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SoundPacman: Audio Augmented Reality in Location-based Games

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***Abstract*—Sound design has received little attention in location-based games research. Typically, existing prototypes heavily rely on visual information with sound only having a marginal role in the game design and development process. This paper investigates the role of sound as primary interface for conveying game information and creating engaging gaming experiences. As a case study, we present SoundPacman, a prototype location-based game, wherein players experience the game space with the use of 3D sounds, which augment the physical environment. Preliminary tests utilizing EEG analysis provide evidence that sound augmentation may significantly contribute towards enhancing the immersion levels of players.**

Keywords—pervasive games; augmented reality; 3D sound; location-based games; EEG;

I. Introduction

Pervasive games represent an emerging game genre, wherein the gameplay is transferred from the virtual to the real world, thus spatially, temporally and socially extending the magic circle of games [1]. Pervasive games are typically based on scenarios exploiting contextual information of the player's environment. Location-based gaming has been the most popular type of pervasive games with available research and commercial games proliferating in the recent years. Despite the enhanced role of the physical environment in the game play, player interfaces are still dominated by the visual medium, often making it necessary for the player to constantly watch her device's screen. The use of sound has received relatively little attention; hence, the sound (if any) typically plays a marginal role in the game design and development process. The evolution of mobile computing has opened new opportunities in exploiting emerging sound technologies in gaming so as to maximize the players' immersion level within a mixed-reality gameplay.

In the context of game design, the immersive power of sound aims to smoothly transferring the player to a virtual world, using synthesized sounds. Nevertheless, this practice has received criticism for raising risks for the players' safety, when augmenting the real world through sounds principally different to the ones heard in normal environments [2]. Along this line, game designers have recently proposed alternative ways to attain a smooth harmonization, mainly through integrating the game sound effects into the physical environment. Consequently, consideration of aspects contributing to awareness of a player's location, for example the orientation of the player in relation with the game's elements, are regarded as key factors for the perception of 3D sound (e.g., through the HRTF[1] [3]).

Herein, we investigate the role of sound as primary interface for conveying game-relevant information. The main research hypothesis investigated is that sound augmentation may contribute towards enhancing the immersion levels of players. As a case study, we present SoundPacman, a prototype location-based game largely inspired by the well-known arcade game PacMan. In SoundPacman, the players perceive the game space with the use of 3D sounds, which augment the physical environment.

The remainder of the article is structured as follows: Section 2 reviews research relevant to our work. Section 3 details the game scenario of SoundPacman, while Section 4 presents its game engine architecture. Section 5 presents the implementation details of SoundPacman. The method used for audio augmentation in SoundPacman is discussed in Section 6. Section 7 presents the results of preliminary tests using EEG analysis. Section 8 concludes our work and draws directions for future research.

II. Related Work

Location-based games claim a major share within the pervasive games market. Many research prototypes as well as some commercial games, like Ingress[2] and Zombies Run[3], use location-aware game elements to support their scenario, considering the player's location as point of reference.

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[1] A head-related transfer function (HRTF) is a response that characterizes how an ear receives a sound from a point in space; a pair of HRTFs for two ears can be used to synthesize a binaural sound that seems to come from a particular point in space.

[2] https://play.google.com/store/apps/details?id=com.nianticproject.ingress

[3] https://play.google.com/store/apps/details?id=com.sixtostart.zombiesrun

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Human Pacman [4] has been a milestone pervasive game, notably, one of the first to transfer the experience of an arcade game out to the physical world. Using a slightly modified game plot compared to the traditional Pacman, players could be enrolled as pacmen, helpers or ghosts. The interaction, as well as the movement of players within the game space, required the use of devices, like sensors and wireless LAN cards, kept in a backpack. The players also carried head-mounted displays, whereon information about the plot of the game and augmented reality content was projected. The use of equipment, the need for orchestration (helpers) and the difficulty to set the game space at any location, seriously limited the portability and openness of the game. The Human Pacman project has inspired the development of PacMap [5]. PacMap enables anytime/anywhere gameplay; the game stage is set around the actual location of the user (comprised of the actual surrounding streets). Unlike Human Pacman, the ghosts are virtual characters handled by the game engine of PacMap and follow a different mobility pattern moving on the map, around the user's area.

Sound has been treated as a central game play element in only a few pervasive games: SoundPark [6], Songs of the North [7], and Viking Ghost [8]. SoundPark is a multiplayer outdoor game [6]. The scenario of the game involves collecting real environment sounds from "Hunter players" and creating a song. Songs of the North is a multiplayer game wherein the player tries to collect elements within the world of the game [7]. The players communicate with each other through sounds, using a virtual drum displayed on the screen of their device. The research prototype Viking Ghost is a location-based game, using sound as its basic component [8]. Considering location awareness, the sound is adapted, trying to guide the player within the game space. The scenario invites the user to assume the role of a paranormal investigator. The user is asked to identify paranormal activity and other elements appearing, using sound effects. The game features three modes, the camera/x-ray mode, the map mode and the frequency scanner mode, which refers to an audio interface. The implementation of the game, in particular its sound design, aims at creating an immersive and emotional experience. Sound represents a key interaction tool in Viking Ghost; the sound is synthesized in accordance with the location of virtual elements in the real world. This is enabled by 3D representation of sound based on Head Related Transfer Functions (HRTF) [9], so that there can be a realistic outcome in the spatialization of sound. The game's evaluation has been undertaken by a sample of 19 participants in order to explore the usefulness of user interface and user game experience.

III. Game Scenario

SoundPacman comprises a follow-up implementation of the PacMap game prototype. SoundPacman is a location-based game, which requires Internet connection and enabled GPS receiver in the player's mobile device. The game space is determined at startup, considering the actual road segments around the user's position as possible walking corridors for the pacman player. The user is supposed to collect all the cookies positioned across the streets. Similarly to PacMap, the movement of virtual objects is handled by the game engine. Following the scenario of the original arcade game, the ghosts are supposed to catch pacman, each following a different mobility pattern moving around the user's area. The main differentiation among SoundPacman and PacMap lies in the fact that the former does not rely on the screen as a means of interaction with the player. In particular, the necessary game information is provided to the player via 3D sound; players become aware of the position of the ghosts and the cookies through interpreting the specific sounds supposedly generated by these elements, as if these elements were placed in the real environment. Fig. 1 illustrates characteristic screens of PacMap and SoundPacman interfaces.

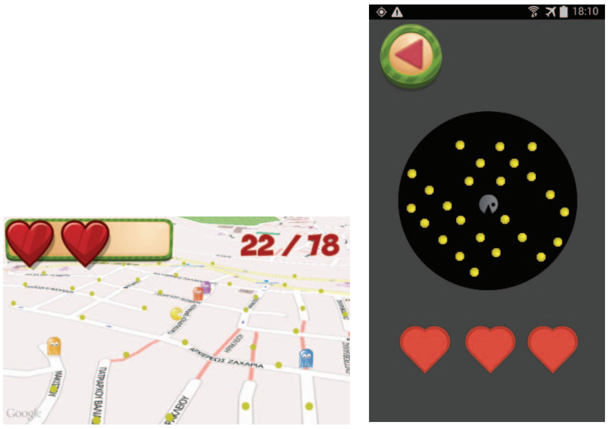

Fig. 1. (a) PacMap and (b) SoundPacman application screenshots.

IV. Game Engine Architecture

SoundPacman adopts a client-server game engine architecture. The server is in charge of the construction of the game, while the client is in charge of the reception of information by the server and its 'translation' to 3D sounds. As represented in Fig. 2, the client sends out its location information to the game server to configure the appropriate game space.

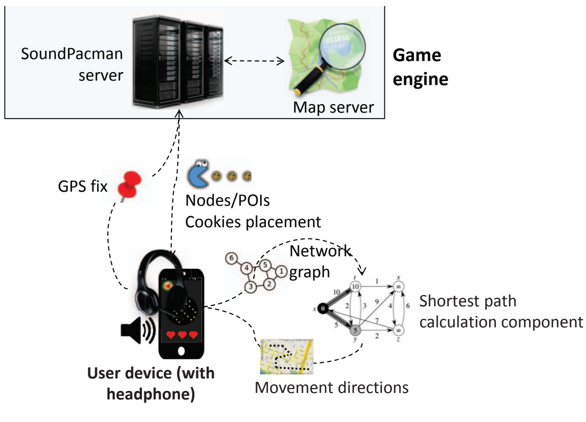

Fig. 2. SoundPacman system architecture.

The latter is confined by a circle around the user's location, with a radius of 200 meters. The game server uses the geolocation information to contact a map server and retrieve the nodes and POIs lying within this imaginary circle (the communication is handled by the OpenStreetMap API[4]).

The arrangement of game components within the game space (e.g. the placement of cookies) is carried out through utilizing the area nodes information. To ensure even distribution of cookies, the game engine firstly measures the distance between two nodes applying the Vincenty's formulae [10]. The latter is based upon two iterative methods, which are used in the field of Geodesy to measure the distance between two points on a spherical surface. Subsequently, the road sections are segmented, so that the cookies can be placed in equal distances.

V. SOUNDPACMAN IMPLEMENTATION

The arcade game Pacman involves ghosts which chase the pacman, with their movement promptly adapting to that of pacman. In order to transfer such functionality to a map-based interface each ghost needs to receive a series of road segments to be traversed. Provided a start and an end location (e.g. the current location of the ghost and the player, respectively) a reasonable approach for the ghost chasing the user is to invoke a 'direction' web service typically offered by commercial map data providers (e.g. the Directions service of the Google Maps API) and then faithfully follow the shortest path walking directions returned by the service. However, if the user location changes too often, direction service invocations (passing the updated ghost/player location parameters) will increase accordingly and soon exceed the invocations limit set by commercial providers (for instance, the free daily quota offered by Google Maps web services is 2,500 requests per developer licence).

Enemy (i.e. ghosts) movement patterns fall into two types, depending on the way they are executed. Orange, blue and purple ghosts repeatedly execute a random movement around the map. To implement these movements, we derive two random pairs of coordinates over the arc of the imaginary circle centered at the user's current position. These two pairs of coordinates (representing the start/end nodes of each successive ghost movement) are submitted to the Directions API service of the map server, thus generating the actual path to be followed by each ghost. From a games research viewpoint, the movement of the red ghost is more challenging as it presumably applicable to many similar map/location-based chase games, since (according to the SoundPacman scenario) it is supposed to follow the user as s/he moves within the game space.

Ghosts movement respects the game space topography, namely the nodes exported from the game server during the game space generation phase (see Fig. 3a). Considering a graph transformation of the game space (connecting adjacent nodes which are connected through a road segment on the actual setting and calculating the distances among them), it is then straightforward to execute a shortest path algorithm to compute the path to be followed by the user (see Fig. 3b). SoundPacman's directions service implements Dijkstra's algorithm[5], wherein edge costs equal the distance between their connected end nodes. For example, the red ghost considers the node nearest to the ghost's current location as start node and the node the user currently heads to as end node (e.g. nodes A and B, respectively, in Fig. 3a).

Shortest paths are derived whenever the user reaches a new edge or turns to another direction. To ensure prompt adaptation of ghost's movement to the player's movement, the device determines the nodes among which the user is located whenever his location (i.e. GPS fix) is updated.

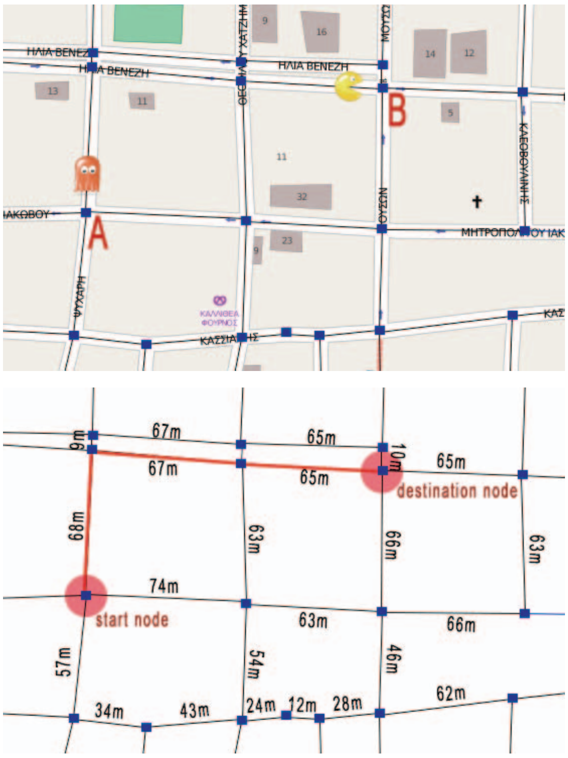

Fig. 3. (a) An example game space illustrating the extracted topology nodes; (b) shortest path derived by a directions service executing Dijkstra's algorithm upon a graph transformation of the game space.

The sole goal of the ghost is to "catch" pacman, i.e. to reach its currently assigned end node, having gone through the edge currently traversed by the user. In case that the ghost arrives at its end node without passing via the player's edge, the algorithm is executed again, with the other end point of that edge set as the new end point for the requested directions.

It is noted that the shortest path algorithm is executed on the client side to eliminate the effect of network latency inherent in client-server interactions. On an average game space, considering 420 nodes, the algorithm takes 95 msec to yield the shortest path when executed on a Samsung Galaxy S4 device (processor: ARMv7 – 1.8 GHz x 4 cores / ram:1.8 GB).

[4] OpenStreetMap is an open-source mapping service, providing developers with useful crowdsourced topographical information.

[5] Dijkstra's algorithm is a graph search algorithm that solves the single-source shortest path problem for a graph with non-negative edge path costs, producing a shortest path tree.

VI. AUDIO AUGMENTATION IN SOUNDPACMAN

The 3D sound theory is based on the fact that humans can localize audio sources in space, by comparing and synthesizing audio elements received from both ears. The difference in arrival time (estimated around 300μs [11]) along with the distance from the sound source are being taken into consideration by humans' hearing system and brain to accurately estimate the position of audio sources. Filters modeling this route from the source to the hearing system are referred to as Head Related Transfer Functions (HRTF) [9]. Several experiments have been carried out on humans providing evidence that HRTF vary depending on the person. Therefore, the use of personalized HRTFs would be ideal, yet, practically unfeasible in existing 3D systems. In most cases, generalized (non-individualized) HRTF are used, since they ensure satisfactory localization accuracy for the majority of the users.

The OpenAL[6] library has been used for the execution of HRTF functions in SoundPacman. OpenAL is an open source, cross-platform, 3D audio API used for the reproduction of sound and music, which is used across several 3D audio applications, including production of sound in PC games and specialized game platforms. OpenAL can enhance the sense of realism in computer-generated sound production by simulating attenuation (degradation of sound over distance), the Doppler effect (change in frequency as a result of motion) and material densities. Therefore, the use of OpenAL with HRTFs provides game designers and developers with a reliable tool for incorporating sound as a principal means of interaction among the players and the game engine, thereby improving the perceived user experience. Clearly, the positioning of virtual audio sources relatively to the player's actual location plays a vital role in the integration of game sounds in the real environment and should be consistent with the players' sensing about where the virtual objects are. Positioning data should be updated as the player's position changes (detected by a GPS sensor).

In the context of SoundPacman, we have synthesized an audio track which is looped throughout the game session. The player moves within the game area (wearing headphones connected to her smartphone) trying to consume cookies while avoiding the ghosts chasing after her. The use of OpenAL allows to programmatically configure the positioning of the sound source, as the player and the ghosts move within the game space. The sound volume is also dynamically adjusted, being inversely proportional to the distance among the player and the ghosts. In this way, the player perceives the positioning of the ghosts relatively to her current location and orientation.

VII. PRELIMINARY TESTS USING EEG ANALYSIS

The objective of SoundPacman is to emotionally stimulate the user while she plays. Given this fact, preliminary tests were carried out, so as to synthesize appropriate sounds to be integrated into the game. Along this line, we have executed a comparative study to investigate the emotional response of users while listening to these sound effects, both in a neutral state and during the game.

[6] https://github.com/AerialX/openal-soft-android

Fig. 4. Mindwave Mobile EEG sensor

In order to improve the accuracy of results, preliminary tests have been undertaken using Mindwave Mobile[7] (Fig. 4), an EEG (electroencephalography) sensor. Mindwave Mobile is a device used to study the cerebral activity of participants while playing. In particular, the electroencephalogram records the electrical activity of the brain, placing electrodes to the outer surface of human sculp. The electrical activity is recorded by the EEG device capturing signals transmitted from neurons, the brain's nerve cells. The reception of signals from a specific part of the brain is, essentially, the sum of signals of all neurons in this specific part. While studying a specific part of the brain, the signals received are divided into four bands, depending on their frequency [12]. These bands are listed below:

- Delta (0,5-3 Hz): these frequencies appear in adults while they sleep and in neonates.
- Theta (4-7 Hz): these frequencies appear in kids and in adults, in the stages before and after sleeping.
- Alpha (8-13 Hz): these waves indicate a state of relaxation and tranquility.
- Beta (14-30 Hz): these waves indicate a state of alertness, deep thought and concentration.

Although there is no binding way to place electrodes, there are still some models used as a reference. The most common one is the 10 – 20 system [13], an international model adopted in our research. This system uses 21 electrodes, whose positions are defined in relation with the higher spot of the nose, at the height of eyes. The "10" and "20" (10-20 system) refer to the 10% and 20% inter electrode distance. The EEG signal reception device, used in the preliminary tests of the application, focuses on the Fp1 spot of the brain, i.e. the area above the left eye (see Fig. 5).

[7] http://neurosky.com/

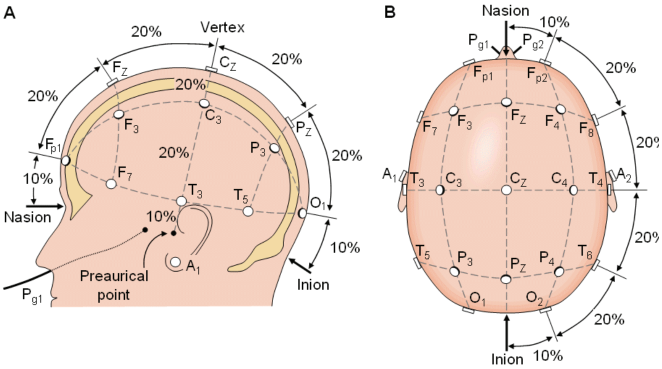

Fig. 5. EEG 10-20 measuring system

In our tests, we recorded the activity of alpha and beta waves [14], in order to observe the transition of the brain states from tranquility to alertness and vice-versa, throughout the game. The implementation of this method enables us to extract useful conclusions with regards to the influence of the game's elements over the user.

The main hypothesis investigated in the context of these tests has been that sound augmentation may contribute towards enhancing the immersion levels of players. Indeed, the compilation of logged data indicated high level of alertness at the times that the ghosts approached the players. Those results agreed with the experiences of players who reported (through follow-up structured interviews) that the lack of visual perception of the sound source generated a feeling of anxiety and promptness whenever the sound level was increased (i.e. the ghosts were 'felt' closer) and motivated them to increase their effort during the game session.

Furthermore, we have employed live observation methods, wherein the players have been questioned with regards to their perception of the game elements' position. Their responses (cross-checked by the developers against the real ghost position traces kept in log files) confirmed that the players could accurately localize the sound sources.

VIII. Preliminary tests results

Ten people aged between 20 to 30 (five women and five men) participated in a preliminary evaluation trial, so as to allow us to extract safer conclusions with respect to the effectiveness of sound augmentation. The methodology of preliminary tests is tailored to right-handed participants [15] .

Experiments have been performed outdoors, in an environment familiar to the participants; the developers ensured that no object would distract their attention. Following the recording of players' raw brain activity data and their analysis (in Matlab), we have cross-checked, time-wise, signal waves against the sounds heard by the participants. It has been observed that at the moments when the sound of ghosts was perceived by participant, beta band rates increased considerably, expressing the feeling of alertness experienced by the user. Fig. 6 depicts the wave sound across time, while Fig. 7 depicts the waves of the raw EEG signal from a user during the experiment.

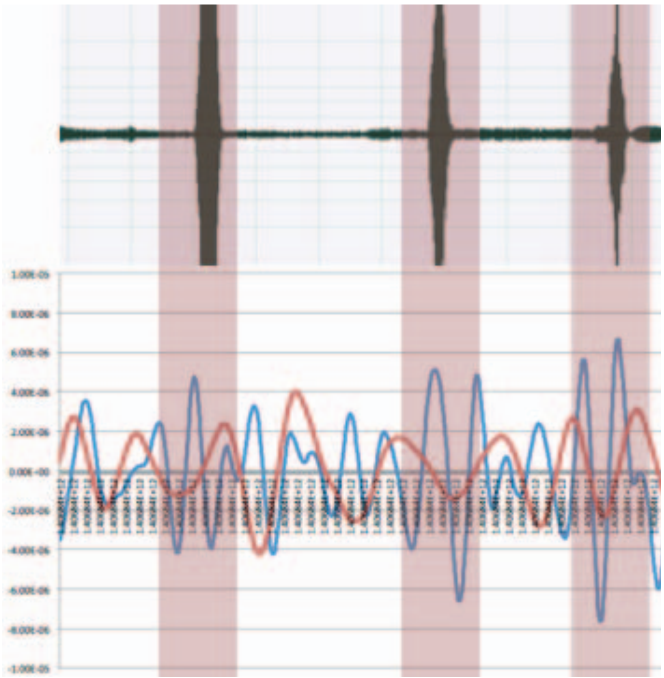

Fig. 6. EEG signal from a user during the experiment.

These graphics enable us to confirm the temporal correlation of player alertness and readiness with the reproduction of ghosts' sounds as evidenced by the coinciding high Beta band rates.

IX. Conclusion and future work

In this paper we introduced SoundPacman, a location-based game wherein players experience the game space via 3D sound. The sound effects are synthesized by using an environmental 3D audio library which approximates the HRTF of the listener. Thus, sound recordings are heard by the players through typical stereo headphones, yet, interpreted as sounds originated in the 3D space (rather than just two points on the head sides). The SoundPacman prototype implementation has been used to investigate the extent to which audio augmentation of the player's physical environment succeeds in creating engaging gaming experiences. Preliminary tests have been undertaken (using electroencephalography sensors) to monitor the brain activity of participants during game sessions. The tests revealed that the effective use of 3D sound may increase the level of alertness measured on players.

In the future, we intend to execute formal user evaluation trials to assess the effect of audio augmentation upon several aspects related with the perceived quality of experience (e.g. enjoyment, interest, immersion). In the context of those field trials, the audio augmentation method proposed in this article will be compared against PacMap, a variant of SoundPacman which utilizes the same game engine and a map-based player interface.

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