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Article

BatSight: A Navigation Game to Map Environmental Information into Audio Cues

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Abstract

By using sound to visualize the real-world environment, audio games can offer a completely new game experience. In this paper, we study how audio cues can be visualized in audio games and their effects on the players' navigation skills, gaming experience, and immersion. Also, factors that impact the system performance in terms of navigation using audio components. To this end, we propose an audio game in which blindfolded players move through a physical maze with the help of audio cues. To realize this game, a sonar headset is designed and built based on ultrasonic sensors, which maps the external environment features into musical sounds. Actually, the design of the sonar headset is the result of design and research efforts.

The gaming environment of this game is a physical maze, where the blindfolded players enter the maze while wearing the sonar headset. A user study was conducted to evaluate the effect of using different sound mapping techniques on navigation performance and playing experience in the game proposed in this paper. The results show that producing musical sound can lead to better navigation performance, game experience, and immersion in players.

1. Introduction

Although vision is crucial for perceiving the environment, non-visual cues can also serve this purpose. In particular, hearing and touch are the two main senses that can be used to understand the environment for the sake of navigation [1]. Sonar-based solutions for avoiding collisions are more effective because sound has more dimensions to transmit necessary environmental data [1, 2]. Research has shown that navigation training in virtual environments through sounds [3] can result in significant improvements in the navigation skills of participants.

Audio Augmented Reality (AAR) combines real-world and virtual audio simultaneously. It can be helpful for users who need to be aware of their surroundings [4]. The use of sound for navigation is not specific to visually impaired people, and its use for navigation has been investigated in audio games for people with normal vision [3, 5, 6]. Audio games can attract both sighted and visually impaired players because of two important features: 1) they can provide an interesting game experience for players through mental visualization, and 2) they can create a sense of sympathy with visually impaired people in sighted players.

In this paper, we investigate how using different sonification techniques in audio games can affect audio-based navigation for sighted people. To this end, we developed a game called BatSight, which is an audio augmented reality mobile game played in a physical maze. This game makes it possible for blindfolded players to move through a physical maze with the help of audio cues.

This game consists of a sonar headset that works based on ultrasonic sensors to map surrounding environment features into musical sounds. To play the BatSight game, players need to wear a sonar headset proposed and developed in this paper. This sonar headset is connected to the BatSight mobile game and maps environmental information to audio cues using different sonification techniques. As shown in Fig. 1, the sonar headset completely covers the eyes and the player cannot see the maze whilst playing.

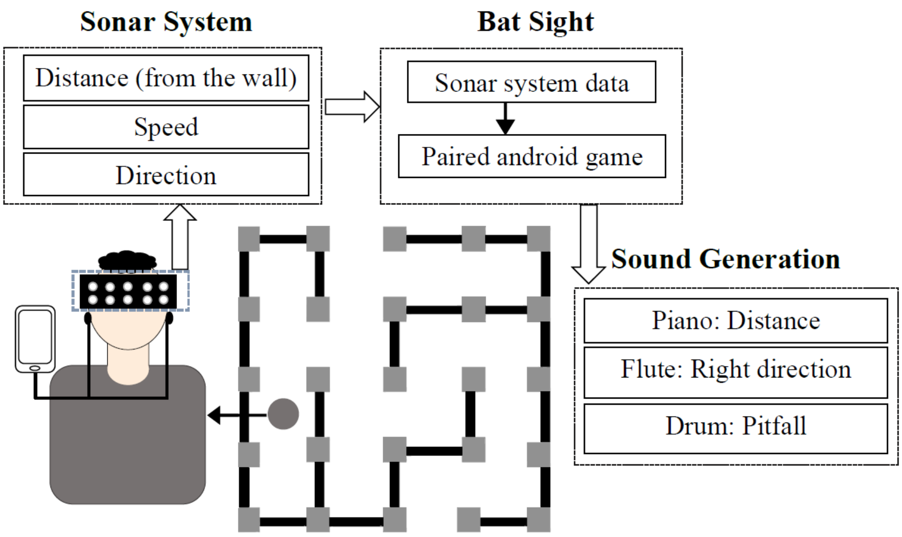

Figure 1. The overall architecture of the sonar system operation in the physical maze.

The BatSight game is motivated by bats' skills in navigation using their hearing ability instead of vision. These animals can detect obstacles around them by sending sounds to objects and listening to the echoes of these sounds for navigation among obstacles and orientation in dark places [7].

Although some portable electronic systems have been developed for visually impaired people to navigate and detect obstacles [8, 9], to the best of our knowledge, no specific sonar system has been developed for gaming purposes in the physical environment. Sonification is the use of non-speech audio to transmit information or data [10]. Study [11] introduces a new approach to conveying visual information using spatial audio with the help of sonification. Results indicate that the majority of users were able to comprehend the spatial representations, construct mental maps based on the auditory cues, and effectively connect them to spatial information.

In this paper, three different sonification techniques were developed and tested using the BatSight game. In the first mode, when a player approaches the maze wall, this player can hear a smooth transition of playing various pitches from (C_3) on the piano in the manner of an ascending scale, while the tempo is not changed. In the second method, a single pitch (C_3) is played repeatedly on the piano at different tempo depending on the distance of a player from the maze wall. In the third technique, pitches and the tempo are changed in the manner of an ascending scale as the player approaches the maze wall. A user study was conducted to evaluate the effectiveness of these sonification techniques.

In particular, the contributions of this paper are:

- Producing an ultrasonic-based sonar headset to map environmental information to audio cues for navigation and orientation in audio augmented reality games.
- Designing and developing a mobile game called BatSight played in a physical maze built for this game using the sonar headset.
- Evaluating the role of different sonification techniques on navigation performance, game experience, and immersion, and suggesting the best sonification techniques in audio games.

2. Related work

This section reviews some audio games developed for sighted and visually impaired players as well as sonar-based devices designed for visually impaired and sighted people.

2.1 Audio Games and Applications

According to [12], a game is an enjoyable match among players in which they should use their skills and play under determined rules and constraints. A simulation game is an activity that includes the fundamental characteristics of games, such as competition and rules, combined with simulations that represent real life [13]. Games can be categorized into different groups, each serving distinct purposes, such as health, education, or social engagement [14]. Audio games do not rely on visual elements that are essential in popular video games. Also, Audio games use sound to design the game mechanics and user interface. Real Sound – Kaze No Regret was one of the first audio adventure games developed for Sega Dreamcast and Sega Saturn in 1999. The whole of the mechanics of this game depended on sound. There has been a growing interest among sound artists and game developers in recent years. Several spatial movement-based games have been developed especially for smartphones and tablets like Papa Sangre II, Sound Swallower, Papa Sangre, and The Nightjar [15].

In an Augmented Reality Audio (ARA) game [16], one of the player tasks is exploration. A sound is played, and the player must hold the device toward the source of the sound to hear it. Then the player enters the action phase to locate the sound source as accurately as possible.

Researchers argued that the proposed technique enhances user immersion in the augmented space.

In [5], authors developed an audio-based VR game called Loud and Clear for sighted people to give a new experience of visual impairment difficulties. This game is without visuals, and the player should rely on audio cues to complete the game. In the game, there are some puzzle rooms that the players should solve.

As mentioned, computer games rely on visual skills to play which are not available for visually impaired people [17-22]. Audio games allow visually impaired people to perceive and interact with the game environment [22, 23]. These audio games utilize sonification techniques for this purpose [11, 24], in which game data is conveyed through non-speech sounds [25]. In a first-person shooter game [26], footsteps audio is applied to find paths. Footsteps will vary depending on the ground material, and correct paths will include distinct sounds from the surrounding areas. Also, various tones show the directions of players. Moreover, it uses sonic radar to identify objects around the player.

A mobile game called GrandEscape has been developed [21] that utilizes various sound elements, such as amplitude and pitch, to make the game playable for visually impaired individuals. In this game, the player takes on the role of a prisoner who must escape from a room and collect keys throughout the game. Since players cannot see anything during gameplay, they must rely on the audio cues generated by the game. The prisoner should collect keys from his friends to escape from the room. She can recognize his friends by their voices in the room and move toward them to get the key. The results of the study indicate that different sound elements can effectively convey gameplay events, enhancing the gaming experience for visually impaired individuals.

In [17], an audio-based game called Pinball was developed for visually impaired people that is played on a mobile device. This game's mechanics are the same as the traditional pinball game with some changes and applied 3D sound effects with varying volume and pitch of the sound to make it playable without any visual elements for visually impaired people. Evaluation of the research represents that the game was enjoyable for the visually impaired and people with normal vision.

In [27], authors developed an audio-augmented Badminton game for visually impaired people that uses a real badminton racket and simple stereo sound feedback to control a virtual shuttlecock. The evaluation shows that the game was enjoyable for the visually impaired and sighted players. In [6], the effect of sound and light cues on player orientation during gameplay was studied. In this research, 134 sighted players navigated inside a virtual maze with the help of sound and light changes during the game. The results of this study showed that audio and visual cues reduce the time to reach the desired goal in the gameplay and they are efficient factors to guide the player in the desired direction in the gameplay. In [28], the application of virtual reality is investigated for visually impaired individuals. This virtual environment is rendered through hearing, and players comprehend the gameplay environment with the help of acoustic information. Also, a tracking method identifies the players' positions. The sound-rendered module is responsible for converting the depth map of a virtual world into an acoustic representation of the scene. In [29], a digital maze game was proposed in which the players can move only with the help of sound signals they hear during the game. They showed using this technique in the maze game can create a novel pleasing game experience for the players [29]. In [10], the use of 3D sound and its effect on the gaming experience and player immersion was investigated. Pepsi organized a soccer match in 2011 in Sweden between two teams of blindfolded and visually impaired soccer players who used a generated device to find out the position of the soccer ball and other players in the game. The study shows that 3D sound enhances player immersion and gaming experience while enabling spatial navigation.

As mentioned, audio augmented reality is helpful for users who need to be aware of the environment, especially tourists. In [4], researchers have developed a prototype called

AudioNear to help tourists explore open urban environments which uses tourists' locations to provide speech-based external information. Audio Legends [30] is an audio augmented reality adventure game for mobile devices in which players have to identify the direction of audio sources and interact with the game by manipulating the device itself (holding, tilting).

2.2 Sonification and Sonar Systems

Sonification is the production of sound to transmit data, and systems that use sonification to present data are auditory displays. Sonification is applied in free-eye applications and assistive tools due to its application in navigation and obstacle avoidance. Sonification has some principles to be useful. One of them is efficiency which means that an auditory display should be meaningful to transmit the necessary information of complex scenes. In most cases, the selection of the sonification method and its parameters relies on researchers' decisions in auditory displays [31]. The context of an application is important to create a pattern for converting data to sound [32].

Traditionally, people with visual impairments rely on a white cane for local navigation and constantly use this device to detect obstacles [33]. However, they cannot adequately identify all the necessary external information, such as the distance between the user and obstacles. In comparison, electronic devices can provide more information about the external environment by integrating multiple electronic sensors. These devices improve the daily lives of visually impaired people [8]. Visually impaired people can benefit from auditory or tactile sensors to obtain external information for navigation [34].

Using voice commands to present environmental information can provide efficient and helpful information for visually impaired people in high-risk urban areas. However, this can be tedious in indoor low-risk environments. In [34], the volume of various musical instruments determines the direction and distance from an obstacle. In this system, a musical instrument is played when the distance between the obstacle and the player is less than 2 meters. In [35], an electronic system was developed to help visually impaired people navigate in urban areas. The system uses ultrasonic distance sensors and a smartphone camera to perceive the environment. It also benefits from machine learning algorithms to determine fixed and moving objects in the environment, regardless of their shape, size, and location, and generate meaningful images. Then, this system provides audio feedback in terms of sound volume to visually impaired people.

In [2], a sonar system was developed to find objects in the external environment. For 3D map generation, the system is placed on the player's head to send a pulse and receive reflections from the objects to calculate the distances from them. In [36], Smart guiding glasses were developed by combining ultrasonic sensors and a camera. In this system, augmented reality glasses and hands-free are used to lead to better obstacle detection and path-finding based on audio cues. They showed that the proposed glasses can improve the mobility of visually impaired people.

In [37], a visual aid system to assist visually impaired people is proposed using a Raspberry Pi 3 Model B+, HC-SR04 ultrasonic sensor, and a camera attached to eyeglasses. The prototype device detects objects using image processing algorithms. Furthermore, the camera and ultrasonic sensor determine the distance between the user and obstacles via voice alarms. Besides converting images to text, the device can provide audio feedback when reading. They found that the proposed system was much easier to use than a traditional cane in controlled environments. In [9], authors proposed a portable system as an assistive tool for visually impaired people, and help them walk to their destination. This system utilizes multiple ultrasonic sensors to avoid obstacles, a camera, and a GPS receiver to determine the best route. It uses earphones and a vibrator as an interactive user interface.

In [38], a system was designed to distinguish between different colors of objects in the environment. Red, green, and blue colors are mapped to DO, MI, and SOL notes, respectively.

To evaluate system operation, participants tested the system in an office environment. After a few seconds of training with this system, individuals could recognize different colors in the office by sound, which they found interesting. In [39], GPS was used to offer directions to visually impaired people in urban areas. In this system, users can express the desired departure and destination locations by voice commands. The results of this study indicated that the designed system can be effective for urban navigation.

According to studies, the majority of research has focused on examining the impact of sounds used to guide visually impaired individuals. However, there has been no effort made to develop musical sounds for sonification systems used by sighted individuals during gameplay.

3. BatSight Game

3.1 Game Play

BatSight is an audio game in which blindfolded players navigate in the physical maze while wearing a sonar headset proposed for this purpose to map environmental information into audio cues. This headset covers the player's eyes and only audio cues can guide the player through the maze. Players must navigate the maze by listening to the sounds produced by the BatSight game based on their position in the maze. Their goal is to reach the end of the maze as quickly as possible while avoiding collisions with the walls of the maze.

The players lose points every time their distance from the walls is less than a threshold. They also lose points if they hit the walls of the maze. The game application generates three virtual pitfalls as bombs randomly in the wrong directions of the maze map to make the game more challenging. So, some pitfalls throughout the game must be avoided while navigating the maze. Players can receive immediate feedback on their mistakes or point reductions through the headset via an audio message.

Although the players carry a smartphone on which the Batsight is installed, they cannot see the user interface of this game while playing as they are blindfolded by wearing the sonar headset. To succeed in this game, players must coordinate their movements with the sounds generated within the gameplay. A video of a player playing BatSight is available here[1].

The BatSight game requires a game facilitator to set up the game environment, which is a physical maze based on a map generated by the BatSight mobile game. The facilitator installs the game environment in the real world, and players use the mobile game to navigate through the maze. By combining the mobile game with the physical environment, BatSight provides a unique and immersive gaming experience.

One of the challenges we faced was the physical installation of the Batsight game. Since the game involved a physical maze, we needed a vacant space measuring 36 m^2. In addition, we had to build a substantial maze that could be securely attached to the floor. To this end, 25 wooden bases are applied to set up the maze construction that is shown in Fig. 2 (left). Accordingly, 25 thin steel pipes are placed on the wooden bases as shown in Fig. 2(left). The facilitator connects the sonar headset to the game via Bluetooth connection and puts the headset

[1] https://www.youtube.com/watch?v=sEIqAKBeKps

on the player's head such that the eyes are covered. This facilitator guides the player to the start place and asks the player to wear the headset and earphones.

Figure 2. Wooden bases on the floor in an empty room and the physical maze construction on the wooden bases (left), a player playing BatSight while wearing the sonar headset (right).

3.2 Sonification Techniques

BatSight utilizes a stereo audio rendering system to provide immersive sound cues for players. To guide the player in the right direction, the game uses a flute tune. It starts to play various pitches on the flute once for 2 seconds in the manner of a descending scale with fixed tempo acceleration and volume to guide the player in the right direction every 60 seconds. Since we only want to determine the correct direction in the maze as a hint, the scale ends at the 7th scale degree and does not complete the octave.

The sample rate of the recorded flute sound is 48000 Hz. Additionally, the player hears a drum tune with a fixed volume in the game when they get too close to pitfalls. These audio cues help to enhance the overall gaming experience and provide important navigational information for players. All the playing sounds are three-dimensional, and the player will be able to recognize the direction of the played sound by hearing it. The mapping functions used to simulate different parameters are shown in Table 1.

When the player gets too close to the maze wall, the piano music is played, which increases in tempo as the player gets closer to the obstacle. The game begins to play the piano sound as the player approaches the walls of the maze. Each distance of the wall from 0.05 to 0.6 meters is mapped to a specific pitch, and the piano continues to play the scale when the player is within the distance of the wall. Therefore, the sound of the piano represents the distance from the wall as an obstacle. We developed three different sonification techniques to inform players when they approach the maze wall. The way to play flute and drum are the same in all three sonification modes while the piano sounds based on the distances from the maze wall are variable.

3.3 Sonar Headset Design and Development

To receive environmental information in terms of distances from objects and obstacles in the real world, a sonar headset was designed and implemented Using five HC-SR04 ultrasonic sensors. It is expensive to use a camera to build a headset. Also, the camera is not helpful in dark places, so we do not use a camera to generate the headset. We used an Arduino Uno board to connect various sensors and develop the headset (Fig. 3).

As shown in Fig.4 (left), the placement of sensors is in a way that the headset covers a 120-degree span, but the entire surface of the headset does not act as a sensor since there are 12-degree plexiglass edges on each side of the sensor array. In addition to ultrasonic sensors, to calculate the positioning and the orientation of the headset, Accelerometer (MPU6050) and

Gyroscope Module 3 sensors were used in the headset as shown in Fig. 3. The connection between the headset and the BatSight game is established through the Bluetooth Module.

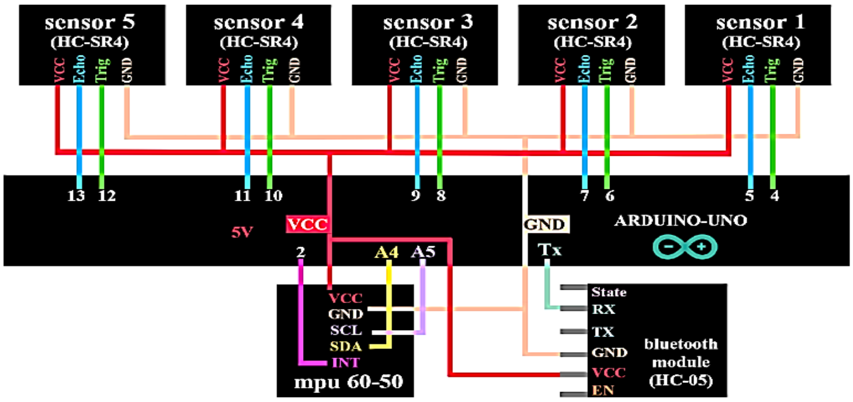

Figure 3. Sonar system structure and jumpers connections to Arduino pins. Connect Arduino pins (4,5), (6,7), (8,9), (10,11), (12,13)} to the first up to the fifth ultrasonic sensors respectively.

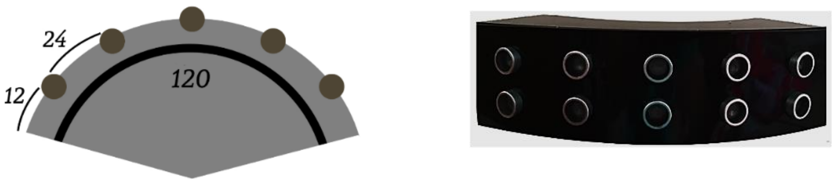

Figure 4. Set all five ultrasonic sensors in the 120° field of view (left) and the final product of the headset

First, five ultrasonic sensors, a gyroscope, and a Bluetooth module were installed on the board and connected to the Arduino UNO R3 with jumpers to test the system's operation (Fig. 5). To measure the distance between an object and the ultrasonic sensor, the player's moving angle, and movement speed, we connected the Arduino board to the PC with a USB cable and programmed it using the Arduino IDE (Fig. 5 (right)). The system relied on batteries to provide the fundamental power, which needed to be replaced every few hours. Therefore, we utilized rechargeable batteries that could supply electricity to the electronic system over an extended period of time.

Arduino Bluetooth Plugin from Unity Asset Store was used in Unity 2019 to receive the sensors' data and convert this data to the required audio output in the BatSight game. Black plexiglass was used to create the structure of the headset as shown in Fig. 4 (right).

Figure 5. The sonar system was tested on the board before final installation (left), and using a USB port to program Arduino (right).

The BatSigt application gets the MPU6050 module data to calculate the distance traveled by the player during the game and apply it to the game map UI. To this end, we use kinematic equations that give the final position in terms of velocity and acceleration for each step of the player.

Δx = 1/2at2 + V0t, v = at + v0

4. User study

We performed a series of experiments to assess BatSight. The main goal was to investigate the effectiveness of different sonification techniques in mapping environmental information to audio cues. As mentioned, the sonification of the game is in three modes. In the last sonification mode, we have tried to produce a musical sound and empirically measured data related to the use of the BatSight game for navigation, game experience, and player immersion, as well as the performance of the developed sonar system in all three sonification modes.

A user evaluation in a controlled laboratory setting was designed to study BatSight. The sonification technique as an independent variable was defined and manipulated in this study. In particular, the sonification is designed based on the use of two sound elements including pitches and tempo that are defined in three modes of Pitches, Tempo, and Pitches-Tempo. Similarly to [21], 3D sonification is utilized to discern directions in the gameplay. The dependent variables in this study were the gameplay variables (time to complete the game and error rates), game experience, sense of immersion, and sonification performance.

The sonification techniques proposed and used in BatSight are:

- **Pitches:** In the first mode of sonification, the BatSight game starts to play various pitches on the piano in the manner of an ascending scale based on the closeness of the player to the maze wall. In this mode, there will be no tempo or duration changes.

- **Tempo:** In the second mode of sonification, the BatSight game starts to play a single pitch (C_3) repeatedly on the piano at different tempo. As the person comes closer to an obstacle, tempo accelerates, and vice versa.

- **Pitches-Tempo:** In the third mode of sonification, pitches as well as the tempo are changed as the player approaches an obstacle. As a player comes closer to an obstacle, he/she will hear ascending pitches while at the same time tempo accelerates.

Table 1. Sound parameters and mapping functions used in BatSight

Data Parameter	Parameter	Mapping Function
Road/Obstacle	Timbre	1.Flute, 2.Piano, 3.Drum
Direction	Azimuth	[1, -60°], [2, -30°], [3, 0°], [4, 30°], [5, 60°]
Distance	Tempo	(0.05 m, 0.3 s), (0.6 m, 1.5 s)
Distance	Pitches	(0.05 m, C6 Soprano C), (0.6 m, C8 Eighth octave)

4.1 Participants

After the announcement of participation in the study, a total of 18 participants were purposefully recruited from the graduate student population within the Faculty of Multimedia at the local university. This group consisted of 16 females and 2 males aged from 21 to 25 (M = 22.83; SD = 2.12). Participants were pre-screened to ensure they did not have any hearing problems. The pre-study questionnaire verified a similar level of education and prior experience with computer games.

4.2 Procedure

After gaining informed consent for participating in the study, a prestudy questionnaire was administered to each participant to measure their education level, prior experience with mobile games, and experience with audio games. Although participants were prescreened to ensure they had sufficient prior knowledge about mobile games, a brief overview of pathfinding games in the maze was provided in order to ensure a common baseline level of understanding of the domain.

Regarding three sonification techniques, a within-subjects design is used in this study. Consequently, each participant played a total of three games with different settings. In order to counterbalance in the grouping phase, six groups were formed based on different orders of three sonification techniques. Therefore, each participant answered 41 questions per condition, with questions asked after each gameplay session. Fourteen questions related to in-game experiences, seventeen were post-game reflections, five pertained to game immersion, and five were about sonar system performance. Then, the facilitator asked the participants to wear the sonar headset. The participants were guided to stand at the entry of the maze to start the game. After playing each of the three modes, participants were asked to answer the questionnaire aimed to measure their game experiences, sense of immersion, and performance.

All the game variables were saved, including elapsed time, number of steps, collisions with maze walls, and pitfalls. In addition, the investigator carefully observed the participants and took detailed notes regarding their performance while playing the game. After finishing the game, a post-study questionnaire was administered to measure subjective reactions to the use of the system in general. Depending on the performance of different participants, each test session took between 45 and 60 minutes to complete the whole experiment. One of the challenges of assessing this investigation was the length of the test. The participants had to play all three levels of the game independently, which could tire the player after a while. To address this challenge, a short period of approximately 5 minutes was allocated for the player to rest between each level.

4.3 Metrics

The Kolmogorov-Smirnov test was used as a normality test to see if data is normally distributed. To evaluate three sonification methods, we used the technique proposed in [40] which is a questionnaire with five questions to measure the sonification performance in terms of scene representation, navigation, complexity, and comfort.

Participants answered to what extent they agreed with the sentences in each question. Seven-point Likert scales ranging from 1 (strongly disagree) to 7 (strongly agree) were used for each sonification method.

5. Results

As shown in Table 2, the significance level of all variables (in-game GEQ, post-game GEQ, immersion, and system performance) in three sonification modes was greater than 0.05, indicating that the data is normal and pair-wise analysis of this data can be carried out using ANOVA.

Table 2. Kolmogorov-Smirnov Z Test Results

Evaluation	Sonification mode	z-score	Sig.
In-game GEQ	Pitches	0.149	0.200
	Tempo	0.128	0.200

	Pitches-Tempo	0.172	0.166
Post-game GEQ	Pitches	0.129	0.200
	Tempo	0.127	0.200
	Pitches-Tempo	0.156	0.200
Immersion	Pitches	0.188	0.093
	Tempo	0.125	0.200
	Pitches-Tempo	0.135	0.200
Sonification Performance	Pitches	0.146	0.200
	Tempo	0.124	0.200
	Pitches-Tempo	0.176	0.145

5.1 Time to Task Completion

During the game, the time it took for players to complete the task - from entering the maze to exiting - was measured. This variable is an index to measure the efficiency of the sonification techniques to guide participants inside the maze.

Table 3. The elapsed time during the gameplay

Sonification mode	minimum	maximum	Mean	Sig.
Pitches	1.01	2.40	1.53	0.499
Tempo	0.35	3.31	1.63	0.797
Pitches-Tempo	0.35	2.0	1.30	0.549

According to the average elapsed time in Table 3, the third group of participants completed the game faster than the first and second groups.

A pairwise analysis of this data using ANOVA found no statistical significance in the differences. As a result, we found that there is a difference in time to task completion that did not meet the significance criteria regardless of sonification type ($F(2,51)=0.425$, $p=0.656$). That is, even though the type of sonification to guide the participants inside the maze was changed, the time to find the exit door and complete the game did not change sufficiently to satisfy statistical significance.

5.2 Error Rates

Two different types of errors were identified based on the gameplay. These included participants' collisions with maze walls and the number of encounters with pitfalls. Due to the low error rate and the high degree of variability in the different types of errors, for statistical verification, we grouped the errors together and performed a single ANOVA analysis. The results from this analysis ($F(2,51)=1.434$, $p=0.248$) show that there is no statistical significance in the error rates as the sonification technique changes. As a result, we conclude participants will make a similar number of errors in finding their way in the maze regardless of the sonification technique used to guide them.

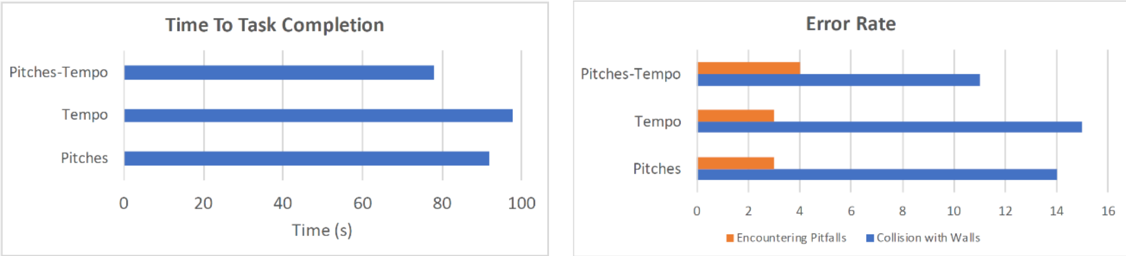

Figure 6. Time to task completion and error rates in different sonification techniques.

5.3 In-game and Post-game GEQ

We used the in-game and the post-game modules of the Game Experience Questionnaire (GEQ) to measure the participants' gaming experience [41]. The in-game questionnaire includes 14 questions, and the post-game module has 17 questions. Participants' responses were rated on a five-point Likert scale(1 is not at all, and 5 is extremely). To evaluate in-game GEQ, the ANOVA test was used to compare three sonification modes. The results of this test are shown in Table 4. According to this table, the results of the ANOVA test show that participants' opinions regarding in-game GEQ in three sonification modes are different in at least one of the groups ($F=0.436$, $p=0.04$). Also, participants' opinions regarding post-game GEQ in three sonification modes are different in at least one of the groups ($F=4.074$, $p=0.023$). Consequently, post hoc analysis was used as a follow-up to the ANOVA to determine which pairwise comparison of means contributes to the overall significant difference. According to the results of the post hoc analysis in Table 5, there is a statistically significant difference between the third and the second mode, and also between the third and the first mode. Therefore, we conclude that the third mode, which is the combination of pitches and tempo works better than pitch or tempo alone in terms of in-game game experience. Therefore, the hypothesis that the combination of pitches and tempo acceleration based on the distance from the maze walls outperforms pitch or tempo alone in terms of in-game and post-game experience is supported.

Table 4. The results of ANOVA test comparing GEQ in-game and post-game experience in three sonification modes

GEQ	Groups	Sum of Squares	df	Mean Square	F	Sig.
in-game	Inter-groups	244.111	2	122.056	0.436	0.04
	Among-groups	1811.889	51	35.527		
	Total	2056.000	53			
post-game	Inter-groups	311.444	2	155.722	4.074	0.023
	Among-groups	1949.389	51	38.223		
	Total	2260.833	53			

Table 5. The results of ANOVA test comparing GEQ in-game and post-game experience in three sonification modes

GEQ	Sonification modes	Mean Difference	Std. Error	Sig.
in-game	Pitches-Tempo/ Tempo	3.88	1.98	0.049*

	Pitches-Tempo/ Pitch	4.94	1.98	0.016*
	Tempo/ Pitches	1.056	1.98	0.598
post-game	Pitches-Tempo/ Tempo	4.889	2.061	0.021*
	Pitches-Tempo/ Pitch	5.278	2.061	0.03*
	Tempo/ Pitches	0.389	2.061	0.851

5.4 Immersion and Sonification Performance

Immersion is an important factor to be considered when developing computer games and virtual environments. Immersion is a term frequently used to measure the quality of a game [42]. Immersion plays a crucial role in persuasion, as studies have shown that higher levels of immersion can lead to increased susceptibility to persuasive messages [43]. We used the questionnaire in [42] to measure the sense of immersion in BatSight. This questionnaire includes five questions, based on the five-point Likert scale, where 1 strongly disagrees, and 5 strongly agree. In order to compare the immersion of players in the game using three different sonification modes, the ANOVA test was performed. Before that, the results of Levene's test on the immersion variable showed that there was no statistically significant difference between the variance of the dependent variable among the groups and the homogeneity of variances is supported (Table 6).

Table 6. Levene's test in three sonification modes for the immersion data

Leven's Test	DF	Df2	Sig.
0.604	2	51	0.550

According to Table 7, the results from ANOVA analysis show that there is no statistical significance in the immersion as the sonification techniques are changed between the groups. Therefore, we conclude that the different sonification techniques did not affect the immersion of players.

Table 7. ANOVA test comparing immersion in three sonification modes

Groups	Sum of Squares	df	Mean Square	F	Sig.
Inter-groups	42.926	2	21.463	3.103	0.051
Among-groups	352.722	51	6.916		
total	395.648	53			

To compare the three sonification modes in terms of the audio performance of the system, the ANOVA test was used. Before that, the results of Levene's test showed that there was no statistically significant difference between the variance of the dependent variable in groups and did not violate the homogeneity of variances (Table 8).

Table 8. Levene's test in three sonification modes for the immersion data

Leven's Test	DF	Df2	Sig.

1.427	2	51	0.249

According to the results of ANOVA test shown in Table 9, participants' opinions regarding the sonification performance of the system in three sonification modes are different in at least one of the groups (F=4.090, p=0.023).

Table 9. ANOVA test comparing immersion in three sonification modes

Groups	Sum of Squares	df	Mean Square	F	Sig.
Inter-groups	122.704	2	61.352	4.090	0.023
Among-groups	764.944	51	14.999		
total	887.648	53			

According to the results of the post hoc analysis in Table 10, We conclude that the third mode, which is the combination of pitches and tempo acceleration works better than the pitches alone. Therefore, the hypothesis that the combination of pitches and tempo acceleration based on the distance from the maze walls outperforms the pitch alone in terms of the audio performance of the system is supported.

Table 10. ANOVA test comparing immersion in three sonification modes

	Mean Difference	Std. Error	Sig.
Pitches-Tempo/ Tempo	3.11	1.29	0.020*
Pitches-Tempo/ Pitches	3.27	1.29	0.014*
Tempo/ Pitches	0.167	1.29	0.898

5.5 Interview

After completing each game, the participants were asked a verbal question: "Did you understand the experience of visually impaired individuals by playing the BatSight game?" All of the participants affirmed that they were able to empathize with visually impaired individuals and gained a unique experience from playing this game.

6. Discussion

In the present work, we aim to develop an audio-augmented reality game with three different sonification modes to assess the impact of various sonification techniques on navigation performance, game experience, and immersion; We have organized the physical environment for the BatSight game in a manner that enables realistic progression and encourags player movement. Furthermore, we have incorporated musical sounds to guide the player, relying on their auditory skills. Previous studies have not explored the utilization of musical sounds for this purpose. It also suggests the most effective sonification techniques in audio-augmented reality games in this specific context.

To this end, we conducted a user study to evaluate navigation performance, gaming experience, and immersion experience in all three sonification techniques. Next, we discuss the best sonification technique. The results could inform the design of audio games and future

AAR systems where the player can navigate with the help of musical sound which enhances the game experience and the player's immersion.

6.1 Limitations and Future Research

One limitation we encountered in the present study was the physical construction of the maze. We purchased wood, steel pipes, and plastic for the maze installation. Therefore, designing a lighter maze can streamline the construction process in other real-world game scenarios. Since the study was conducted in a closed-off area during the COVID-19 epidemic, the variety and number of participants were limited. So, exploring the game's effectiveness across a broader demographic, including individuals with varying levels of visual impairment, could enhance the applicability of the study.

For future work, we aim to equip our sonar headset with image-processing tools to detect and map different kinds of obstacles. This way, the game will not be limited to a specific maze and can be played in less controlled environments. We also aim to investigate other sonification techniques including changes in the pitch, changes in the musical instruments, and other musical features to reach the best possible sonification solutions. We will utilize the presented sonar system with advanced spatial audio processing and haptic feedback to investigate their impacts on the navigation of visually impaired people in future research.

7. Conclusions

In the present paper, we investigated the effect of different sonification techniques on the navigation performance of players in audio games. To this end, we proposed an audio augmented reality game called Batsight that is played in a real maze built for this purpose. We also designed and built an ultrasonic headset for players of this game that is used to map environmental information to audio cues. According to the current study, a game like this could be utilized in various contexts, including classrooms, museums, or escape rooms that start with a maze.

Our approach to addressing the research questions involves the utilization of five ultrasonic sensors arranged in the form of a headset, effectively covering the human field of vision at a reasonable cost. This system has been engineered to receive environmental information and convert it into sound through a custom-developed program. The assessment of system performance, based on both a questionnaire and recorded game data, indicates that the system successfully acquires and translates environmental information into sound.

A user study was performed to investigate how different sonification techniques can affect the performance of players in terms of detecting maze walls and pitfalls using audio cues. In particular, we implemented the BatSight game using three sonification techniques including pitches (playing various tones on the piano based on the distance from the wall), tempo (playing C_3 repeatedly on the piano at different speeds based on the distances from the walls), and the combination of pitches and tempo. Participants' performance in terms of time to complete the game wells as their errors during the gameplay were recorded to examine the effect of different sonifications on the navigation performance. They were also asked to answer questionnaires regarding game experience and sense of immersion. For playing performance that was measured in terms of time to complete the game and the number of errors while playing the game (collision with walls and pitfalls), the result showed that using the combination of pitches and changing the tempo as a sonification method works better than either sonification techniques alone. So, we have concluded that this sonification technique can lead to better navigation performance. However, the statistical analysis of data found no statistical significance in the differences.

The results of the post hoc analysis, which served as a follow-up to the ANOVA test on the in-game, post-game, immersion, and sonification performance questionnaires found that the combination of pitches and tempo acceleration in the sonification of the sonar system is more effective in providing a superior game experience, and audio performance compared to using pitch or tempo alone. Thus, the hypothesis suggesting that the combination of pitches and tempo acceleration based on the distance from the maze walls outperforms other techniques in terms of game experience and audio performance of the system, is supported.

At the end of the game, we also interviewed the players about the game experience, and most of them mentioned that playing this audio-based game provided them with a unique experience, as it did not rely on sight. Also, they were able to understand visual impairments.

The outcomes from the system performance questionnaire evaluation reveal that the deliberate crafting of a harmonious blend of sound can influence the efficacy of the developed system. Additionally, adeptly incorporating environmental information and utilizing sound components enhances the overall performance of the designed sound system.

7.1 Data Availability

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Conflicts of interest

The source code of BatSight as well as all data regarding the evaluation will be available on reasonable request. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

1. I was interested in the game's story.
2. I felt successful.
3. I felt bored.
4. I found it impressive.
5. I forgot everything around me.
6. I felt frustrated.
7. I found it tiresome.
8. I felt irritable.
9. I felt skillful.
10. I felt completely absorbed.
11. I felt content.
12. I felt challenged.
13. I had to put a lot of effort into it.
14. I felt good.

Post-game Module GEQ:
1: low 5: high
1. I felt revived
2. I felt bad
3. I found it hard to get back to reality
4. I felt guilty.
5. It felt like a victory.
6. I found it a waste of time.
7. I felt energized.
8. I felt satisfied.
9. I felt disoriented.
10. I felt exhausted.
11. I felt that I could have done more useful things.
12. I felt powerful.
13. I felt weary.
14. I felt regret.
15. I felt ashamed.
16. I felt proud.
17. I had a sense that I had returned from a journey.

Game Immersion:
1: not very important 5: extremely important
1. How important do you feel sound is in a game?
2. How immersive was the flute sound in the game?
3. How immersive were the sound effects in the game?
4. How much did the levels without sound bother you?
5. What level in the game did you prefer?

Sonar System Operation:
1: strongly disagree 7: strongly agree
1. I can understand the position of obstacles and find the way through this sonification method.
2. I know if there are obstacles ahead and how to avoid them through this sonification method.
3. I feel relaxed and don't have to concentrate all my attention on the subtle changes of sound.
4. I think the sound effects are not noisy and the device can be used for a long time.
5. I like this sonification method.