Comprehensive Creative Technologies Project: Realistic Echolocation Visualisation

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Abstract

This report details a more realistic simulation of current implementations of human echolocation in an environment within games and how this was achieved in Unreal Engine 5 (UE5). The goal of this project was to present a visualisation of echolocation through the mind of individuals who are visually impaired. The result of this artefact displays the use of blueprints and shaders to obtain an outcome where the appearance of the environment is dependent on sound and user movement, as well as the volume and materials of certain rooms and objects.

Keywords: Unreal Engine 5, blueprints, shaders, echolocation, visualisation

How to access the project

All project files and videos are held on this OneDrive link: https://uweacuk-my.sharepoint.com/:f:/g/personal/asli3_baltaci_live_uwe_ac_uk/Eqz5xAfx_m9Fux5GhV-VHDgBMMYBqxk3mV6EIhssLuSPwQ?e=wucaQ6

1. Introduction

Echolocation is used to acquire information about one's physical surroundings. It is a technique used by a small number of animals, and some humans with visual impairment (Ayers, 2021). Since the phenomenon of echolocation cannot be directly experienced as no one with the ability can create the simulation, there are many theories on how it may be visually represented and how it helps animals and people who possess this capacity to perceive their surroundings. When the brain is deprived of visual cues, humans exhibit the unique ability known as blindsight to create images that are not truly present in the dark (Weiskrantz, 2011).

Some games, such as Lurking and Perception, have created a material which reveal the wireframes of the environment, and a burst effect that highlights everything within a certain radius, with a slightly altered colour effect (Guo Xiong et at, 2014) (The Deep End Games, 2017). The current approaches include normal mapping, a method of enhancing surface detail, light spawning, to create lighting effects, and post-processing effects.

This project's objective was to develop an interactive simulation that would enable users to experience how visually impaired people can perceive their surroundings through audio cues, which in this instance are frequent flashes that travel along the environment within a certain radius of the player. The speed at which the player moves will determine the circumference, intensity, angle, and distance the pulses travel and reflect off surfaces. There is a lack of disability representation within modern media, which results in a lack of understanding of blindness and echolocation. This project could help more people become aware of this impairment and understand how certain individuals who can echolocate live with it.

The artefact was created using UE5s graphics which have become more popular within the industry due to its advancements (Giant, 2022). Using UE5s shader features, the pulsating VFX will be very easy to alter and implement into different games due to its adjustable nature. Blueprints were used instead of the C++ language. Using nodes instead of C++ code makes things much simpler to follow.

The key objectives for this project are to:

- Create a pulse so its circumference and intensity are dependent on player movement.
- Integrate an optimised post-processing audio-pulse that exposes the players' surroundings.
- Develop a method to represent how different materials appear through echolocation due to their density.

The deliverables of this project are:

- An interactive visualisation based on research.
- A shader which generates the VFX.

2. Literature review

Echolocation is the ability to locate and collect spatial information from sound waves. The clarity of these objects is determined by the material, distance, surface area, and size of the object within the environment.

Current literature on the topic of echolocation has sought to test individuals' echo-detection sensitivity. Scholar, Tirado Aldana (2011) categorised echolocation as the capacity to detect, localise, discriminate, and, overall, gather spatial information from sound reflections. Aldana's research found that participants performed better in echo-detection than the echo-localisation tasks, but noted his study was a "general discussion of the plasticity and temporal limits of the PE". Aldana defines echo-localisation as "the ability both to detect and also localise an object using echoes as the main cue", and echo-detection as a method to detect whether or not an object is present within the given area. Some individuals may have the ability to unlearn the precedence effect (PE). PE is when our auditory system prioritises spatial information from the first wave reflected instead of the spatial information from the second wave for perception and localisation (Litovskya et al, 1999). This affects the way the simulation will be presented as the player should only be able to see the environment after a small delay as the first projected wave is of more significance, and the brain requires time to learn where obstacles are within the area after a certain time period, and any movement after the initial projection will affect the visual localisation of objects. The simulation will attempt to reflect this effect.

Depending on the given medium, sound waves partially reflect off of surfaces. Given mediums can cause alterations to the perception of the echo, pitch, and intervals depending on its density. Sound waves travel a lot slower in the air as gas consists of much fewer particles, therefore the reflection of the wave from a surface depends on the medium. A medium like concrete causes sounds to reflect off it as it is a local disturbance whose propagation is achieved by collisions between particles in a material (Ashish, 2022). Particles in a solid are packed closely together and as a result, the vibrations that these particles experience are passed onto other particles. Because of its rigid and dense properties, it cannot transmit or absorb sound.

The transmission of sound is caused by particle vibrations that cause nearby particles to vibrate as well, allowing the sound wave to travel to different locations. Whereas the absorption of sound occurs when the waves are not reflected and are converted into heat energy (Vedantu, 2023).

When Wood causes the sound to travel slower as it is a porous and inconsistent material, therefore resulting in attenuation, which reduces the waves oscillations, size and scattering of the wave (Ritchie, 2023). Glass conducts sound, which guides the sound waves to a different location depending on its resonant frequency. Certain types of glass have high mass within a small width, resulting in absorption, and due to its non-porous nature, preventing sound from leaking through.

In an interview with Nathan Hurst (2017), discusses how visual understanding is perceived through vocal clicks. Previously, researchers believed echolocators navigate by activating their visual cortex. The visual cortex processes contrast, colour, and movement. The perception of the surroundings, when sound reflects off mediums, are like flashes which cause a continuous-like vision and has more clarity and focus with every flash. According to the interviewee, the appearance of 3D geometric objects appears fuzzy (see Fig 1). The sound waves and flashes allow knowledge of the object's structure, position, density, and texture. However, small details or sharp corners are not as visible due to their surface area and size.

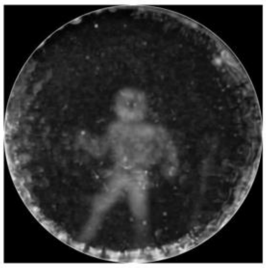

Fig 1: Visual example of an entity through dolphin echolocation, possible similar outcome as a human's visualisation of 3D objects (Lewis, 2015)

Three methods can be implemented into UE5 to recreate echolocation: post-processing materials, Niagara fluids and raytracing.

Post-processing is the process of altering the environment using effects to improve visual quality. Done through UE5s' colour grading and others, it is a vital part to ensure it looks visually appealing and accurate.

Niagara systems can create real-time fluids. Its array of parameters that can be modified and the behaviour in which the particles move and collisions against surfaces may be used to highlight how the waves reflect. However, this method may not work as currently it is mostly used for smoke and water, and multiple in a scene can cause optimisation issues (Zhu et al, 2022).

Raytracing is a method of graphical rendering that simulates the physical behaviour of light. The radius of the raytracing is used to identify what type of medium a surface is in the game, which can trigger a different effect visually.

3. Research questions

The equations to determine the speed and reflected wave of sound waves are needed in order to recreate echolocation as they will help get a better understanding the mathematics and movement of waves, as well as accurately recreating the angles at which they travel within the project.

The wave equation is used to calculate fluid movement. The equation can specifically be used to determine the changes in velocity and pressure that occur in a fluid as a result of disturbances or external forces. The speed at which the reflected wave travels affects how fast the individual can interpret the environment.

Sound waves return in the same medium while following the principles of reflection. The reflecting surface must be larger than the wave's wavelength in order for the sound wave to be reflected (Haygot, 2023).

Echolocation is done by emitting high-frequency, short wavelength sound waves, and listening to the echoes that are reflected. Depending on the animal, the pitch can range from 20 to 200 kHz, which is above the range of human hearing (Van Ryckegham, 1998).

Visual aspects that need to be taken into consideration are how it will be represented, how the environment and objects will appear, and if the sound wave will reflect.

Movement within the prototype can affect how the effect appears as the environment should only be clear if they remind still and be fuzzy whilst moving, affecting the clarity of objects and details.

The following questions have been outlined as key research questions for this project in order to get an in-depth understanding of raytracing, post-processing and the mathematical and visual aspect of echolocation:

1. What are the equations to sound wave reflection?
2. What visual aspects need to be taken into consideration?
3. How can the effect be altered for wave reflection and movement?

4. Research methods

The research conducted in this document uses predominantly qualitative secondary research techniques, academic articles and journal sourcing. Through the search engine Google, information could be gathered using the terms such as 'Echolocation and Spatial Awareness in Games', which lead to the implementation of videos using post-processing materials and raytracing. These methods were chosen as they allow vast amounts of information gathering around the relevant content from a variety of sources, in result, refining the quality of the research undertaken as a greater number of inputs were taken into consideration, thus allowing informed decision-making during development.

To ensure that no important sources were mistakenly missed, another search engine called Ecosia. This allowed search results that were not personalised and prevented a search filter that limits the amount of information shown.
Quantitative research was conducted to gain a strong understanding of how sound waves travel and interact with types of surfaces. This allowed a greater understanding of specific formulas needed to implement to create wave motion. The main reason for the use of qualitative secondary research is due to the various papers discussing how participants who are blind can visualise objects and distance. Looking into this helped create a better idea of how to approach the project visually.

Other implementation methods and sources explaining how echolocation works in different contexts provided insights on how to approach the project. Raytracing and post-processing materials have been created many times for different purposes, so the methods are well-known, however, using them in this context has not been done before. Because this project focuses on the visualisation of echolocation, parts of this report will focus on interpretations and implementations of echolocation to see if they aid in answering the questions.

Because this project is developed in Unreal Engine 5.0.3 (UE5), there can be a slight bias with the research and implementation as knowledge of how its system and blueprints are handled in UE5 is needed for a successful implementation. However, it may be possible to apply the implementation and research into another engine.

5. Ethical and professional principles

An important ethical consideration for this project was the appropriateness of the context of this project. As visual impairment falls under the category of people with disabilities (PWD), it can be considered a controversial topic where views and opinions differ greatly. This controversy stems from traditional views and a lack of knowledge in the area, however, there are recent studies and members of society advocating for awareness of disabilities. It is important to understand visual impairment not simply as a lack of vision, but as a fundamentally different way of being. Neuroscientific research explains there is a distinction between visual functions and visual experience from experiments undergone from 1970 to the present, The lack of understanding can cause unethical behaviour without being aware of it.

6. Research findings

Sound waves create particles in a medium to vibrate, generating primary and secondary waves as it interacts. The brain ignores the second wave and uses the initial wave to piece together a visualisation of the surroundings through wave reflections. Sound bounces off most surfaces which are flat and have a lot of mass, causing the sound to reflect off at a certain angle, depending on the angle of impact, sound waves can travel in any direction (Fig 2).

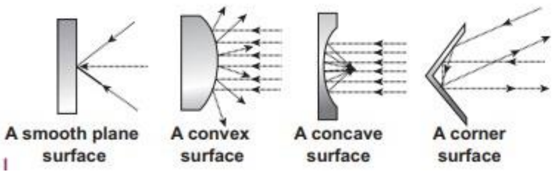

Fig 2: Reflection of sound on different surfaces (BrainKart, 2023)

Post-processing is a process where the environment is modified using effects. This can be done by altering the colour grading applying textures, lighting and more. It is an important part of any project to ensure it looks finished as it elevates the environment to ensure it is to a good standard. This implementation method appears to be the best approach to echolocation imitation as it can be used to alter the environment and the appearance.

By creating an effect that creates a flashing effect from the player every time a noise is created, it can simulate a flash sonar.

This sonar does not highlight any refined details of surfaces, however, can indicate what are different mediums. The more porous a medium is, the less visually clear it will be as sound waves can still travel through it, whereas non-porous mediums such as concrete, will reflect the wave back as the particles are tightly compacted, therefore will not absorb the sound waves.

The speed of sound traveling within a given medium of an object can be determined with the equation:

$$v = \sqrt{(B/\rho)}$$

Where *v* is the speed of sound, *B* is the bulk modulus of the medium, and *ρ* is the density of the medium). The equation relates the physical characteristics of the medium sound waves travel through to the wave speed. The resistance of the medium to compression is represented by the bulk modulus, and its mass per unit volume is represented by its density.

The speed of sound within a medium is determined by the time taken to travel through a medium and the materials' density and rigidness. The denser, the slower the sound travels. The more rigid, the faster sound travels as there are more particles vibrating with each other (Urone et al, 2020).

To calculate sound wave reflections, the following equation can be used where *a* and *b* are positive constants (Haygot, 2023):

$$y_1 = \mathrm{Acos(ax + bt)}$$

Post-processing materials can easily be used to create a flashing sonar. Small details and corners will be ignored as objects appear fuzzy, and the environment appears black and white. Different mediums can be determined using specific tags within Unreal Engine (UE) or using different post-processing materials.

Due to optimisation and performance, it was important to investigate which engine is best to use for this project. A paper published about post-processing in games analyses the differences between Unity and UE's post-processing (Laukkanen, 2018). The performance test was undergone using the application Fraps by Beepa (Fraps, 2013), which displayed the results. This test showed that the engine performance was almost identical, with only minor differences in lighting and colour. Both engines have variating options in visual quality, which indefinitely affected optimisation performance. The conclusion was that the engine type did not matter much (Fig 3).
However, visual quality and adjustability were very different. UE was lacking adjustability; however, Unity did not have adequate visual quality.

Engine	PP Quality	Avg (FPS)	Min (FPS)	Max (FPS)
Unity	High-quality	184.9	181	194
	Low-quality	287.3	285	292
	Off	535.8	525	541
Unreal	High-quality	176.4	173	180
	Low-quality	305.6	293	309
	Off	514.2	497	520

Fig 3: Performance comparison of post-processing in Unity and Unreal Engine 4 (Laukkanen, 2018).

A thesis by Šmíd (2017) explains how UE is more powerful as its blueprints allows a variety of tools for materials that Unity cannot. UE and the addition of in-built post- processing provide greater power that Unity may only gain through external plugins. Specific shader graphs would be needed in Unity to recreate a flashing sonar as the post-processing in the engine cannot create results like UE5.

7. Practice

The development of this artefact was split into three different sections: create the core mechanic, display visually how sound waves interact with different surfaces, and plan an interactive level. To achieve an accurate representation of echolocation described through the research conducted, multiple prototypes had to be tested. The initial approach was to create an outline material within UE5 so the outlines of the environment would be revealed to the player as they emit sound. To create this effect, the object's screen position and texel size are needed. These combined together are to render the screen-space position, creating a consistent resolution and allows offsetting. These nodes are multiplied together with a scene depth multiple times. This is then connected to the emissive colour node. The problem with this prototype was that the outline would work well with a cube, however, with a sphere, the outline would only be one radius on a specific spot rather than consistently outlined as the player moves. Modelled objects with unique structures would not work with this material as well as the emissive colour would illuminate excessively, causing the scene to become white due to the intensity of light (Fig 4).

This prototype did not work for this simulation as any object that was not a cube would cause the material to stretch, highlight excessively and not billboard the outline. Another reason this was not used was the fact that the effect did not represent how objects would be revealed during echolocation.

Fig 4: Outline material display working on the cube and not on other shapes.

The second prototype had a different approach. This method was to attempt to create an outline wave that projects from the player's centre. The scale of the wave was made using frequent pulses using a time node with a clamped period of 0.1 to 2 seconds. This was chosen for testing to see whether the material was working correctly, as well as create variety. Using a lerp to connect the chosen parameters with the time period, the effect is fed to a scalar and radial gradient node, allowing us to adjust the radius and offset the centre point of the effect. A sine wave allows an oscillating-like waveform. The oscillation effect helps represent how sound waves travel through an environment as the sine waves travel longitudinally rather than latitudinally, depending on the medium it propagates through, which means they travel in the same direction that is perpendicular as the energy transfer (Zola, 2022).

This node is duplicated and multiplied with the first copy of the node. Finally, applying the colour multiplied with the other variables together, it is fed into the emissive colour. The main problem with this effect was that although it would remain on the players location, it would not travel up walls and objects, as well as create two waves instead of one negating the objective of this project (Fig 5).

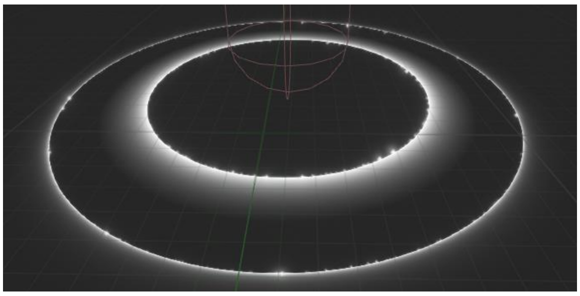

Fig 5: Second prototype creating an emissive pulse with two waves rather than one.

This prototype could have been used to recreate PE but was visually inaccurate as the environment did not become visible after the first wave, nor travel up walls. This was due to the effect being attached directly onto the players feet, causing it to be not possible to detect whether or not the effect had come in contact with a surface. When object or material effect is attached to a player, it is relative to only the player, causing no visual changes to the environment in the project.

Despite this prototype failure, it was a big step towards the right direction for this artefact as it provided a clearer understanding of how to approach the representation of sound waves travelling through an environment.

A follow-up iteration was based on the second prototype. This method was much more simplified. The material uses similar aspects to the first discarded attempt of a pulse, however, by removing the nodes that compile the adjustable time period scale, it emits one wave rather than two. Despite this minor improvement, attempting to make the material travel up walls was not achieved.

To recreate an effect where the sound waves would bounce off the walls of the environment, raytracing was used. A sound bounces off walls similarly to light, the sound waves can be

recreated this way as raytracing is often used to detect when and where the particles in the scene collide with other objects. To test this approach, within the First-Person Character script, a raytracing function was made.
Using the capsule component held within its viewport, a nodes that collect data about the world rotation forward vector and location of the player are connected. The world rotation returns the rotation of the capsule within the world space, which is then fed into a get forward vector. This connection allows rotation to the forward vector of the player depending on the given rotation. The world location of the player is also required as this displays where the pulse will emit and affect the environment. These are fed into a multiply and add a component that connects a for loop of the last index to a 'SphereTraceByChannel' node. By doing this, the raytracing sphere sweeps along a given line and returns the first object that it collides with. The visibility of the raytracing was enabled to see if the function was working, as well as a description of the object it collided with (Fig 6).

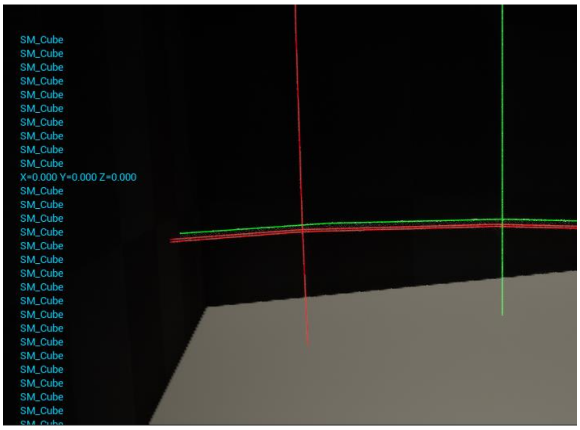

Fig 6: Visible raytracing sphere with descriptions of collided objects referenced on the left.

Although the outcome of this method worked, upon more research, attempting to develop it to allow the particle collisions to reflect off walls was deemed to be quite difficult.

Through reflection on the research undergone for the project and discussions with the supervisor, the decision to create a final iteration of a wave that slightly illuminates the environment with a fuzzy look, as discussed by Hurst, was chosen to create a more realistic, less game stylised pulsating sound wave.

The final iteration of this effect was created using a post-processing material and volume. Within the material, a sphere mask is used with connecting the parameters: radius and hardness. The sphere mask uses the camera position to create a sphere centred around the camera position. The radius parameter is used to alter the distance of the pulse from the camera and the hardness is to control the width of the pulse. With these connecting nodes, it creates a sphere that highlights the environment in a blurred way (Fig 7).

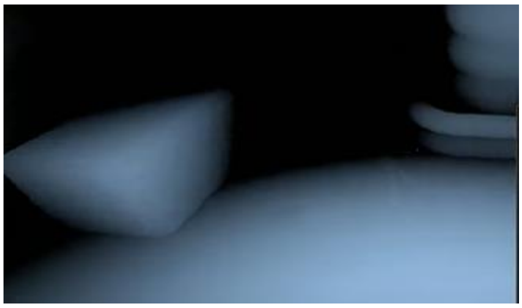

Fig 7: Sphere that highlights the environment using a sphere mask.

For gameplay reasons, this sphere was changed to a ring increasing in radius making the effect appear as if it is travelling across the environment. Using a sine equation, the sphere is transformed into a large ring from the camera position. The parameters used for the sphere can be applied to the ring for customizability. As echolocation is represented as a fuzzy appearance of objects as the sound reflects to the individual, a choice to create a noise texture was made. The texture used combined with a 'WorldAlignTexture', along with the other functional nodes create a texture within the scene where the ring is visible. It was important to include a world space normal to prevent texture stretching, making the effect more realistic (Fig 8).
As the effect is dependent on player movement,

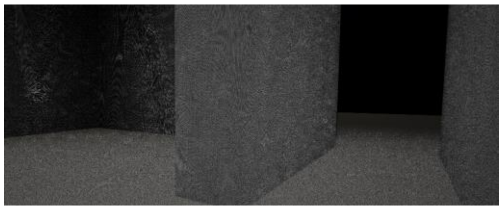

Fig 8: Texture applied with ring effect on the environment.

the radius is to be accessible. This accessibility is done by creating a material parameter collection that contains a scalar parameter called 'Radius', which is then added as another variable within the sphere generation. These radii are set fixed variables that alter each other to create differentiation of the effect. To have the effect move through the environment, a timeline was made within the First-Person Character blueprint. This is set to a loop to have the effect of consistently playing. Having this attached to player movement causes the effect to appear brighter and clearer when players remain still, whereas there is less clarity when they move.

As this artefact is a simulated game, an environment with interactable objects is required. Due to the effect causing small details on objects difficult to see, a highlighting effect was implemented. After enabling the custom stencil setting, applying a custom stencil within the material and adding masks to the emissive colour, the chosen objects will be highlighted with a different chosen colour (Fig 9).

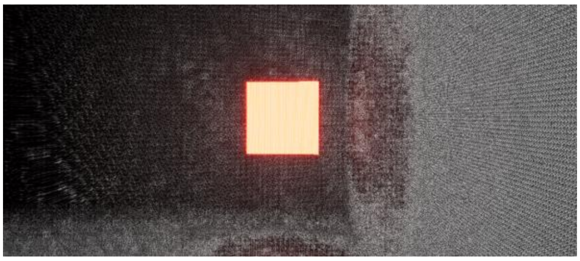

Fig 9: Object highlighting.

The propagation and echolocation of sound waves can be influenced by several mediums, including air, water, and solids. When objects are visible through echolocation with different types of density and rigidness, it can make them appear differently from other aspects within the environment.

To recreate this effect, the same method to create object highlighting was used. This allowed different colours and tones on objects and materials within the scene. As materials such as wood and foam would absorb the sound waves easily, the colour parameter was set to black to show how the effect does not affect the object. Objects which are low in density will be represented with the black material glow to show sound absorption, whereas materials such as concrete and metal will not have that effect and will simply reflect the post-processing material.

In this echolocation simulation, various objects in the environment can change how sound waves bounce and travel, which can represent important details about how echolocation functions.

To display how different materials affect the sound waves and how they alter as they bounce off different surfaces, several rooms with various objects within them were made.

The rooms created to demonstrate the prototype were:

- A soundproof room.
- Outdoor area.
- A small house.
- A large room.

Echolocation can be demonstrated by building a soundproof room since it can assist with noise reduction and reverberations, as well as provide a controlled acoustic environment. To mimic this controlled environment, multiple acoustic foam panels are needed which are commonly found in rooms where individuals would produce a large amount of noise. These are often sculpted with multiple pyramids across the panel (fig 10).

Fig 10: Acoustic foam panel within the soundproof room (Left: with effect, right: without effect).

This is due to the fact that by exposing more surface area to the air space increases the panels' ability to absorb the sound wave reflections (Netwell, 2014). Additionally, within this room, objects with small details such as a keyboard or pens (GET PICTURE OF THIS FROM PROJECT) were included to display how a small surface area can affect the sound waves. Due to their surface area, these details are not as clear to the individual.

Many animals that can navigate through complicated outside settings that are continually changing. By creating an outdoor area for this simulation, it displays some of the complexities of the natural world in an outdoor setting.
Furthermore, an outside setting makes it possible to see how the open space affects the sound waves as there are little particles to interact with each other, altering how sound waves propagate through the atmosphere, bounce off of objects, and affect the precision and dependability of echolocation.

A factor that highly impacts sound waves in an outdoor setting is the weather, in particular, temperature and wind. When temperature increases, the air particles move faster and spread out, making it harder for sound waves to travel as the there are fewer particles to interact with, causing it to lose energy and decrease its amplitude. Windy weather can cause the waves to change direction, slow down, speed up, decrease or increase the wave amplitude. For this project, it is assumed that the air is stationary with no noise pollution to prevent overcomplicating the prototype and visual aspects of the material (Fig 11).

A small sized house is particularly important for this simulation in order to display the difference of room size and how it affects echolocation as it is heavily reliant on the sound waves reflecting off surfaces. Different items can alter the echoes they make, as well the room's size, shape, and reflective qualities.

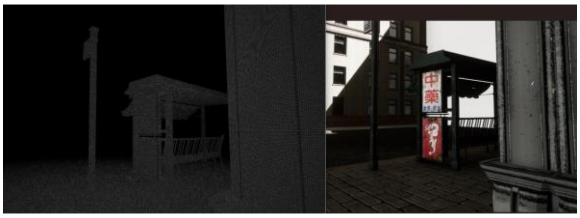

Fig 11: Outdoor area with the assumed still air and no noise pollution (Left: with effect, right: without effect).

As a small soundproof room has little space within it as well as surface area, the waves bounce off the walls repeatedly, causing the information to be sent back to the individual, but also can cause interference and confusion due to the number of waves reflecting off of a cluttered room.

Similarly, a large room would allow for more accurate representation of the effects of echolocation. The room will provide ample space for the sound waves to travel, bounce off objects and return back. However, it can also display the limitations as the waves have to travel far, and if there is no nearby surface to reflect off of, nothing would appear.

With all these rooms scattered around the environment for the player to explore to see how the prototype behaves, interactions between rooms were created. This was a gameplay decision as the environment would have been uninteresting as the player would only move through the level. Using the stencil highlighting feature as mentioned before, objects such as doors, buttons and handles are used to progress through the environment, which are designed to section off each room for the technical reason of having each area a confined experience.

8. Discussion of outcomes

Despite the multiple trials and errors initially, this prototype project's result exceeded expectations. Finding a method that would be effective for this job took time because there were numerous methodological approaches. However, this provided a deeper knowledge of both the functionality and the intended appearance of the project. The final prototype was strong as a result of the gradual evolution.

The simulation accurately reflected the conducted research and followed it. Small details on objects were not apparent due to their surface area, the effect does not curve around corners like sound waves would, and it becomes clearer as the player stands still and less clear as they move. The many areas of the map provide the player with the chance to encounter various surroundings and observe how various things and materials would affect how soundwaves travel through them. Designers, developers, and others who are interested in learning how sound moves through various materials and environments may find this to be a very helpful simulation.

The final visualisation of the prototype could be used as a method of bringing more awareness to blindness and echolocation. To make the simulation more interesting, the player can show how the prototype can be placed into a game. it includes an environment where the player must interact with to gain access to certain areas.

Firstly, the simulation presents an environment altered through echolocation with a post-processing material, depending on the distance, size and material type within a given area. This also is an approach that other games have taken, for instance, the game Perception. Other approaches through previous games include normal mapping to represent the sound waves (Peel, 2017), which is a method of enhancing surface detail without adding more polygons to 3D models, light spawning, used to create lighting effects and improve performance, and post-processing effects. The simulation created in this project not only displays a more accurate recreation but contains aspects that previous games have not.

The aspects within this prototype present how distinct and unique materials are revealed differently to the rest of the environment to signify the effect that porous and rigid materials have on the sound waves being projected from the individual. This feature created a deeper immersion for players and a clearer understanding of echolocation.
The modelling of echolocation created in this project may be applied to produce more realistic and engaging gameplay.

The simulation can be used in a variety of contexts, including adventure games where the player explores mysterious and dark locales. To move about the world, the player might employ echolocation, finding secret passageways and things along the way. Another way the simulation could be used is to develop a more accurate echolocation system for the bat to explore its environment in a game where the user controls it. This might improve the gaming environment and increase the players' sense of intrigue and excitement.

In a wider context, the simulation could influence new methods in a variety of industries, such as robotics and medical. For example, it might be utilised to create sophisticated prosthetics or robotic systems that employ echolocation to improve the blinds' ability to navigate their surroundings.

Additionally, with the simulation, players could improve their spatial awareness and have the ability to move more quickly through virtual surroundings due to the prototype.

Animals like dolphins, bats, and other species employ echolocation. The simulation demonstrates how the environment and waves interact. This may also contribute to increasing public awareness of the value of preserving the natural habitats of echolocating animals.

Although the project offers new and unique aspects to echolocation simulations, the prototype could improve in a few ways.

Despite creating a more accurate echolocational effect compared to other games, the simulation is missing a variety of visual material changes, sound, a delay due to the precedence effect, and a visual display of the sound waves reflecting off surfaces.

Within this project, only one material change is visible when the player explores the map, represented in a mat black colour. Although this works well for some objects within the project such as the foam panels, other things like glass and wood would have a similar effect, but not as dark. The method used to create the effect had major issues when attempting to increase the brightness of the material to show different mediums. When increasing the brightness of the colour within the shader, the result within the prototype would cause the object to become overly white and bright and remain that way no matter how low the tone was. To resolve the issue, a separate material that interacts with the main material should be used, as well as removing the emissive colour to prevent excessive brightness projecting from the object.

Although there is one sound within the game, the effect is not associated with it. The effect remains in a constant loop, which was a gameplay choice to show how the effect works in full detail. To use this in a professional context, the timeline within the FP character's blueprints would have no loop, but a trigger when the player uses any movement key. To make the prototype even more immersive, AI animals or external noises could have been implemented to represent how the sound waves from other entities and objects may interfere with the sound waves of the player, as well as the environment.

Initial research led to the discovery of the precedence effect, which is a crucial component of echolocation. Due to time restrictions, this was not included in the prototype. A method to implement this into the prototype could be when the player selects a movement key, there would be a 1.5-second delay before the world became visible. If this approach was chosen, it would be necessary to replace the projecting effect that was created with a reveal effect that does not travel from the player, but instead illuminates the area inside the specified radius.

Finally, even though the way the sound waves interact with corners is visible, a method of showing how sound waves reflect off of different surfaces could have been another aspect to display within the prototype. This could be done using raytracing. To do this, rays from the player's position are traced to the surrounding walls, and the sound waves are then calculated to determine how they will reverberate off of those walls. Once these were calculated, the raytracing would be used to visualise how they reflect off the waves by using ray marching or voxelisation, where ray marching is used to calculate the interactions of a ray that cannot be represented with geomantic shapes (Walczyk, 2020), and where voxelisation is used to convert a 3D mesh into a volumetric representation of elements (Magalhães, 2020).

Raytracing was partially implemented within the project, but then was discarded as the mathematics involved with calculating the angle at which the waves would reflect depending on the distance and angle of the player, it becomes complicated.
Apart from these aspects within the simulation that could be improved upon, in terms of applying the simulation in a game, visual changes could also be altered. Visually representing echolocation as accurately as possible is generally quite difficult and is hard for players to navigate through a full-scale game due to the lack of detail in objects around the environment. To improve this, the first and second waves projected from the player could

be shown as an expanding circle that travels through the environment in the same way as the post-processing effect does. This would not only help players see if there are objects present, but it would also help them navigate easier.

The prototype is one of the very few echolocation simulations produced to show how it may be interpreted more accurately, rather than focusing on gameplay aspects, as well as bringing more awareness to blindness. Few games represent disabilities and impairments, but there are little to none relating to blindness as it is subjective depending on the individual since no one can experience and recreate it directly.

The results from the research and development of the echolocation simulation can be said to have demonstrated a more visually accurate representation of echolocation compared to previous methods developed.

9. Conclusion and recommendations

In conclusion, the echolocation simulation visualisation was implemented.

The project successfully produced an effect in UE5s' post-processing functions that reflected the movement of sound waves and how they interact with the environment which reflects back to the individual. The effect effectively projects from the player to the environment within a given radius, showing a fuzzy white appearance to everything within it.

The future direction of the project should include improvements in the sound wave effect, audio and material distinction. The prototype has been designed in a way that it can be expanded without difficulty. Possible features that could be added would be AI animals within the environment that sent off sound waves that the player could see once it reaches them, as well as external noises such as cars or a television.

Benefits of the prototype include the prospect of using it to help sighted people understand how echolocation functions and might also be utilised as a training tool for those who are visually impaired. This additionally could bring awareness to environmental protection as multiple animals require echolocation to navigate.
The project's long-term future could be seen as a good way to represent a simulation similar to blindness and echolocation, as well as help visualise how sound waves travel and interact with environments.

Despite certain issues encountered initially while bringing the prototype to life, the finished product is satisfied as it serves the intended function and accomplishes the project's objective.

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Appendix A: Project Log

Day	Task Set	Outcomes
10.10.2022	Meeting with supervisor.	Discussion on potential dissertation proposals. Three topics were discussed, Level generation through emotions was chosen to research upon.
15.10.2022	Meeting with supervisor. Write up of the proposal.	Upon research, the proposal topic was changed to an echolocation simulation.
18.10.2022	Thorough background research of previous game echolocation and its mechanics. Meeting with supervisor. Initial research.	A good understanding of how human and animal echolocation works. No previous games using this mechanic provide documentation or explanations on how they were made. Proposal draft feedback was given over email.
25.10.2022	Update final proposal. Submit proposal.	Task completed.
28.10.2022	Download Unreal Engine 5. Create first iteration effect using materials.	First prototype outcome was faulty, discovered another approach had to be done.
30.10.2022	Create second iteration effect using materials. Meeting with supervisor. Begin writing research document.	Changed to a different approach. Effect worked as the player moved, sending pulsations, but did not travel up walls. Faulty. Started research document.
10.11.2022	Rework second prototype.	Altered sections of the second prototype in an attempt to fix the issue. One wave was removed.
13.11.2022	Hand in research document.	Task completed.
15.11.2022	Discarded second iteration. Attempted use of raytracing.	Implemented raytracing into the project with surface detection.
20.11.2022	Meeting with supervisor. Create base of final iteration using post-processing. Created a basic level.	Discussion on how echolocation should appear, altering the clarity of the environment and objects. Discussed the approach of post-processing. Created a post-processing material and volume.
1.12.2022	Set up basics of the effect with a spherical radius.	Added a radius aspect with a spherical shape. Now everything in a certain, stationary radius can be seen with a fuzzy highlight.
10.12.2022	Attached effect onto player position. Added texture.	Added to the player location in order to have to play as the player moves. Added texture to make the environment have less clarity.

5.01.2023	Altered effect so it sends out pulsations.	Added a time scale in order to allow movement to the effect, similarly to sound waves.
10.01.2023	Implement object highlighting in the post-processing material.	Added object highlighting for gameplay and to display important objects.
15.01.2023	Add sound to player movement. Removed features.	Added footsteps to player as they move. Removed lighting, and roof of level.
23.01.2023	Prototype demonstration video.	Task completed.
2.02.2023	More research into material representation. Meeting with supervisor.	Researched into ways to represent different materials through post-processing. Discussed ways to approach this issue.
13.02.2023	Attempted rework of post-processing material for material altering.	Attempted to alter code in a way that objects with specific names would appear differently. Outcome did not work.
28.02.2023	Changed aspects of level.	To get an idea of how the final design would appear.
13.03.2023	Created an effect that changes depending on material.	Used previous object highlighting to create material altering.
17.03.2023	Designed an outline of the final level.	Noted what types of rooms would be in final design. What the interactions would be.
18.03.2023	Begin final document.	Task completed.
29.03.2023	Meeting with supervisor.	Presented first draft.
02.04.2023	Continued working on final document. Downloaded assets from Marketplace.	Task completed.
10.04.2023	Finalised final level design.	Task completed.
20.04.2023	Continued working on final document.	Task completed.
25.04.2023	Submit final document.	Task completed.

Appendix B: Project Timeline

Month	Task	Duration Period (Days)
October	Start proposal document. Initial research. Create first and second iteration of effect.	15 3 8

	Final proposal submission 25.10.2022.	N/A
November	Create third iteration of effect. Create basic level. Start research document.	2 1 5
December	Research document submission 13.11.2022. Start final iteration of effect.	N/A 7
January	Prototype Demonstration submission 23.01.2023. Tidy up blueprints. Create object highlighting. Add sound.	N/A 1 2 1
February	Change level design. Rework of post-processing material.	1 4
March	Final level design. Start final document. Create effect that appears different on varying materials.	4 10 2
April	Final report submission 25.04.2023.	N/A

Appendix C: Assets used in the Project (not included in word count)

Edith Finch: House and Common Areas: https://www.unrealengine.com/marketplace/en-US/product/ef-house. Copyright free. Unreal Engine.

Modular Building Set: https://www.unrealengine.com/marketplace/en-US/product/modular-building-set. Copyright free. Unreal Engine.