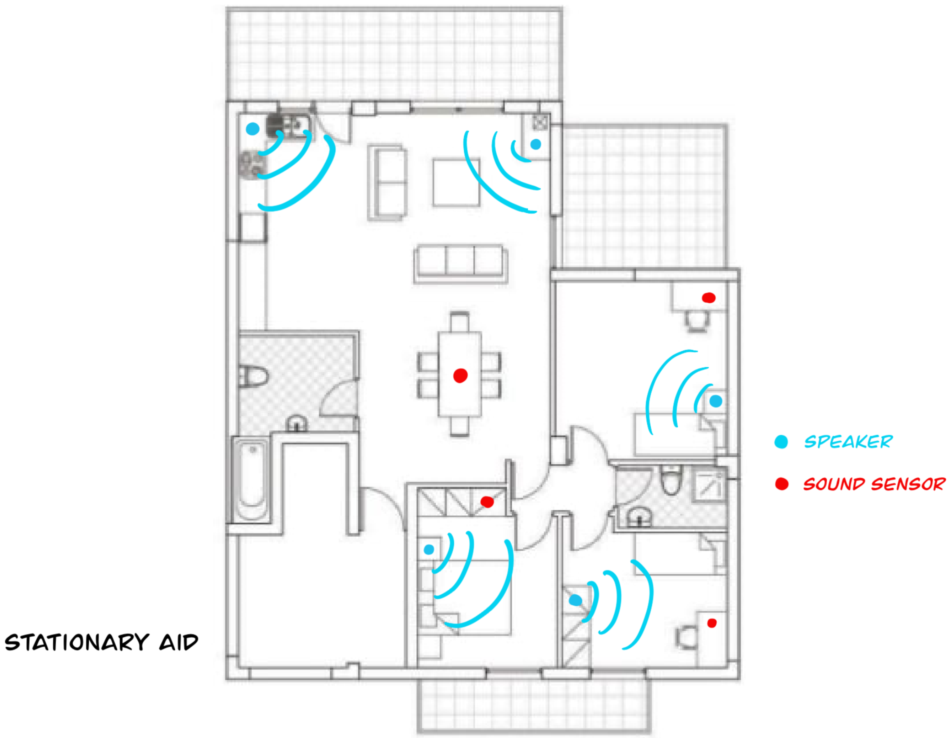

Figure 4: Concept of how a stationary aid would function in a normal household

5 Final design concept

Out of the three concepts, the group decided to continue with the stationary device that creates a lively home environment for deaf people.

In more detail, it is a device that detects the sounds in your house and points to their origin, making the user feel safe as they are more aware of their surroundings. To accomplish this, the device uses an array of sensors in order to determine the accurate position of the sound origin, while also distinguishing between different intensities. It makes use of an LED ring that encompasses the device 360 degrees, part of which lights up in order to guide the user towards the sound. By reacting to sound, and not specific signals, it is able to work with technologies that are already part of the household, unlike the already existing counterparts, which force you to replace preinstalled devices.

The first step in designing the appearance of the device was to search existing, similar products in order to get inspired and avoid already made products. To the group's surprise, similar devices do not exist on the market right now. As such, there was a clear canvas to design and to experiment with any design we liked.

The idea for the design is a simple, flat, circular box-like object. This is because coming up with a simplistic design is better than trying to go for something extraordinary as it would be much more appealing to users and easier to adapt to different environments of different households.

The main aspects that were thought of as necessary to include in any design that we would make are that the device should be flat and the ring should be on the top. The device will lie on top of a table and the ring has to be completely visible from all angles, something that is only achieved with these aspects.

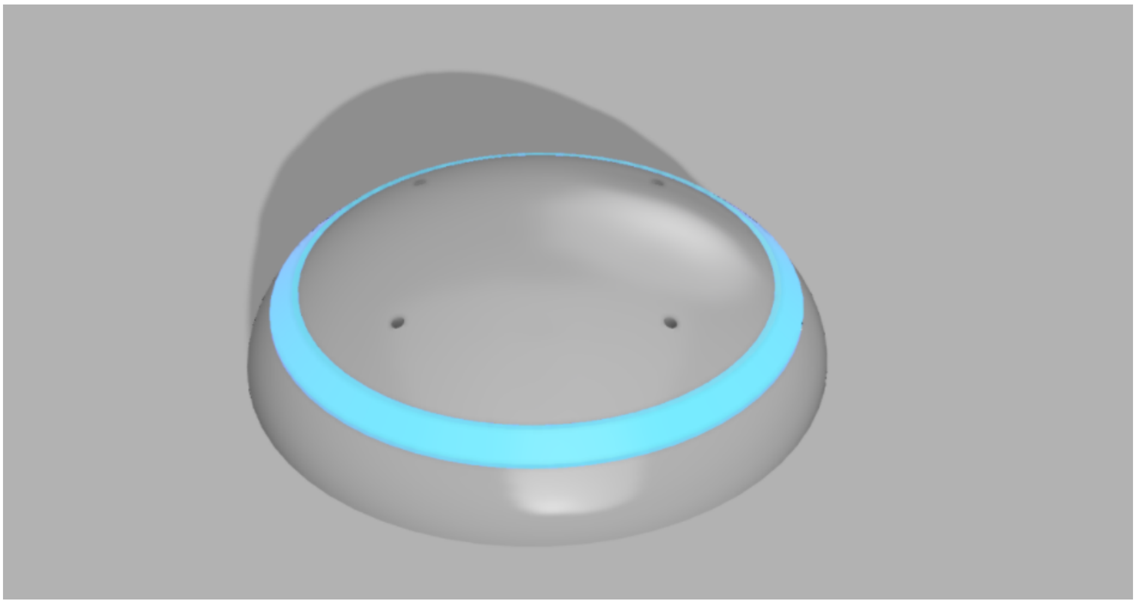

Figure 5: Concept render of the final design for the device

6 Technical specification

To recap, the idea that our team decided to go through with is a sound detector for deaf people that is able to read the intensity of the sound and guide the user towards its origin, notifying them accordingly.

When it comes to technical specifications, there were numerous ideas presented during the early meetings by all of the group members. As the product itself is not based on a complicated concept, we decided that the best way to make it stand out is by heavily working on the "features" side of the project. However, in order not to over-complicate the seemingly elegant concept, most of the features had to work with the already existing hardware, instead of relying on new parts. The intended functionalities at the start of the project can be seen in the table below, presented according to the MoSCoW prioritization method.

Table 1: Features of the device according to the MoSCoW prioritization method

Must have	Should have	Could have	Won't have
Sound intensity detection	The capacity to wake you up	Sound differentiation	A battery
A pleasant design	Noticeable LEDs during the day	Notifications	A screen
The ability to show the direction	The ability to show the direction precisely	Bluetooth connectivity for more devices	
Autonomy 24h a day	Ambient light detection		
Color coding			

From table 1, it becomes apparent that the list of functionalities is extensive and that the order in which they are displayed is different from the early concept. As such, there were numerous solutions needed in order to implement all of them, some of which were programming dependent.

To begin with, the sound intensity detection represented one of the main priorities, as the user needs to be informed about the nature of the detected sound in order to act accordingly. This functionality makes use of the fact that stronger sounds are generally used to notify the user of more urgent matters. As such, a sound detector that outputs a float variable (a real number), instead of a boolean one (true or false) was needed. Fortunately, the sound sensors on the market already had both properties, allowing the user to switch the output based on their needs, which meant that only a conversion formula was needed in order to create an easier to use scale (the dB scale for example). As such, when choosing the sensor, the sensitivity and the size were the main criteria used. The amount of users was also factored in as a sensor that is widely used has a larger documentation as well, helping with troubleshooting.

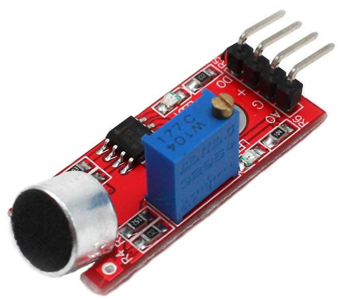

Figure 6: A widely used KY-037 sound sensor that has both an analog and a digital output

The color coding was another key aspect of the project that goes hand in hand with the sound intensity detection, as it provided the user with an easy to understand medium of communication that does not require the use of a manual. For this to be achieved, an RGB light source was required instead of a normal one. As such, an RGB LED strip was used in order to produce a large array of colors without using too many pins from the main board. The signal from the sound sensor can then be used in order light up the LED strip in the according color. When choosing the intended LED strip, the brightness was also taken into account as the LEDs should be ideally seen during daylight. Moreover, they should also be able to wake up the user during night time in case the fire alarm starts. Unfortunately, there is little information regarding the brightness of LEDs, and while the candela count can help, it is not of great use as the solid angle of the LEDs is not provided. However, most LED strips are advertised as being bright enough for every day use, so the best quality to price ratio was chosen.

A light detector should also be part of the setup, as this would allow for the LED brightness to match the outside light. During daytime the LEDs should work at full power continuously, unlike at night when low sound alerts should be dimmed off (the strong sound alerts will remain at full power).

The ability to show the origin of the sound was also a key part of our product, as it was something innovative and eye catching. However, for such a thing to happen, two previously mentioned criteria had to be changed. First, four sound detectors had to be used instead of one, which is what is considered the minimum amount of sound sensors required in order to pin point the position of the emitter. Second, the RGB LED strip must be individually addressable in order to allow for specific LEDs to light up instead of the whole strip. Also, in order to guide the user to the origin of the sound accurately, a high count of LEDs should be used so that each LED accounts for a smaller section of the room (36 LEDs would be the minimum value here as this would mean that one LED would account for 10 degrees).

Figure 7: An individually addressable IP20 RGB LED strip

As the product is intended for permanent use, a battery cannot be implemented as it would either need charging or replacing, both of which are not ideal as they mean that the device is off for a period of time. While charging could have been an alternative, a large amount of calculations, predictions and estimations were needed. As the components of the circuit were yet to be decided, it would have been far too risky to implement a battery. Moreover, the effects of draining the battery were also potentially dangerous as that would have increased the chance of misreadings and errors. As such, the device will be plugged in.

While not crucial, ideas such as Bluetooth connection, sound differentiation or notifications were also considered during the designing part, but were dropped off as they needed individual parts that were either too expensive or hard to implement. In the case of sound recognition, the computational power of the Arduino would not have been enough to handle the large amount of data and computations required to distinguish frequencies. In addition to that, special, more sophisticated microphones would have been needed in order to read sound frequencies, which would have been too big of a strain on the budget. On the other hand, the Bluetooth modules required the building of more devices in order to show its functions, which would not have been possible as it would have split our budget in half.

Last but not least, the design of the product had to be pleasant and minimalist in order to fit in every home.

All in all, we consider our device to be feasible overall, with a balanced amount of achievable features for the initial product and an even larger array of functionalities that can be further implemented in the future. This, in our opinion, combined with the pleasant looks, makes for a device worth having in one's household.

7 Detailing

As the device was mainly dependent on the individual components of the circuit, such as the sensors, there were not a lot of calculations needed for the completion of the final project. Nonetheless, there were some key areas that needed investigation before everything was complete.

First, for the sound position to work, there was a need of a barrier that would stop the sound reaching one sensor to affect the readings of the other. As such, not only had the design of the product to be pleasant and minimalist in order to fit in every home, but it also had to serve as a barrier for the sound. As such, a rounded box-like shape was chosen in order to block the sound coming from directions other than the one perpendicular to a sound sensor, decreasing the chance of all sound sensors outputting the same sound intensity value for the same sound. This was used as a measure of precaution, as the sensitivity of the sound sensors was unknown at the time.

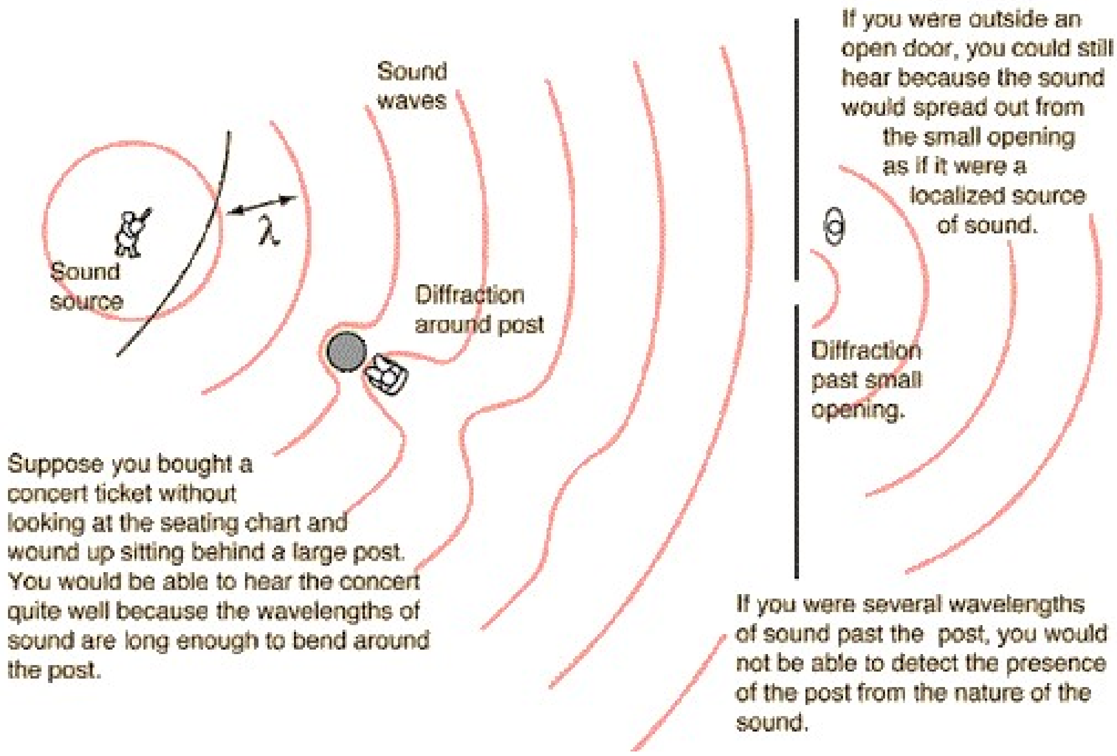

Figure 8: Explanatory image of how sounds reacts around objects; source: Hyperphysics

As can be seen in figure 8, while the presence of our box-shaped product would not be sensed by an individual, it would definitely be sensed by the sound sensors, as the sound would interact with the shape of the outer case, thus reaching the four sensors with different intensities. This however, only applies for sounds that have short wavelengths, while sounds with higher values (fire alarms for example) would not encounter difficulties to bend around the case, thus allowing for detection of specific noises that require the attention of the user. This is in addition to the fact that the sound sensors will face in different directions, which has other implications such as the fact that one sensor would detect the reflections of the sound heard on the other side.

As a result, when the 3D design of the device was made, it was mandatory for it to be encased (e.g. there was a proposal of having only the skeleton of the device for aesthetic reasons) and have a box-like shape.

Another aspect that needed attention was the number of LEDs used for the LED ring. While the idea that more LEDs meant a higher accuracy when pointing into the direction of the sound was self explanatory, there was no formula to tell us how many of them are enough. Thus, we decided to calculate the angle of the circle that each LED corresponds to by dividing the 360° of the circle to the number of LEDs. As such, we had a 12 (30° per LED), a 16 (22.5° per LED), a 24 (15° per LED), a 32 (11.25° per LED), a 40 (9° per LED), a 48 (7.5° per LED) and a 60 (6° per LED) LEDs option available on the market. While the ones below 40 were too small for our device with a diameter below 13 cm and provided poor results regarding the degrees per LEDs, the 60 LEDs one was too large with a radius of almost 20 cm. This would not have been a problem for the circuit, but for the 3D-printing, which was already very strict in the amount of hours allowed per print. As such, we decided to go with the 48 LEDs, which offered us a 7.5°coverage per LED.

Now that we knew the degrees per LED count, we needed to calculate the area of the room that each LED was corresponding to in order to find the precision of the direction in case we are able to show the direction without having predefined positions (that is, to have the direction as a continuous function). We considered the largest room diameter we believed to be possible in the average house, that being 6 meters, and we set the smaller limit to 3 meters. We then considered two cases, one in which the device was placed in the center of the room and one in which it was placed in the corner of the room. Because we did not want to over complicate the calculations, we assumed the room to circular with a diameter equal to the diagonal of the square. We then calculated the area of each room and we divided it by the LED count to see that area that each LED corresponds to. The results are presented below, together with a graph.

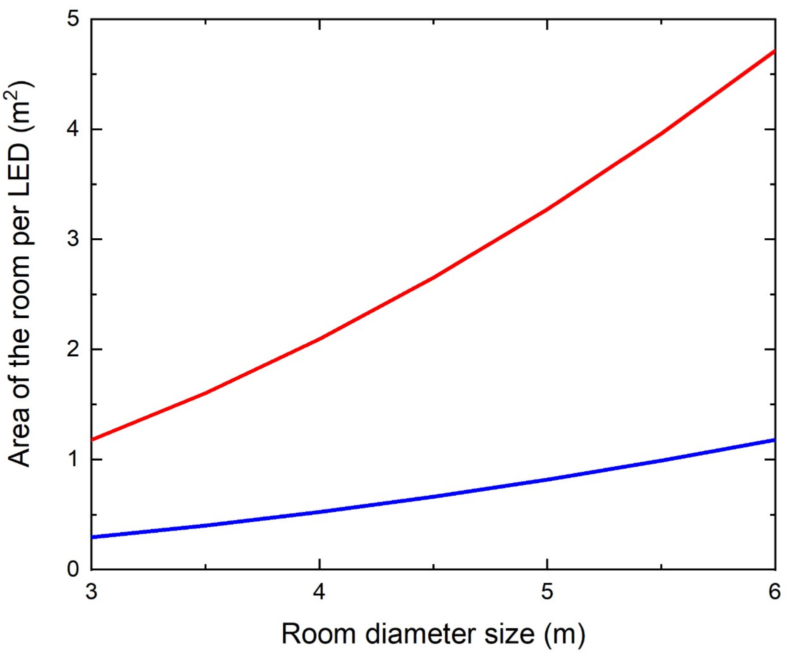

Figure 9: Graph displaying the area of the room that each LED corresponds to in terms of the room size; blue line represents the case in which the device is in the center of the room, red line represents the case in which the device is in the corner of the room

The main outcome of the graph is the fact that for a small room of 3 meters and when the device is placed in the middle of the room, the area of the room that one LED accounts for is around 0.3 m^2. Moreover, for larger rooms and when the detector is placed in the corner, the area assigned to each LED grows to more than 4 m^2. However, one has to take into account that the area of the room is approximated as one of a circle with radius equal to the diagonal, which is not the case in real life. This was done in order to monitor the worst case scenario, but in reality the results are far better than this and the area should never reach more than 3.5 m^2 if the room is treated as a square.

As such, we concluded that the 48 LEDs ring that was used in the project was the right one and that the results it provided to the user are above expectations, managing to achieve very good numbers. This is helpful, as it means that the user is unlikely to be confused when it comes to the direction that the LEDs are pointing towards, resulting and less stress and lowering the chance that the device causes the person to panic.

8 Realization

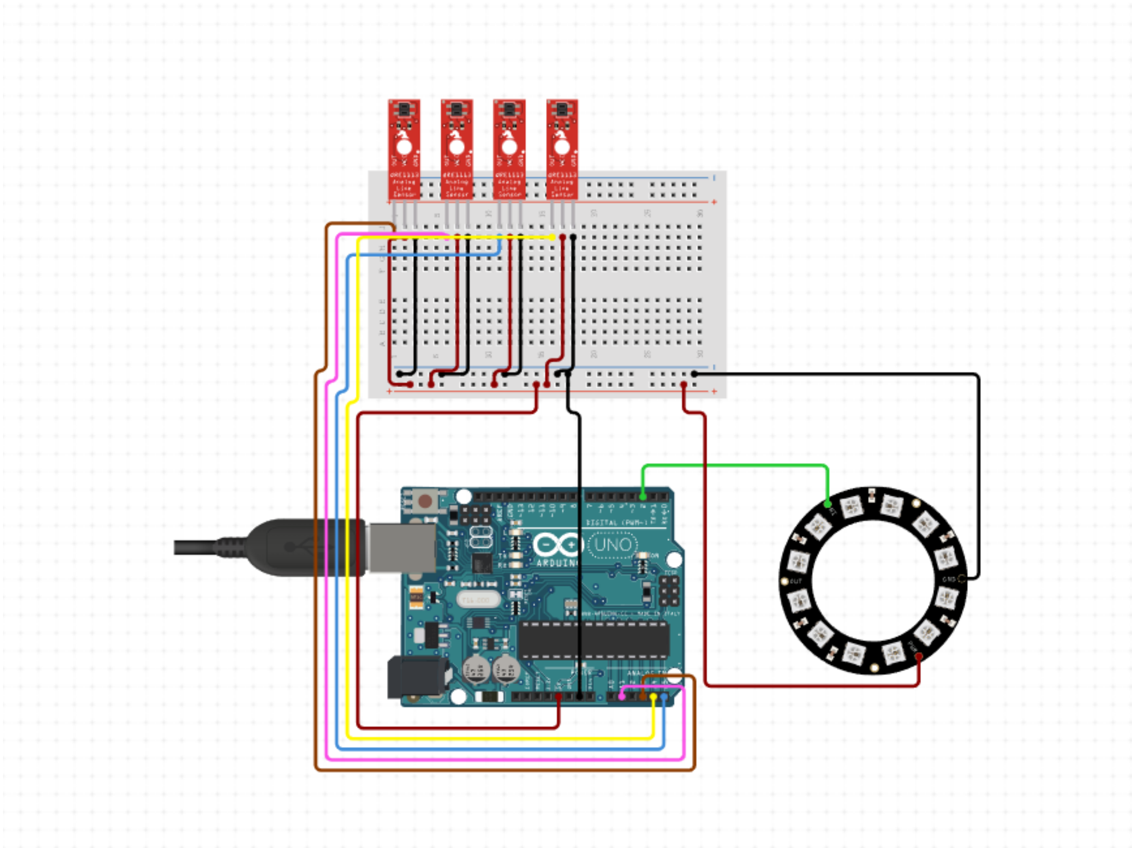

Figure 10: Blueprint of the circuit used for the device; the blue board represents an Arduino UNO, the red parts represent the KY-037 sound sensors, the black circle represents the SK6812 Digitale 5050 RGB LED Ring with 48 LEDs

Above, a picture of the blueprint used to make the circuit can be found, together with the names of the individual parts used. However, for explanatory reasons, the list of components used and reasoning behind them can also be found below:

- four KY-038 sound detector clone were chosen as they provided high sensitivity while also having a very large documentation available due to the widespread use. With a dimension of only 44 by 15 by 10 mm and a capacity to detect sounds from 50 Hz to 20 kHz, they provided the best performance and quality to cost ratio available;
- an SK6812 Digitale 5050 RGB LED Ring with 48 LEDs has been chosen as it offered good all around stats while having a circular shape and a high number of LEDs;
- a 25x12 breadboard as it provided the precise amount of pins that we needed;
- a 220 Ω resistance to make the LED ring output smoother and to protect it against burning;
- an Arduino UNO because of the number of analog pins, as each sound sensor needed an analog pin.

In addition to that, a 3D case has been designed in order to cover the circuit and protect it from external factors. Several aspects of the design changed until the final design was decided.

The first design that was ready to be printed was made having only in mind fitting the electrical components as spaciously as possible on the inside. This design was two pieces: one that would hold the breadboard, the arduino and the sensors inside of it and another that would be a lid that would close the bottom part while also holding the led ring in place.

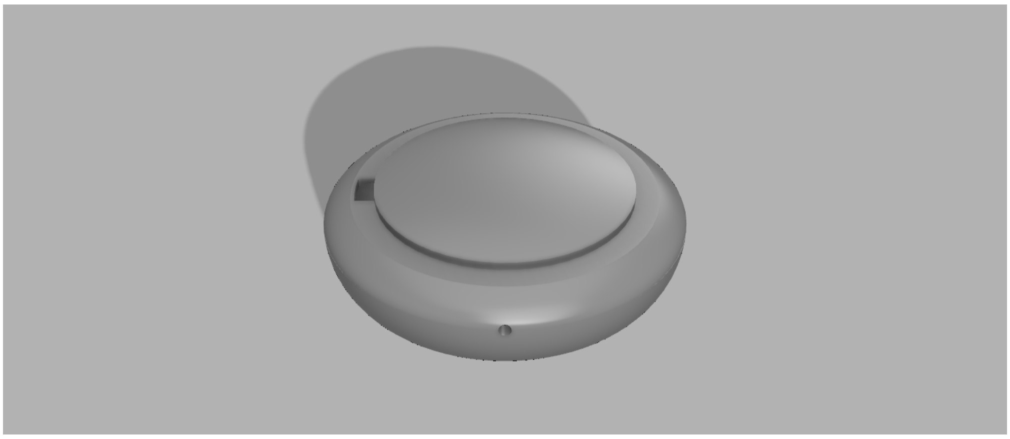

Figure 11: First - 2 pieces design for printing (both pieces)

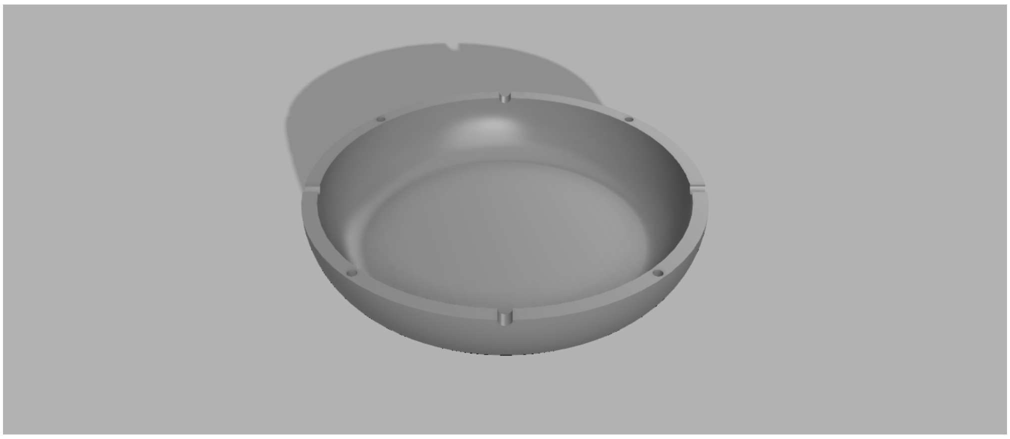

Figure 12: First - 2 pieces design for printing (bottom piece)

However, a lot of drawbacks were found on that design before printing that, by preventing them, would morph the final shape. The main issue was that it was too big. It was both too big to print, as both parts needed at least 10 hours for each to be printed, and it was also too big for a device that was supposed to be non intrusive.

Taking into consideration all these, the final design is one piece with a much smaller footprint. In this way, the print was reduced to 7 hours. To achieve this reduction in printing time the bottom is left as a whole with edges that protrude towards the center that would let a cardboard or foam lid to stay in place. Additionally, its smaller footprint makes it able to fit in many more places around the house. Finally, the reduced height also helped in making the led ring visible from more angles, mainly from a lower angle.

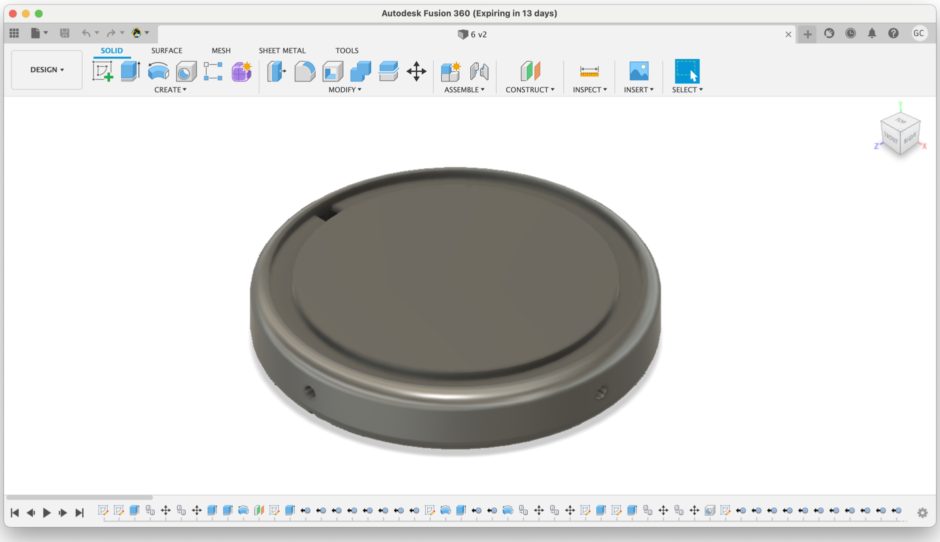

Figure 13: Final - 1 piece design design for printing, as seen from above

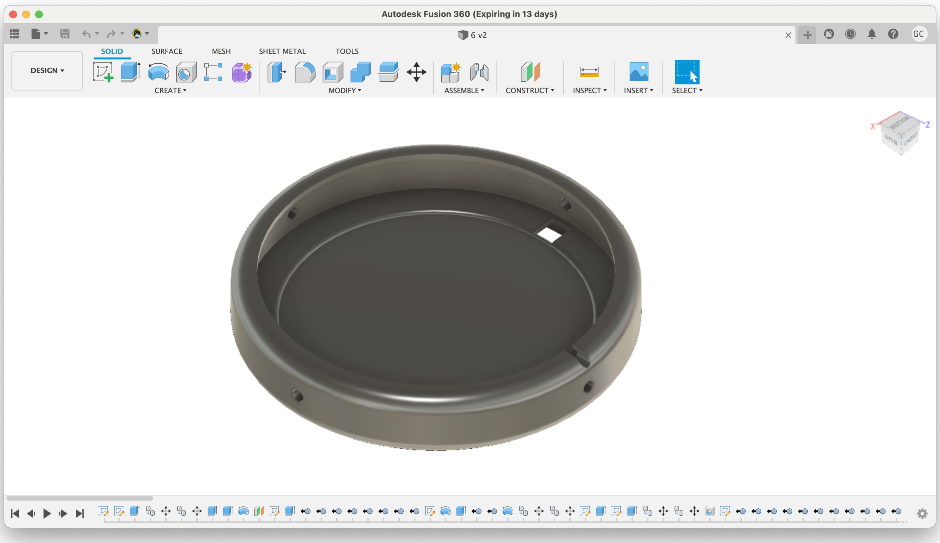

Figure 14: Final - 1 piece design design for printing, as seen from bellow

It was then printed using a third-party 3D printer, the price being included in the bill of material.

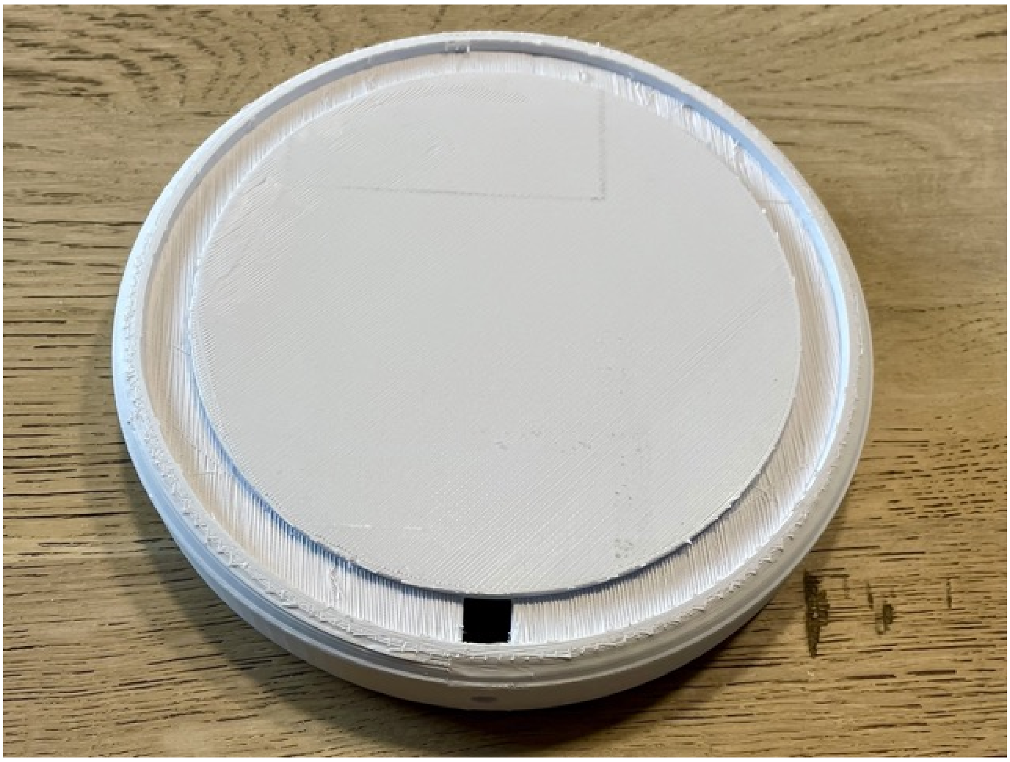

Figure 15: 3D print, as seen from above

Figure 16: 3D print, as seen from bellow

All of the parts, together with their individual brands, suppliers and prices were then added to the final bill of material in order to prove the presence within the bounds of the budget. The purchase links were also added to allow for verification.

The bill of materials can be found in the table below:

Table 2: Bill of materials

Name	Brand	Supplier	Price	Quantity	Sum
Geluidssensor module voor Arduino	-	Otronic	2,49 €	x4	9,96 €
SK6812 Digitale 5050 RGB LED Ring - 48 LEDs	-	Tinytronics	12,00 €	x1	12,00 €
Arduino UNO	Arduino	Arduino	20,00 €	x1	20,00 €
Breadboard 400 points	-	Tinytronics	3,00 €	x1	3,00 €
Case	-	-	5,00 €	x1	5,00 €
Charger	-		8,00 €	x1	8,00 €
Total					**57,96 €**

To better explain the realization process of the device, the chapter is split into to sections: "Circuit" and "Programming the Arduino".

8.1 Circuit

The construction of the circuit consisted of many separate steps in order to check that each part of the circuit was working as expected. The first step was to solder the led ring. This step was mandatory to connect the led ring to the breadboard and start the basic testing. After that, the basic connections of the sound sensors and the led ring to the Arduino and the breadboard were researched to make sure that the right first steps were followed.

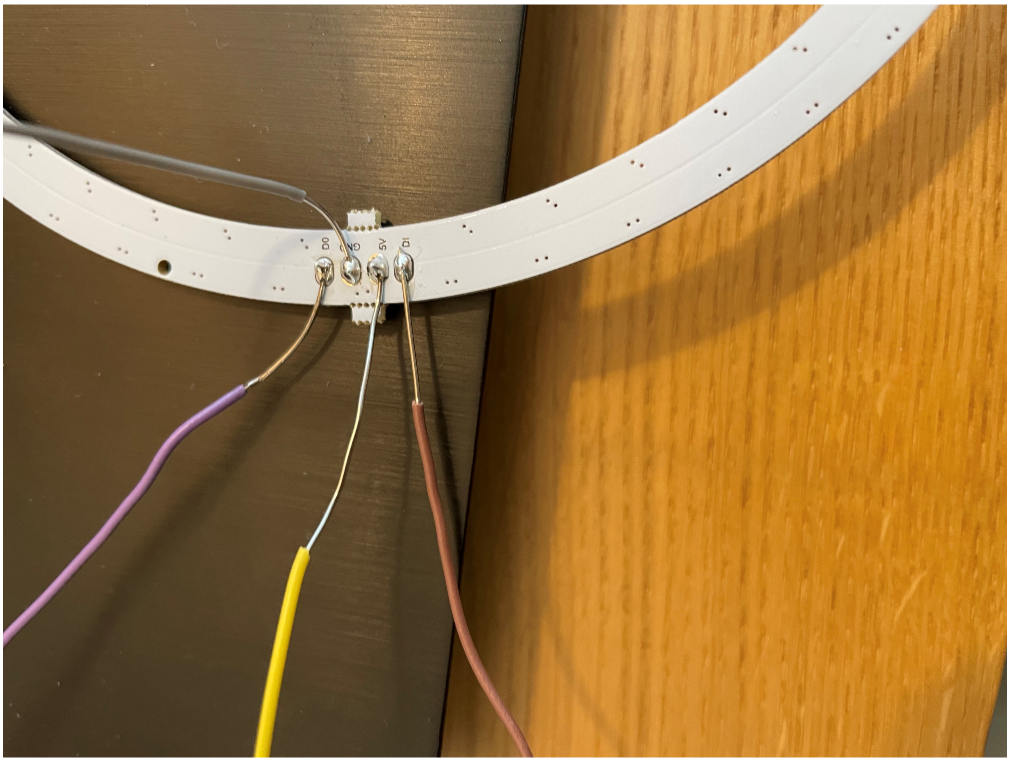

Figure 17: Soldered pins of the led ring

With those two first steps done, the group could start with the first part of the testing of the circuit, collaborating with the programming part and the basic code that was needed to make the system work. The main purpose of this test was to make sure that the color coding properly worked, so the color of the ring changed depending on the intensity of the sound. This test was done only with one sound sensor connected to the Arduino and the led ring also connected to the Arduino with the use of an extra resistor of 220 Ω in order to avoid burning some parts of the ring. This first test was completed successfully with every part of the circuit working as expected.

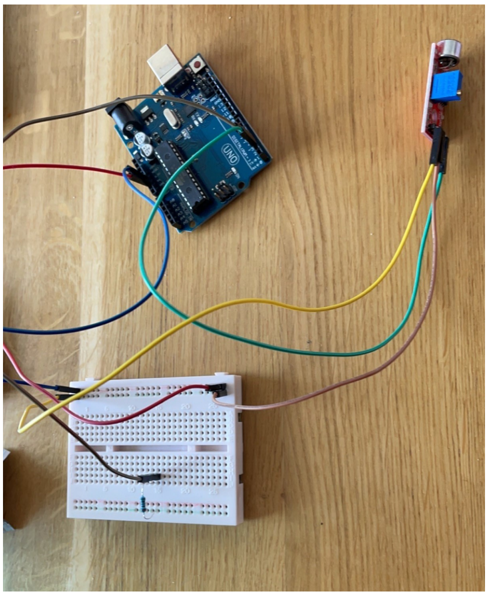

Figure 18: Circuit used for the initial testing with 1 sensor

The next and final part of applying the basic electronics to our product was to add the 3 extra sensors so that we were able to also test the direction sensing of the device, more specifically if the led ring lights up depending on the direction that the light came from. The addition of the other sensors was done by simply connecting them in series with the first sensor, following the same concept as the one used before. After that the new circuit with the new part of the code added was tested to see if the device works well overall and we can use this setup as our final one. This test also ended up being successful. Therefore, the group was able to finalize the circuit layout with all the tests being done.

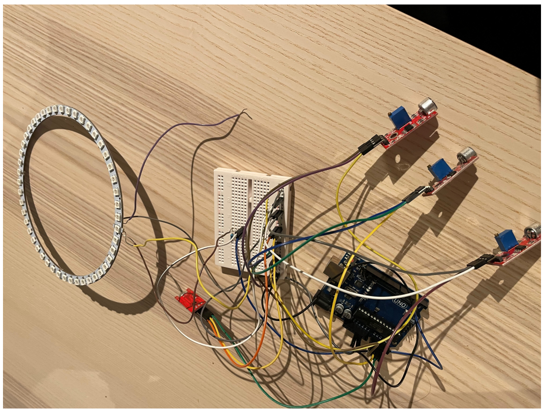

Figure 19: Final circuit with all 4 sensors applied

8.2 Programming the Arduino

As expected from the beginning, the main functionalities that the device had to have were achieved via programming: the color coding of the magnitude of the sounds and the pointing towards the direction from where the sound originates. As such, the Arduino IDE was used to create the code, which can be found in the appendix section.

In order to achieve the the aforementioned goals, we first needed to understand what kind of input we get from the sound sensors. Fortunately, the Arduino Integrated Development Environment (IDE) has a very convenient Serial plotter tool that helped us plot and understand the signal by offering us a visualisation.

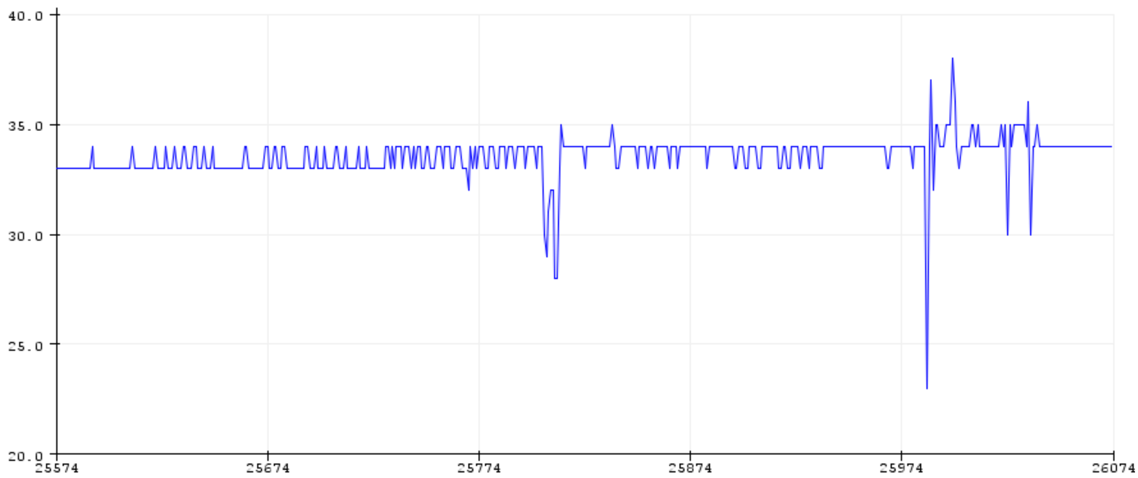

Figure 20: Outcome of one of the sound sensors used in the device

The first thing we see is that the value we get when the sensor when it does not detect any sounds is not 0, but some other number that we will name "initial value" (IV) for the sensor. This value is always different when the system starts, which makes it very hard to operate with it. In order to have more explainable, repeatable and robust performance every time the system starts it is mandatory that it computes this IV number and subtract it from the series so that normal value becomes 0. This also helps us by having all of the sensors outputting values in the same region.

After we have set this up, we needed to test how the signal behaves when different sounds are heard in the room, as the scale used by the sound sensors was different from the scales usually used to describe sound. By doing that, we created the main guidelines needed to be followed when choosing the thresholds for the color coding. Moreover, as can be seen from the graph above, the values of the sound sensors can also go in the negative area. Thus, we needed to work with absolute value of the signal, because when the sensor detects any sound it can be in either + or - direction (that is another reason why no sound being at 0 is beneficial). The initial colors used to display the information read by the device to the user can be found in the table below:

Table 3: Color coding

Absolute signal value	**Color**
< 2	no indication
$= 2$	blue
≥ 2 and < 4	green
≥ 4 and ≤ 10	red
> 10	red (the entire ring)
$=$ for three or more sensors	white

The reasoning behind this is that, in general, the sensors are very sensitive, which means that almost every time they detect some kind of sound which has an absolute value of 1. Also, sometimes the thresholds that the program reads during the initialization phase is close to the needed value, but not equal to it (e.g. 72 instead of 71), which means that an offset of one can still be found sometimes. That is why all sounds detect that are below 2 are considered insignificant and thus not represented by any color.

Listing 1: SetColor function

```
void SetColor(float abs_value, int n){
    if (abs_value == 1)  {
      for (int i = (n-1)*6 - 3; i <= n*6 - 3; i++){
        if (i<0){ledring.setPixelColor(i+48, white);}
        else {ledring.setPixelColor(i, white);}
        ledring.show();
      }
      delay(pause*10);
```

```
    }
    else if (abs_value > 1 && abs_value <= 2){
      for (int i = (n-1)*6 - 3; i <= n*6 - 3; i++){
        if (i<0){ledring.setPixelColor(i+48, blue);}
        else {ledring.setPixelColor(i, blue);}
        ledring.show();
      }
      delay(pause*10);
    }
    else if (abs_value > 2 && abs_value <= 4){
      for (int i = (n-1)*6 - 3; i <= n*6 - 3; i++){
        if (i<0){ledring.setPixelColor(i+48, purple);}
        else {ledring.setPixelColor(i, purple);}
        ledring.show();
      }
      delay(pause*10);
    }
    else if (abs_value > 4 && abs_value <= 10) {
      for (int i = (n-1)*6 - 3; i <= n*6 - 3; i++){
        if (i<0){ledring.setPixelColor(i+48, red);}
        else {ledring.setPixelColor(i, red);}
        ledring.show();
      }
      delay(pause*10);
    }
}
```

As mentioned before, pointing into the direction of the sounds requires the use four sound sensors. When we connected all of them to the Arduino, it was found that all of them have different IVs. Thus, the procedure described earlier for one sensor was now adapted in order to do the same for all off the other sound sensors. As a result, after the data processing is performed, we get all four inputs aligned along 0 when no sound is heard around them.

Figure 21: Plot showing the output from all 4 sensors after the re-scaling has been done

In order to point towards the location of the sound precisely we first split the ring into 8 general directions; each sound sensor corresponds to one of four sections and there is another in between every two sensors. Our ring has 48 LEDs, so when split into 8 parts it results into 6 LEDs responsible for any of the 8 directions we mentioned.

After we have established that, the second step is to compare the signals we receive at each moment from all four sensors and compare the output values. In a situation where one sensor detects the highest sound this means that the sound comes from the direction at which the given sensor faces, so we light up the corresponding part of the ring. In case two sensors detect the same values and that value is higher than the other two sensor values we know that the sound comes from between the two mentioned sensors and we light up the part of the ring that is responsible to the direction between the two sensors.

In case more than two sensors detect the same highest value we light up the whole ring in a white light. For the case that any sensor detects a value higher than 10 we consider that to be an emergent situation so, as a response, we want to attract the attention of the user as much as possible. That is why we light up the whole ring in red.

9 Test plan and results

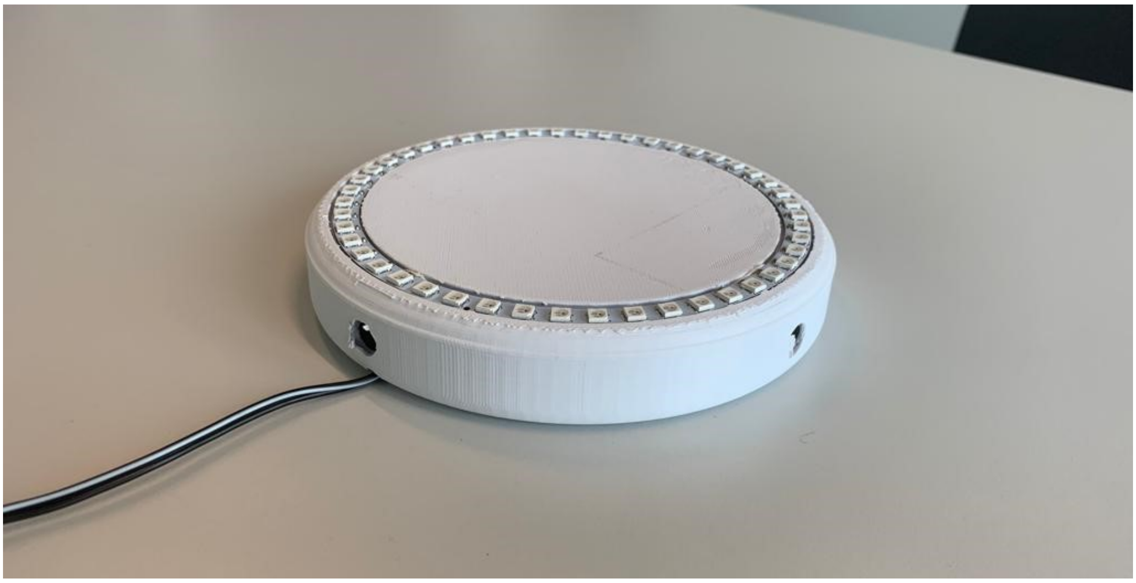

Figure 22: Picture of the finished device

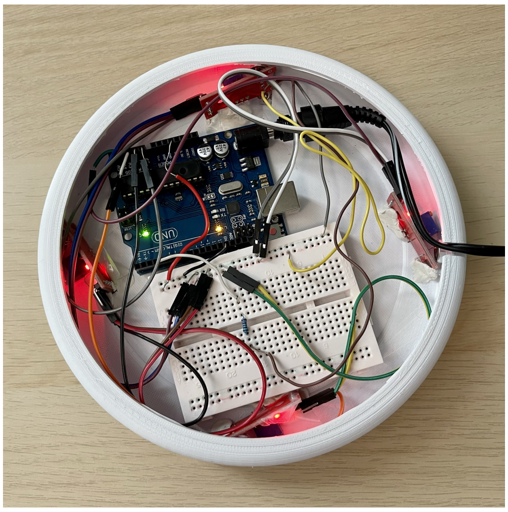

Figure 23: Picture of the finished device (inside - circuit)

After the device was finished, testing had to be done in order to determine the functionality of the device. However, as most of the project was based on the programming part, there was no mechanical part that needed to be tested nor were there calculations to be made.

The following code has been used in order to inspect the output of the sound sensors while the device was running:

Listing 2: Sound senor output monitoring code

```
Serial.print("Sensor1:");
Serial.print(analogRead(sensor_pin1) - threshold1);
Serial.print(',');
Serial.print("Sensor2:");
Serial.print(analogRead(sensor_pin2) - threshold2);
Serial.print(',');
Serial.print("Sensor3:");
Serial.print(analogRead(sensor_pin3)- threshold3);
Serial.print(',');
Serial.print("Sensor4:");
Serial.print(analogRead(sensor_pin4) - threshold4);
Serial.println();

delay(pause);
```

By using this code, the color coding was adjusted in order to provide the best possible experience for the user. This was possible because the code offered insight into what the sound sensor is reading during a normal run, allowing the group to understand the correlations between the output and the sounds heard. As expected, it was found that common sounds such as talking or knocks usually give an output of one, meaning that a primary threshold of one should definitely be implemented, being denoted by the color white.

After that, the colors were also changed in order to account for people who have color blindness by changing the color pair red-green to red-blue. That also helped with the visualisation, making it easier for the user to see what is happening around him.

The device was then left open throughout the day in order to see how the user experience can be rated. It was found that a delay was needed for when the ring was all lighting up in one color, as for now those events would only last for a few milliseconds, making it hard to spot during the run time. It was also found that the brightness could have been improved in order to increase the chance of a user spotting the light from the corner of his eye. As such, the brightness was set close to the maximum limit (to be more exact, 98% of the maximum capacity).

During the testing, it was found that although the sensors are detecting most of the sounds around it, they are not able to detect all of them. Despite our expectations, that was not ideal as sometimes the device was not able to pick up sounds that were clear and, to an extent, loud. Moreover, it was found that the sound sensors are more likely to detect vibrant sounds instead of loud one, the hypothesis being confirmed by the fact that sometimes yells were not able to get an output, while punches in the table were. As such, depending on the sound vibration, certain alarms or ringtones would stay undetected for the most part, making the device unreliable.

In spite of the aforementioned inconvenience, the product did its job. While not perfect, it was still able to improve the life of somebody with impaired hearing by giving important insight into the sounds from the outside world. To our surprise, although not perfect, the in between directions also worked well.

However, a few hours into testing, the LED ring started to act up, constantly glowing in white. The wires were removed and then connected again in order to test for electronic problems, but to no avail. The sensors were also inspected while looking for bad contacts, but that also proved to be unhelpful as no irregularities were found. Finally, the device was plugged to a laptop and the serial plotter function was added again in order to inspect for any faulty behaviour. Surprisingly, the sensors were outputting values between zero and one, thus explaining the unexpected behavior.

While numerous hypotheses were proposed at first, none of them could have explained the behaviour entirely. One theory could be the fact that wither the sensor or the Arduino is overheating, making it output faulty results.

Regardless of the cause, it meant that something had to be done otherwise the user would have to deal with false positives. It also has to be said that, while the number of false positives was concerning in itself, the light delay that was added in order give more time to the user to notice an alert would make the matter worse, as the false positives would delay the next detection for a second, thus making the device potentially dangerous.

As such, when all things were considered, it was decided that the best course for action would be to set the initial threshold back to two, thus ignoring a large amount of reads. While this definitely hurts the user experience and limits the capabilities of the device, it is better than offering misinformation.

10 Design evaluation

As for the final design evaluation, there are numerous points that can be made, underlining both positives and negatives.

On the one hand, the device was working properly. The sound sensors were able to pick up sounds from the environment that are noticeable while ignoring those that would not pose any significant importance to the user. This can be best portrayed by the fact that the device was not picking up sounds from the outside when the windows was left open in the upwards direction. While not perfect, the in between directions were also working, giving additional information to the user in order to ease their job when trying to detect the sound source. The LED ring was bright enough to be easily noticeable while also being able to display clear colors when needed, decreasing the chance of ambiguity in the output given. The Arduino also did a good job processing the continuous flow of data and did not show any signs of lagging behind when sending signals to the LED ring. The 3D cover, while not the one intended in the beginning, was good enough to encompass all of the circuit and allowed for a compact device that would fit nicely in every home. The final device was still innovative and kept a lot of its initial creative features, such as the direction pointing technique.

On the other hand, the device was not as sensitive as it was intended to be in the beginning. While it detects sounds, it is very likely to miss noticeable sounds that could signal important actions, such as the doorbell. The lack of sensitivity also hindered our attempt to come up with a more complex direction detection, as the output was not constant at times. As such, premade directions had to be made, thus increasing the area corresponding to one direction, making the initial calculations redundant. The sound sensors output did not allow for a transitional color coding as it consisted of mainly integer values in the range of 0 to 10, thus making the use of steps necessary.

Looking into retrospective, less time should have been spent on the LED documentation, as in the end it did not provide any benefits to the final device whatsoever. While the brightness and the colors of the chosen LED ring were surely useful, they did not enhance the user experience in any way as the output did not allow for a more complex animation or smoother transition techniques. This does not mean, however, that the purchase of the LED ring was a bad choice, but on the contrary, it proved to be a valuable part in a not so optimal device. It can be noted that a glass dome would have been a good addition as it could have helped disperse the LED light, making it more visible from lower angles.

In addition to that, the 3D printing should have been treated with a more realism by the group members. While the group was captivated by the marvelous designs proposed in the meetings, none thought of the printing time, which was limited for our course. As such, a fast solution was needed close to the final stage of the project, which put a lot of pressure on the design department. Although in the end everything worked out fine and the final design, despite the compromises made, looked very good, it should have been managed differently as the outcome could have been a lot worse.

The key aspect that should have definitely been researched a lot more was the sound sensors. While this was understandable to a degree as there is no easy to use scale in order to grade sensors (the same one cannot say which pair of headphones is better only by looking over the specifications), more time should have been spent in understanding the functionality of the sensors and finding the best ones that suit the goal of our device. As such, the lack of time spent ended up hurting the device, limiting its capabilities as a medical aid. Better sound sensors could have meant more sensitivity and reliable output, which could have been later used to create a more complex formula for direction detection. However, it also has to be mentioned that there are not a lot of sound sensors easily available on market for Arduino projects meaning that the time spent researching could have proved to no avail in the end. Another option would have been finding a solution for the misbehaviour of the sensors, lowering the chance of false positives and allowing for a lower threshold thus increasing the usefulness of the device. A third option would have doubling the amount of sound sensors and implementing some sort of checkups for the output that could have been done using data processing techniques together with noise reduction.

That being said, the group is proud of the final device and all of the mistakes presented above will be used as improvement grounds for the future. The hard work that was put into the device cannot be contested and at no point was there any attempt to cut corners for convenience reasons. The results obtained using the available setup were also compelling, proving that the design goal is actually achievable, and could be further used for the making of an actual device. Price cuts can also be obtained for the micro controller, as there are numerous Arduino alternatives that are considerably more affordable. As such, a better device could be made while still remaining under a 50,00 € margin.

All of that adds up to a bright outlook, proving that the serious disability that was chosen can be dealt with by creating a device that aims at improving the quality of life at home for deaf people.

References

[1] The health of deaf people: communication breakdown. *Lancet (London, England)*, 379(9820):977, 2012.

[2] Johannes Fellinger et al. Mental health of deaf people. *Lancet (London, England)*, 379(9820):1037–44, 2012.

[3] Katia Gilhome Herbst and Charlotte Humphery. Hearing impairment and mental state in the elderly living at home. *British medical journal*, 281(6245):903–905, 1980.

[4] Timothy Reagan. A sociocultural understanding of deafness: American sign language and the culture of deaf people. *International Journal of Intercultural Relations*, 19(2):239–251, 1995.

A Appendices

The code used can be found below.

```

// Initialize the neopixel library for the LED ring
#include <Adafruit_NeoPixel.h>
#ifdef __AVR__
#include <avr/power.h> // Required for 16 MHz Adafruit Trinket
#endif

// Initialize the LED ring
int ledring_pin = 3;
int pixel_number = 48;
Adafruit_NeoPixel ledring(pixel_number, ledring_pin, NEO_GRB + NEO_KHZ800);

uint32_t blue = ledring.Color(0,0,255);
uint32_t green = ledring.Color(0,255,0);
uint32_t red = ledring.Color(255,0,0);
uint32_t white = ledring.Color(255,255,255);
uint32_t purple = ledring.Color(255,0,255);

// Initialize the variables for the sound sensors
// Sound sensor 1
int sensor_value1 = 0;
int abs_value1 = 0;
int sensor_pin1 = A0;
int threshold1 = 0;

// Sound sensor 2
int sensor_value2 = 0;
int abs_value2 = 0;
int sensor_pin2 = A1;
int threshold2 = 0;

// Sound sensor 3
int sensor_value3 = 0;
int abs_value3 = 0;
int sensor_pin3 = A2;
int threshold3 = 0;

// Sound sensor 4
int sensor_value4 = 0;
int abs_value4 = 0;
int sensor_pin4 = A3;
int threshold4 = 0;

// Time delay (in milliseconds)
int pause = 50;


void setup() {

  // Setup serial
  Serial.begin(9600);
  threshold1 = analogRead(sensor_pin1);
  threshold2 = analogRead(sensor_pin2);
  threshold3 = analogRead(sensor_pin3);
```

```
  threshold4 = analogRead(sensor_pin4);

  // Initialize NeoPixel strip object (REQUIRED) and set all pixel colors to 'off'
  ledring.begin();
  ledring.clear();
  ledring.show();

  // Set the brightness
  ledring.setBrightness(200);

  // Perform an introductory animation for the LED ring
  int n = 0;
  for (int i = 1; i <= pixel_number; i++) {
    n = n + 1;

    if (n<=16) {
      ledring.setPixelColor(n, 255-n*15.93, n*15.93, 0);
      ledring.setPixelColor(n-1,0,0,0);
      ledring.show();
    }

    if (n>16 && n<=32) {
      ledring.setPixelColor(n, 0, 255-(n-16)*15.93, (n-16)*15.93);
      ledring.setPixelColor(n-1,0,0,0);
      ledring.show();
    }

    if (n>32 && n<=48) {
      ledring.setPixelColor(n, (n-32)*15.93, 0, 255-(n-32)*15.93);
      ledring.setPixelColor(n-1,0,0,0);
      ledring.show();
    }

    delay(pause);
  }

  // Clear the lights on the LED ring
  ledring.clear();
  ledring.show();
}

void SetColor(float abs_value, int n){
    if (abs_value == 1)  {
      for (int i = (n-1)*6 - 3; i <= n*6 - 3; i++){
        if (i<0){ledring.setPixelColor(i+48, white);}
        else {ledring.setPixelColor(i, white);}
        ledring.show();
      }
      delay(pause*10);
    }
    else if (abs_value > 1 && abs_value <= 2){
      for (int i = (n-1)*6 - 3; i <= n*6 - 3; i++){
        if (i<0){ledring.setPixelColor(i+48, blue);}
        else {ledring.setPixelColor(i, blue);}
        ledring.show();
      }
      delay(pause*10);
```

```
    }
    else if (abs_value > 2 && abs_value <= 4){
      for (int i = (n-1)*6 - 3; i <= n*6 - 3; i++){
        if (i<0){ledring.setPixelColor(i+48, purple);}
        else {ledring.setPixelColor(i, purple);}
        ledring.show();
      }
      delay(pause*10);
    }
    else if (abs_value > 4 && abs_value <= 10) {
      for (int i = (n-1)*6 - 3; i <= n*6 - 3; i++){
        if (i<0){ledring.setPixelColor(i+48, red);}
        else {ledring.setPixelColor(i, red);}
        ledring.show();
      }
      delay(pause*10);
    }
}


void loop() {

    //Serial.print("Sensor1:");
    //Serial.print(analogRead(sensor_pin1) - threshold1);
    //Serial.print(',');
    //Serial.print("Sensor2:");
    //Serial.print(analogRead(sensor_pin2) - threshold2);
    //Serial.print(',');
    //Serial.print("Sensor3:");
    //Serial.print(analogRead(sensor_pin3)- threshold3);
    //Serial.print(',');
    //Serial.print("Sensor4:");
    //Serial.print(analogRead(sensor_pin4) - threshold4);
    //Serial.println();

    //delay(pause);

  // Read the output of sensor 1
  sensor_value1 = analogRead(sensor_pin1);
  abs_value1 = abs(sensor_value1 - threshold1);

  // Read the output of sensor 2
  sensor_value2 = analogRead(sensor_pin2);
  abs_value2 = abs(sensor_value2 - threshold2);

  // Read the output of sensor 3
  sensor_value3 = analogRead(sensor_pin3);
  abs_value3 = abs(sensor_value3 - threshold3);

  // Read the output of sensor 4
  sensor_value4 = analogRead(sensor_pin4);
  abs_value4 = abs(sensor_value4 - threshold4);

  // Color coding dependent on the output of all sound sensors without the direction
  // float sound = 0;
  // float intensity = 0;
  float compar1 = max(abs_value1, abs_value2);
```

```
  float compar2 = max(abs_value3, abs_value4);
  float intensity = max(compar1, compar2);

  if (intensity > 10){
    ledring.fill(red);
    ledring.show();
  }

  else if (compar1 > compar2){
    if (abs_value1 < abs_value2){
      SetColor(abs_value2, 3);
    }
    else if (abs_value1 > abs_value2){
      SetColor(abs_value1, 1);
    }
    else {
      SetColor(abs_value1, 2);
    }
  }

  else if (compar2 > compar1){
    if (abs_value3 < abs_value4){
      SetColor(abs_value4, 7);
    }
    else if (abs_value3 > abs_value4){
      SetColor(abs_value3, 5);
    }
    else {
      SetColor(abs_value3, 6);
    }
  }

  else {
    if (abs_value1 > abs_value2 && abs_value3 < abs_value4 && abs_value4
        == abs_value1){
        SetColor(abs_value1, 8);
    }
    else if (abs_value1 < abs_value2 && abs_value3 > abs_value4 &&
        abs_value3 == abs_value2){
        SetColor(abs_value2, 4);
    }
    else if (intensity > 1)  {
        ledring.fill(white);
        ledring.show();
    }
  }

  ledring.clear();
  ledring.show();
  delay(pause);
}
```