Creating Immersive and Aesthetic Auditory Spaces in Virtual Reality

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ABSTRACT

Creating immersive and aesthetic auditory spaces in virtual reality primarily focuses on enhancing the quality of an interactive experience for the user by utilizing a sophisticated combination of advanced immersive audio techniques and tools. While emerging Virtual Reality (VR) audio design and development best practices are documented herein, specific real world examples are also presented which demonstrate the need for experimentation and real qualitative user testing while respecting the established knowledge base for immersive audio design. In this paper, we discuss specific immersive and aesthetic auditory design techniques as applied to create full-motion, multi-participant virtual reality game experiences for live commercial Location Based Entertainment (LBE) installations. We introduce fundamental design considerations and emerging best practices used in spatially responsive virtual reality audio design and implementation, and complement these with the practical examples that embraced the complexities of immersive and aesthetic audio design in virtual reality.

Keywords: Immersive audio design, aesthetic auditory design, virtual reality, virtual reality audio, augmented reality, Location Based Entertainment (LBE), creative techniques, soundscape, art.

Index Terms: H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous

1 INTRODUCTION

In the years since the first mobile game was enabled in 1994 [1] by the introduction of the mobile phone, a global and fast growing mobile game industry was created worth over $29 billion annually by 2015 [2]. This history has inspired the promise of virtual reality and has driven artists, game developers and audio designers to adapt their console, PC and mobile game development experience to a burgeoning 3D, Virtual and Augmented Reality (AR) market for games and experiences.

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While Virtual Reality has been in existence for several decades with waning and waxing enthusiasm over the years, the most recent incarnation of Virtual Reality game and experience design advanced significantly after the introduction of software development kits from Oculus, HTC and Sony from 2013 through 2015 with initial commercial production units for all three launched throughout 2016. Global development of virtual reality games and experiences grew substantially in anticipation of the release of these wired consumer grade systems which include stereoscopic Head Mounted Displays (HMDs) and handheld interaction devices combined with graphics intensive computers and software applications.

Business grade systems also emerged commercially in 2016 to provide Location Based Entertainment including VRcade, THE VOID and Zero Latency. The audio design discussion in this document is based on content developed for commercial VRcade installations, the only full-motion, multi-player, untethered system of the three which was not implemented with a backpack computer or mobile phone to provide the computing resources to render the virtual reality experience.

Advanced techniques from a body of virtual and augmented reality development informed the design of the VRcade content, however, several complexities were introduced in these first-of-their kind location based virtual reality projects that required adaptation and further refinement of techniques based on real user feedback, business objectives and customer requirements. As Graham Pullin writes, "the best way to design the experience is to experience the design" [3].

In this paper, we'll describe thought processes and audio design techniques and decisions based on design goals and objectives that can be used to advance story and gameplay in virtual environments while sharing projects that involve full-motion, multi-participant VR location-based games.

2 VR SYSTEM DESCRIPTION

The VRcade game development was specified to be approximately three minutes in length, support two simultaneous players in the same virtual and physical space and allow for a full range of player motion in physical spaces ranging from 225 to 900 square feet (approx. 21 to 86 square meters). A picture of a typical VRcade installation is shown in Figure 1.

The VRcade system allows games to run on dedicated high powered computers, and then streams the content wirelessly to the players' HMD without the need for wires, mobile phones or backpack computers. The HMD is a display with essentially no processing. This unique architecture provides a state of the art, crystal clear and completely untethered experience. It also defines the capabilities that can be utilized in the development of the content.

Figure 1: Typical VRcade Installation

3 Key VR Design Considerations

Each game has several parts that must coexist in harmony for the user to have a truly immersive experience where no individual part of the design stands out, but rather a new reality is created that replaces the actuality the user existed in before the game started. The narrative and gameplay bound the environmental art, characters and actions, but do surprisingly little in absence of audio to define the mood and drive emotional responses to accompany the virtual reality visuals playing out on the display in a stereoscopic, time varying and positionally responsive manner. When done properly, the audio design combined with the video induces a wide range of desired emotions, triggers coerced movements that define gameplay, and creates complete immersion in an experience that exists only within virtual reality.

3.1 The Power of Sound

Audio is an extremely powerful storytelling, design, and communicative agent. Audio has the ability to affect individuals on a deeper level than most might expect—often on a subliminal level that they aren't even aware of. Sound is an immensely powerful narrative device that plays a crucial role in our emotional lives. It can imply actions or items which cannot be depicted through graphics. It can also alter our perception of events on a deeper level than graphics, story or character. Sound affects us on a deep emotional level because we are continually experiencing it. Unlike our eyes, the ears never "blink".

In summary, well-designed audio has the potential to craft the story elements of a product, control the pacing of an experience, enforce the narrative, elicit and influence emotion, create mood, shape perception, and reinforce the way people experience characters. As such, audio must be considered a fundamental storytelling, characterization, communicative, and design mechanic.

3.2 Audio and the VR Environment

The authors put forth that the VR environment is created more in the audio space than in the visual space for several reasons. First, audio can represent all of space rather than just what the viewer is seeing, e.g. sounds behind the user (not in their field of view) or ones where sources have not been graphically rendered. Second, the complexity allowed by the body in audio reception is greater than that allowed by the eyes for the visual reception. The auditory system can simultaneously process multiple frequencies with a variety of amplitudes whereas visually each bit in an image corresponds to a specific color, but cannot represent multiple colors simultaneously. Audio can be received vibrationally, i.e. physiologically, by several parts of the body simultaneously in addition to the ears. Audio can affect us on a subconscious, psychological, and physiological level.

Very early in the design process, we need to consider how we approach the creation of the spaces we are building and throughout the process to create spaces that are coherent, consistent, and cohesive within the story and game space.

The narrative of the game and the desired gameplay set the foundation for the visuals of each setting within the game, but adding the audio brings them alive, making it effectively real in the player's mind.

3.3 Non-Diegetic Music & VO in VR

Finally, special consideration must be given to music and VO if they are to be included in a VR experience. Non-diegetic music, which is music that does not emanate from the world or have any apparent source in the world or the world that is being created, is common in traditional (i.e., non-VR) games and experiences and is often referred to as "underscore". However, in VR the use of underscore is still being debated, with many disagreeing how this should be treated in VR. Some argue that non-diegetic music breaks immersion while others put forth that it helps to create immersion by guiding the players' emotional states and interpreting the actions they see before them.

Unlike the original *Leviathan* AR experience for CES 2014 that one of the authors (Summers) had worked on and discussed in "Sonic interaction design for virtual and augmented reality environments," [5] there was no music in the encore *Leviathan* VR experience for the 2016 Sundance New Frontiers Festival. Even though the world of *Leviathan* is fantastical, it was also a goal to have it be "realistic" in nature. This required that music would need to be emanating from a diegetic source versus having a non-diegetic underscore. Originally, there was going to be an elevator inside *Leviathan* where players would hear elevator music but that idea was ultimately not implemented in the design due to time constraints. Similarly, all VO emanated from the characters within the experience. The scientist in the experience gave participants instructions on what they needed to do; there was no "Voice of God" voice-over narration. This piece was specifically designed without "Voice of God" narration and a non-diegetic score to create a more "realistic" space. The use of VO and non-diegetic music in VR should be based on the desired look and feel, scenarios and project objectives.

4 Barking Irons

Barking Irons, an arcade style shoot-out set in the Old West, was launched at the CVR conference in Vancouver, British Columbia in May, 2016. This was the first VRcade game to support multiple simultaneous players occupying the same physical and virtual space in a completely wireless environment. The game is designed for physical spaces up to 30ft x 30ft with two users moving across the entire area (you can physically move around — even run and jump around — within the physical capture space). In addition, multiple capture volumes can be networked together for additional players to play in the same virtual space.

In *Barking Irons*, players start in the desert just outside of town, where they can test their guns on destructible targets like bottles and barrels (see Fig. 2). Players see each other as futuristic robot avatars and are equipped with a Western revolver with a sci-fi twist. When ready, the current sheriff of the town introduces the rules and loads the players into the center of a Wild West town.

Animatronic bandits spawn throughout the town and start shooting at the players. The player who can dodge incoming bullets and shoot the most bandits will be crowned the new sheriff. This experience was specifically designed to be a fun and easy-to-play arcade experience for participants of all ages and skill levels.

Figure 2: Barking Irons game environment

4.1 Physical Limitations

Barking Irons from the start was designed to be a multiplayer, location-based game where multiple players compete in the same physical and virtual space where players see each other as futuristic robot avatars, each equipped with a Western revolver. Since a player's face is covered in VR by the HMD, it is important to make sure that players do not collide or hit each other with their props, i.e. LightGuns™ , in the heat of the moment in the game. The ability to see an avatar of the other player in the space was a sufficient replacement for actual vision of the player. In other words, people know and understand where the players are relative to themselves, and therefore avoid collisions, as long as there is a one-to-one correspondence of real space to virtual space and extremely precise tracking of movements with very little delay as is the case with the VRcade system. Avatars can also be made a little larger in appearance to give some physical buffer.

As with most VR games and experiences, some mechanism must be present in the game to indicate to the player when they are "going out of bounds" or moving beyond the allowed play area. Visible gridlines are commonly used for this purpose. *Barking Irons* was the first game in which VRstudios experimented with placing natural limits in the game space by utilizing elements in the story world, such as barrels and wooden boxes as capture volume barriers thereby theming the grid walls with the experience. Audio cues can also be utilized and naturally built into an experience to indicate game boundaries.

4.2 Game Environment & Environmental Audio Design

For the ambient western audio, the goal was to create an immersive, believable, organic space that had some dynamic variation to it. This was accomplished by creating a seamless game world through the use of "acousmatic" audio: sounds whose sources are intentionally not visible.

To truly be immersive, it was important that players felt like they had stepped into the Old West. The right balance and a cohesive combination of environmental and gameplay audio was required.

Additionally, in order to have a more believable and complex soundscape, the sounds that comprised the environment needed to not seem repetitive and on a "cycle." With any type of shooter in VR, players are extremely sensitive to the sounds associated with guns, shooting, explosions and impacts. This introduces a heavily weighted opportunity to elevate the player's experience. To that end we wanted to make sure that we had extremely satisfying impact and gun sounds with many variations to each.

The organic nature of the environments in Western-themed video game *Red Dead Redemption* is impressive and the environment in *Barking Irons* was modeled after this type of organic design. The goal was to create something at least as subtle, putting the player in the middle of a very personalized experience! This subtlety is even more important in immersive VR than in a traditional video game, as you are actually inside of the experience.

4.3 Balancing Audio for the Environment & Gameplay

The main objective for *Barking Irons* was to strike a balance between creating effective audio that satisfied basic gameplay requirements, and building a soundscape that worked well and cohesively within the world – supplying you with auditory cues so you can play the game while also making you feel like you're truly in some futuristic world drawn from the Wild West.

The soundscape/ambience incorporated sounds like wind, tumbleweeds, birds, horses galloping by, rattlesnakes, coyotes in the distance, and a train going by on train tracks even though the development team was not going to render any of this out graphically. One of the awesome things with audio is that we don't need to see any of these objects to make them real for the player; we can just imply them through audio. And we set each of them up to trigger appropriately, so (for instance) you wouldn't hear a train traveling by you every few seconds.

The "appropriate" audio was then spatialized and attenuated in the VR environment. An early reflection model was built in conjunction with a Wwise RTPC (Real Time Parameter Control) for player_height. This project was built in the Unity engine using Wwise from Audiokinetic and Two Big Ears' 3Dception.

Not all sounds need to be spatialized in the VR experience, hence the term "appropriate." There may be sounds that are static or head relative. For instance, the Sheriff VO is attached to the Sheriff robot in the Lobby scene and attenuates as you move your head and walk around in the space. But in the game level, since you don't see the Sheriff when he alerts you to the start of a new round, his VO announcements are in simple stereo as they are just there to communicate info to the players. However, for the individual environmental sounds mentioned earlier (e.g., the coyote sounds, the rattlesnakes, birds, horses, train, tumbleweeds, etc.) User-defined Wwise 3D positioning was used. This enabled the definition of the "spatial positioning of an object in a surround environment using animation paths" [4] that follows head tracking, so you can place things in the world without even needing to anchor them on a game object in the world. Hence, the individual ambient world sounds are always positioning as you rotate your head, and therefore, you always feel a sense of direction and depth within the world. A more natural and immersive environment was created as a result of this design.

At this point, 2D looped stereo ambiences (i.e., general ambience that we did not feel required spatialization) were mixed in with individual 3D mono spatialized sounds which worked quite well and felt very natural. The wind and general ambience was not designed as a quad-array with emitters placed around the listener in all directions, as we didn't find that necessary with this experience. All these environmental sounds also played a key part in immersing the players within the space since these subtle sounds blended with the environment in a dynamic way. As a side note, people who played the game remarked that the non-diegetic music also really made them feel like they were in the space, as it set the tone for them.

While the environmental sounds induced emotion and helped to create a truly immersive experience, it was essential to balance the environmental sounds with the sounds that were essential for gameplay. The gameplay design efficacy is greatly reduced if the players don't look where they need to look at any point in time during play. Great care was also taken to not overwhelm and distract players with too much sound.

4.4 Iterative Design & Testing

It is very important to test and see where people are looking and responding with regards to your audio cues. Then, adjustments can

be made based on that data. It is very difficult to theorize and predict people's responses in such a complex soundscape. Multiple iterations of the design – test – modify – test process is mandatory to achieve a high quality and effective experience.

Because of this, we ended up doing some experimentation with the animatronic bandit spawning sounds, as having effective and well-positioned audio cues was key to the gameplay. The original spawn sounds (kind of futuristic transporter sounds), while very cool sounding, were just not reacting well with all the gun shooting between the two players. The spawning sounds were too subtle and were getting masked and overwhelmed when players were shooting rapidly and new animatronic bandits spawned in. So, the team had to think about what would be a better sound that would be more attention-getting. The requirement for the sound is that it needed to be very clearly positional, alerting the players to look in that direction. It was suggested by the development team that perhaps a grand whoosh could be interesting for the new spawn sound, however that idea was eliminated immediately as that sound would be too non-transient since it would be very similar to the current spawn sound in the game. As a result, the sci-fi sounds were changed to be strong whip cracks which were very satisfying sounding. This was a win-win as it worked well with the story, environment, and gameplay. It was crucial that these bandit spawn sounds be very prominent audio cues and not subtle like the environmental sounds!

Sounds that are too quick or too soft can be challenging to locate. Wide band or broad spectrum sounds will spatialize better. With low frequency sounds, it's harder to tell where they are emanating from. Low end is good for the feeling of a sound and affecting physiology and great for giving an object weight, presence, and size! Sounds that are primarily low frequency like an energy pulse or a rumble are well suited to being stereo sounds.

During testing, it was agreed that projectile whiz-bys on the bullets would be very helpful and effective in providing a more immersive experience. As mentioned previously, an early reflection model had been created so that players could hear the enemies when they shot at them and to assist with further localization of the audio sources by getting more reflections from the animatronic bandits. An occlusion prefab that filtered out certain sound frequencies when players ducked behind barrels and boxes was also put in place. The resulting effect was quite subtle, but very effective.

The Enemy Take Damage sounds were originally one single sound that would get triggered, but as that seemed too repetitive, the team changed these to have several variations. We also removed the initial electro-static audio layers from these sounds and kept them as "successful" sounding metal hits. This was due to the testing we performed and noticing that we couldn't distinguish whether the player was being hit or the enemy was being hit, as both incorporated electricity sound layers (since both the players' avatars and the bandits were robots).

In addition to this, the Player Take Damage variant sounds were modified due to testing with various people. It was noted by several participants that they could not tell when a bullet hit them. In response, the bullet impact sounds were made to be more visceral so that players would get a physical feeling and effect from them – when they got hit by the bandits' bullets. Originally, the sounds started out as metal sounding hits, and while they sounded great, no one was really feeling impacted by them. Another sound layer was created that had more of a negative quality to it that would signify deep consequences to make people feel even more immersed in the experience and to motivate and incentivize them to move to avoid being shot. Electricity sparks were added on top of the metal sounds for when a player got hit (we created variations for this as well!). The static-like sound was reinforced and some low frequency content was also added in, so players would feel the sound in addition to hearing it.

Experimentation became a key element of the design, development, and testing processes. Again, the driving philosophy for the sound design was to make sure that the participants felt like they were in the space and that they had clearly localized sounds in order to play the game effectively. Testing and user feedback allowed specific areas needing improvement to be quickly identified and then validated the effectiveness of improvements once made.

4.5 Music

The team incorporated non-diegetic music into the game. There are different schools of thought regarding whether non-diegetic scores can be used in an immersive VR experience. As mentioned, the authors strongly believe that how you approach VO and music in VR will be based on the scenario you are creating and what your objectives are for your project.

For this project, the team determined that a non-diegetic layered score would be a very important aspect of the game as it would set the tone of the game, lend to the ambient environment, and contribute to the game playing mechanic, as the music layers were driven by a parameter indicating how well you are doing (player_success), with the music transitioning to higher intensities as you succeed in the game.

Everything was built in layers that loop so the track would play indefinitely in a particular intensity level until a parameter told it to move on to the next mood or intensity. It is important to point out that it was also very essential to make sure that the sound cues were never masked by the music.

Per the request of the developer wanting to experiment, the audio team even built a real-timer fader - "Head Volume Fader" RTPC (player_ducking_musicvolume) to explore the idea of having a fader dial attached to the players' heads in which the music would change based on ducking activity, but we ended up not using it as we deemed it could sound "wrong" and disruptive to the experience if we kept changing the music based on the players bobbing up and down to dodge the bandits' bullets.

4.6 Headphones

Another factor to take into consideration in the audio design was the Bluetooth wireless headphones as the ones used for this experience also utilized virtualization. 3Dception is designed to be in a stereo field, i.e. it relies on a stereo experience. The headphones had to be tested in combination with 3Dception to see if the concatenated effect would be detrimental to the audio. Is the virtualized software "hurting" the sound or are the effects benign? The testing resulted in adjusting the virtualization software settings for the Bluetooth headphones, as the virtualization software, while making the experience seem fuller, was ultimately affecting the precision of the localization.

In general, it is never a good idea to have headsets that perform sound virtualization when there is already real-time/dynamic sound virtualization that you are doing within the engine.

Furthermore, the design had to account for Mumble, an open source, low-latency voice chat software that allowed the players to communicate with each other in the experience. As Mumble, like most voice chat solutions, attenuates all other audio in an application to 50% by default in order to be heard, the developers needed to adjust the Mumble ducking settings to leave more headroom for the game's audio middleware engine (Wwise), and also to adjust all other in-game volumes to ensure the appropriate sounds cut through the Mumble ducking.

The attention to detail, trial and error, and sophisticated audio design contributed substantially to the commercial success of the game and the quality of the VR experience.

Figure 3: PlanktOs game environment

5 PLANKTOS: CRYSTAL GUARDIANS

Many of these same concepts were then applied in very different ways to a very different title. Launched at the Immerse Technology Summit in October 2016 in Seattle, WA, *planktOs: Crystal Guardians* is a beautiful and immersive undersea bubble blasting game that emphasizes the themes of adventure, wonder and joy, and sets a new standard for family friendly virtual reality experiences (see Fig. 3).

Like *Barking Irons*, *planktOs* is a multiplayer game with players either cooperating to maximize group score or competing to get the best score in the group. In the game, players find themselves in a beautiful underwater reef (a fantastical stylized environment) in which they see each other as wearing big metal scuba suits, equipped with a bubble gun and charged with protecting a precious crystal from incoming attackers that happen to be "corrupted" fish – or fish covered in an inky black cloud. Players use their bubble gun to "cleanse" (NOT shoot!) the fish from the evil inky blackness released by Planktos Corp and the Weatherbird II. These fish spawn around the players and move towards the crystal to pass on their corruption and destroy the crystal. The player's goal is to protect the crystal, save the fish, and cleanse the ocean!

5.1 Game Environment

In adapting the original PC game, developed by Blot Interactive**,** to VR, we set out as one of our key goals to create an incredibly immersive but "good feeling" environment through audio. We aimed to create an immersive, stylized, natural and organic space with somewhat realistic (and hence, "serious") underwater ambience, which would then leave room for the bubble gun and all the related impact effects to be wonderful and fun!

Since part of the game is wonder and exploration, other interactive aspects were included that were separate from the main gameplay, but allowed for unexpected delight: shooting a starfish with a bubble made it giggle while shooting a clam caused it to release bubbles and to jump.

This project was built on the UE4 engine and was a shorter scope project than *Barking Irons*. In the interest of time, it was decided to avoid middleware completely and go with Unreal's native audio controls. There was enough new development and a multitude of operational questions with this project, that the distraction and hurdle of implementing audio middleware was just not practical.

As *planktOs* did not use HRTF filtering, UE4 attenuations and spatializer were used instead of the 3Dception product which was used in *Barking Irons*. Interestingly, the development team initially thought the spatialization was more positional in *planktOs* (before we created the environmental model for *Barking Irons* that is!) and that's because HRTF filtering reduces the hard stereo panning – which can often be assessed as sounding less positional.

5.2 Music

This game included non-diegetic music as well and was a major contributor to the soundscape and environment.

The design was centered around a "Finding Nemo"/Thomas Newman-esque styling, as this type of style provided the perfect elements of wonder and excitement, yet still had a bit of a serious side to it. The ambience and music were more on the "serious" side with the gameplay elements having more of the fun effects with really fun sounds.

Three music layers were created from that foundation and were designed to escalate in additive intensity between the three stages in the game. The musical framework was designed such that Stage 1 would go from 0-30; Stage 2 would go from 20-50; and Stage 3 would go from 40-100. These musical segments were then connected by the bubble particle chamber sequence which is the sound-based level transition with no music. The challenge here was to make this music ramping while ensuring that the intensity layers didn't feel disjointed with only a few seconds in between. We utilized the non-diegetic music to heighten emotional impact, set the mood, tone, and pacing of the environment, and as a game design mechanic with transitioning intensity layers as indicators of player success.

Finally, as in *Barking Irons*, we needed to adjust the virtualization software settings for the Bluetooth headphones, as the virtualization software was muddying up the mix a bit.

The resulting game was exciting and fun, and based on user comments the audio was the key factor that drove the very favorable player response to this game. Indeed, many players remarked that the environment was so comfortable and relaxing that they just wanted to stay in the experience.

6 LESS IS MORE

In both titles, a deliberate "less is more" approach was taken with the audio design. The team didn't want to overload the environment and suffocate the story. We wanted to be subtle. So, we were extremely careful about filling the space up with too much sound. Even though we would be dynamically mixing the assets and prioritizing sounds, we knew that too much sound would saturate the spectrum and the experience would end up losing clarity and focus. It could be overwhelming or too distracting to the listener. But worst of all, the story would become "suffocated" with sound. The result was in both cases a wonderful balance of environmental and gameplay immersion.

7 CONCLUSION

Audio can and should be an integral design element from the start, conveying elements of narrative, characterization or gameplay by itself and in concert with other game elements. Audio must be more than a list of assets to be compiled and assembled like the items on a shopping list.

Rather than just coupling each of the visual elements of a game with a corresponding functional sound element, audio should always further the goals of story, characterization, and the creation of a holistic ecosystem. Well-executed sounds and a brilliantly composed soundtrack have minimal value when accompanied by nothing more than surface meaning. The techniques discussed provide ways for an entire production team to work together in order to create a cohesive, holistic unit of all the elements as well as a "rhythm" within a game experience.

Games can and should aspire to delivering more impactful experiences by taking into account that sound enhances the underlying meaning of the experience in a very personal way and contributes to a deeper meaning within a game.

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