IMPERIAL COLLEGE LONDON

EE2-PRJ E2 Project

Group number: Group 17

Group name: Noise-cancelling Window/Project Peacemaker

Supervisor: Dr Cong Ling

Group members: (Remember CID number)

Jin Lian (CID: 00937797)

Zihao Wu (CID: 00945015)

Sida Niu (CID: 00976191)

Martin Chan (CID: 00808152)

Christodoulos Stylianou (CID: 00819357)

Chao Lyu (CID: 00979113)

Jason Yuan (CID: 00954645)

Date of submission: 17th of January

Contents

Abstract

The aim of this project is to test the feasibility of a product that use active noise reduction or ANR to create a portable “zone of isolation”, that isolates a group of people within the zone from sounds outside of the zone. The product aims to create an output wave exactly out of phase with an input wave, cancelling the input wave and attenuating unwanted sounds. This would improve the lives of people in noisy urban areas, especially students and working professionals, by providing a portable solution to annoying and disruptive noise from city life.

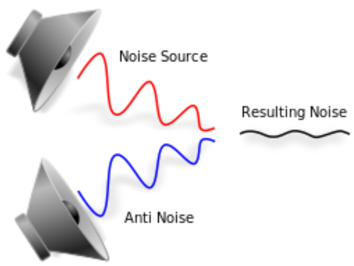
The report discusses how 10 design criteria from the product design specification (PDS) are chosen to determine the direction of the project; focus was placed on making an effective solution that is effective, portable and affordable for our target customers. The features, implementation choices and possible extensions to the design shall then be discussed. This is followed by elaborations on areas for implementation and plans for future work.

Introduction and background

Life in the 21st Century is extremely noisy. Numerous solutions are sought to drown out annoying and disruptive sounds as people go about their daily activities. Unbearable noise actually inspired the central idea for the project, when a group member sought to find a solution to deal with the noise from trains passing near his home. Conventional means of sound reduction, such as increasing the thickness of walls and windows, were impossible due to lack of funding and permissions to modify the home. This lead to the initial idea of using a noise-cancelling device placed on the window that would cancel noise as it came through the window.

Through researching solutions to this problem, the group found many existing solutions and mature products offered for achieving noise cancellation; these include noise-cancelling earphones or devices that cancel sound passing through a window (for instance, SONO by Rudolf Stefanich). Unfortunately, no such solution exists in a portable form that can isolate one region in a room from sounds coming from other areas in the room.

The group aims to do a feasibility study on the use of active noise reduction (ANR) to create a “zone of isolation” to insulate one region in a room from sounds coming from other adjacent regions. ANR is the process of using electronics to create an antiphase signal, or a signal 180 degrees out of phase, that is played through an audio output to cancel unwanted noise. If the antiphase signal and the original signal are of equal amplitudes and exactly opposite phases, they will cancel each other out.



A radical example of how this concept might be applied is allowing different group conversations to continue in the same room without disturbing each other. The group believes that the end product would be valuable to people living in noisy urban environments, such as students and working professionals, and can be extended to restaurants or offices. The potential benefits from development such a product makes it an exciting prospect worth pursuing.

As a result of this new goal, the group has decided to rename the project as “Project Peacemaker”.

Design Criteria

Below is a discussion of 10 discussion criteria that are determined to be very important:

1. Performance

Satisfactory performance is vital for any product. The following performance criteria are target aims of the project:

a) The incoming noise must be attenuated to a level significantly lower than normal conversation level, around 65 decibels. [See Appendix B]

b) The output level of the device cannot be too loud. This needs to be determined so that the amplitude of the antiphase signal does not exceed that of the original.
c) Extensions of the product intend to selectively filter exceptionally loud noises above conversation level must be filtered out. Train noise, busy traffic and construction sites are all examples of noise that is louder than normal.
d) There must be a large enough frequency range to target noise that may be of a higher frequency.

Ideally, a state of isolation is achieved within the target area from external sounds. The project shall investigate to what extent this ideal can be achieved.

2. Environment

The end product needs to be portable, making the operating environment important. The devices needs to be able operate at room temperature in all seasons and in most indoor environments.
Other considerations:

a) While the product is designed mainly for indoor operation, this can be extended for outdoor operation through protection against the weather.
b) There is no aim to have the product operating in extreme temperatures, such as sub-zero temperatures or high heat as this will increase overall cost of the product.

3. Life in Service

The product must be able to be repeatedly used over a period of time. The target product lifespan is one year on full performance. Additionally, there is a target a length of 4 hours of continuous performance on rechargeable batteries, which is necessary to extend the device's portability.

4. Target Product Cost

The target market - students and working professionals may have a relatively low-budget. The aim is to make the product as cheap as possible, without compromising on portability or performance which is our main consideration.

5. Competition

ANR is not a new idea. There are similar technologies available in the market, such as noise cancelling headphones and noise cancelling systems in cars that can cancel noise very efficiently. A number of characteristics exist that distinguish our product from its competitors:

a) The "zone of isolation" concept to allow interactions in an area without outside interference.
b) A portable device that can be set up in different locations with flexible positioning.
c) Adjustable output levels.
d) Selective filtering of particular sounds.

6. Customer

The target customers are currently primarily students and home professionals. They are the ones most likely to be dealing with a noisy urban environment, and require a cheap but effective solution to interact while being shielded from external noise. The aim of the project is to find whether the product can provide a portable solution for these customers.

The solution would however generally benefit anyone who works in a noisy environment, where they can interact without being disturbed. This is applicable to restaurants, cafes and offices, where these devices can be used to isolate groups of people from one another.

7. Aesthetics, Appearance and Finish

The product must be trendy, attractive and appealing enough for potential customers. The end product should be modern, elegant, and blends in with a variety of indoor environments. Different colours and other forms of customisability can be considered for the final product.

8. Quality and Reliability

Related to life in service and environment is quality and reliability. As customers will rely on the product to carry out activities and socialising without disturbances, the accuracy and reliability of cancellation is very important. Ideally, the product must be able to reproduce a satisfactory drop in the noise level every time, and cannot break down within the targeted life of service.

9. Patents, Literature and Product Data

As mentioned before, ANR is not a new area of research. The group is aware of existing patents such as on "Open-air noise cancellation systems" (Nishikawa, 2007) and "Wide area noise cancellation systems" (Christopher A. Brown, 2012) do exist and will avoid infringing on any intellectual property laws. Our product shall be distinguished by portability and cost.

10. Installation

As portability is a very important criteria, the product needs to be easy to set up; it must be simple enough to allow anyone to set it up with ease. The aim is to have convenient setup and minimal controls to allow for intuitive and easy use.

Design Concepts

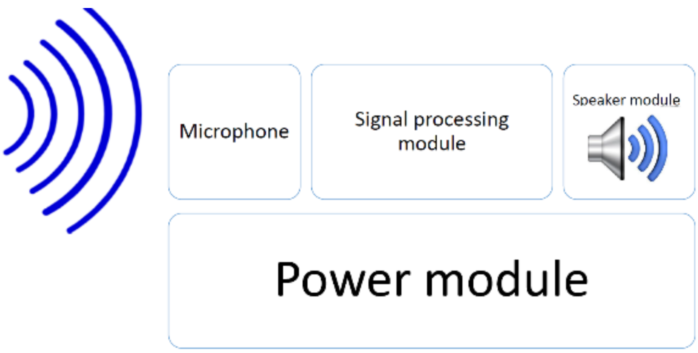
The choice of ANR is motivated by finding means of achieving effective noise reduction in a portable and relatively inexpensive form, so that it is available for use to customers who need a convenient and inexpensive solution.

This consists of a core design, in addition to a number of implementation choices and extensions. These form the basis for our product and testing.

Core Design

The core design is based around the assembly of a combination of 4 modules:

1. A microphone
2. A signal processing module
3. A speaker module
4. A power module

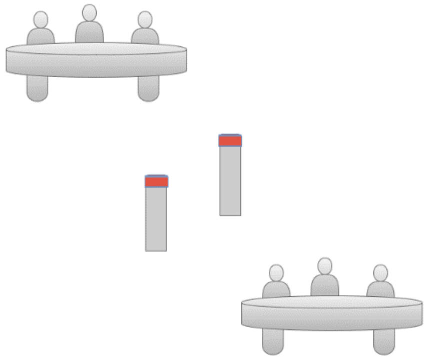


Unwanted sound is picked up by the microphone, is converted to an antiphase signal and amplified by the signal processing module in real time. This antiphase signal is then sent to the speaker and theoretically acts to cancel the original unwanted noise.

Initial designs of the project involved only a single self-contained device with all 4 modules, which is cheap and relatively simple. However, this is likely to be unfeasible for a solution that needs to cancel sound entering into an area, as it is unlikely that just one speaker and microphone is sufficient for the whole area.

Another consideration is to use a combination of multiple speakers and microphones with a central unit to process all the signals, which would have a significant improvement in performance over the first design due to multiple inputs and outputs. This is unlikely to be the most feasible solution as it requires complex processing of interactions between the microphones, speakers and processor.

The solution that the end product uses is an array of identical devices containing all 4 modules. Unfortunately, it is the most expensive solution. However, it is simpler to implement than the second solution and should perform significantly better than the first design. Furthermore, the modularity and scalability of the solution is a large improvement over the second solution, only requiring more devices to be added to cover a wider area.



For clarity, one of the self-contained devices shall be referred to as an ‘ANR subsystem’.

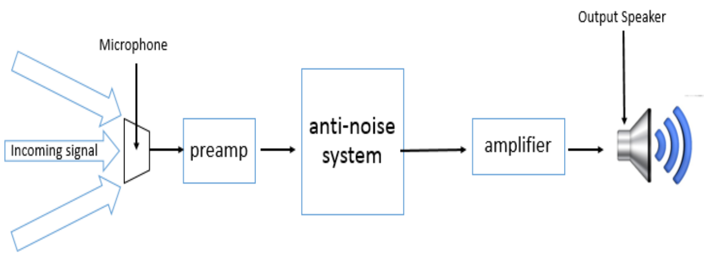
The core design contains several features that are listed below along with their justifications:

1. <u>The use of batteries</u>

It is mandatory for the product to be portable. Hence, batteries are preferred over mains as they enable to devices to be used anywhere. The plan is to use lithium ion batteries due to their high energy density.

To estimate power usage, there is a need to look at the rest of the circuit. We roughly estimate that the total energy consumption for our circuit is around 5W; 0.5W from signal processors like DSP chips, 2W for a decent speaker and another 2.5W for other electronics.

2. <u>The use of multiple microphones and speakers</u>



To achieve a zone of isolation, a minimum of several microphones and speakers are needed to generate the “wall of sound” to insulate that area from the environment.

3. <u>The use of a pre-amplification circuit for the microphone and the use of an amplifier for the speaker.</u>

It is likely that amplification is required as the electrical signal that is received by the control circuit is most likely insufficient to give a good enough signal to noise ratio (SNR) for effective processing.

4. <u>Simple on and off controls, and a controllable output volume.</u>

This is to allow for inexpensive control and maintenance of the device for customers, who want a convenient and uncomplicated solution.

Costing

The price estimate is about £40 per device. On the side is a rough costing chart of components that may be used in this product. The battery is estimated to be expensive - to provide the energy density and operating hours required we require more expensive power sources.

Component	Typical Price (£)
DSP	5
Speaker	3
Microphone	2
Battery	20

Implementation Choices

A number of possible choices in implementation alternatives for components and processes in the design shall be elaborated in the following sections.

<u>Analogue or Digital Processing</u>

There is the choice of using either analogue or digital methods as the control circuit in signal processing. Below is a table listing both advantages and disadvantage of the 2 systems.

Digital	Analogue
Resistant to electrical noise	Easily corruptible by electrical noise
Highly flexible	Difficult to change processing system
Simpler implementation of processing	Complex processing more challenging
Requires sampling	Works directly on input signal
Uses more power	Uses less power on average
Generally slower	Generally faster

Digital systems are determined to be better after weighing up the advantages and disadvantages of both. Digital systems are flexible, resilient against noise and most importantly, able to reliably implement complicated signal processing algorithms. However, the speed and power may be insufficient and may force us to use a purely analogue system.

FPGA or DSP

Digital signal processing can be carried out by a number of devices. There is a choice between general purpose microprocessor, digital signal processors (DSP), a type of microprocessor specialised towards signal processing, and Field Programmable Gate Arrays (FPGAs). The FPGAs are the fastest as they can manipulate signals at gate level. In turn, while generally slower than FPGAs, DSPs are generally faster than microcontrollers as they are purpose built for signal processing. This also corresponds inversely with ease of implementation - Hardware Description Languages (HDL) are required for FPGAs, while C style languages can be used for DSPs. Due to the group's greater proficiency in C style languages, DSPs will be more familiar to use than FPGAs. Additionally, the DSP has more prebuilt libraries available. (Hunt Engineering, 2012) FPGAs are also far more expensive than DSPs and are unlikely to be appropriate for use

DSP chips are likely to be used due to the cost of FPGAs, and general-purpose microprocessors likely too slow. A DSP theoretically provides a good balance between performance and cost.

Extensions

Additional investigation can be done on a number of topics made into whether certain loud and annoying sounds can be removed through a system of targeted noise cancellation.

Furthermore, investigations may be carried out on a form of adaptive filtering – where the processing filter is continually adjusted using a feedback loop connecting the output and the filter. (Cowan & Grant, 1985) One such use of this is in the least-mean squares algorithm, which allows us to determine weights of components allowing adjustments in filtering and processing accordingly to improve performance. (Friedlander, 1985) However, this will mean that some form of digital processing should be used as it is prohibitively complicated to implement such a system using a purely analogue system.

Areas of Investigation

The group estimates that the scope of developing the whole product would be too large, and will be narrowing investigations down to a single device for the 1-dimensional case. There are many challenges associated with a multi-device system, such as dealing with devices interfering with each other, the arrangement of multi devices and 2/3 dimensional cases. The group feels that this is beyond the scope of the time available.

The nature of the project means that most work will be done on feasibility research and not implementation. This section details numerous challenges and principles that need to be investigated.

Frequency response

Sound often consists of many different component frequencies. As a result, different frequencies may be processed differently by the ANR control circuit than others. In particular, propagation speeds of higher frequency signals differ from lower frequency ones, leading to phase delays. This means some phase compensation will probably be required.

Additionally, high frequency noise is harder to process; for instance, they interact with capacitances in the circuit to make it noisier.

A digital system can separate input waveforms into components of different frequencies through the usage of Fourier transforms, before processing them. In contrast, an analogue system has no simple way of separating the waveform into components of different frequencies. Complicated circuitry is required in an analogue system to give the correct phase difference for a large bandwidth as simple filters will adjust the phase differently for different frequencies. Hence, we are required to investigate and overcome these challenges.

Further filtering will be done should certain frequencies be deemed to be problematic.

Processing Speed

Processing speed is a major limiting factor for the device. The processor needs to be fast enough to process the signal so that output antiphase wave is exactly out of phase with the input signal. Hence, the processing speed needs to be fast enough so that the output will cause the input to be cancelled.

This is a potential problem for digital systems, as they are slower in real-time processing than analogue ones. To alleviate this, faster digital processors can be used. Alternatively analogue front ends (AFEs) can be used, analogue circuits that condition the signal before it is processed, to allow for less computation for the microprocessor.

Power Requirements

Power requirements is often overlooked but an important aspect. There needs to be an estimate on a power budget and a determination on whether the device can operate with adequate performance. Should the power budget be insufficient, the power supplied to the system needs to be increased. The proposed battery is lithium ion, due to the high energy density and long battery times.

Amplification

Amplification levels need to be optimal enough to avoid amplifying the antiphase signal above that of the original signal – this will lead to reduced attenuation of the original signal and even amplification of the noise. Hence, an optimal amplification range for the device needs to be determined. The final product should have a range of adjustable amplification.

Microphone

The directionality of the microphone will also need to be tested. There are many different microphone patterns and directionality that can be used, and the optimal one needs to be determined.

Omnidirectional microphones are the proposed choice be at this current moment, as they can capture sound from a greater range of angles. This may however complicate calculations as the angle of waveforms becomes a significant consideration.

Future Work and Deliverables

Future work and deliverables are split into separate phases. As the scope of the project is massive and time limited, there is a need to choose only a select amount of areas to investigate. This section details these phases. A project plan in the form of a Gantt chart is available in appendix A.

Take note that the process is iterative - there is anticipation that of iteration to a previous phase should there be a roadblock.

Phase 1: Waveform Analysis and Parts Sourcing

In this phase, waveforms of sound and how they appear to an oscilloscope and a processor are analysed. This is to gain understanding of the input signal and its components; spectral composition and weighting of different sounds that may be classed at noise will be analysed.

During this phase, parts for testing and prototyping will also be sourced.

Phase 2: Algorithm and Circuit Building

In this phase, the power and control circuit will be built. This includes the design and building of circuits involved in powering and biasing the control circuit, and development of algorithms, software, and circuitry that are used in the control circuit.

Phase 3: Prototyping and Testing

The device shall be built and tested according to the devised schematic. Attenuation of a signal of a single frequency shall be tested, and then a more complex signal. A final and possible test is the attenuation of real-life sounds such as train noise.

This is the point that determine whether the product will use a digital or analogue system. The initial plan to test the system with a digital control circuit first; an analogue system will be considered should the speed limitations prove too severe.

While outside of the planned scope, plans exist to test adaptive filtering, the filtering of particular frequencies, and the interaction of multiple ANR subsystems if time is available.

Conclusion

In conclusion, project peacemaker intends to be an investigation into using electronics to solve an important problem - portable sound cancellation. The group believes that if this is indeed proven to be possible, this will lead to a convenient and highly sought after technology. Further extensions of the technology can lead to whole sections of a large space such as a room or a laboratory working in isolation; eliminating the need for the erection of permanent physical barriers to cancel sound.

Bibliography

Christopher A. Brown, J. F. S., 2012. *Wide area noise cancellation system and method.* US, Patent No. US20120237049 A1.

Cowan, C. F. & Grant, P. M., 1985. Introduction to Adaptive Filters. In: C. F. Cowan & P. M. Grant, eds. *Adaptive Filters.* Englewood Cliffs, New Jersey, United States of America: Prentice-Hall, Inc., pp. 1-14.

Dangerous Decibels, 2015. *Exposure Time Guidelines.* [Online]
Available at: http://dangerousdecibels.org/education/information-center/decibel-exposure-time-guidelines/
[Accessed 13 01 2016].

Friedlander, B., 1985. Adaptive Algorithms for Finite Impulse Response Filters. In: C. F. N. Cowan & P. M. Grant, eds. *Adaptive Filters.* Englewood Cliffs, New Jersey, United States of America: Prentice Hall, Inc., pp. 29-59.

Hunt Engineering, 2012. *Choosing FPGA or DSP for your Application.* [Online]
Available at: http://www.hunteng.co.uk/info/fpga-or-dsp.htm
[Accessed 15 01 2016].

Ling, C., 2015. *MSc- Adaptive Signal Processing Assignment.* [Online]
Available at: http://www.ee.ic.ac.uk/msc_csp/dw1.pdf
[Accessed 12 12 2015].

Nishikawa, M., 2007. *Open-air noise cancellation system for large open area coverage applications.* US, Patent No. US20070223714 A1.

Parker, M., 2007. *FPGA vs. DSP Design Reliability and Maintenance.* [Online]
Available at: https://www.altera.com/en_US/pdfs/literature/wp/wp-01023.pdf
[Accessed 14 01 2016].

Prevention, C. f. D. C. a., 2013. *NOISE AND HEARING LOSS PREVENTION.* [Online]
Available at: http://www.cdc.gov/niosh/topics/noise/noisemeter.html
[Accessed 05 01 2016].

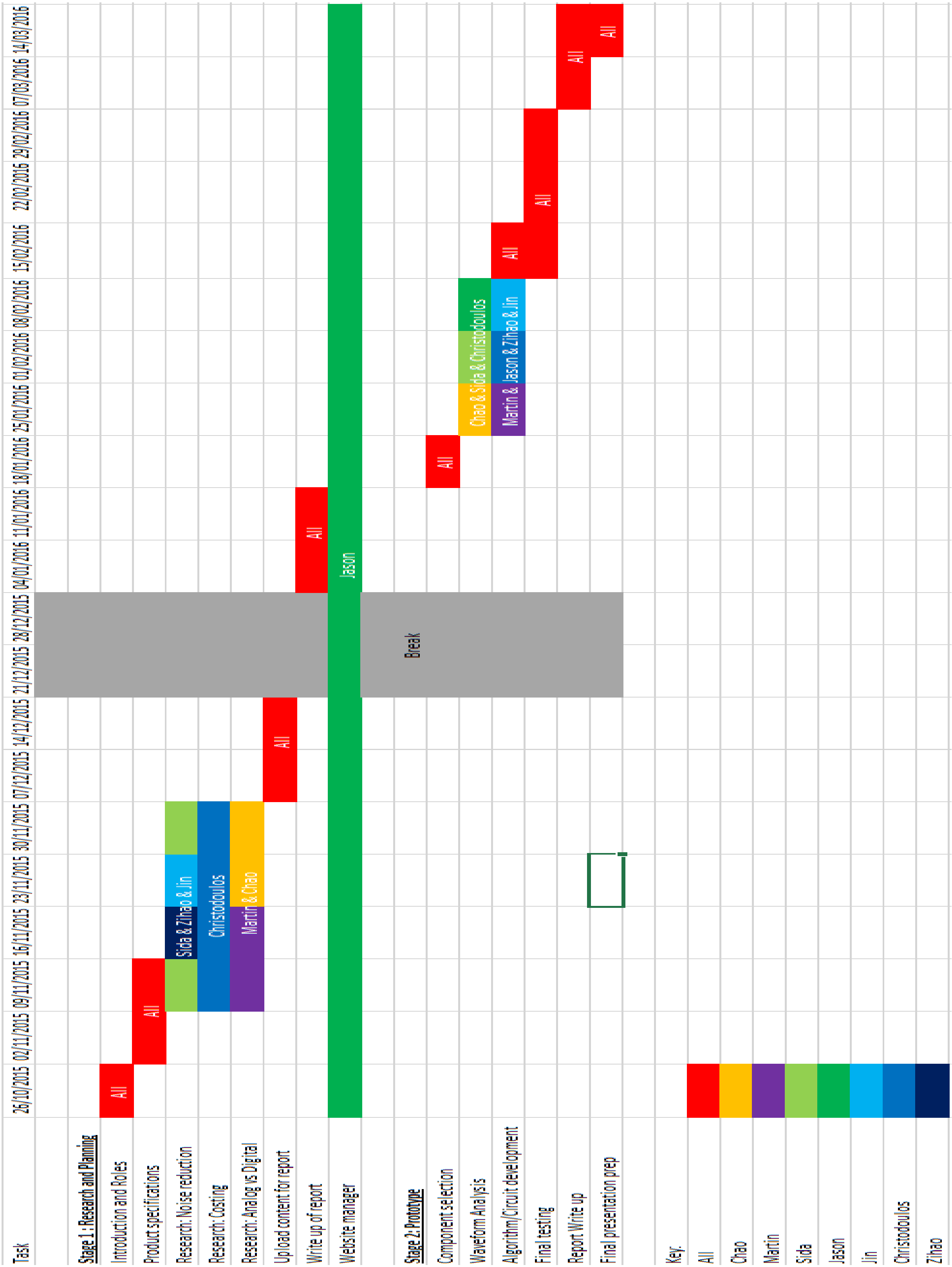
Stefanich, R., 2012. *SONO.* [Online]
Available at: http://id2studio.at/content/noise/
[Accessed 20 12 2015].

TI, 2015. *Digital Signal Processors.* [Online]
Available at: http://www.ti.com/lsds/ti/processors/dsp/getting_started.page
[Accessed 12 01 2016].

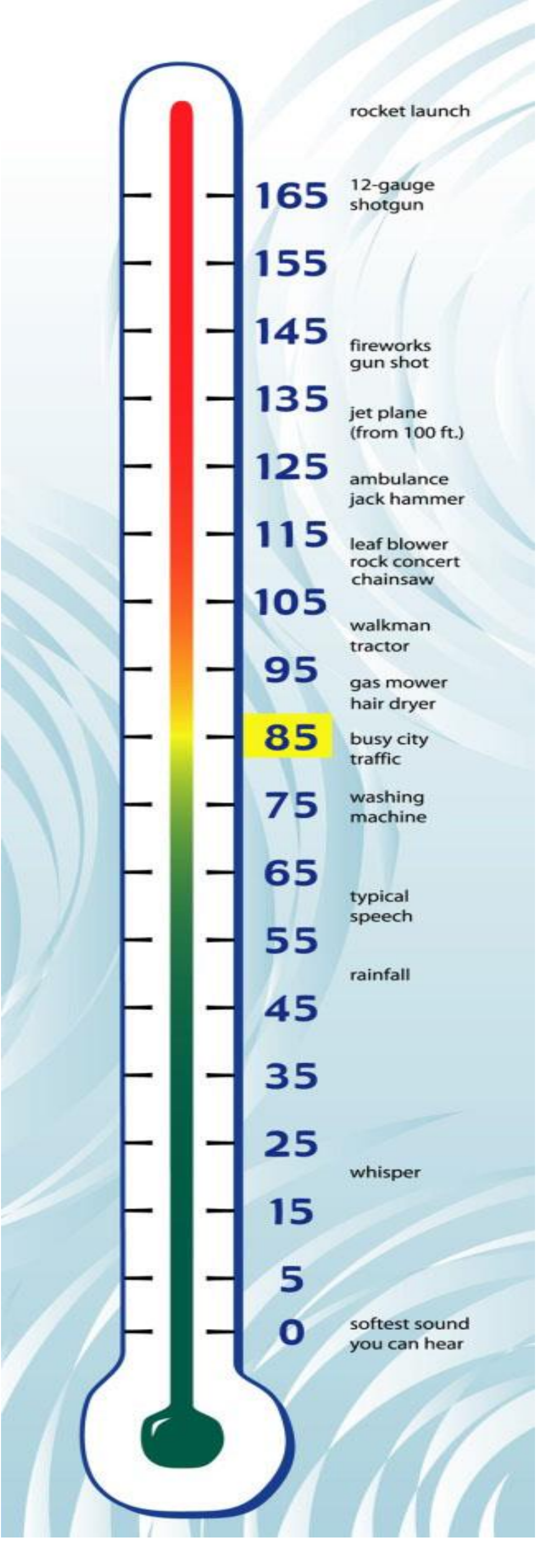
Appendix:

Appendix A: Gantt Chart of Project plan

Project plan



Appendix B: Noise level chart



Noise level chart shows different sounds and their associated decibel level. Taken from Dangerous Decibels (Dangerous Decibels, 2015).

Appendix C: Product Design Specification

Product Design Specification

Project: Peacemaker

Date: 30/11/2015

Author: Group 37

1. Performance

Satisfactory performance is vital for any product. The following performance criteria are target aims of the project:

a) The incoming noise must be attenuated to a level significantly lower than normal conversation level, around 65 decibels. [Appendix B]
b) The output level of the device cannot be too loud. This needs to be determined so that the amplitude of the antiphase signal does not exceed that of the original.
c) Extensions of the product intend to selectively filter exceptionally loud noises above conversation level must be filtered out. Train noise, busy traffic and construction sites are all examples of noise that is louder than normal.
d) There must be a large enough frequency range to target noise that may be of a higher frequency.

Ideally, a state of isolation is achieved within the target area from external sounds. The project shall investigate to what extent this ideal can be achieved.

2. Environment

The end product needs to be portable, making the operating environment important. The devices needs to be able operate at room temperature in all seasons and in most indoor environments.

Other considerations:

a) While the product is designed mainly for indoor operation, this can be extended for outdoor operation through protection against the weather.
b) There is no aim to have the product operating in extreme temperatures, such as sub-zero temperatures or high heat as this will increase overall cost of the product.

3. Life in Service

The product must be able to be repeatedly used over a period of time. The target product lifespan is one year on full performance. Additionally, there is a target a length of 4 hours of continuous performance on rechargeable batteries, which is necessary to extend the device’s portability.

4. Maintenance

No need for regular system maintenance, aside from charging the batteries. The intention is to use materials that don't attract as much dust to ease of the cleaning the exterior of the product.

5. Target Product Cost

The target market - students and working professionals may have a relatively low-budget. The aim is to make the product as cheap as possible, without compromising on portability or performance which is our main consideration.

6. Competition

ANR is not a new idea. There are similar technologies available in the market, such as noise cancelling headphones and noise cancelling systems in cars that can cancel noise very efficiently. A number of characteristics exist that distinguish our product from its competitors:

a) The "zone of isolation" concept to allow interactions in an area without outside interference.
b) A portable device that can be set up in different locations with flexible positioning.
c) Adjustable output levels.
d) Does not require the use of a surface.
e) Selective filtering of particular sounds.

7. Shipping

Product for the time being will only be delivered in place of manufacture to ease shipping.

8. Packing

No special packing for the product required.

9. Quantity

One set per user. Quantity of modules undetermined at this point.

10. Manufacturing Facility

Not applicable.

11. Customer

The target customers are currently primarily students and home professionals. They are the ones most likely to be dealing with a noisy urban environment, and require a cheap but effective solution to interact while being shielded from external noise. The aim of the project is to find whether electronics can provide a portable solution for these customers.

The solution would however generally benefit anyone who works in a noisy environment, where they can interact without being disturbed. This is applicable to restaurants/cafes and offices, where these devices can be used to isolate groups of people from one another.

12. <u>Size</u>

Related to aesthetics and appearance is size, a crucial criterion in the project. The devices used in the solution cannot be too big; they need to be small and light enough to be portable. As a result, the product should be small enough to be moved around.

13. <u>Weight</u>

Relatively light around 2 kilogram or less

14. <u>Materials</u>

Could potentially use material that are to prevent damage in case of household accidents like spilling water or leaks. Materials that affect performance will not be used.

15. <u>Product Life Span</u>

Dependent on company requirements.

16. <u>Aesthetics, Appearance and Finish</u>

The product must be trendy, attractive and appealing enough for potential customers. The end product should be modern, elegant, and blends in with a variety of indoor environments. Different colours and other forms of customisability can be considered for the final product.

17. <u>Ergonomics</u>

Not applicable.

18. <u>Standards and Specifications</u>

Not applicable.

19. <u>Quality and Reliability</u>

Related to life in service and environment is quality and reliability. As customers will rely on the product to carry out activities and socialising without disturbances, the accuracy and reliability of cancellation is very important. Ideally, the product must be able to reproduce a satisfactory drop in the noise level every time, and cannot break down within the targeted life of service.

20. <u>Shelf Life</u>

As most of the components used will be primarily electrical components that have a relatively long shelf life. 3 years or more predicted.

21. <u>Testing</u>

Testing procedure detailed in report.

22. Processes

Not applicable.

23. Time Scale

Projected 1 year or more.

24. Safety

Minimal safety risk.

25. Company Constraints

Constraint of roughly £50 for product prototype. The cost of the product targeted lower than £40 to produce to ensure a good profit margin.

26. Market Constraints

Due to the daily evolution of technology, constant product feedback is required to ensure the product does not fall out of the market.

27. Patents, Literature and Product Data

As mentioned before, ANR is not a new area of research. The group is aware of existing patents such as on "Open-air noise cancellation systems" (Nishikawa, 2007) and "Wide area noise cancellation systems" (Christopher A. Brown, 2012) do exist and will avoid infringing on any intellectual property laws.

28. Legal

Not applicable

29. Political and Social Implications

Not applicable

30. Installation

As portability is a very important criteria, the product needs to be easy to set up; it must be simple enough to allow anyone to set it up with ease. The aim is to have convenient setup and minimal controls to allow for intuitive and easy use.

31. Documentation

A full specification of the product including voltage, current and power will be included on the product's documentation. A user's manual will be provided to ensure customers can use the product with ease.

32. Disposal

Proper disposal of the product is documented in the user manual.

Appendix D: Meeting Minutes

Minutes: (26/10/2015 – 11/1/2016)

26 Oct 2015:

Attended: Whole Group

Discussed about the main idea of the project. Tried to understand the objectives of the active noise reduction.

2 Nov 2015:

Attended: Whole Group

Roles have been assigned:

- Circuit and PCB design (Chao and Sida)
- Theory and Research (Jason and Jin)
- Mathematics (Zihao)
- Digital Design/Filter Design (Martin and Christodoulos)

Discussed between Low and high frequency Active Noise Reduction (ANR). Decided to go with Low-Frequency ANR.

9 Nov 2015:

Attended: Whole Group

Started specifying the product, its limitations and any desirable extensions. Research tasks have been assigned to everybody.

Extensions:

- PCB Design
- Targeted Noise reduction
- 3-D noise reduction

Limitations:

- Costly and difficult to detect and anti-phase high frequency waves.
- Digital system may be to slow (consider analogue signal processing too).
- Natural frequency of glass can cause shattering.
- Concerns regarding size of device (trade-off between performance and portability).
- 3-D requires a lot more microphones and speakers.
- Power considerations (battery or mains).

16 Nov 2015:

Attended: Whole Group

Organise meeting with supervisor.

Rough time-plan.

Start working on PDS.

18 Nov 2015: (Supervisor Meeting)

Attended: Dr Cong Ling, Whole Group

Met with our supervisor, Dr Ling, to discuss our progress and give us some feedback and his opinion.

Adaptive Signal Processing methods and algorithms have been introduced [Least Mean Square (LMS) and Recursive Least Squares (ALS) adaptation algorithms in the context of echo cancellation].

Supervisor suggests microprocessor instead of an FPGA.

23 Nov 2015:

Attended: Whole Group

Worked on PDS.

Decided to set a meeting with Mrs Perea to discuss for clarifications.

23 Nov 2015: (Meeting with Mrs Perea)

Attended: Mrs Perea, Martin, Christodoulos

Talk about all possibilities and considerations before narrowing down (can use bullet points)

PDS is required (but not all criteria will apply, or not enough data at least)

Project direction is NOT set in stone

Project primarily a feasibility study (impossibility does not denote failure)

7 ideas as guideline and not rule

Advised to contact academics who might know about subject - but come with a concrete question

Can look outside the department

30 Nov 2015:

Attended: Whole Group

Finished PDS.

Start thinking about the device and more technical parts.

Start thinking of report structure.

Made a rough time plan

Made a rough plan on how the work is to be divided among members

30 Nov 2015: (Meeting with Mrs Perea)

Attended: Mrs Perea, Martin, Christodoulos, Chao

Can send PDS headings to allow for assessment

Project Plan must be present, inclusive of management plan

Minutes in the appendix

Do not put confidential information on Facebook (e.g. patents)

Gantt Chart is essential to show project plan

Possibility of updating description of the group

7 Dec 2015:

Attended: Whole Group

Shortlisted the most important PDS points to elaborate on.

Divided the report and each group member has been assigned with a task to work on.

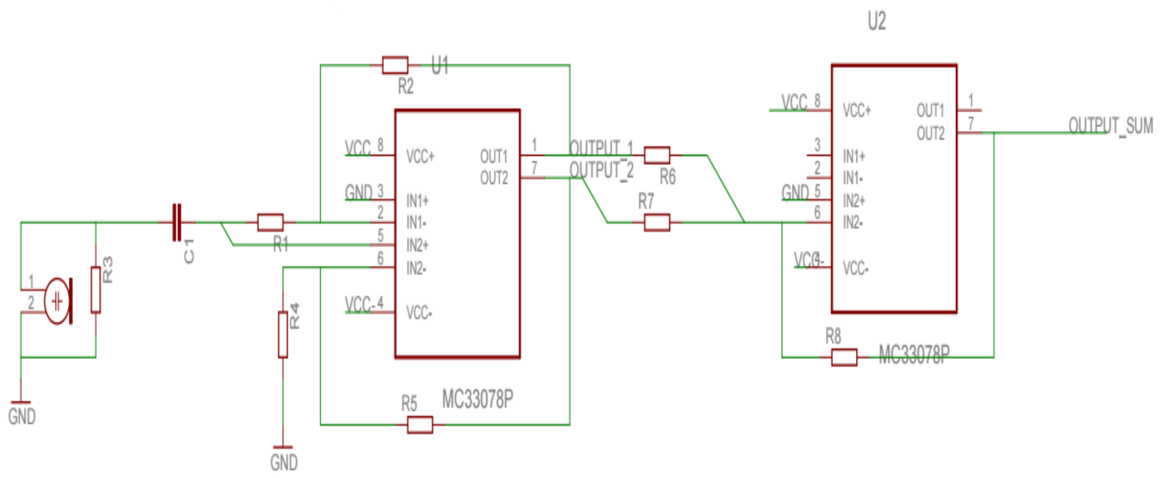
11 Jan 2016:

Attended: Whole Group

First meeting after Christmas holidays.

Detailed report writing started.

Appendix E: Demonstration Circuit



As a demonstration circuit, we create a circuit with a microphone and a 3 general purpose op-amps. The output of the microphone is fed into a non-inverting amplifier and inverting amplifier with a gain of approximately 10 each. This is then connected to a summing amplifier. We ran a demonstration of this circuit and recorded a video of the process, accessible at: https://www.youtube.com/watch?v=RWkwaNf_YDk&feature=youtu.be

We run a series of tests:

1) Measuring output of inverting amplifier with voice input to microphone
2) Measuring output of non-inverting amplifier with voice input to microphone
3) Measuring output of summing amplifier with voice input to microphone

While the outputs of the inverting and non-inverting amplifiers are very large in magnitude, the output of the summing amplifier is very small. This demonstrates the principle of ANR at a theoretical level.