Project: Using Audio Ray Tracing to Acoustically Map Aircraft Interiors

Date: 01/09/22

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Version	Date	Author	Changes/Comments
1	01/09/22	Alex McDermott	Project Proposal

Update as of 02/09/22

On this date, Andras and I had a scheduled meeting with Clinton to discuss the direction and further details about the project. We were then informed that Airbus had backed out of supervising the project as they were unable to find anyone to take up the role. This was unfortunate as we were excited to work with the company and get more information regarding the project but sadly this didn't work out. Despite this Clinton has been supportive regarding this abrupt change in project leadership. He made it clear that we are free to take the project in any direction that we wish and was happy to help acquire any resources that may need for its completion. At the time of writing, it has not been decided if the project focus will change dramatically or not but it appears likely that we will stay with the theme of active noise cancellation but possibly move away from the aircraft environment. The majority of this proposal had been written before hearing this news and hence has remained unchanged with the remainder being written in the context of the project staying the same for the sake of coherence and to avoid a topic change mid-report.

General Objective

Given the noisy nature of aircraft cabins, and the current solution to noise reduction being cumbersome and somewhat uncomfortable damping headsets, this project was formulated as a possible solution. The idea is to create, and constantly update, an acoustic map of the rear cabin of a helicopter and use this information to play counter phase sounds into the environment. Theoretically, this could create quiet zones and lead to a vast improvement in noise levels, thus, reducing stress and increasing comfort. The research question, is this process feasible? Is it possible to cancel noise in a larger 3D space such as around a passenger's head? With the research conducted throughout this project, as well as the literature review outlined in this proposal, we aim to answer these questions and work towards a feasible solution.

Key Finding from the Literature - Impact on Your Project Design

There were several key takeaways that were gained from analysing previous literature in this space. Firstly, the need for this project was justified by a study that expressed the negative effects on well-being due to high noise levels in aircraft and transport. Another fundamental takeaway solidified by literature was the general structure of current active noise cancelling systems and how approaches vary between headphones, cars, and aircraft. These papers provided excellent information and their ideas will likely contribute greatly to the technical approach of this project. Finally, it was evident some approaches would not be applicable in the context of the project. The dynamically updating spatial map and ray traced simulation approach that was initially suggested by Airbus will likely be disregarded due to its apparent infeasibility after comparison with approaches seen in the BatMapper literature reviewed below.

Stakeholders & Resources

Several stakeholders must be kept up to date on this project's progress and deliverables. Firstly, there is the fellow student I am collaborating on this effort with, Andras Tribe. Secondly, there is Professor Clinton Fookes who is our QUT representative project supervisor. Finally, there is an industry partner and original pitchers of the project, Airbus. Currently, despite having been in contact with a representative from Airbus we are yet to meet our official industry supervisor as the original contact has since moved on and a replacement is still being found. Working under extremely limited industry guidance and after the confirmation that there has been no previous work on this project, we have taken this as a blank slate with limited restrictions on design possibilities.

In terms of required resources, we have been informed that we can gain access to GPU instances through both QUT and Airbus which will likely be very necessary throughout this project. We have also pitched the idea of using FPGA devices for lower latency and our QUT supervisor Clinton has graciously agreed to purchase some if needed. Another aspect that is yet to be determined completely is what sort of environment will be used for testing and data sourcing. Will we have access to a cabin through Airbus? The current consensus is that this is not likely for most of the development. Although a site visit might be possible at some point, it will most probably be for exposure to the company's operations and would not be a suitable chance for testing. Another crucial part of this project will be the audio equipment, mainly the microphone setup that will be used to assess the acoustic environment of the cabin. Based on the literature review included in this proposal it is highly probable that several microphones will be needed. The acquisition of this hardware has not yet been discussed and will be covered when we begin physically building our first interim deliverable which will be discussed below.

Project Methodology

This project will be conducted following the engineering method. Currently, we are in the early stages of Project Definition, researching current and historical work in the form of a literature review included in this proposal. Although completed as part of this deliverable, it is an ongoing process and staying up to date with the field allows the incorporation of new work that may be released over the course of the project. As part of these early stages, Andras and I are working on outlining additional deliverables and milestones that we would like to complete alongside those outlined by QUT as part of the thesis honours project. This is inteded to break down the problem into smaller more achievable chunks that can eventually be incorporated together into a bigger more complete solution.

In later stages, once a physical or simulated prototype has been established, it will be required to thoroughly test and verify that it is working as intended. This by nature, is an iterative process and as issues are discovered they will be fixed and improved before repeating the same process until a desired level of polish is reached. This level is yet to be defined due to limited contact with Airbus at this stage but will likely be a deciding factor in the complexity of the project.

Timeline and Deliverables

The majority of the deliverables outlined below are those laid out by QUT as part of the honours thesis project which provides a good structure for keeping industry partners and supervisors up to date on project progress.

At this early stage, we have two additional high-level deliverables planned. Firstly, a small-scale active noise cancellation proof of concept. Due to the complex nature of this project, we aimed to set this as an achievable goal by the end of the semester. To summarise, we aim to have noise simulated as a sine wave by a speaker, a microphone to act as a passenger, as well as a second microphone and speaker to facilitate the interception and cancellation of incoming noise. This is expected to provide a good indication of the kinds of latency we can expect as well as assess the amount of precision needed to provide a satisfactory result at that scale.

Our second interim deliverable at this stage is to test a microphone array's ability to pinpoint sound sources in a three-dimensional space. We intend to create a spherical array of microphones while having a speaker emitting noise from a specified point. Utilising the differences in intensity at each microphone, their physical offset, and the time delay between them, we hope to be able to determine the location of the sound source.

We plan on introducing more smaller deliverables as we test the feasibility and difficulty of these two approaches. It is hoped that with experiences from these smaller tasks as well as leveraging the knowledge gained from the literature review, we will be able to combine them into a more complete solution.

Number	Name	Due	Dependency	Type
1	Project Proposal	W7, Sem 2, 2022	N/A	Assessed
2	Small Scale ANC Proof of Concept	W13, Sem 2, 2022	1	Interim
3	Project Progress Report	W13, Sem 2, 2022	2	Assessed
4	Locate Noise in 3D Using Mic Array	W7, Sem 1, 2022	2	Interim
5	Oral Presentation	W13, Sem 2, 2022	3	Assessed
6	Final Project Report	W13, Sem 1, 2023	3	Assessed
7	Oral Defence Presentation	W13, Sem 1, 2023	5	Assessed

Risks, Requirements & Constraints

Despite having had limited contact with Airbus, in the brief conversation we had with one of their temporary representatives, he confirmed that this project had received no previous work and would thus be a blank slate for approaches we were able to take. Being a software-based project with a harmless application and non-existent potential for physical harm, the biggest risk this project poses is a financial one, albeit quite small. If Andras and I decided to take an FPGA-based approach to this project and were unable to create a working solution, that could be a financial loss to QUT in the case they could find no use for such a device. Although this is quite unlikely as the project supervisor, Clinton had stated he recently purchased some for the lab which indicates they are indeed being used. Despite the risk being relatively small compared to that of physical injury in other fields, to minimise its potential, we will only pursue the purchase of the required hardware once we believe we can utilise it fully.

Quality & Sustainability

Within the literature review, a paper was analysed that outlines a method for measuring the performance of active noise cancelling systems over a spatial domain. Currently, we are looking at this as a potential metric to benchmark the quality of this project against both industry and our previous attempts as a method of measuring iterative performance gains or losses. Due to this project primarily taking a software approach to the defined problem, sustainability is less of an issue compared to some other resource-heavy industries. Despite this, rare metals found in some electronics are finite resources so if required it will be made sure that these parts are sourced and disposed of responsibly. In terms of power consumption, this project should not draw an abnormally large amount considering how commonplace computing is within our everyday lives. It is still important to be mindful of one’s carbon footprint however and to use sustainably sourced energy when available.

Management of Project Changes

Being a collaborative project, it is inherently necessary that Andras and I established and maintain close contact concerning research and progress towards our solution. Despite being a student led project is also extremely important to keep the project supervisor, Clinton, relatively up to date on significant changes whereas smaller updates can likely be compiled together for a later meeting in the interest of time efficiency on both sides. Our industry partner Airbus will also undoubtedly need to be kept up to date on project progress although it is yet to be decided on what interval these meetings will be held. As per the engineering method, it is standard that these project changes will be recorded in documentation of some kind for future reference by ourselves and others. This could either be in the form of a report or presentation, with comments and version control of source code also being options for more technical changes.

Sign off

	SIGNATURE	DATE
STUDENT ENGINEER	Alex McDermott	01/09/22

Appendix: Review of Literature

Introduction

When undertaking a research project, it is crucial to gain an understanding of work that has already been done in the field. This analysis of previous approaches is often done for approach inspiration, feasibility assessment, and increasing knowledge of industry context among other reasons. This literature review was performed based on the initial project outline provided by Airbus and has four key focuses. These are the effects of cabin noise on passengers, active noise cancellation history, its current use and application in vehicles, methods to evaluate its performance, and finally a look at the feasibility of spatial mapping to assist in the noise cancellation process. Several papers will be reviewed to get a grasp of these topics and the core ideas will be compared to the requirements and constraints required to operate under the context of this project.

Key themes

Effect of Cabin Noise on Passengers

Given that the primary motivation of this project is to decrease stress induced in passengers via aircraft noise, it is important to investigate any research that had already been done in this area. In the 2012 paper “Effects of aircraft cabin noise on passenger comfort” [1] it was found that sound pressure levels (SPL) along with noise frequency, were significant factors in predicting passenger wellbeing. In their test’s, rising SPL was followed by a significant increase in the sensations of “depression, grouchiness, irritation, anxiousness, and nervousness” [1]. Correspondingly, this caused “significant decreases in euphoria, cheerfulness, and relaxation” [1]. Although this doesn’t mean lower is always better in terms of SPL. In the 2003 study “Effects of Masking Sound on Train Passenger Aboard Activities and on Other Interior Annoying Noises” [2] it was found that some level of semi-consistent background noise can be beneficial. This was attributed to the fact it somewhat masks other more disrupting and annoying sounds such as phone calls and other passengers. Although the annoyances created by many other passengers are not as much of an issue in small helicopter cabins. This is still an interesting anecdote that suggests the possibility that a low amount of consistent background noise could be somewhat beneficial. In terms of the effect of noise frequency, surveyed passengers described optimal aircraft noise characteristics as being less “shrill and bright and more monotonous” [2]. This indicates that in terms of frequency components, higher frequencies may warrant more attention and their minimisation would result in a more rewarding result in terms of cabin comfort.

Active Noise Cancellation (ANC) in Headphones

Traditionally ANC has primarily only been used in headphones due to its convenience and the much smaller volume of the ear canal and headphone cup being a lot more feasible to model. Although it is still quite complicated technology and has only really become available to consumers in the last two decades or so despite being used within the industry for much longer. The 2018 paper “Signal Processing Challenges for Active Noise Cancellation Headphones” [3] outlines some common approaches and the complexities associated with them. A notable point they make for the argument on headphones vs spatial cancelling is the padding and sound insulating of an ear cup is a “feasible and cost-efficient” [3] solution to provide some passive attenuation of SPL. Although in the case of this project we are looking to get away from headphones, it is important to look at this previous work in ANC to serve as a performance and feasibility baseline. Providing a high-level overview for this report, they discuss differences between feedforward and feedback approaches, which is primarily microphone placement inside or outside the cup. They also express that these two approaches can be combined, as well as detailing notation for the different transfer functions, filters and weights that need to be identified to theoretically cancel unwanted incoming noise. Sadly, the report uses heavy technical notation which in some places is difficult to read and keep track of while doing little to explain how they are calculated. Although given the title, an in-depth procedure should not be expected, the report was still beneficial, as it provides context to current solutions and helps identify our need for a feedforward system.

Active Noise Cancellation in Vehicles

Having identified these needs, the earlier 1994 paper “Single-Sensor Active Noise Cancellation” [4] states their “proposed system is able to adapt to the changing noise statistics” [4] in a nonstationary environment. They outline, in much more technical detail, their autoregressive method for achieving 45 dB noise attenuation within a simulated helicopter environment. They also go on to state that “since the algorithms are adaptive in nature, they may be particularly useful in enhancing nonstationary signals such as speech” [4] which would be a great asset in this project as it could allow for the passthrough of pilot communication, alarms and other crucial cockpit or cabin auditory information. Similar results have been documented in the 2015 paper titled “Spatial Noise Cancellation Inside Cars” [5] where an attenuation of 30 dB for frequencies up to 500 Hz was achieved within a spatial region of 10cm radius. They achieved this by utilising the car's built-in sound system coupled with an array of microphones spaced throughout the car with a specific focus on the headrests. Utilising a hybrid feedforward/back system they were able to achieve this attenuation in a “real in-car environment” [5]. Another paper from 2022 titled “Active Noise Control for Aircraft Cabin Seats” [6] continued this theme of headrest noise cancellation, achieving an 18dB attenuation averaged across the two systems for the ear. They were able to create “an artificial comfort zone of 0.35 x 0.40 x 0.5m around the passengers head” [6] which is large enough in most cases to allow for common vertical and lateral head movements. It is important to note that these results were achieved in heavily controlled semi-anechoic conditions and were restricted to periodic noise, although this is common in a helicopter environment. The authors also worry that instabilities could be introduced with adjacent seats and the feasibility of the large increase in weight and cost from hardware and processing equipment.

Performance Evaluation of Spatial Active Noise Cancellation

If a solution is going to be developed that extends upon this existing work, it would be convenient and desirable to have a cohesive performance metric to compare between them. This is what is proposed in the 2016 paper “Evaluation of spatial active noise cancellation performance using spherical harmonic analysis” [7]. They succinctly define the core idea of the metric stating that the “acoustic potential energy within a spherical region can be expressed by a weighed squared sum of spherical harmonic coefficients” [7]. They propose to evaluate this by utilising a spherical microphone array. Testing its effectiveness with a series of narrow and wide band experiments. This approach proves to be beneficial when compared to existing approaches that take only two measurements at the ear microphones of the system. Due to its larger spatial sampling, it was recorded that when compared to the two-microphone system, “the potential energy attenuation is significantly worse compared to the 5-channel case, and the value even became positive (higher noise level with ANC active) at some higher frequencies” [7].

Dynamic Spatial Mapping and Ray Traced Acoustic Simulation

In their initial project listing, Airbus expressed the intention to tackle the problem with a dynamically updating spatial map coupled with the use of audio ray tracing. Having observed the above prior research on common approaches in the field and not seen a similar approach could be cause for concern with regards to its feasibility. Despite this, it highlights an interesting approach that is worth investigating as a possibility. The team behind “BatMapper: Acoustic Sensing Based Indoor Floor Plan Construction Using Smartphones” [8] released their paper in 2017 which documents their sound-based approach for interior space mapping. They devise a complex system of “robust probabilistic echo-object association, recursive outlier removal and probabilistic resampling algorithms to identify the correspondence between distances and objects” [8]. Through this process, their BatMapper solution can achieve “1 – 2cm distance accuracy in ranges up to around 4m” [8]. These are fantastic results and would be a great asset in taking a ray-traced approach to approximating sound wave bounces within a helicopter cabin. Although their solution relies on the user’s movement throughout space and the phone's gyroscope and accelerometer, correlating this data with the collected acoustic information to compare the relative distances to reconstruct room geometry. A stationary system within a cabin would not have this movement although a solution could be tested where speaker-microphone pairs are embedded throughout the cabin walls and their known locations could be used for spatial reconstruction. It is unlikely this solution would be able to achieve the same accuracy as BatMapper without the movement information. It may also encounter problems with the lower footprint, higher detail objects such as humans and chairs as opposed to walls in a room.

Conclusion

Reviewing the above papers as well as others throughout the literature review process has greatly helped increase my understanding of current and historical approaches within the field of active noise cancellation. The need for this project was solidified via the findings discussed in the first reviewed paper which looked at the effects of noise on passenger wellbeing. Several useful ANC were also identified, and although some did not directly relate to the helicopter-specific environment at hand, they provided useful information and processes that could be adapted to work in the target use case. There was also some information that was interesting, although not quite applicable to this project. Primarily, the last reviewed paper did achieve quality results in its application although its adaption to a more complex stationary environment would likely not be feasible or worthwhile. To conclude, the above papers have cemented the need for this project while refining its scope to focus on the useful techniques currently being employed and already achieving successful results in practice.

Appendix: References

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