SPATIAL AUDIO AND REVERBERATION IN AN AUGMENTED REALITY GAME SOUND DESIGN

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In this paper we describe the sound design of a location based mobile phone game and investigate the role of spatialised audio and reverberation. Particular attention was given to the effect of audio on immersion and emotional engagement of participants. We present the sound design, implementation and evaluation of our working prototype, *Viking Ghost Hunt* and the results and interpretations obtained. Evaluation of the game was undertaken over a three-day period with the participation of 19 subjects in which the prototype was evaluated for game immersion and engagement. Further tests of a subset of participants was undertaken in order to test the specific audio parameters of spatialised audio and reverberation and their effect on game immersion and engagement. The results indicated that audio and specifically reverberation, play an important role in immersing a player within the game space.

1 INTRODUCTION

Game audio has evolved considerably in the last 35 years where it has moved away from the dependence on midi based wavetable synthesis of bleeps, beeps and simplistic melodies to three dimensional (3D) sound effects, orchestral soundtracks and believable dialogue. It has therefore become an indispensible part of the game not only for conveying important information but also for immersion and emotional engagement. In console gaming there is more processing power available to synthesise sounds and have real-time complex sound effects, 3D localisation and reverberation – especially in a 5.1 surround sound configuration. Hence there is a trend to replace a part of recorded audio by real time generated sounds and music. Therefore, for a composer and sound designer there are many more avenues available in creating a complex and immersive soundscape. Such game console examples are *Silent Hill* [21] and *Thief* [24], which present engaging, complex sound designs and an interactive use of audio. The audio in *Thief* is used in a unique way compared to other games in that it is an integral part of the gameplay. This game audio scenario involves complex sound propagation and is a multi-sensory approach using realistic audio algorithms in representing movement.

With the introduction of Personal Digital Assistants (PDAs), gaming is not only console based but has also become mobile. PDAs capable of greater processing power than their predecessors, have allowed mobile gaming audio to move from midi wavetable synthesised sound to now include richer soundscapes. An example of this is *Soul Trapper* [22], which is an iPhone application that uses spatialisation and an orchestral audio backdrop to convey narrative elements. However, most mobile phone based games still pay minimal attention to the overall audio design, and concentrate instead on audio feedback conveying game information in the form of user interface sounds. Global Positioning System (GPS) enabled mobile phones, have now allowed developers to create real world location based gaming where the virtual world can be overlaid onto the physical world. As audio has developed for console applications, the challenge is now to incorporate some of these features onto a location based scenario on the mobile platform that is immersive and emotionally engaging. Developing a sound design that incorporates reverberation and spatialised audio on a limited mobile phone Central Processing Unit (CPU) creates challenges and requires innovative approaches and compositional ideas.

First we shall take a brief look at the background of location based applications on the mobile platform, then describe *Viking Ghost Hunt* as our working prototype and the sound design and subsequent implementation. The user trials undertaken examined the usability of the game interface and the overall game experience, which included audio elements. Specifically the immersive quality of the audio and the role spatialised audio and reverberation may play was investigated. The user trials and evaluation process will be described together with the results obtained and their significance. Finally we

conclude on the possible role of audio in location based gaming and directions for further research.

2 RELATED RESEARCH

With the increasing popularity and availability of PDAs that incorporate integrated GPS capabilities, there has been an interest in location based gaming. Location based gaming uses physical locations within the game structure and overlays a digital mediascape onto the physical world that respond to contextual cues such as GPS. This creates a real and virtual world integration thereby merging the virtual and physical world [6] producing a sense of the place (a space is a physical environment and a place has greater meaning) [17]. Due to the constrictions of a small visual display, the sound design of a location based game can convey important game information such as navigational information and instructional dialogue thereby enabling the user to look away from the visual graphical interface and remain engaged within their physical space. Listening to audio requires less cognitive attention than visual information and therefore reduces the amount of player distraction from the game, hence encouraging the player to remain in the game space [6]. Research has already shown that the use of a realistic sound design can help build excitement and tension in the game world and that there can be an enhanced sense of immersion, without the use of visual graphics [26]. However, a multisensory approach of using both visual and audio interfaces is preferred, with audio playing a significant role in locative gaming [11].

Most research into location based spatial audio has focused on non-gaming applications, artistic installations or navigational tools for the visually impaired. Investigations into spatialised sound in locative games undertaken by Dr. Kirsten Cater and Dr. Richard Hull et al [3] is an example of audio research with an academic application. In their prototype, a 2-axis compass, Bluetooth GPS and HP iPAQ was used to receive user location updates in order to spatialise audio. Their research shows that participants are able to accurately navigate their way in the physical world using a spatialised soundscape related to the physical location. They also suggest that representing spatial sound accurately can increase participant immersion in virtual reality applications [12]. *Syren* [28] is a location based sound installation that is presented as an onboard ship exhibit at the 12th International Symposium on Electronic Art in August 2004. It was a continuous three-day spatial audio experience that augmented the landscape of the Baltic Sea islands. A multi-channel speaker array was placed onto the upper deck of the ship with a handheld GPS receiver providing positional and direction data that was used by the software system to drive parameters of the spatial audio representation. The ambient background was developed to have spatialised, unrecognisable random-sounding audio effects from given audio samples. This is a good example of overlaying spatial audio to reflect real world movements using a creative sound design.

Demor [8] is another location based 3D audio shooter game primarily designed for the blind but which sighted players can also enjoy. This game investigates psychoacoustic properties in the presentation of sound in order for audio to be accurately used for physical space navigation. In this prototype, a laptop, GPS tracker and headphones with a head-tracking device together with a joystick was used. An example of reverberation and spatial audio for immersion is *RevRooms* [13]. This application uses real-time audio rendering (for 3D spatialisation) together with room acoustic simulation (convolution reverb) that the authors refer to as 'aurlisation' [15]. The prototype was implemented using a visual interface and loudspeaker configuration with cross talk cancellation (for a binaural presentation). The model represented a virtual world of four rooms of increasing size and each room had a location fixed human figure with a looped speech message playing from the co-ordinates of its head position. It was found that users felt greater immersion due to the inclusion of room acoustics which matched the virtual room size together with the spatialised audio.

These examples of spatial audio and reverberation were not based on the mobile platform and do not focus solely on the immersive properties or experiential feedback. Additionally, the applications often involve complex and bulky technical set-ups. These would not be ideal for gamers who wish to be unencumbered during gameplay. There is extensive research on console game audio in regards to spatialisation, reverberation and sound design [5], however sound design for the mobile game industry has not been fully investigated or the effects or implementation of spatialised audio and reverberation.

3 GAME PROTOTYPE

Viking Ghost Hunt (VGH) is implemented on the Android platform and is a working prototype for a location based game in Dublin city centre, Ireland. In this prototype, the GPS enabled HTC T-Mobile G1 mobile phone is used which utilises GPS update information and an internal 3-axis compass in order to discern player location and direction. The game is driven by a linear story line and played around the old Viking sites of Dublin with the player acting as a paranormal investigator. The gamer uses various visual and audio interfaces together with stereo headphones to locate and interact with the ghosts. The *VGH* aim is to immerse the player in the game world which is overlaid

onto the physical world, with the PDA acting as a paranormal investigative device. The aim of the audio design was to create a soundscape that is both informative for navigational purposes and that is immersive and emotionally engaging. Sound also supports the contextual element of *VGH* to create a believable space and to blur the real and virtual world borders. The aim of the game is to locate paranormal activity and gather evidence that manifests visually or aurally. This evidence may give information about the ghostly activity and clues for moving through the game space. The paranormal device (mobile phone) has different modes or interfaces that the player must choose in order to locate paranormal manifestations in the real world space and to capture audio-visual evidence.

The modes (interfaces) of paranormal investigation consist of camera/x-ray mode, map mode, radar mode and frequency scanner mode. The frequency scanner mode is an audio interface reminiscent of Electromagnetic Voice Phenomenon (EVP) often used by paranormal investigators. Paranormal investigators believe that 'ghostly voices' can be heard when radio static is analysed. Gamers must use the frequency scanner in order to find the correct ghost frequency (Hertz), record the white noise audio and subsequently hear the decoded ghostly message on playback. This is an integral part in the game mechanics for player interaction, game information, evidence retrieval and in the delivery of the game narrative.

Figure 1: Radar mode

In addition to the frequency scanner, audio is also used for all of the user interface choices in the form of button, sonar and click sounds in order to support the concept that the mobile phone is a paranormal investigative device that in turn provides player feedback.

4 SOUND DESIGN

The aim of the sound design is to create an immersive experience in which the player remains engaged with their physical environment. Therefore a balance between the ghostly atmosphere of the game and the location environment is maintained. Hence, sounds are representative of both the location environment and game atmosphere. The sound samples used for *VGH* were stereo field recordings using the Zoom H2 digital audio recorder, sourced samples or were created electronically using a midi synthesiser and various audio sequencers. The sounds recorded and created were placed into four categories: paranormal, environmental, musical and user interface sounds. The table below shows some of the sound samples used.

Paranormal	Environmental	Musical Elements	User Interface
footsteps	*animal sounds*	*minors*	*old AM*
floorboards	*church bells*	*chromatics*	*radio*
creaking	*laughing*	*pitched and*	*sounds*
bangs	*children playing*	*unpitched*	*white noise*
high pitch	*school bell*	*drones*	*audio static*
metallic	*paper flying*	*drums*	*and*
squeal	*around*	*ghostly pan-*	*interference*
breathing	*thunder*	*flute*	*metal*
screams	*wind*		*detector*
whispers	*rain*		*sounds*
faraway	*traffic*		*dial clicks*
voices	*dog barking*		*Geiger*
growls	*chimes*		*metre clicks*
scratching	*birds*		*button*
moaning	*leaves*		*sounds*
modulated	*wind in trees*		*sonar*
voices	*people talking*		*sound*
rattling			*compass*
chains			*sounds*
battle sounds			*transitional*
ghost			*sound*
dialogue			

Table 1: Sound Categories

The role of audio in the prototype was to create a background atmosphere, provide relevant sound effects, act as a feedback for user interface interactions and present the dialogue. Hence the appropriate sound files relevant to the narrative were organised into these functions for playback. The background sounds are managed by using the SoundPool class in Android which plays audio resources for applications. This proved to be a challenge as the maximum audio file size was found to be 750 KB, which depending on the sound content gave about 2-4 seconds of sound. Hence file playback was randomised within the application code so that the files overlapped to create a continuous background sound. SoundPool was also used to playback isolated sound effects. The Android MediaPlayer class presented the dialogue as it was capable of streaming larger files in a compressed format. It was found that SoundPool had a quicker file loading time and hence worked well for looping and playing back smaller numerous files simultaneously, whereas MediaPlayer demonstrated a certain amount of

playback latency and was not as successful in file looping or playing files simultaneously. All game content files and the game application is pre-loaded on the Secure Digital (SD) memory card before the game.

The audio is triggered by pre-determined GPS coordinates being received by the phone. In the sound design, concentric rings of audio are organised around a GPS defined location with varying radial distances. This means that as the player reaches the outer ring, the ambient background sounds begin. As the player moves towards the centre point (the paranormal zone) additional sound effects are triggered until finally the dialogue is heard in the centremost region. Therefore sound files are triggered by using GPS update information provided by player movements. For example, as the player comes to the outer region of a paranormal zone a looped drone sound begins (rumbling, low frequency) together with environmental sounds (e.g. wind). The mixing of environmental and game sound supports the blending of the virtual and real world to such an extent that the player may believe some sounds to be part of the physical locations. As the player continues to move towards the central point of activity, sound effects are triggered that are related to the paranormal activity. These sounds are descriptive of the game narrative and historical location of the game and consist of short sound effects (e.g. chains etc) that may be randomly triggered, overlaid or looped. Hence players can get some information related to the game space without looking at the mobile device display.

As the player reaches the GPS defined location, an escalation of sounds due to increasing amplitude and the further addition of sound files signals to the player that they are entering a paranormal zone. This is coupled with changes in the visual interface which indicates whether the paranormal manifestation is visual or aural and the player must choose the appropriate mode to gather the evidence (i.e. if audio they must use the frequency scanner, if visual they must use the camera mode). As the player leaves the location after obtaining the evidence (which may be a piece of dialogue or overlaid game visual taken by the mobile ‘s camera) these sounds gradually dissipate in intensity and fade away. Therefore different sounds enter and remain for different lengths of time depending on the location of the player in relation to the GPS location, hence providing an interactive, immersive experience. The ambient audio soundscape is always triggered automatically by player proximity to GPS defined game locations.

4.1 Spatialisation

Psychoacoustic properties were considered in the sound design. A ‘natural’ audio presentation that reflects real world sound has been found to be more immersive and engaging for augmented reality applications [13]. The psychoacoustics of sound in the real world in relation to spatialisation and reverberation are an important element in developing the sound design for *VGH* as well as the creative composition.

In the real world sound is presented in a three dimensional manner (3D) and human survival depends on the ability to establish a sense of spatial orientation. This is needed for localisation, distance perception and recognition [1] of objects, and spatialisation and reverberation in an artificial soundscape can mimic how sound is heard in the real world. In order to perceive from where a sound is emanating, the human brain uses information derived from the interaction of the sound wave with that of the torso, shoulders, head and ears. Interaural time differences (ITD) and interaural level differences (ILD) of sound as it interacts with the head help to localise sound in space. For example, if the sound were located to the right, the right ear would hear the sound first and then the left with a slight time delay (ITD). The amplitude (volume) level would also be greater on the right ear than the left (ILD) and therefore the sound is perceived to originate from the right [10]. Perceptually humans use a combination of these systems, however ITD and ILD do not work as well for sound originating on the azimuth axis (vertical plane) and therefore can be poor for front and back sound localisation.

For most applications, a stereo representation of sound is adequate for an enhanced audio field but is not truly 3D. The use of Head Related Transfer Functions (HRTFs) give a realistic spatialisation of sound because it takes into account the unique individual interaction of the user’s head with the sound wave [11]. By using HRTFs individually a player sometimes cannot tell virtually spatialised sound from the real thing.

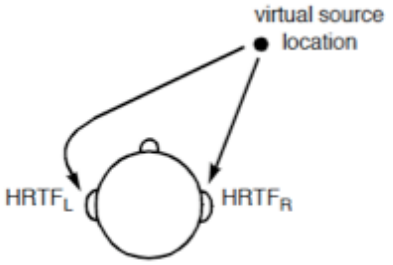

Figure 2: ILD, ITD and HTRF [13]

However this is not realistic for a mobile phone (PDA) application as it requires real-time processing of audio filters which is CPU intensive and unachievable at this

level for PDAs at this time. Therefore in the *VGH* prototype, a simplified approach was implemented. Spatialised sound was applied in a pre-rendered format utilising the Panorama 5 Wave Arts plugin (binaural simulator). Panorama is a tool for creating realistic 3D audio scenes using regular stereo sound and can reproduce psychoacoustic sound localisation and distance cues, allowing sounds to be panned in 3D. Panorama combines HRTF-based audio panning with acoustic environment modelling which include wall reflections, reverberation, distance modelling, and the Doppler pitch effect. However, as the spatialised audio is pre-rendered it is not contextualised for the physical location, therefore the sounds are not anchored in the real world space. As spatialised sound has been found to facilitate immersion [13], it was seen as an important part of the sound design to include an aspect of spatialised sound in a pre-rendered format.

Figure 3: Panorama 5

The role of audio as navigation is also supported by providing contextual navigational instructions via dialogue, and by triggering sounds near paranormal locations that increase in volume and complexity as the player moves closer to that location. This navigational strategy also includes the addition of various sound effects related to the paranormal activity – again informing the player that they are entering a paranormal zone. Constant background sound between paranormal locations is avoided so as not to overload the user experience and take away from the immersive experience.

4.2 Reverberation

Reverberation is another important psychoacoustic consideration when developing the sound design. Reverberation is sound that is reflected from physical surfaces and back into the environment. These numerous 'early' reflections are then themselves reflected to form an 'ambient' sound field [18]. Sound reflections have been found to contribute to the sense of space and the perception of sound source size and distance [2]. The addition of reverberation in the sound design of a locative game can add a sense of realism and envelopment (sense of immersivity in a reverberant sound field) for the user [13]. Synthetic reverberation was used in the sound designs and reverberation involved the use of an audio sequencer plug-in (a software module which adds to the sequencer functionality) with control of various reverberation parameters such as time delay, room size, number of early and late reflections. Waves Renaissance Reverberator was used to implement synthetic reverb on chosen sound files. This plugin allows for the modification of important reverberation parameters. These settings were modified depending on which sound sample was being used and in which physical location they would be triggered. Hence audio files were pre-processed using synthetic reverberation with different settings depending on the context within the game space. The use of reverberation was an important stylistic element in creating a ghostly atmosphere.

In order to create a dense and engaging game atmosphere, the sound design involved the playback of a complex configuration of multiple and varied simultaneous audio files that were created with keeping in mind psychoacoustic principles and the game narrative.

Figure 4: Waves Renaissance Reverberator

5 EVALUATION

5.1 Methods of evaluating the sound design

Objective findings such as physiological changes are difficult to measure for emotional response and immersivity to sound and music [17] as it does not take into account cognitive aspects. Therefore for a phenomenological experience (experienced from the first-person point of view), subjective reports in the form of questionnaires were used for the assessments. The questionnaire consisted of 29 open-ended questions that assessed the overall game experience (e.g. "Did you feel more or less engaged at different stages of the game? Which part of the game was immersive and why?" and "Which features of the interface most helped guide you to the places where the ghosts were located? Please describe). The open-ended questions were designed specifically not to lead the volunteers to comment on the audio unless it had a significant impact on the game experience. It also consisted of a set of statements in which 9 (out of 22) were specifically

related to audio with players responding by using a 5-item Likert scale (strongly disagree to strongly agree). Audio statements included "The sound made the game feel scary", "I feel that the sound was reactive to my movements" and "The audio was seamless and felt a real part of the game".

The location based prototype, *VGH* was evaluated over a period of three days. The 19 participants were provided with the HTC T-Mobile G1 phone and headphones and included male and female volunteers with ages ranging from 20 to 45 with a mixture of previous game experience to little or no game experience. The participants were not briefed regarding the importance and evaluation goals of the sound design.

5.2 Results of the audio game experience

The numerical data from the Likert scale questions regarding the audio was analysed and it was found that 70% of participants responded to agree and strongly agree that they enjoyed the game. An important question in regards to sound was in participant expectation of the role of audio in augmented reality gaming. It was found that the respondents expected the role of audio to be roughly equal in the form of narrative and sound effects.

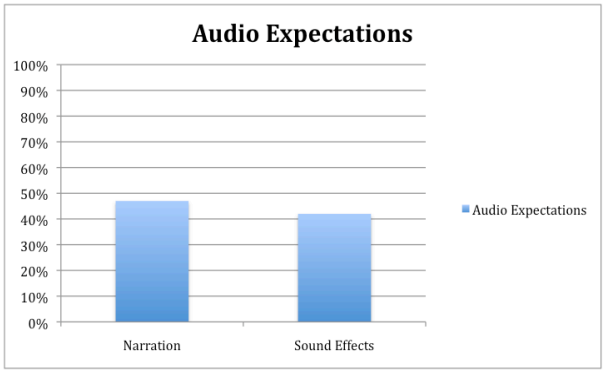

Figure 5: Audio expectations in augmented reality gaming

For the open-ended questions when participants did mention audio they responded positively to the sound design, especially in its role for immersion and engagement within the game space with comments such as:

"Addition of audio greatly increased the atmosphere and engagement."

"I felt immersed in the game"

"It was a very immersive experience. A couple of times I found myself not realising that I am on a street and there are people around me."

"At the moment it seems like the atmosphere is the unifying element (also one of the strongest aspects of the game)."

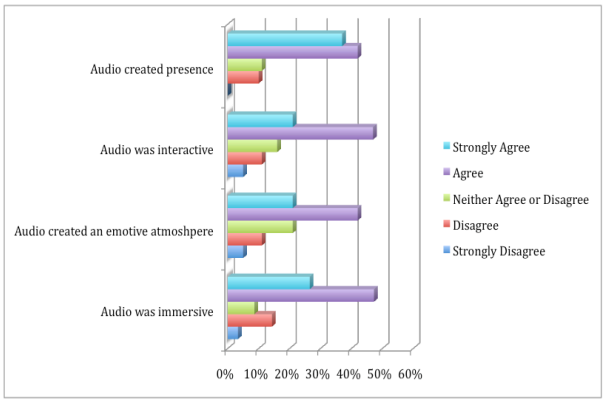

Figure 6: Summary of audio feedback

This was an encouraging outcome of the sound design. Positive feedback in relation to audio mainly related to creating a sense of immersion. By creating an engaging and complex soundscape and dialogue, taking into account psychoacoustic considerations, participants felt involved in the game and in their role as a paranormal investigator. This engagement and immersion adds to the possible development of an emotional response felt or perceived within a game space. When asked whether the game audio contributed to the game feeling scary, 63% of participants responded in the Likert questions in agreement or strong agreement that the "sound effects created a scary atmosphere."

Another important factor of the design was for sound to have an element of navigation. As discussed previously, audio reactivity to player movement was achieved by volume changes and deletion and addition of sound files. These audio changes were triggered by varying distances from given GPS locations, together with the implementation of realistic paranormal investigative user interface sounds. This supported the visual information and aided in navigating towards paranormal hotspots. The aim was for the device and player actions to be perceived as coupled and realistic. In multi-modal presentations, congruency is an important factor in reinforcing a natural mode of interaction [27]. That is, the game world should reflect the experiences of real world interactions which increases the likelihood that there is a wiling suspension of belief and hence immersion [4]. Participants were asked whether they found the sound reactive to the physical environment and if they thought the user interface sounds complemented the visual interfaces and paranormal device sounds. In response, 84% of testers agreed and strongly agreed that the user interface sounds supported the role-play element of the game play and 68% (strongly agreed and agreed) felt that the game sound

was reactive – which supports the blending of the virtual world and physical one:

"The backing audio changing as I moved location was a good touch".

"Loved the sound – that was new for mobile gaming – location sensitive."

Additionally, 79% of testers felt that the audio supported the game environment in the physical locations. In regards to navigation, the current sound design alone was not heavily relied upon by participants in locating paranormal activity. The majority of players (79%) depended upon the visual and tactile interface (phone vibrations) with only 10% using audio feedback for navigational purposes. Yet, 79% of testers did agree that a combination of the interfaces helped them find the paranormal activity.

In creating a complex sound design with many layers and types of sounds playing simultaneously, care must be taken in the presentation of the audio files. This was evident in some of the feedback as sound effects were at times found to overpower the narrative dialogue, which is essential to the game play. Hence a balance must be struck between important audio game information and ambient background or sound effects:

"Felt a little scary, however the first time the ghost spoke I had difficulty understanding what he said over the sound effects. Though the sound was quite good."

This brings to light another challenge for location based audio – external noise and busy environments. Even though in this example most testers did not feel distracted or interrupted by external noise this might have been due to the fact that a quiet location was sourced as a testing ground. Therefore augmented reality game locations must be carefully sourced:

"Stopping in the middle of a path was distracting as I felt I was in the way [of people]….isolated paths and lanes were more atmospheric and I felt more immersed."

Generally the results obtained from the user trials were extremely positive in regards to the sound design aim of trying to create an immersive and potentially emotive environment by the use of spatialised and reverberant audio. As one tester noted:

"The sound – that was new and reminded me of Silent Hill on PS2 (brilliant because of sound)."

Therefore mobile phone gaming audio in a location based application has the potential to be immersive and engaging even when faced with the challenges of slower processing speeds and limited memory space.

5.3 Results of reverberation and spatialisation

A small subset of participants involved in the *VGH* user trials (6) were further tested on the specific audio parameters of spatial audio and reverberation and the effect on immersion and emotional engagement. This was evaluated away from the game space and instead in a dimly lit testing room to remove any possible distractions. Each volunteer was played sound samples with reverberation or no reverberation and spatialised audio or no spatialisation. After each set of audio samples (there were 6 sets) were played, testers were asked which sample they felt was more immersive and which was more emotionally engaging. The reverberated samples used the Waves Renaissance Reverberator plugin using the Hall 1 preset with the wet/dry signal ratio set to 84 %.

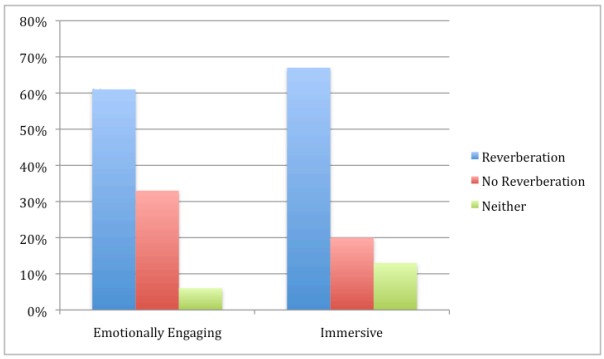

Figure 7: Reverberation results

The majority of testers (67%) found the reverberated samples more emotionally engaging with 77% also perceiving these samples to be more immersive when compared to the dry audio samples.

Samples were then spatialised using the Panorama 5 plugin and testers were then presented with spatialised and non-spatialised audio samples and asked which they felt to be more immersive and emotionally engaging. Testers unequivocally (no testers chose 'neither') felt spatialised sound was only marginally more immersive and engaging than non-spatialised sound. This was an interesting outcome as according to these results, reverberation in particular was found to be of more importance when tested alongside spatialised sound, in creating an immersive and emotionally engaging soundscape.

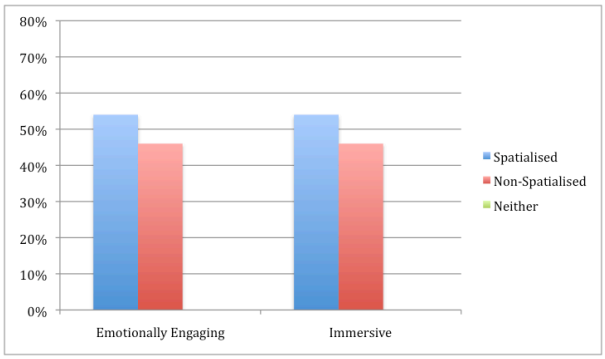

Figure 8: Spatialised audio results

6 DISCUSSION

In designing, implementing and testing the ambitious soundscape design for *Viking Ghost Hunt*, it was noticed that there are two main challenges when developing a location based game that impacts on all aspects – GPS inaccuracy, unreliability and mobile device technical constraints. During the user trials, GPS updates at certain times either did not occur or were inaccurate in determining the player location. Due to the effect of surrounding buildings and atmospheric changes, the GPS declination gave an error of 8 metres on average. This produced graphical user interface anomalies and resulted in audio files not being triggered at the intended locations. It was obviously a distraction from the game play and affected enjoyment and immersion.

The other main issue for audio in augmented reality applications is the processing speed of the device and the memory available. Very little processing power is available for audio manipulation. In order for audio to be truly reactive and to accurately represent sound spatially, live processing of sound in regards to GPS and compass positions in a physical location, must be possible. This would allow for spatialisation of audio that could incorporate not only ILD but also ITD and even HRTF filters. Additionally, real-time changes in reverberation could be possible where the proportion of reflected to direct sound could be altered depending on player distance from the GPS locations. In real-world acoustics, the level of direct sound increases and reflected decreases as one moves closer to a sound source. When coupled with accurately contextualised spatial audio, a sound design incorporating these aspects would be quite effective in location based gaming. An example of this presentation is *Demor* [8] which uses real-time processing of spatialised sound in order to create a truly 3D audio virtual space. Players can accurately hear sounds emanating from the left and right in relation to their head positions and physical location. Players can also judge if a sound is located at a distance or placed close by. The sounds are reactive to the players GPS locations and are adjusted accordingly by live processing on a specially written audio-engine. The audio engine designed for *Demor* [8] would most likely have used a non-individualised HRTF (Head Related Transfer Function) database for the 3D representation, which would involve large amounts of data processing. Simplified psychoacoustical considerations have been implemented in the *VGH* prototype however this has centred on including most of the spatialised sound in a pre-rendered format. Location sensitive left and right audio panning will be investigated for future location based prototypes in order to represent virtual sound in a static physical location by using GPS co-ordinates and internal phone compass sensors.

In regards to the user trial results of immersion and emotional engagement, it was found that audio has a significant role to play in augmented reality gaming. Sound can be an integral tool for overlaying and blending a virtual space onto a physical one and for creating a sense of presence. In testing which parameters may account for creating player immersion, it was found that reverberation, was of more importance than spatialisation. This was surprising as it was assumed that the more 'natural' a sound design is, the more immersive it would be. However, according to these results, players preferred an 'augmented' use of reverberation for creative applications. This technique of real world exaggeration is also seen in the film industry in which colours are enhanced to visually immerse viewers.

Creating a sound design that intends to bring the sonic richness of console gaming that includes spatial audio and reverberation into pervasive applications requires the consideration of many factors outside the realm of audio. The combination of technical constraints, GPS imprecision, and creative composition all add to player emotional engagement and immersion.

7 CONCLUSIONS AND FUTURE WORK

In this paper we have presented the sound design, implementation and evaluation of our working prototype *Viking Ghost Hunt*. A creative sound design together with the integration of simplified psychoacoustic aspects can be implemented on a mobile device, even with the challenging technological constraints. This research highlights the importance of sound in location based gaming for emotional engagement, immersion and for the overall game experience. However, to fully understand the impact of spatialisation and reverberation in locative gaming, a more intense investigation with a larger sample size would be required. Also, further investigations into the emotional affects of these audio parameters could

include objective physiological responses. It is the hope of this investigation to present the importance of sound, and especially reverberation and spatial audio in location based gaming and that it may inform future applications for this increasingly popular genre.

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