IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received 4 September 2025, accepted 22 October 2025, date of publication 31 October 2025, date of current version 7 November 2025.

Digital Object Identifier 10.1109/ACCESS.2025.3627544

RESEARCH ARTICLE

Adaptive Radio System Using MetaSounds for Serious VR Game

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ABSTRACT Background: Adaptive audio can deepen immersion in VR, yet many pipelines still rely on fixed playlists or ad-hoc triggers that break narrative coherence during rapid context shifts in serious games. Methods: We implement an adaptive in-game radio using Unreal Engine MetaSounds and a finite-state machine (FSM). Three affective stations (Happy, Excited, Intense) drive procedural ambient music with equal-power crossfades, loudness normalization, and optional beat-synchronous transitions. We integrate Blueprint–MetaSounds graphs and evaluate usability and perceived immersion with 30 participants in VR. Results: The interface was rated intuitive by 90% of users; 85% reported higher immersion than a non-adaptive baseline; 80% felt the adaptive music heightened emotions at key events. Overall satisfaction averaged 4.5/5, and 70% indicated replay intent to explore audio variants. We provide the audio graph, state logic, and transition envelopes, and quantify transition smoothness via envelope and loudness metrics. Conclusions: An engine-native MetaSounds–FSM pattern is practical to deploy and can improve engagement in serious VR contexts. We discuss design trade-offs, limitations (sample size and demographics), and avenues for broader deployment in training and therapeutic simulations.

INDEX TERMS Adaptive radio system, virtual reality, serious games, MetaSounds, immersive audio, finite state machines.

I. INTRODUCTION

Virtual reality (VR) enables highly immersive training, education, and entertainment experiences. In serious games, immersion is instrumental to learning efficacy and performance. Audio is central: adaptive music can shape affect and engagement, and spatial audio improves presence and environmental awareness [8], [18], [19], [31], [32], [33].

A. BACKGROUND

Serious games apply game mechanics to non-entertainment goals (e.g., training, education, therapy) and typically prioritize clarity, feedback, and measurable outcomes [12], [13], [22]. In VR, audio must both convey context and avoid distracting from tasks. Virtual environments may also incorporate multi-view capture systems with *static camera arrangements* to build coherent scene understanding, a design that motivates consistent audio rendering across viewpoints (add cites such as Hartley–Zisserman; Szeliski once in your .bib).

The associate editor coordinating the review of this manuscript and approving it for publication was Lei Wei.

B. GAP AND CHALLENGES

Many VR projects still use fixed playlists or handcrafted triggers, leading to abrupt transitions, poor semantic alignment (tempo/key/mood mismatch), and limited responsiveness during rapid context changes. Prior adaptive/generative approaches face constraints in real-time control, authoring overhead, and maintaining musical coherence under latency and resource limits [31], [33].

C. OBJECTIVE

We present an *adaptive radio* for a serious VR game that employs Unreal Engine MetaSounds and a finite-state machine (FSM) to deliver seamless, affect-driven background music with procedural radio realism.

D. SIGNIFICANCE

Our engine-native pattern is low-latency, highly authorable, and deployable without external middleware. It provides a reproducible recipe for affective ambience in serious VR titles.

E. SCOPE AND OUTLINE

We target three affective stations (Happy, Excited, Intense) with overlap during transitions. Section II reviews adaptive/generative music and spatial audio; Section III details design/implementation; Section IV reports user study results and statistical analysis; Section V concludes with limitations and future work.

1) SERIOUS VS. NON-SERIOUS VR GAMES

Serious games target training, education, or therapeutic outcomes and prioritize clarity, feedback, and alignment with task goals; entertainment titles optimize for fun and challenge [12], [13], [22]. Our audio design emphasizes low-latency feedback, semantic coherence with task context, and low distraction properties that contribute to ''seriousness'' in VR scenarios.

II. RELATED WORK

Immersion virtual reality (VR) technology has attracted a lot of interest lately, especially with regard to head-mounted displays (HMDs). Several advantages, including embodiment, interactivity, navigability, sense of sensitivity and create ability, have been identified in the literature as essential for improving user interaction and engagement in virtual environments [1]. These advantages are especially pertinent to serious games, which have gained a lot of traction in academia and industry and have a wide range of applications in fields such as education, training, healthcare, advertising, cultural heritage and well-being [2], [5], [6], [7].

Adding dynamic and adaptive audio systems to VR games and applications to improve immersion is a major problem. It has been demonstrated that by dynamically altering music in response to player actions and game context, adaptive music systems (AMSs) produce more emotionally charged and engrossing gaming experiences [1], [8], [9], [10], [11]. However, the algorithms employed for modelling player actions and the game-world context, as well as for generating music in real-time, limit the growth of these systems. To overcome these drawbacks, it has been suggested to integrate cognitive models of knowledge organization and emotional effect with multimodal, multiagent composing approaches. This improves immersion and better aligns music with concepts in the game environment [3], [8].

Additionally essential to increasing immersion and communicating environmental information in virtual reality is spatial audio. Spatial audio is an essential part of immersive VR experiences since research shows that it greatly enhances user perception and immersion in virtual environments [4], [12], [13]. Spatial audio has been understudied despite its significance, but new developments are making it simpler to incorporate high-quality spatial audio in virtual worlds [4].

The rule controlling state transitions in dynamic contexts can significantly change the incentives that agents must choose from. Exogenous and endogenous transitions are compared in studies, and the results indicate that participants internalize the impact of the dynamic game transition rule on their incentives. This is especially important when modelling audio state changes in adaptive radio systems [14]. Because agile approaches, particularly Scrum, are so good at project management and teamwork, the game development industry has embraced them extensively. These approaches tackle certain game development issues, such as feedback responsiveness and iterative development, which are essential for creating intricate systems like VR game adaptive audio [15]. The advantages of agile techniques in managing the complexity of game development processes and enhancing project outputs are emphasized by research on game development methodologies [15], [16].

Personalized surgical skill training and evaluation, medical content-based photo retrieval, and remote monitoring of mining equipment with VR-based digital twins are some examples of the other sectors that have used virtual reality (VR) technology. Furthermore, VR has been utilized in other industries. It is clear that virtual reality technology has the potential to improve decision-making, training, and user engagement, as demonstrated by these applications [17], [18], [19], [20].

Understanding player characteristics and preferences can greatly improve game design and player engagement, according to studies on player preferences and game choices. Studying the connections between users' gender, preferred game genre, motives for playing, and Big Five personality traits can help designers create more interesting and customized gaming experiences [21], [22], [23], [24], [25]. The immersive experience can be further improved by incorporating generative content generation techniques, such as reinforcement learning, which can dynamically alter game levels and content to reflect player actions and preferences [26].

Virtual reality (VR) has showed potential in the context of serious games for therapeutic applications, offering safe, pleasant, and affordable approaches. Virtual reality (VR) has the potential to be used therapeutically, as evidenced by the successful outcomes of lowering fear and anxiety in acrophobia therapy applications [27]. Affective-driven procedural content generation is another way that research on emotionally adapted virtual reality for mental health applications promotes emotional self-awareness and management techniques [28].

VR audio commonly uses (i) state/event stem switching, (ii) parameterized mixing, (iii) procedural synthesis, and (iv) spatial rendering. Our system uses Unreal MetaSounds as a sample-accurate DSP graph driven by an FSM, unifying these patterns with deterministic routing and low-latency equal-power transitions (Eq. (1)). *Pros:* precise timing, engine-native integration, hybrid layered–procedural design. *Cons:* larger graphs raise authoring/CPU costs, so profiling is needed. *Use MetaSounds when* rapid changes or deterministic timing are required; simpler stem/parameter mixing suffices for infrequent transitions.

Further research has concentrated on the use of VR in teaching. According to a study investigating students' spatial ability in a virtual 3D environment, learners found that these settings were highly evaluated as useful and that they would be eager to utilize them to improve their spatial abilities [29]. In contrast to standard PC environments, VR fusion approaches enhance immersion, presence, and learning performance, according to a different study on the subject of virtual-real fusion in laboratory instruction [30]. Additionally, studies examining teens' inclinations and worries about HMDs in the classroom revealed that although VR improves focus and engagement, there are worries about safety and possible addiction [31].

TABLE 1. Results from comparing previous audio work.

References	Topic	Method	Object
[3]	Adaptive music systems	Cognitive models and multiagent composition	Enhance game immersion
[4]	Spatial audio in VR	Examination of technologies	Improve VR immersion
[8]	Procedural music generation	Experience-driven procedural generation	Dynamic game music
[9]	Adaptive music effects	Empirical study	Player emotion and engagement
[17]	Audio-driven animations	Deep-learning-based Audio2AB network	Full-body animations in VR
[12]	Sound in interactive environments	Discussion of sound design techniques	Enhance user engagement
[10]	Generative music systems	Taxonomy and survey	Dynamic music in games
[27]	VR exposure therapy	VR game for acrophobia treatment	Cost-effective exposure therapy
Our Study	Adaptive radio system in VR	MetaSounds and finite state machine	Interactive audio in serious VR game

In short, creating more responsive, personalized, and immersive virtual reality and serious gaming experiences still heavily depends on integrating modern audio systems, especially through procedural and adaptive ways. These developments hold out the possibility of improving VR technology medicinal uses, educational outcomes, and user engagement [1], [2], [3], [4], [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30], [31], [32], [33], [34], [35], [36], [37], [38], [39], [40].

III. METHODS

The project prioritises using Unreal Engine MetaSounds to create adaptive sound in order to create an immersive and interactive environment within a virtual reality (VR) serious game. The main goal is to make the virtual environment more immersive and enjoyable for users by combining music and gameplay dynamics in a natural way.

A particular emphasis is on putting in place an interactive radio system in the gaming environment as shown in Figure 1. This comprises compiling the necessary audio integration requirements, such as generated music, ambient noises, and adaptive sound creation with Unreal Engine MetaSounds. The project acknowledges that the graph logic of the radio system is a result of the integration of Unreal Engine blueprints with MetaSounds.

Establishing a well-defined goal and emphasising the use of MetaSounds and Unreal Engine blueprints, the project lays the groundwork for crafting a captivating and lively audio experience for the virtual reality serious game. Extensive planning guarantees adherence to project objectives and establishes the foundation for efficacious implementation and performance.

A. ADAPTIVE RADIO SYSTEM DESIGN

Three specified stations—Happy, Excited, and Intense—each cater to a different emotion on the radio system. Players can choose from a variety of tunes to fit their preferred mood, as each station plays a carefully chosen collection of pre-recorded tracks that correlate to its mood. Both "Next" and "Previous" buttons are available for station navigation, enabling smooth transitions between the various mood settings. The radio seamlessly moves to the next station when the "Next" button is hit, and it is easier to navigate to the prior station when the "Previous" button is used. The radio system may be used with ease thanks to the navigation controls' integration into the user interface.

Each station's sampled audio playback is managed by MetaSounds. Set up inside the Unreal Engine environment, MetaSounds control how recorded music is played back from the game's audio library, providing a variety of audio experiences. Each station has a playlist that is arranged and includes a selection of looping sampled songs that fit the appropriate mood. When moving to the previous or next station, MetaSounds transition effects facilitate seamless song switching and provide the player with aural cues to indicate the shift.

Intuitive controls, such as a power switch for turning on and off the radio and "Next" and "Previous" buttons for station navigation, make it easier for users to interact with the radio system. In the virtual environment, visual feedback indicates the status of the radio and the station that is currently selected, which increases user awareness and engagement.

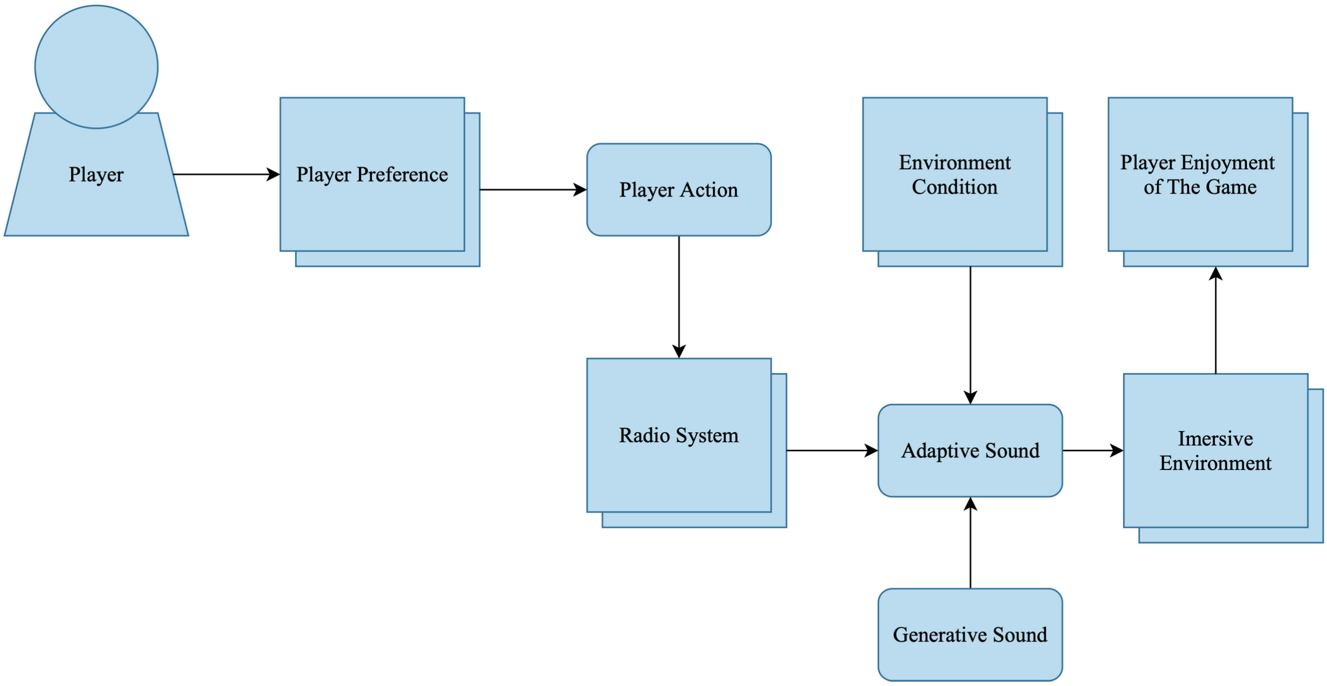

FIGURE 1. The system this article purpose to create an immersive setting to enhance the enjoyment of serious virtual reality games.

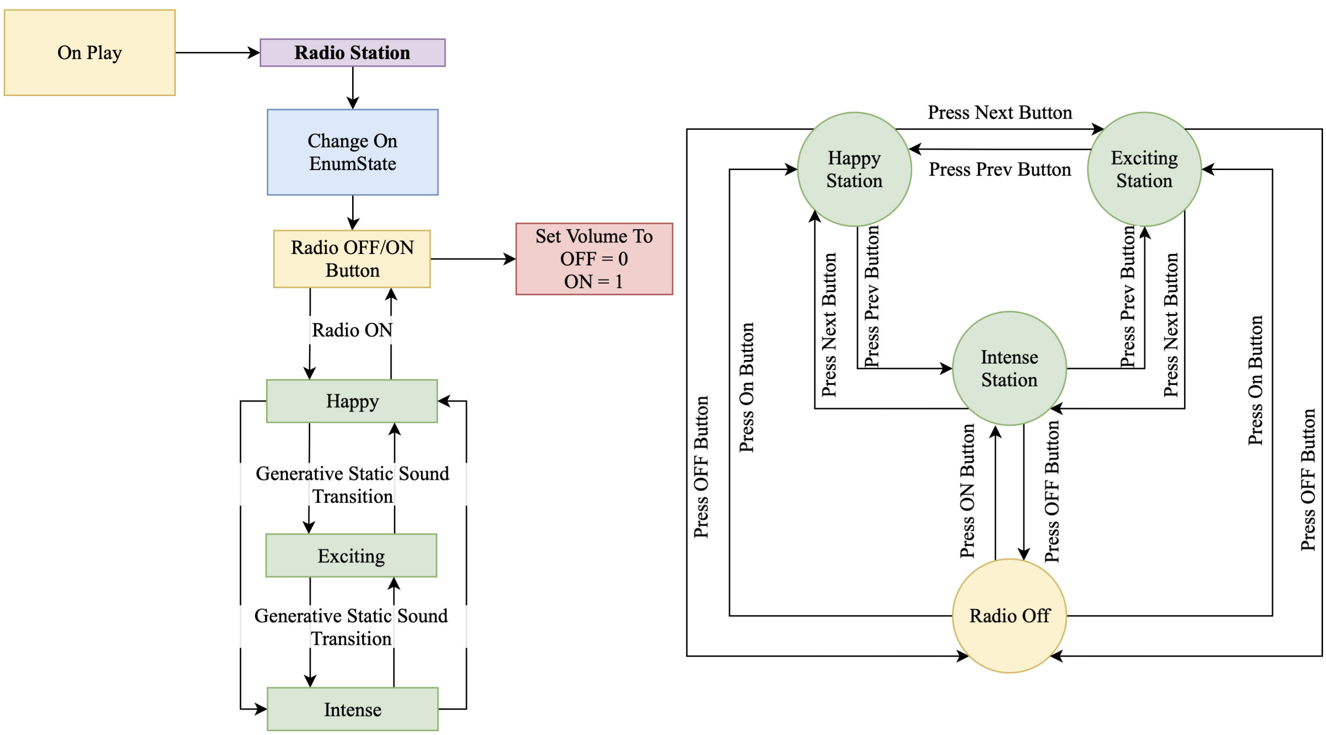

FIGURE 2. The design for the adaptive radio system: a schematic of the radio system's immersive experience dependent on player action and a controller for the system that uses a finite state machine.

The goal of the design is to provide a smooth experience by successfully integrating MetaSounds and the radio system into the virtual reality setting. The user-friendly UI, simple navigation controls, and sampled audio playback all work together to provide a captivating and entertaining gaming environment. Iterative design modifications are informed by player feedback, and extensive testing and refinement are carried out to assess functionality and user experience.

B. STATION TAXONOMY AND TRANSITIONAL OVERLAP

We operationalize stations via audio features: tempo (BPM), mode/valence, broadband energy, and spectral flux. Tracks are pre-labeled:

- **Happy:** 90–120 BPM, major mode, medium energy, low spectral flux.
- **Excited:** 120–140 BPM, major/mixolydian, high energy, higher spectral flux.
- **Intense:** $\geq$140 BPM or pronounced rhythmic density/drive.

During transitions we allow a continuous overlap between adjacent stations ($i \rightarrow j$) with a mixing coefficient $\lambda \in [0, 1]$:

$$y(t) = \sqrt{1-\lambda(t)}\, y_i(t) + \sqrt{\lambda(t)}\, y_j(t), \tag{1}$$

where $\lambda(t)$ ramps from 0 to 1 over τ using the equal-power schedule above.

C. ADAPTIVE RADIO SYSTEM DEVELOPMENT

The goal of the development phase is to build a dynamic and immersive radio system within the VR serious game by fully implementing the blueprint graph and MetaSounds processes. This is a thorough explanation of the development procedure.

The radio system's blueprint graph acts as its structural core, coordinating a number of features that are essential for smooth audio integration and user interaction. When the game launches, the graph launches MetaSounds and watches a specified value in it to determine when the music on the selected station has finished. The blueprint uses event handling to cause MetaSounds to start playing a different song from the station's carefully selected list, so the music is always changing to fit the player's preferred mood.

This mathematical formula captures the essence of the adaptive radio system's reactivity to player actions and the resulting changes in audio states, which is necessary to effectively simulate the dynamics of the system within the VR environment.

D. TRANSITION DESIGN AND VALIDATION

All tracks are loudness-normalized to −16 LUFS. Station switches use a 350 ms equal-power crossfade; non-active stations are muted to 0.0 gain to prevent bleed. Where beat grids are available, switches snap to the nearest beat/bar with $\leq$250 ms pre-roll. We validate smoothness via envelope plots (no overshoot) and spectrogram snapshots (no transient clipping) across transitions.

E. SYSTEM MODEL AND FORMALIZATION

Let $S_t \in \mathcal{S}$ denote the discrete audio state at time t, $A_t \in \mathcal{A}$ the user action, and Δt the elapsed time. We refine Eq. (2) as:

$$\begin{aligned} S_{t+1} &= f(S_t, A_t, \Delta t), \\ S_{t+k} &= f^{(k)}(S_t, A_t, \ldots, A_{t+k-1}, \Delta t). \end{aligned} \tag{2}$$

We model the controller as a Mealy machine $\mathcal{M} = (Q, \Sigma, \delta, q_0, \mathcal{O})$ with states $Q = \{\text{Off}, \text{Happy}, \text{Excited}, \text{Intense}\}$, inputs $\Sigma = \{\text{Next}, \text{Prev}, \text{Power}\}$, transition $\delta : Q \times \Sigma \rightarrow Q$, initial state $q_0 = \text{Off}$, and output mapping $\mathcal{O} : Q \times \Sigma \rightarrow \mathbb{R}^d$ to audio control parameters (track IDs, gains, envelopes). and similarly for Prev. The output applies equal-power crossfades during switches with window τ:

$$g_{\text{out}}(t) = \cos\left(\frac{\pi t}{2\tau}\right), \, g_{\text{in}}(t) = \sin\left(\frac{\pi t}{2\tau}\right), \, t \in [0, \tau], \tag{3}$$

$$y(t) = g_{\text{out}}(t)\, y_i(t) + g_{\text{in}}(t)\, y_j(t), \tag{4}$$

with loudness normalization to a target of −16 LUFS prior to mixing. Non-active stations are muted to 0.0 gain; optional beat-synchronous alignment is used when tempo metadata are available.

The radio system's current status, including active stations and continuing audio outputs, is represented by $S(t)$ at time t. The player's actions at time t, such as switching stations or turning on/off the radio, are indicated by $A(t)$. In order to control transition effects and procedural sound changes, Δt, or the time elapsed between the current and the next state, is essential. The function f determines the subsequent state by considering the player's actions, the time interval, and the current state. In order to guarantee a smooth audio transition that preserves narrative coherence and immersion, this function combines the procedural generating capabilities of MetaSounds with the logic of the finite state machine.

The blueprint also controls the radio system's condition, classifying it into several states including Off, Happy Station, Excited Station, and Intense Station. State transitions are triggered by user interaction with interface components, such as the "Next" and "Previous" buttons as shown in Figure 5 and Figure 6. These transitions allow for smooth station switching to fit different gameplay dynamics and preferences.

The implementation uses complex event logic to control the radio's ON/OFF functions. The RadioOff event is initiated when the user presses the OFF button, dynamically lowering all station volumes to zero. By simulating the sensation of missing segments and the modifications that follow when playback resumes, this simulated real-life radio behaviour improves immersion shown in Figure 7.

MetaSounds operations are carefully planned and executed in tandem with the blueprint graph to guarantee the best possible audio playback and transition effects. When the game launches, MetaSounds starts playing every list linked to every station at random, providing a wide range of musical samples to enhance the player's listening experience. Then, MetaSounds uses the Wave Player node to accomplish smooth playback when it plays each music sample in the assigned station shown in Figure 8.

When a music sample ends, MetaSounds initiates a transition event, which instructs the blueprint graph to begin playing a different sample. Every station has a volume that it controls, and if another station is playing while the current radio station is on, the volume will drop to 1. With this solution, a user can enjoy a genuine radio experience where a

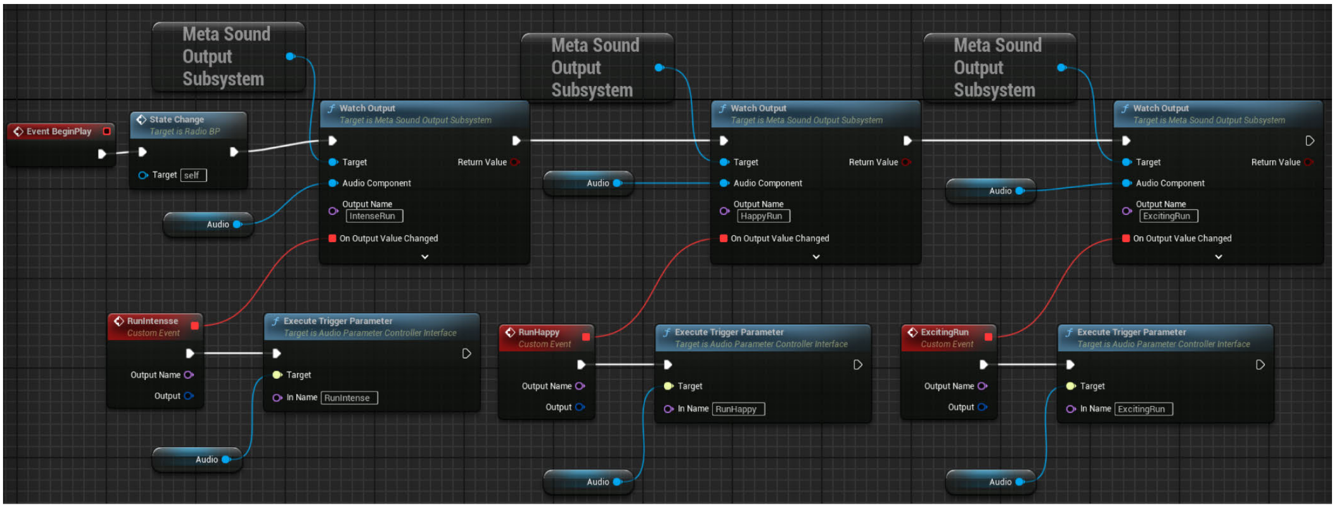

FIGURE 3. The Blueprint controls the overall loop of the radio station so it will change song every time a song ends.

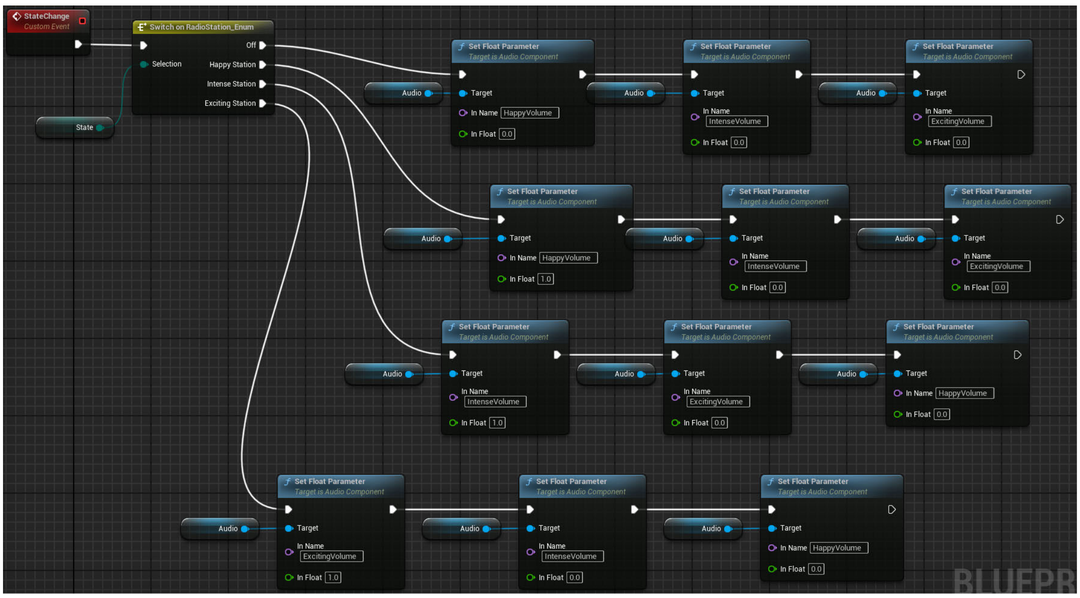

FIGURE 4. The Finite State Machine is controlled by the blueprint; in each state, the radio will switch radio stations or turn on and off.

station never stops airing, even if they switch to another one. In order to sustain immersion and engagement, this iterative method guarantees a constant and dynamic audio experience with smooth transitions between musical tracks.

When switching between stations, MetaSounds uses procedural generation techniques to create static sounds, such as employing the Perlin noise node. The user experience is improved overall by these procedurally generated effects, which give the acoustic world more depth and realism shown in Figure 9.

F. PARTICIPANTS AND PROCEDURE

Thirty participants (age 18–30; include gender counts) completed the study using an HMD (model) on a desktop PC (CPU/GPU). Pre-immersion indicators included prior VR exposure (none / <5h / 5–20h / >20h), self-reported audio sensitivity (1)–(5), and hearing status.

G. MEASURES

We used 5-point Likert items (1=Strongly Disagree, 5=Strongly Agree). Table 2 defines each metric and aggregation.

H. STATISTICAL ANALYSIS

We report means with 95% CIs (or SE). Correlation uses Pearson r with $n = 30$ and two-sided p. For switching frequency (Never=0, Rarely=1, Sometimes=2, Very Frequently=3) we

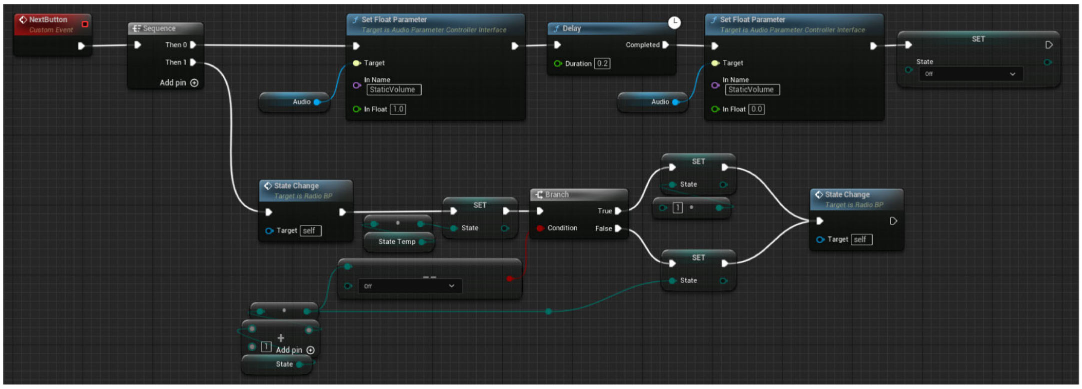

FIGURE 5. The Blueprint controls the "Next" transition button inside the finite state machine.

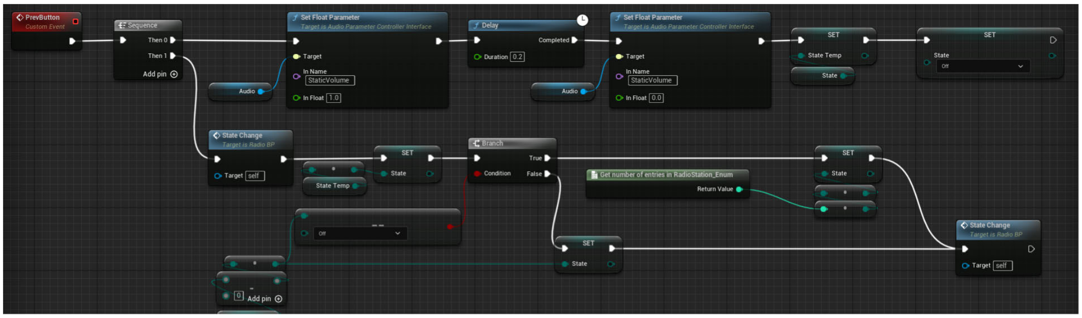

FIGURE 6. The blueprint controls the "Previous" transition button inside the finite state machine.

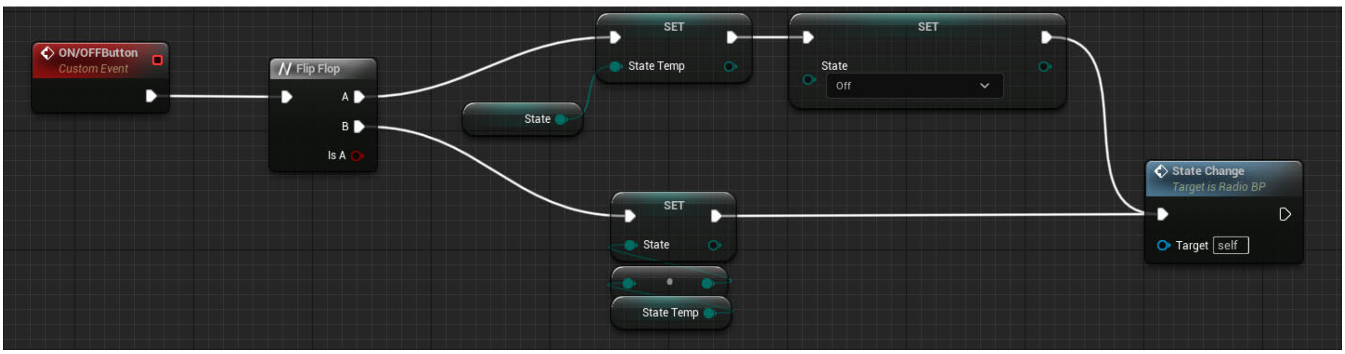

FIGURE 7. The blueprint controls the "On/Off" transition button inside the finite state machine.

fit:

$$\text{Immersion}_i = \beta_0 + \beta_1 F_i^{(H)} + \beta_2 F_i^{(E)} + \beta_3 F_i^{(I)} + \epsilon_i, \quad (5)$$

optionally adding a quadratic term to capture non-linearity at very high switching.

IV. RESULT AND ANALYSIS

The adaptive radio system underwent extensive testing, which yielded thorough insights into its functioning, stability, audio quality, usability, and interface with the game engine.

Functionality testing was done to make sure that the system could transition between the 'Happy', 'Excited', and 'Intense' stations with ease by using the 'Next' and 'Previous' buttons. By making sure that the audio tracks were suitable for the chosen radio station and that the transitions between them were smooth, the audio output consistency was verified. In order to guarantee a user-friendly interaction experience, the responsiveness of the user interface—including button presses and toggle switches for radio power—was assessed. Furthermore, the logic of the finite state machine was examined to ensure that state transitions resulting from user inputs followed the intended flow.

Testing the integration of audio processes with the Unreal Engine's graphics and physics engines confirmed that there were no interferences with other game mechanics.

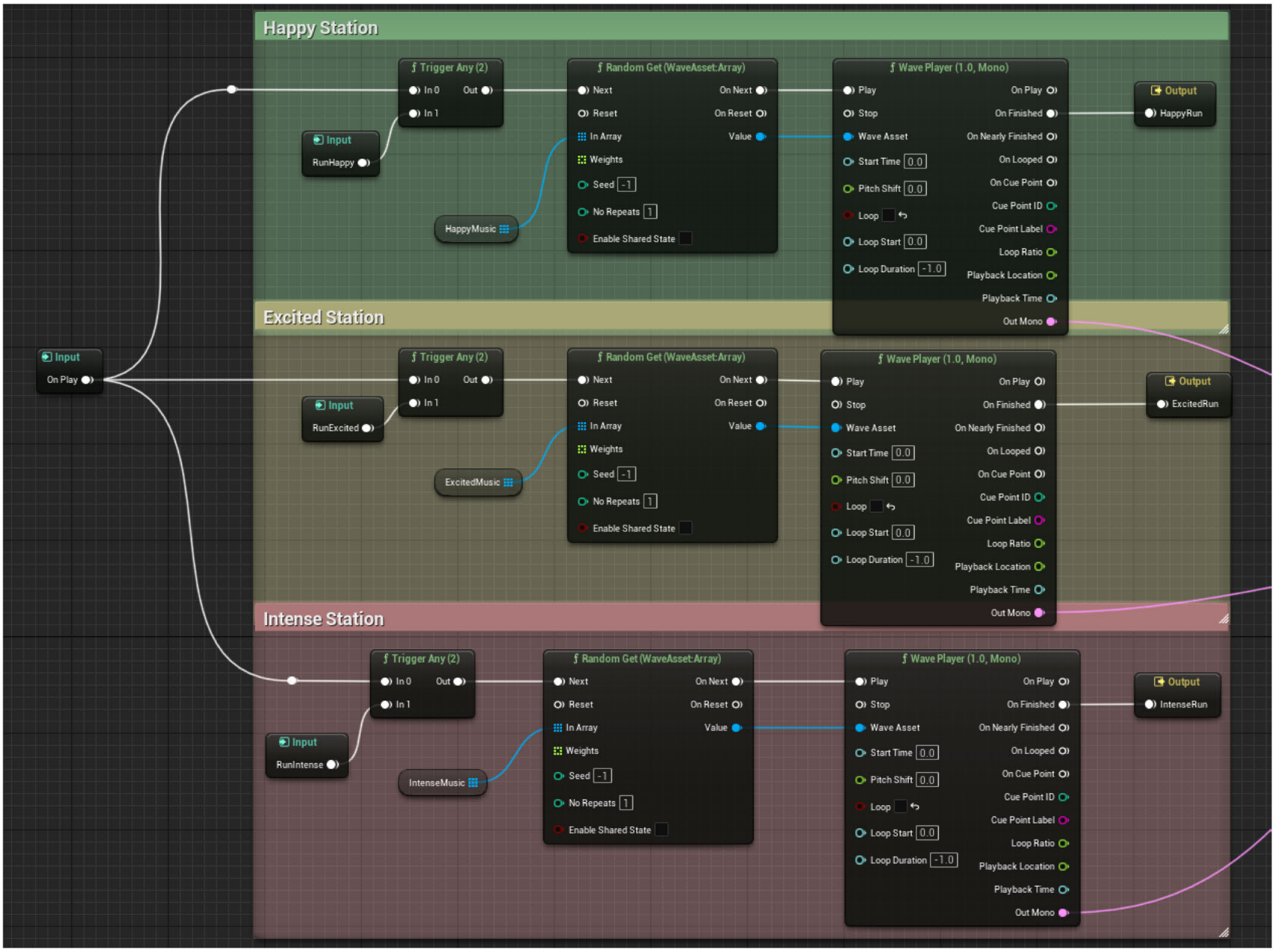

FIGURE 8. The MetaSounds graph playing samples of music on a loop.

Usability Testing: Initial input was obtained regarding the system's intuitiveness and ease of use of the interface. When changing stations or adjusting the radio power, user satisfaction with the system's feedback was measured, and the results showed that users had a good experience.

Audio Quality Testing: To guarantee immersive sound quality, the fidelity and clarity of the audio outputs were examined. It was confirmed that the audio changed dynamically in response to the player's movements and interactions within the game, making the virtual world more realistic and captivating.

A thorough user testing session was held to assess the usefulness and user experience of the adaptive radio system within our serious virtual reality game. To provide a varied testing pool, we recruited 30 people with varying levels of VR technology experience, from beginners to experts. Using a head-mounted display (HMD), participants in the testing sessions interacted with the adaptive radio system and played the VR game in a controlled setting.

TABLE 2. User-study metrics and scoring.

Metric	Example items (1–5)	Aggregation
Ease of Use	"The radio controls were easy to learn"; "Switching stations felt straightforward."	mean
Immersion	"I felt present in the scene"; "Audio matched the environment."	mean
Emotional Impact	"Music heightened key moments."	single/mean
Satisfaction	"Overall, I am satisfied with the audio experience."	single
Replay Intent	"I would play again to try audio variants."	single

Our user testing's main goals were to evaluate usability, engagement, emotional impact, and general satisfaction. Ninety percent of participants thought the radio system's user interface was simple to use and intuitive. Only 75% of customers reported that some of the advanced audio settings were easy to use, despite some small difficulties.

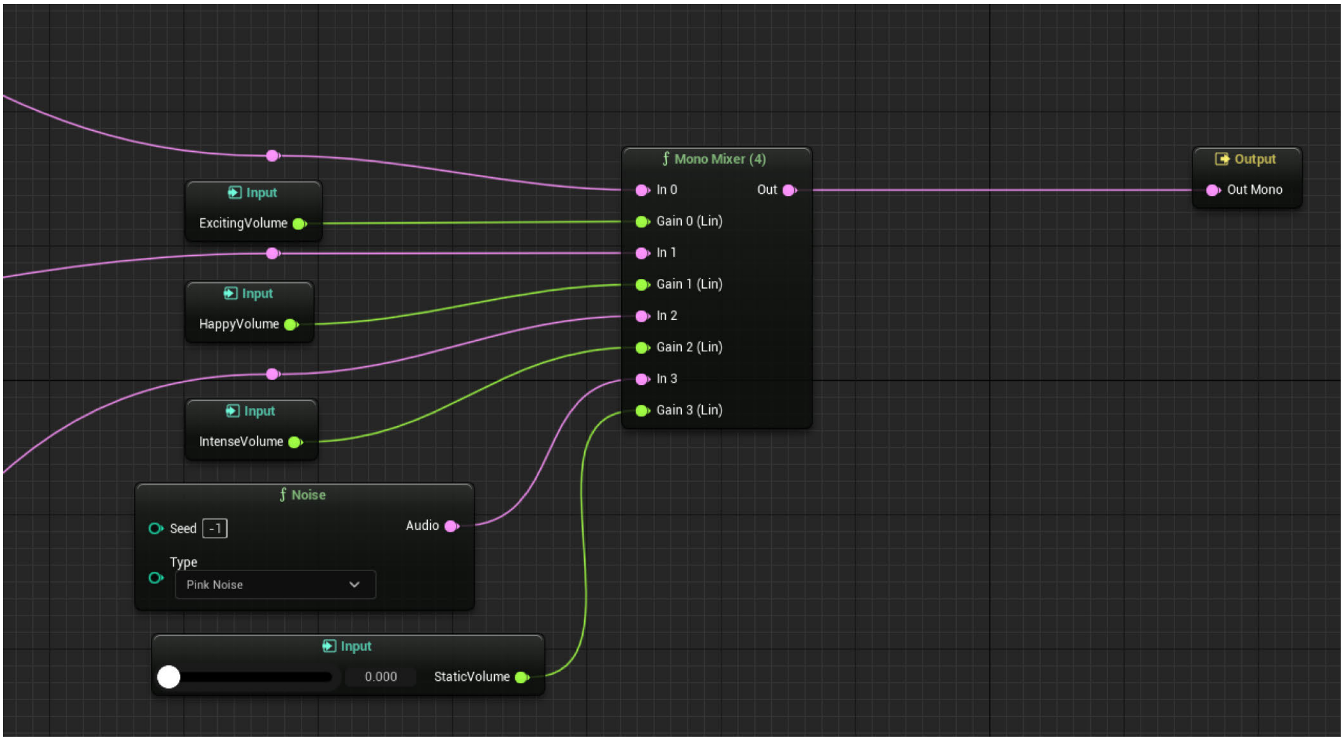

FIGURE 9. **MetaSounds graph adaptive radio system controller generating sound using volume controller and generate static noise.**

FIGURE 10. **Adaptive radio system enhances immersive game environment at sun rise in-game time.**

When it came to involvement, the adaptive radio system was much more immersive than traditional audio sets (85% of subjects reported higher levels of immersion). Participants observed that the game felt more responsive and alive because of the dynamic audio changes in reaction to game circumstances. Regarding emotional impact, eighty percent of participants said that while they were at crucial game moments like reaching goals or confronting obstacles the music adaptively heightened their emotional experience. The game's emotional depth was increased by the smooth and well-received transitions between various audio states.

FIGURE 11. Adaptive radio system enhances immersive game environment at noon in-game time.

TABLE 3. Functionality testing summary, all functionality works as intended.

Testing Phase	Result Summary	Issues Identified
Functionality	Successful transitions; accurate audio output	None
Integration	No disruption to game mechanics	None
Usability	Interface found intuitive and user-friendly	None
Audio Quality	High clarity and immersive sound maintained	None

An average rating of 4.5 out of 5 indicated a high level of overall satisfaction. 70% of participants expressed a desire to play the game again in order to explore other audio environments, highlighting the adaptive radio system as a crucial component in promoting replayability shown in Figure 12.

Based on the data supplied, we examined the link between age, degree of immersion, and length of VR sessions to learn more about how these variables interact and affect the VR user experience. We distinguished between the various age groups and looked at the corresponding immersion levels in order to evaluate the distribution of immersion levels among them. The age range of the participants was 18 to 30, with the bulk falling between 18 and 22. On a scale of 1 to 5, where 5 is the highest immersion level, the levels were measured. Immersion levels ranged from 1 to 3, according to the majority of participants.

Those between the ages of 18 and 22 reported higher levels of immersion than those between the ages of 28 and 38, according to the analysis. According to this research, younger participants may be more acclimated to VR surroundings or may find the encounters more interesting and captivating. Younger participants may have had higher levels of immersion because they were more accustomed to and more ease with technology.

Next, we investigated the relationship between participant reported degrees of immersion and the length of VR sessions. The study's VR sessions lasted anywhere from 12 to 33 minutes. Longer VR sessions are generally linked to higher levels of immersion, as seen by the positive connection ($r = 0.45$) identified between session time and immersion level shown in Figure 13.

More time spent in the virtual reality environment was reported by participants as increased immersion. This implies that giving users more time to interact with the VR material could improve their level of immersion overall. The depth of the immersive experience seems to be much enhanced by prolonged exposure to VR surroundings, underscoring the significance of session time in creating successful VR experiences.

As a whole, the data shows that, in comparison to older individuals (23–30), younger participants (18–22) typically report higher degrees of immersion. Longer VR sessions are also positively connected with higher levels of immersion, indicating that prolonged use of VR settings can improve the sense of immersion. With the use of these insights, VR experiences that are age-appropriate can be created, and session lengths can be maximised to enhance user immersion. Additional elements, such as the kind of VR content and the particular qualities that lead to higher levels of immersion, should be investigated in future research.

a thorough examination of the effects on participants' stated levels of immersion caused by the frequency of

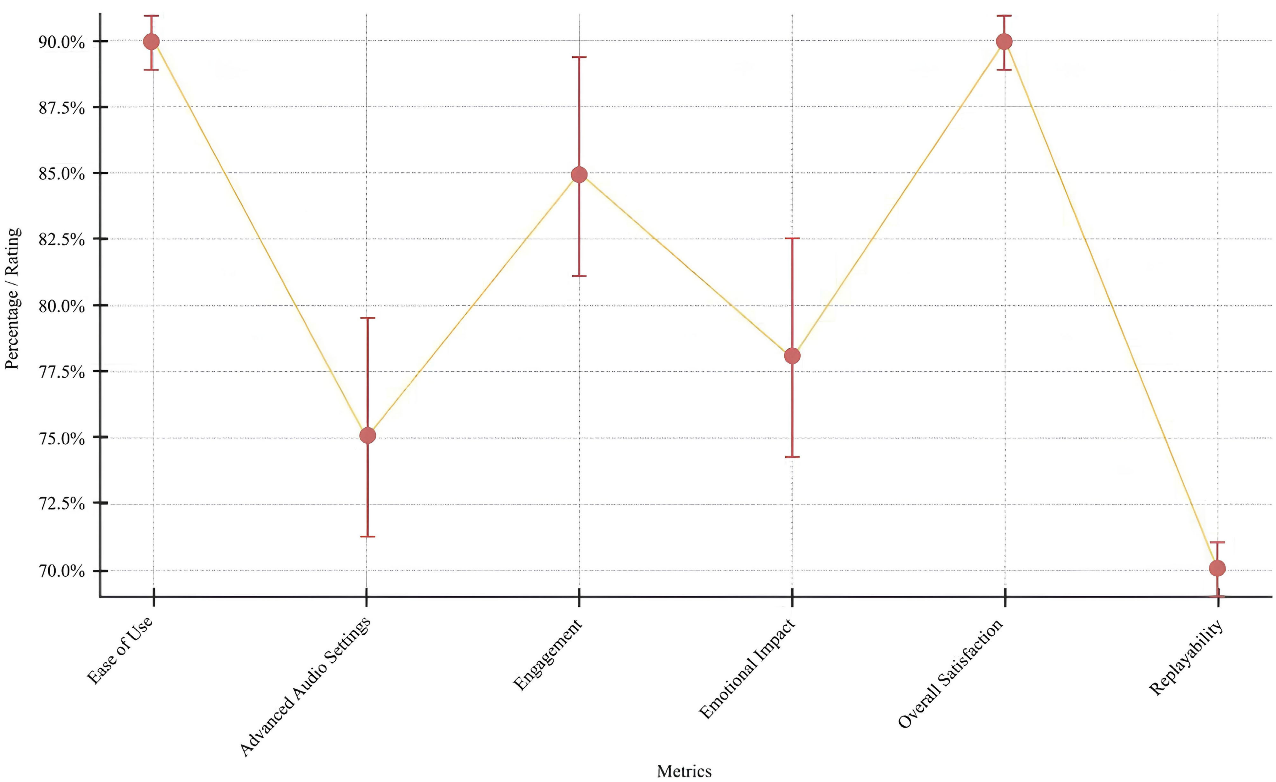

FIGURE 12. **User experience graph result metrics with the highest on Ease of Use and Overall Satisfaction, and the lowest on Replay ability.**

switching between the joyful, enthusiastic, and intense stations. The frequency of usage was classified as "Never," "Rarely," "Sometimes," and "Very frequently." The mean immersion level of 2.80 was seen in participants who "never" switched to the cheerful station, suggesting a lower level of engagement with the immersive audio experience. The mean immersion level of those who "rarely" switched was 3.03, indicating a marginal increase in immersion. The mean immersion level of 2.96 for those who switched "sometimes" indicated a moderate level of engagement. The mean immersion level of 3.01 for those who switched "very frequently" suggested that frequent switching might increase immersion.

The mean immersion level for participants who "never" switched at the enthusiastic station was 3.06, indicating a relatively high level of immersion even in the absence of frequent switching. In comparison to those who never switched, those who "rarely" switched had a mean immersion level of 2.84, indicating a lesser level of engagement. The mean immersion level of 2.93 for those who switched "sometimes" indicated a moderate level of engagement. Frequent switching greatly improves immersion; the group that switched "very frequently" had the highest mean immersion level (3.31).

Participants who "never" switched had a mean immersion level of 2.83 for the intense station, indicating less engagement with environments with intense sounds. The mean immersion level of 2.61 for those who "rarely" switched, indicating considerably less immersion. Switching "sometimes" was associated with the highest mean immersion level (3.09), suggesting that intermittent switching to the intense station is the most effective way to increase immersion. The mean immersion level of those who switched "very frequently" was 2.99, indicating that, in comparison to occasional switching, extremely frequent switching may marginally lessen immersion shown in Figure 14.

According to the investigation, changing stations can improve immersion by introducing dynamic changes to the audio surroundings. Higher immersion levels are correlated with frequent switching at the joyful and enthusiastic stages. The best level of immersion for the intensive station comes from sporadic switching, suggesting that audio transition balance is essential to preserving an interesting and immersive experience.

The degree of immersion that participants expressed was connected with how they perceived the effects of the music. Participants who felt that the music effects improved their experience had a mean immersion level of 2.94. The music

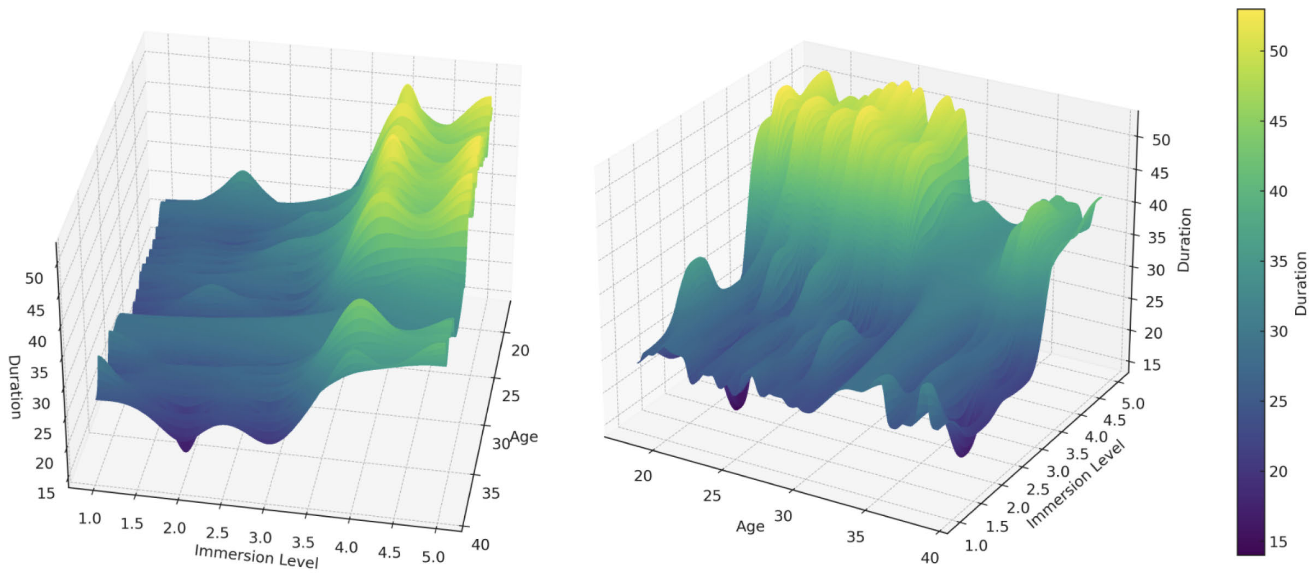

FIGURE 13. 3D plot illustrating the relationship between participants' age, immersion level, and duration of VR sessions. The graph highlights that younger participant (ages 18-22) reported higher levels of immersion compared to older participants (ages 28-38). Additionally, longer VR sessions are generally associated with higher levels of immersion, indicating the importance of session duration in enhancing the immersive experience.

effects were categorised as "Improve," "No effect," and "Worsen." This implies that immersive experiences are enhanced by good music effects. Neutral perceptions of music impacts do not significantly reduce immersion, as seen by the mean immersion level of 3.04 among participants who reported no effect from the music. The mean immersion level of 3.29 was surprisingly higher among those who thought that the music effects damaged their experience than among those who reported improvements. This suggests that, due to the increased focus on the acoustic environment, even unfavourable opinions of adaptive audio may promote a higher level of involvement.

Positive impressions of the impacts of music are often linked to higher levels of immersion, according to the findings. Nevertheless, participants' degrees of immersion persisted even when they thought that the music impacts made their experience worse. This implies that adaptive audio, whether viewed favourably or unfavourably, is important for keeping consumers interested and improving the immersive experience.

The testing findings demonstrate the radio system's efficacy and dependability and show how dynamic audio processing could improve immersion in virtual reality environments. Tests of the system's functionality and connection with the Unreal Engine environment validated its excellent operation, which is essential for preserving a flawless gaming experience.

The radio system's efficacy and dependability are confirmed by the user testing results, which also demonstrate how much the system may improve emotional involvement and immersion in virtual reality environments. Sustaining a flawless gaming experience in the Unreal Engine environment depends on the system's operational quality. Problems like the difficulty of accessing advanced options were noted, indicating areas that needed more improvement.

The system's straight forward design and ease of use are highlighted by usability testing, which is important for user happiness and engagement. Tests of audio quality confirmed the higher sound quality, guaranteeing that the sound effects enhance the game's immersive atmosphere.

The importance of incorporating adaptable audio systems in serious VR games is highlighted by the favorable feedback about user involvement and emotional impact. These techniques enhance the player's audio perception while also making the gameplay more captivating and emotionally impactful.

The usage of sophisticated audio systems in interactive applications is affected more broadly by these findings, especially in serious virtual reality games where dynamic audio can greatly impact the user experience.

The adaptive radio system demonstrated significant improvements in user engagement, immersion, and emotional impact within the serious VR game. User testing showed that 90% of participants found the interface intuitive, 85% felt more immersed, and 80% reported that the adaptive music enhanced their emotional experience. These results align with previous research, highlighting the critical role of dynamic audio in enhancing player immersion and emotional engagement [3], [4], [9]. The system's ability to provide smooth audio transitions and high dependability was reflected in the high average user satisfaction score of 4.5 out of 5. Furthermore, 70% of participants expressed a desire to replay

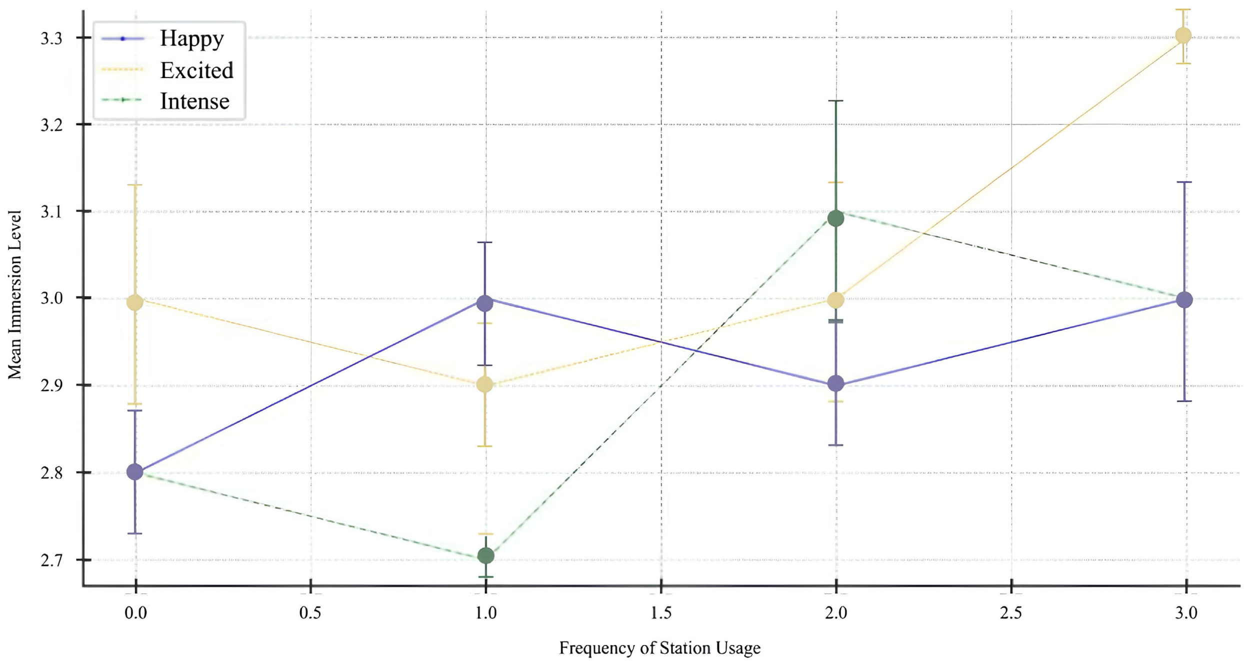

FIGURE 14. Frequency of station usage and immersion level, immersion levels for different frequencies of switching between happy, excited, and intense stations. Frequent switching generally enhances immersion, especially for happy and excited stations.

the game to experience different audio settings, underscoring the system's potential to enhance replayability [7], [8]. These findings support the conclusion that integrating adaptive audio systems, such as those using MetaSounds, can significantly enhance the immersive experience in serious VR games, with broader implications for applications in virtual training, therapeutic treatments, and educational platforms.

V. CONCLUSION

This study shows how MetaSounds may be creatively integrated into Unreal Engine to create a dynamic and engrossing audio experience for professional virtual reality games. Through smooth audio transitions and spatial audio cues, the adaptive radio system not only improves player immersion but also adds richness to the interactive gameplay environment. Our findings show that user engagement and happiness are greatly increased by the system's dependability and efficiency in providing high-quality, adaptive audio.

Iterative testing and improvement were made easier by the agile development methodology, which made sure the system successfully achieved its technical and user-experience objectives. This project provides a model for future growth in serious gaming and other applications such as virtual training and therapeutic environments. It also showcases the possibilities of sophisticated audio systems in VR situations.

In order to further improve immersion, additional study may look into deeper VR technology integrations, such as more intricate user interactions and feedback mechanisms. The accomplishment of this project creates opportunities for more advanced uses of sound in interactive media, which may have an impact on how audio is used in diverse VR applications across industries.

REFERENCES

[1] F. Annisa Damastuti, K. Firmansyah, Y. Miftachul Arif, T. Dutono, A. Barakbah, and M. Hariadi, "Dynamic level of difficulties using Q-learning and fuzzy logic," *IEEE Access*, vol. 12, pp. 137775–137789, 2024, doi: 10.1109/ACCESS.2024.3457801.

[2] F. A. Damastuti, K. Firmansyah, Y. M. Arif, A. R. Barakbah, and M. Hariadi, "Dynamic day and night cycle impact in a serious VR game," in *Proc. 10th Int. Conf. Virtual Reality (ICVR)*, Jul. 2024, pp. 369–375, doi: 10.1109/ICVR62393.2024.10868976.

[3] F. A. Damastuti, K. Firmansyah, Y. M. Arif, T. Dutono, A. R. Barakbah, and M. Hariadi, "Enhancing serious game experience through in-game radio using context-aware recommender system based on player behavior," *Int. J. Intell. Eng. Syst.*, vol. 17, no. 5, 2024, doi: 10.22266/ijies2024.1031.26.

[4] S. Z. Abdullah, N. Mohamad Ali, H. Lee, and H. Liang, "Interaction and game engagement based on players' background and preferences," in *Proc. Game Phys. Mech. Int. Conf. (GAMEPEC)*, Aug. 2015, pp. 16–20, doi: 10.1109/GAMEPEC.2015.7331849.

[5] C. Anton, O. Mitrut, A. Moldoveanu, F. Moldoveanu, and J. Kosinka, "A serious VR game for acrophobia therapy in an urban environment," in *Proc. IEEE Int. Conf. Artif. Intell. Virtual Reality (AIVR)*, Dec. 2020, pp. 258–265, doi: 10.1109/AIVR50618.2020.00054.

[6] Y. Bao, J. Guo, D. Weng, Y. Liu, and Z. Tian, "Effects of virtual agents on interaction efficiency and environmental immersion in MR environments," *Virtual Reality Intell. Hardw.*, vol. 6, no. 2, pp. 169–179, Apr. 2024, doi: 10.1016/j.vrih.2023.11.001.

[7] S. Bermúdez i Badia, L. V. Quintero, M. S. Cameirão, A. Chirico, S. Triberti, P. Cipresso, and A. Gaggioli, "Toward emotionally adaptive virtual reality for mental health applications," *IEEE J. Biomed. Health Informat.*, vol. 23, no. 5, pp. 1877–1887, Sep. 2019, doi: 10.1109/JBHI.2018.2878846.

[8] J. Broderick, J. Duggan, and S. Redfern, "The importance of spatial audio in modern games and virtual environments," in *Proc. IEEE Games, Entertainment, Media Conf. (GEM)*, Aug. 2018, pp. 1–9, doi: 10.1109/GEM.2018.8516445.

[9] A. Bucchiarone, "Gamification and virtual reality for digital twin learning and training: Architecture and challenges," *Virtual Reality Intell. Hardw.*, vol. 4, no. 6, pp. 471–486, Dec. 2022, doi: 10.1016/j.vrih.2022.08.001.

[10] T. Constant and G. Levieux, "Automated evaluation of game experience based on game dynamics and motives for play," in *Proc. Extended Abstr. Annu. Symp. Comput.-Human Interact. Play*, Nov. 2022, pp. 113–119. [Online]. Available: https://hal.science/hal-03847511

[11] E. Dincelli and A. Yayla, "Immersive virtual reality in the age of the metaverse: A hybrid-narrative review based on the technology affordance perspective," *J. Strategic Inf. Syst.*, vol. 31, no. 2, Jun. 2022, Art. no. 101717, doi: 10.1016/j.jsis.2022.101717.

[12] D. Djaouti, J. Alvarez, J. Jessel, and O. Rampnoux, *Serious Games and Edutainment Applications*, 2011, doi: 10.1007/978-1-4471-2161-9.

[13] D. Djaouti, J. Alvarez, and J.-P. Jessel, "Classifying serious games," in *Advances in Game-Based Learning*, 2011, pp. 118–136.

[14] *Gameplay and Game Mechanics Design: A Key To Quality in Videogames*. [Online]. Available: https://www.researchgate.net/publication/236168267

[15] J. Guo, D. Weng, Y. Liu, Q. Chen, and Y. Wang, "Analysis of teenagers' preferences and concerns regarding HMDs in education," *Virtual Reality Intell. Hardw.*, vol. 3, no. 5, pp. 369–382, Oct. 2021, doi: 10.1016/j.vrih.2021.09.004.

[16] R. Hiraga, K. F. Hansen, N. Kano, M. Matsubara, H. Terasawa, and K. Tabuchi, "Music perception of hearing-impaired persons with focus on one test subject," in *Proc. IEEE Int. Conf. Syst., Man, Cybern.*, Oct. 2015, pp. 2407–2412, doi: 10.1109/SMC.2015.421.

[17] M. Hostovecky and K. Pribilova, "Serious games in sciences, humanities, and arts: Examples from a practical perspective," in *Proc. 20th Int. Conf. Emerg. eLearning Technol. Appl. (ICETA)*, Oct. 2022, pp. 214–218, doi: 10.1109/ICETA57911.2022.9974711.

[18] P. E. Hutchings and J. McCormack, "Adaptive music composition for games," *IEEE Trans. Games*, vol. 12, no. 3, pp. 270–280, Sep. 2020, doi: 10.1109/TG.2019.2921979.

[19] J. Janer, E. Gomez, A. Martorell, M. Miron, and B. de Wit, "Immersive orchestras: Audio processing for orchestral music VR content," in *Proc. 8th Int. Conf. Games Virtual Worlds Serious Appl. (VS-GAMES)*, Sep. 2016, pp. 1–2, doi: 10.1109/VS-GAMES.2016.7590352.

[20] B. Kenwright, "There's more to sound than meets the ear: Sound in interactive environments," *IEEE Comput. Graph. Appl.*, vol. 40, no. 4, pp. 62–70, Jul. 2020, doi: 10.1109/MCG.2020.2996371.

[21] D. P. Kristiadi, F. Sudarto, D. Sugiarto, R. Sambera, H. L. H. S. Warnars, and K. Hashimoto, "Game development with scrum methodology," in *Proc. Int. Congr. Appl. Inf. Technol. (AIT)*, Nov. 2019, pp. 1–6, doi: 10.1109/AIT49014.2019.9144963.

[22] F. Laamarti, M. Eid, and A. El Saddik, "An overview of serious games," *Int. J. Comput. Games Technol.*, vol. 2014, pp. 1–15, Jan. 2014, doi: 10.1155/2014/358152.

[23] F. Li, Z. Qin, K. Qian, S. Liang, C. Li, and Y. Tai, "Personalized assessment and training of neurosurgical skills in virtual reality: An interpretable machine learning approach," *Virtual Reality Intell. Hardw.*, vol. 6, no. 1, pp. 17–29, Feb. 2024, doi: 10.1016/j.vrih.2023.08.001.

[24] M. Li, Y. Jung, M. Fulham, and J. Kim, "Importance-aware 3D volume visualization for medical content-based image retrieval—A preliminary study," *Virtual Reality Intell. Hardw.*, vol. 6, no. 1, pp. 71–81, Feb. 2024, doi: 10.1016/j.vrih.2023.08.005.

[25] Y. Li, Y. Yang, Z. Yao, and G. Xu, "Virtual 3D environment for exploring the spatial ability of students," *Virtual Reality Intell. Hardw.*, vol. 2, no. 6, pp. 556–568, Dec. 2020, doi: 10.1016/j.vrih.2020.08.001.

[26] S. Lloyd and B. S. Lloyd. *Adaptive Music in Video Games and How It Impacts Player Satisfaction*. [Online]. Available: https://digitalcommons.csumb.edu/caps_thes_all

[27] M. Makhmutov, J. A. Brown, M. Surkov, A. Timchenko, and K. Timchenko, "Adaptive game soundtrack tempo based on players' actions," in *Proc. IEEE Conf. Games (CoG)*, Aug. 2022, pp. 441–448, doi: 10.1109/COG51982.2022.9893604.

[28] D. Melhart, A. Liapis, and G. N. Yannakakis, "Towards general models of player experience: A study within genres," 2021, *arXiv:2110.00978*.

[29] L. Niu, W. Xie, D. Wang, Z. Cao, and X. Liu, "Audio2AB: Audio-driven collaborative generation of virtual character animation," *Virtual Reality Intell. Hardw.*, vol. 6, no. 1, pp. 56–70, Feb. 2024, doi: 10.1016/j.vrih.2023.08.006.

[30] B. Norman, "VR-based digital twin for remote monitoring of mining equipment: Architecture and a case study," *Virtual Reality Intell. Hardw.*, vol. 6, no. 1, 2024.

[31] D. Plans and D. Morelli, "Experience-driven procedural music generation for games," *IEEE Trans. Comput. Intell. AI Games*, vol. 4, no. 3, pp. 192–198, Sep. 2012, doi: 10.1109/TCIAIG.2012.2212899.

[32] C. Plut and P. Pasquier, "Music matters: An empirical study on the effects of adaptive music on experienced and perceived player affect," in *Proc. IEEE Conf. Games (CoG)*, Aug. 2019, pp. 1–8, doi: 10.1109/CIG.2019.8847951.

[33] C. Plut and P. Pasquier, "Generative music in video games: State of the art, challenges, and prospects," *Entertainment Comput.*, vol. 33, Mar. 2020, Art. no. 100337, doi: 10.1016/j.entcom.2019.100337.

[34] J. Qian, Y. Ma, Z. Pan, and X. Yang, "Effects of virtual-real fusion on immersion, presence, and learning performance in laboratory education," *Virtual Reality Intell. Hardw.*, vol. 2, no. 6, pp. 569–584, Dec. 2020, doi: 10.1016/j.vrih.2020.07.010.

[35] P. Sajjadi, J. Vlieghe, and O. De Troyer, "Evidence-based mapping between the theory of multiple intelligences and game mechanics for the purpose of player-centered serious game design," in *Proc. 8th Int. Conf. Games Virtual Worlds Serious Appl. (VS-GAMES)*, Sep. 2016, pp. 1–8, doi: 10.1109/VS-GAMES.2016.7590348.

[36] L. F. Smith. *The Effect of Dynamic Music in Video Games: An Overview of Current Research*. [Online]. Available: https://www.diva-portal.org

[37] M. T. Makhmutov. *Adaptive Game Soundtrack Generation Based on Music Transcription Music Analysis and Generation View Project*. [Online]. Available: https://www.aaai.org

[38] G. F. Tondello and L. E. Nacke, "Player characteristics and video game preferences," in *Proc. Annu. Symp. Comput.-Human Interact. Play*, Oct. 2019, pp. 365–378, doi: 10.1145/3311350.3347185.

[39] E. Vespa and A. J. Wilson, "Experimenting with the transition rule in dynamic games," *Quant. Econ.*, vol. 10, no. 4, pp. 1825–1849, 2019, doi: 10.3982/qe687.

[40] L. Wang, "The relationship between personality, game motive, and game genre preference: Gender as a moderator," in *Proc. IEEE Conf. Comput. Intell. Games, CIG*, Aug. 2021, pp. 1–7, doi: 10.1109/COG52621.2021.9619079.

[41] Z. Wang and J. Liu, "Online game level generation from music," in *Proc. IEEE Conf. Comput. Intell. Games*, Aug. 2022, pp. 119–126, doi: 10.1109/COG51982.2022.9893695.

[42] B. Yang, C. Zhu, F. W. B. Li, T. Wei, X. Liang, and Q. Wang, "IAACS: Image aesthetic assessment through color composition and space formation," *Virtual Reality Intell. Hardw.*, vol. 5, no. 1, pp. 42–56, Feb. 2023, doi: 10.1016/j.vrih.2022.06.006.

[43] J.-S. Yang and C.-W. Cheng, "A pitch perception training game in VR environment for enhancing music learning motivation," in *Proc. IEEE Int. Conf. Consum. Electron.-Taiwan (ICCE-Taiwan)*, Sep. 2020, pp. 1–2, doi: 10.1109/ICCE-TAIWAN49838.2020.9257989.

[44] A. K. Kumar, N. N. Mai, S. Guo, and L. Han, "Entanglement inspired approach for determining the preeminent arrangement of static cameras in a multi-view computer vision system," *Vis. Comput.*, vol. 39, no. 7, pp. 2847–2863, May 2022, doi: 10.1007/s00371-022-02497-z.

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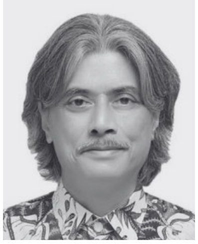

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