

Rose Plumley Project Proposal

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Using Raytracing for Accurate Sound
Simulation in Gaming and Virtual
Environments

Research Proposal

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1. Introduction

1 Raytracing refers to a rendering technique whereby graphics are generated by “tracing the path of light from the view camera, through the 2D viewing plane, out into the 3D scene, and back to the light sources” [1]. As the “ray” travels through the 3D scene, it interacts with different objects in the scene, which depending on an object’s properties, causes effects like reflection, refraction, and absorption [2]. In this way, raytracing mimics the real-world behaviour of light for the sake of greater physical accuracy. In gaming, more accurate simulation of complex physical behaviours and interactions is used to create more immersive environments and experiences. However, this need not be limited solely to rendering. As raytracing is based on the interactions and physical properties of light – namely the processes of reflection, refraction, and absorption – then these same properties can be applied to simulate other environmental factors outside the realm of rendering techniques, such as for sound. By focusing on achieving greater accuracy for sound simulation in gaming, more realistic and immersive experiences can be created, resulting in more enjoyable experiences for the end user. In addition, a focus on realism has applications to both casual and competitive gaming – better sound simulation could be applied to games where sound plays a critical role in information gathering, such as in determining an enemy’s location relative to the player, just as much as it may induce greater immersion (or to a lesser degree, engagement, or engrossment [3]) from diegetic and environmental sounds.

2. Literature Review – Background to Proposed Research

2 Considering raytracing for sound, one must first understand its properties, as well as its interactions within an environment. For instance, Jansen and Steckel [4] show how raytracing can be used as the basis of an acoustic modelling system for simulating echolocation behaviour of bats. They produced “SonoTraceLab,” an open-source software package which simulates sonar systems in complex scenes by using a combination of raytracing for specular reflections, and an application of a Monte Carlo approximation for the diffraction echoes, for the sake of solving the Helmholtz equation, according to acoustic wave theory [5]. This is used as a cheaper and more time-efficient alternative to building, and performing with, a typical measurement setup – the article notes a typical setup would take at least over a working week to obtain first measurements, whereas use of the software would take at most two hours.

More focused on virtual and interactive environments, Pisha and Yadegari [6] show that, while ray or path tracing is used for simulation of sound propagation, the wave nature of sound means that realistic approximations of reflections may prove difficult, both from an accuracy perspective, and a time-efficiency perspective, especially in dynamic environments. The authors proposed an alternate method for reflection modelling: Spatially Sampled Near-Reflective Diffraction (SSNRD), which addresses the accuracy and efficiency concerns, able to produce results accurate to 1-2 dB when compared to edge diffraction, at a rate of thousands of paths in a few milliseconds in large scenes, scaling linearly with scene size after

an initial overhead. SSNRD is accomplished through “a combination of a combination of specific path generation methods, spatially sampling the scene with rays around reflection points, and approximating ground-truth edge diffraction results to within 1-2 dB with a [Deep Neural Network]”.

Irrespective of sound simulation methods, sound design for games in general should be considered, especially under the context of user experience and immersion. Nacke, Grimshaw and Lindley show how “the combination of psychophysiological and psychometric methods can provide reliable methods of affective user experience,” [7] focused on the presence of sound and music in a first-person shooter game. The research posits a statistically significant link between sound and user experience based on a Game Experience Questionnaire (GEQ), adapted from Ijsselstein, Poels, and De Kort [8] with a significant main effect on immersion, tension, competence, flow, negative affect, positive affect, and challenge, but additional recordings of electrodermal activity (EDA) and facial muscle activity (EMG) resulted in a lack of effect of sound on EDA or EMG. Results were taken via a two-way repeated-measures factorial ANOVA using sound and music as independent variables (on or off), and GEQ, EDA and EMG dimensions as dependent variables. A correlational analysis was also performed between GEQ dimensions and psychophysiological measures:

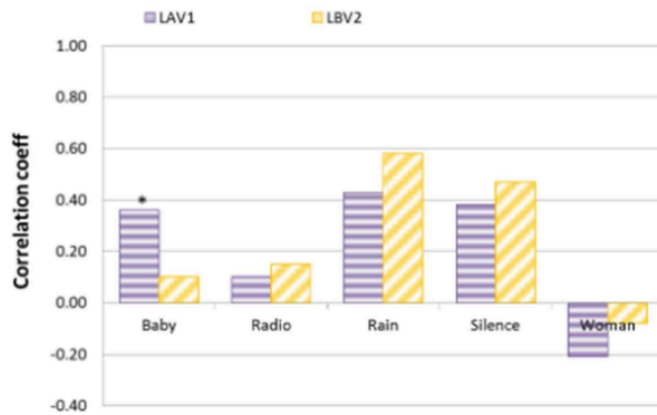
GEQ dimensions	Sound	Music	EMG OO	EMG CS	EMG ZM	EDA
Competence	On	Off	-.40	-.42		
Flow	On	Off				-.42
Sensory and imaginative immersion	Off	Off		.38	.40	
Flow	Off	Off			.40	
Positive affect	Off	Off		.34		
Challenge	Off	Off			.36	
Sensory and imaginative immersion	Off	On				-.37
Flow	Off	On			.36	

Note. Only statistically significant (2-tailed, $p < .05$) correlations are reported. For the condition *sound on, music on*, no significant correlations were found. [7]

The researchers suggest future research on phasic psychophysiological analysis of sound and music attached to game events, accounting for repeated game events, such as firing a gun.

More on the impact of sound on user experience, Graja, Lopes and Chanel [9] explored the effects of visuals, audio, and in-game interactions on a player’s experience in a horror game through a correlational study to determine which effects had the strongest physiological reactions, by comparing galvanic skin response (GSR) and self-reported participant emotional reaction in response to tension from different in-game events. Results showed

that sound-related events, particularly diegetic (non-ambient) sounds, were the most effective in stimulating tension and anxiety in players, achieving the highest relevance rates between GSR and participant emotional reporting, based on a binomially distributed pairwise correlation coefficient between GSR and annotation of different level scenarios in the horror game, calculated using the Kendall τ significance test.



[8] Graph

demonstrating correlation of each sound event in level A (LAV1) and B (LBV2), $p < 0.05$ represented by *.

Additionally, the project would benefit from knowledge of hardware limitations on user experience, namely through peripherals like headphones, which are themselves limited to bidirectional stereo audio, unlike a real-life scenario. To mitigate this, various developments towards acoustic rendering techniques have been made alongside hardware developments, such as Jot, Audfray, Hertensteiner and Schmidt's [10] approach to designing 6-degree-of-freedom object-based interactive audio engines; especially relevant for more recent wearable technologies like virtual reality headsets. The proposed rendering engine and programming interface prioritise plausibility and immersion, with minimal computational footprint and application complexity – with particular capability of simulating acoustic reverberation decays of different rooms and rendering of clustered reflections between objects for perception-based distance simulation.

Supplemental to the 6-degree-of-freedom approach to audio, considering user location, Cui, Cai and Yu [11] demonstrate the importance of auditory localisation of spatial sound sources through a graphical user interface (GUI) based azimuth-collection method involving 12 loudspeakers arranged in equal azimuthal intervals of 30 degrees horizontally, with azimuths reported using an assistant, a motion tracker, or the aforementioned GUI method. Two experiments were performed, one involving the loudspeakers, another involving a 2D GUI and virtual sound sources, both recording differences in localization accuracy. Results found slightly more inaccurate determinations in the GUI method, with absolute positioning error

in the range of 5-to-10 degrees, though this is only about 3 degrees larger than methods involving an assistant or a motion tracker, with no statistically significant difference between each method. Conversely, performances decreased proportionally as sound sources deviated from the front plane across each method.

Also of note, the project should consider environmental acoustics. Scerbo, Savioja, and De Sena [12] explore the differences between geometrical acoustics (GA) models for computing impulse responses at interactive speed, and delay-network-based models for modelling room acoustics at low computational cost, presenting two extensions of the designs; the first involving a physically-based and stability-preserving design of feedback matrices (for more accurate control of scattering and late reverberation properties), and the second involving the modelling of an arbitrary number of early reflections with high accuracy. Ultimately, both extensions were combined to approximate Acoustic Radiance Transfer (ART), with this model evaluated based on frequency-dependent reverberation times, normalised echo density build-up, and early decay times. Results found a significant improvement over baseline models.

3. Research Problem Statement

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This project seeks to improve simulation of real-world sound phenomena in a virtual environment for the sake of increased immersion.

4. Research Aim and Objectives

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The project aims to create a visual representation of a raytracing-based solution for accurate sound simulation in a virtual environment, with the goal of improving simulation of real-world sound phenomena for the sake of increased immersion. This should focus especially on audio reflection, refraction, and absorption, with consideration towards audio source direction, environmental objects as obstacles, their materials, and how they may affect sound quality. The goal at minimum is to create a visual representation based on raytracing methods and algorithms, but this should be expanded upon as a combined visual and sonic solution.

As a bullet-pointed list, the project aims:

- To design a raytracing algorithm for the sake of modelling sound propagation
- To implement and integrate this algorithm into a virtual environment, visually demonstrating sound as "rays," developed graphically using software like OpenGL or Vulkan
- To develop this implementation further, considering reflection, refraction, and absorption
- To consider environmental objects and their effects on sound "rays," such as obstruction and material composition

5. Research Methodology

5.1 Research Design – Philosophy and Approach

9 Using Saunders et al.'s "research onion" as a basis [13], the project's research design should be mainly based around positivism – focused on objective based and measurable reality. While an argument could be made towards interpretivism (focused on understanding the user experience, behaviours, or interactions), the project's development should be focused primarily on objective accuracy. The user experience or "level of immersion" could be explored as a subsequent evaluation of the implementation's success, though this is not strictly necessary.

Using a positivistic research philosophy as a basis, this means that any following research methods should be, by majority, deductive in nature – beginning with a hypothesis based on existing theory, and then designing a research strategy to test this in turn [14].

5.2 Methods and Materials

Based on the research philosophies outlined above, any methods should be quantitative in nature. The project by majority will be focused on developing an algorithmic solution to sound simulation, and thus any data needed or collected will likely be numerical. However, there is room for methods to become mixed – as the research aims to increase immersion through the implementation, a measurement of success could be based on subjective user experience, which would be measured more qualitatively. However, this would also rely on the application of the completed implementation into a more concrete and approachable environment, like that of a game.

The research strategy should thus follow software development [13]. The aim is to create a raytracing-based solution to sound simulation, and thus software needs to be developed to test this as an effective proof-of-concept. Should the completed project be applied to a more conventional game environment, a comparative study could be made between the raytracing-based implementation and a more typical sound design solution, with qualitative measurements collated from participants via survey or interview. However, this is more suited to further or supplemental research, and thus the current project is best suited to software development as a strategy.

As for development specifics, as the project is based around raytracing, any software should use relevant graphics programming libraries or source development kits (SDKs), such as Vulkan or OpenGL. This also implies the use of an integrated development environment (IDE) such as Visual Studio 2022, likely in C++. Analysis and evaluation should be related to real-world sound metrics, how similarly the proposed raytracing solution acts to actual sound waves, be it from outlined

behaviours (reflection, refraction, absorption), decay time (especially considering absorption as a point), or other external behaviours not yet accounted for (such as resonance). Ethically, any data collected has low risk; the project is solely focused on software development, and thus no external participants are strictly necessary.

As for other materials, the project necessitates a laptop or computer capable of performing raytracing in a timely manner, ideally with a more conventionally powerful GPU (such as the Nvidia GeForce RTX 30 Series) and accompanying CPU, though this is more for the sake of convenience; integrated graphics will work just as well when creating a prototype. Additionally, accompanying theory should be acquired based on graphics programming in general, Vulkan (documentation), ray tracing and algorithm examples, etc.

6. Project Plan

 11 list of milestones:

- Practice graphics programming in OpenGL to learn the basics
- Perform further research into raytracing, substituted with additional resources such as the Ray Tracing in One Weekend series [15]
- Perform initial research into Vulkan, reading documentation, making note of necessary SDKs and libraries
- Practice using Vulkan to develop a simple graphics project, such as creating a cube in 3D space.
- Attempt implementation of a raytracing algorithm using Vulkan (not necessarily sound-based)
- Adapt the raytracing algorithm with sound in mind (e.g. rays cast not just from the camera and viewing plane, but from all directions from the user in a virtual environment). Actual sound feedback (i.e., not just visual rays emitted by a central character or camera) could be introduced at this stage.
- Develop the sound implementation further, such as implementing ray culling, improving upon the base solution
- Continue to develop the implementation by incorporating reflection, refraction, and absorption properties for rays
- Adapt ray properties according to environmental variables in the developed virtual environment (e.g. sound obstruction, object material composition, and their effects on sound rays)
- Evaluate implementation based on real-world acoustic properties such as reverberation, sound decay, etc. ==> is the implementation comparable to real-world scenarios?
- Adjust implementation based on evaluation, e.g. developing new sound ray properties to better mimic real-world conditions and effects

- If time remains, adapt the implementation to a game environment as further proof-of-concept

At regular intervals, and especially at each milestone, regular time should be taken to check in with a supervisor for advice, support, and feedback. As for a rough timeline of events, milestones 1 through 4 should be completed between November and December 2025, grouped together as a practice/experimentation phase. Milestone 5 should be completed by the end of January as an initial foray, leaving plenty of time to research, experiment, and adapt. Further raytracing exercises and implementations should be completed faster from this point, with milestones 6 through 9 being completed by the end of March at the latest. Milestone 10 is delicate, and will involve the most data collection and statistical analysis, and thus April should be set aside for it. The final two milestones are not as necessary, but should ample time remain, they can be addressed through May. Note however, that the final project deadline should be on the 11th, coinciding with an expected exhibition poster and materials hand-in.

7. References

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GRADEMARK REPORT

FINAL GRADE

67 /100

GENERAL COMMENTS

Introduction/Aims & Objectives: 13/20

Background/Literature Review: 16/20

Project Design/Methodology: 16/30

Resources/Planning: 12/15

Document Presentation: 10/15

This proposal demonstrates technical understanding of raytracing and identifies an interesting application domain in acoustic simulation for gaming.

The literature review is comprehensive, strong evidence of engaging with academic sources and demonstrating familiarity with current research including quantitative performance metrics.

Literature review mostly descriptive rather than critically evaluative. Critical evaluation of sources in a literature review is essential to ensure the reliability, validity, and relevance of evidence supporting your research. It enables you to distinguish between rigorous, well-conducted studies and methodologically flawed work, identify gaps in existing knowledge, and construct a credible, well-founded argument that strengthens your research's intellectual foundation.

The introduction effectively contextualises the research problem and sets the stage for a strong proposal.

The objectives are not formulated in SMART format whatsoever - they lack any measurable or quantifiable targets. Phrases like "design a raytracing algorithm" and "develop this implementation further" provide no basis for objectively assessing completion or success. Additionally, there is confusion about whether this is primarily a visualisation project ("create a visual representation", "visually demonstrating sound as rays") or an acoustic simulation project. This fundamental ambiguity needs resolution.

PAGE 1

PAGE 2

PAGE 3



Comment 1

Excellent contextual introduction that demonstrates strong understanding of raytracing principles. The analogy between light and sound propagation is well-articulated and provides clear justification for the research direction. The discussion of practical applications in both casual and competitive gaming shows thoughtful consideration of real-world impact.



Comment 2

Good engagement with relevant academic literature with specific quantitative comparisons (setup time: >1 week vs. 2 hours). The reference to SonoTraceLab provides a useful existing framework. To improve this add critical analysis. Instead of just describing SonoTraceLab, evaluate its limitations



Comment 3

I liked the inclusion of quantitative performance metrics

PAGE 4



Comment 4

Strong inclusion of user experience research with detailed statistical methodology (two-way repeated-measures factorial ANOVA). This shows understanding that technical accuracy must be validated through human perception studies. Whilst describing the statistical methods is good, lacks critical evaluation



Comment 5

Use captions to describe images/tables



Comment 6

Literature review is becoming descriptive rather than critical. You are summarising papers without evaluating their methodologies or identifying gaps. Each paper should be followed by analysis: What are its limitations? How does it relate to your proposed work? What questions remain unanswered?

PAGE 5

PAGE 6



Comment 7

Very short



Comment 8

ambiguity about project focus. The aim states "create a visual representation" and "at minimum is to create a visual representation" but also mentions "combined visual and sonic solution". Is this primarily: (A) A visualisation tool showing how acoustic rays propagate? OR (B) An actual acoustic simulation system that generates spatialised audio? This must be clarified immediately as it fundamentally changes the project scope, technical requirements, and evaluation criteria.

Objectives are NOT in SMART format. They lack Specific targets, Measurable outcomes, Achievable scope definition, Relevant connections to aim, and Time-bound deadlines.

No success criteria defined. How will you determine if the project succeeded?

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Comment 9

Good discussion of research philosophy with appropriate academic references (Saunders et al., Wilson). Positivist approach with deductive reasoning is well-suited to software engineering research focusing on objective acoustic measurements.



Comment 10

Appropriate technology choices (Vulkan/OpenGL, Visual Studio, C++). Good identification of relevant evaluation metrics (reflection, absorption, decay time, resonance). These are the correct parameters for acoustic validation.

No detailed evaluation protocol specified.

Statements like "related to real-world sound metrics" and "how similarly the proposed raytracing solution acts" are too vague

Ethics discussion is minimal and contradictory.

Statement "no external participants are strictly necessary" conflicts with earlier mentions of user experience evaluation. If conducting ANY user testing, you MUST address this with the ethics form.

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Comment 11

Comprehensive milestone structure (12 milestones) showing logical progression: learning fundamentals (OpenGL, Vulkan) → implementation (raytracing, acoustic adaptation) → refinement (reflection/absorption, environmental effects) → evaluation. The gradual build-up from basics to complex features is sensible and realistic. Recognition that game environment integration is optional ("if time remains") shows appropriate scope management.

Milestones lack measurable completion criteria.

PAGE 9



Comment 12

No Gantt chart or visual timeline. Visual representation aids understanding of task dependencies and parallel activities.

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PAGE 11
