Audio Augmented Reality Outdoors

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Figure 1: a. AR portal b. Within the AR-portal's digital environment c. Precise AR reconstruction placement

ABSTRACT

Audio Augmented Reality (AAR) is a novel and unexplored area of AR representing the augmentation of reality with auditory as well as visual content. AAR's interaction affordances as well as accurate real-world registration of visual as well as sound elements are challenging issues, especially in noisy, bright and busy environments outdoors. This paper presents a novel, mobile AAR experience that is deployed in a city environment while walking past six archaeological excavation sites in the city of Chania, Crete, Greece. The proposed AAR experience utilizes cutting-edge gamification techniques, non-linear storytelling, precise AR visualization and spatial audio, offering innovative AAR interaction while exploring the city's archaeological sites and history, outdoors.

CCS CONCEPTS

• **Human-centered computing → Mixed / augmented reality**; **User centered design**; • **Software and its engineering → Interactive games**.

KEYWORDS

audio augmented reality, interactive experience, outdoors

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1 INTRODUCTION

Audio Augmented Reality (AAR) is a novel and relatively unexplored area of AR representing the augmentation via digital information superimposed onto the real-world, in the form of audio or even musical elements [7, 50]. A recent survey explored AAR in navigation, location-aware assistance, entertainment, recreation, telepresence, education and training and importantly, healthcare [50]. The spatial arrangement of physical instruments can guide users' attentional focus [47], therefore, AAR could enhance user engagement. The process of augmenting a user's real-world acoustic environment through the integration of digital auditory content combined with 3D superimposed elements in AAR is challenging, especially in noisy, bright and busy environments, in cities, outdoors.

Creative agencies are seeking novel ways to promote their content by introducing interactive technologies and serious games (SGs) in order to engage their audience [37, 39, 41]. Gamification and rewarding techniques allow the audience to complete tasks, improving immersion and fun [24]. Augmented Reality (AR) is increasingly used for interactive entertainment [20, 22]. Historical facts should be digitally presented without obstructing the real-world. A seamless narrative between reality and virtuality is crucial [9, 16, 25].

This paper introduces a novel mobile AAR experience integrating spatial auditory and musical content, 3D graphics, and SG elements providing interactive exploration of six archaeological excavation sites in Chania, Crete, Greece, while a user is walking in a busy and noisy environment outdoors. The players are tasked with locating the music sources of 3D artefacts through spatial soundscape exploration [Fig. 1a-b]. The melodies attached to each 3D artefact are based on its material properties and historical knowledge provided by the Ephorate of Antiquities in Chania, Greece, relevant to the music and melodies of Ancient Kydonia. Players must locate and collect them on the screen of their handheld devices while walking inside and out of the soundscapes. Our system is optimized for outdoor use through implementation of custom technical improvements of the Mapbox geo-navigation software development kit (SDK) for enhanced GPS accuracy, enabling the SDK to provide reliable and efficient geo-navigation in outdoor environments.

Our specific contributions include:

- A methodology of spatial integration of sound, music and 3D graphics, promoting historical documentation
- A non-linear storytelling experience starting from any Point-of-Interest (POI) out of the six available
- Playful city navigation outdoors based on a digital-game over an interactive map consolidating music and sound design for a noisy setting
- Accurate AR placement of less than 0.3m accuracy without image markers
- A methodology of presenting subterranean sites, not open to the public via 3D portals superimposed on the real-world POI, integrating spatial sound
- Adapting 3D graphics of AR visuals based on real-world lighting conditions introducing adaptive lighting techniques
- Employing a practical Graphical User Interface (GUI), visible and effective even in direct sunlight.

Excavation artifacts, parts of the settlement of Ancient Kydonia and burial monuments, based on Life and Death are included in the proposed AAR experience. The Life's chapter POIs are visible from the street [Fig. 2] , while the Death's chapter POIs are mostly subterranean archaeological monuments [Fig. 3] not accessible to the public. The audience has the freedom to explore the POIs in a non-linear path, allowing them to select where to begin the experience.

The gameplay of the AAR experience begins by retrieving the GPS location of the player which should be in Chania, otherwise users are prompted to visit Chania in order to use the experience. Upon accessing the main menu, players are presented with options to 'Start Experience', use the SoundScape Generator, access the Settings, or view the Credits. If players select 'Start Experience', they must select one of the six POIs to initiate their journey [Fig. 5a]. The interactive map [Fig. 4] will display and guide them to the location of the selected POI. Upon arrival, the players are prompted to activate the AAR mode on their handheld devices and point it towards a designated location where the 3D monument will appear [Fig. 1c]. The audiences may explore and interact with the 3D monuments from different angles. The SoundScape Generator feature allows players to create personalized soundscapes by placing the collected 3D artefacts around them, each with its unique melody.

Figure 2: a. 2nd POI - The Archive, office of the service that controls and manages the goods of the Minoan palace of Chania. b. 3rd POI - The Adyton, a small shrine for important ceremonies

Figure 3: a. 6th POI - An underground tomb with many chambers, belonging to a wealthy family of the 3rd c. BC b. Person exploring the 6th POI

The GUI prompts the players to select an artefact from the available ones and place it in the physical world at a desired location. Players can add or remove artefacts to the scene as desired. The spatialized sound works seamlessly due to the use of AR technology. Players can explore the artefacts and their melodies by moving closer to them, creating a personalized soundscape.

2 RELATED WORK

2.1 Audio Augmented Reality (AAR)

Audio Augmented Reality (AAR) is an emerging field representing the augmentation of reality blended with virtual auditory content [7, 23, 50]. Spatialized sounds could be used for reporting system feedback, alerts, errors in diagnostics or even added to enhance user experience when developing AAR for creative technologies. Compared to vision augmentation, audio augmentation still remains under-employed across AR application domains. Recently, AAR prototypes have been presented in museums and city-based SGs as well as for training [10, 27, 36, 46]. Within the AAR systems discussed in [50], approximately 49% incorporated "implicit" interaction characterized by the absence of user initiation. Instead, the system detects the user's surroundings and actions within the environment, subsequently providing the corresponding desired virtual sounds. Approximately 8% of AAR systems featured a mobile application or game interface, providing touch screen interactions with buttons and menus. An AAR city-based SG deployed sound as the primary interface for conveying game information to the audience based on their GPS location [10]. The significance of multimodal AR in the form of AAR is shown through electroencephalography sensors monitoring brain activity and indicating increased alertness and reduction of stress [27]. While, in some cases, the construction of a historically authentic auditory environment improved the audience's experience, the efficacy of the audio placement is limited by the reliance on GPS coordinates with an accuracy range of 3-5 meters [45].

As previous work in mobile AAR employed mostly audio augmentation without 3D content, it is challenging to combine accurate placement of both augmented spatial audio and 3D content while a participant is outdoors [50], challenging due to the GPS's low accuracy. In this work, a novel approach to improve accuracy is presented by employing 3D sound technology which was generated following comprehensive scanning of the physical environment. 3D AR anchors were placed at specific locations based on feature points, leading to a precise visual and virtual auditory content placement.

2.2 Interaction in AR & AAR in Cultural Heritage (CH)

Museums and heritage organizations seek sustainable ways to enhance audience engagement [8, 16, 37, 39, 48]. Besides AR audio guides [35, 48], 3D visualization of AR reconstructed artefacts is often included [19, 33, 38]. By means of AR markers and geo-positioning, visitors can observe 3D reconstructed buildings at designated locations [30, 49] also including customized 360-degree smell-dispensers [34]. Dependence of AR research experiences on black-and-white image markers poses challenges as they are unsuitable for outdoor usage in busy and brightly-lit city environments, when the user is in motion. AR experiences are mainly designed for indoor use [16, 30]. AR systems developed for outdoor use pose technical and location-specific challenges, such as being viewed from a specific angle and functioning under extreme levels of light and noise [33, 49]. According to a recent survey on XR experiences in CH [32], only 25 out of 380 XR Experiences provided interactivity for the users and were mostly operating indoors. The absence of user evaluations for non-experts is highlighted. In our work, we accurately place 3D visual material superimposed on the real world (accuracy<0.3m), depending on the specific POI, without image markers. The precise placement of a 3D building reconstructed to be superimposed on the actual archaeological excavation which contains limited physical structures of a past monument, allows the users to walk around the POI, not limiting them to a specific view angle.

Unlike traditional linear storytelling, where players must complete Task A to proceed to Task B, non-linear storytelling offers players active choices [12, 28]. Our work utilizes non-linear storytelling, allowing players to freely navigate to any POI. Therefore, the users can start the experience from any out of the seven POIs. The non-linear narrative is adapted based on the progress of collecting digital artefacts at each POI visited. Players do not need to gather all artefacts, proceeding at an individual pace, advancing the game play. A 2D character serves as a narrator providing historical information, helpful tips, and instructions based on their progress, actions, and performance.

2.3 Dynamic Light

As photorealism is the ultimate goal for computer graphics, mobile AR of usually low computation power, strives to achieve similar photorealistic effects [4, 17, 29, 31, 43, 44, 51]. Photorealism is achieved based on shadows and lighting simulation essential for depth perception [1–3]. High quality illumination and shadows casting in AR has been put forward [4, 6, 18, 21, 40, 51], however, past research has focused on controlled lighting of interior spaces rather than AR outdoors.

Past research has shown that human vision in the peripheral area is essential for recognizing a scene's essence [26]. Peripheral vision has a major role in environmental perception and decision making [5, 42]. Experiments in Virtual Reality have highlighted the significance of peripheral vision, somehow, diminished in on-screen viewing, especially with displays of small Field-of-View [13]. Peripheral vision gathers information about real-world lighting, color intensity and temperature of the environment, which should match the central vision's perception of the environment as the act of relating is a constitutive feature of human agency [11]. In this work, we consider the mobile AR experience occurring on a handheld mobile device's screen as central vision and the real-world surroundings as peripheral vision. Innovatively, our goal is to match the 3D content's illumination as viewed on the screen (central vision) to the day-time lighting of the real-world (peripheral vision) based on real-time weather information.

3 IMPLEMENTATION

3.1 Designing the Interactive AAR Experience

This paper introduces a multimodal AAR experience offering an engaging exploration of the city's real-world archaeological sites. We introduce non-linear storytelling guided by a character [Fig. 5a]. The main character, whose design is inspired from an ancient artifact, represents a musician who provides the audience with written narratives based on their progress. Text was selected instead of auditory narrations so that the final size of the application is reduced. A playful map is employed to guide them [Fig. 4] as

Figure 4: Playful map, featuring precise live geo-location

Figure 5: a. Storytelling by main character b. Collectable items with descriptions

audiences visit POIs to trigger immersive 3D visualizations [Fig. 1a-b] and geo-located AR reconstructions [Fig. 1c] both including spatial soundscapes. Within the reconstructed scene, environmental sounds are placed linked with ancient artefacts and designated music melodies generate an immersive spacial soundscape for the audience to explore, spatially located in the scene. Audiences can walk in AAR mode within the generated audiovisual 3D-scapes and collect recreated digital artefacts. By collecting digital artefacts, visitors learn about their significance [Fig. 5b] and can create their own spatial soundscapes using the AAR SoundScape Generator.

3.2 Music & Sound Design

The players are assigned with the task of exploring the spatial soundscape to locate the music sources of 3D artefacts. The music created is based on ancient musical instruments used during that period. The sound design is a combination of artefact properties, type of use, and environmental sounds. The artefact properties refer to the materials of each artefact and how they were used, such as the sound design of an amphora used to store olive oil while it is being moved. The environmental sound design includes sounds such as fire pits and rustling leaves. The auditory content is placed spatially within each POI scene, thus, creating a unique soundscape. The players can navigate the AAR scene by physically moving within the actual environment, with their handheld device serving as the pose driver for the spatial auditory content.

The AAR SoundScape Generator mode allows players to create their own personalized soundscape by selecting the digital CH artefacts they have collected through the main game. When entering this game mode, players are prompted by the Game Manager to select an available digital CH artefact through a user-friendly interface. The AR Manager then scans the environment for suitable surfaces and feature points to accurately place the AAR content, ensuring that both the visual and audio components are correctly positioned for an immersive and interactive experience. The use of AR technology guarantees accurate spatialized sound without any inaccuracies. As audiences approach the CH artefacts they navigate through their unique and personalized soundscape.

3.3 System Architecture

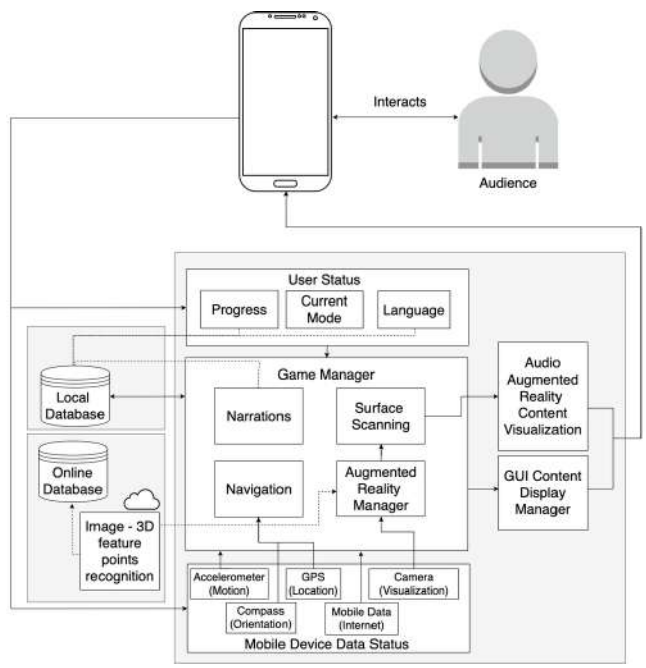

Figure 6: System architecture

The AAR experience has been developed in Unity both for Android and iOS devices with the use of the ARFoundation SDK [Fig.6]. Unity's native Audio plug-in and its Audio Spatializer was used for the spatialized sound system. The handheld mobile device is employed for pose tracking. Our system employs the Accelerometer for Motion, the Compass for Orientation, the GPS for Location, Mobile Data for Internet and the Camera for Visualization. The proposed AAR system employs a central manager, called Game Manager, which coordinates data transfer among different modules. The Game Manager is designed to handle user status data, including Progress, Current Mode, and Language. The system offers three Current Modes: Navigation Map mode, AAR visualization at POI mode, and AAR SoundScape Generator. The Game Manager will either enable the Navigation Manager or the AR Manager. The Navigation Manager utilizes compass and GPS data to guide users to desired POIs through an interactive map GUI. The AR Manager enables the AAR visualization at POI mode, which prompts users to use their device's camera and search for the desired location through a 2D image. Upon arrival at the designated location, the AR Manager initiates the 3D feature point recognition process via the network. The system accurately determines a 3D anchor point for optimal placement of the 3D model. By internally scanning the physical environment and recreating feature points, the device precisely anchors the recreated 3D model to the physical world, resulting in a seamless and immersive AAR content visualization.

To match the environmental lighting condition in a handheld mobile device without computationally expensive computer vision, we use openWeather API to get weather information clouds' coverage. Combining this information with user's geo-location for sun movement, photo realistic dynamic lighting for handheld mobile devices can be recreated, as seen in [Fig.1a,c] where ambient cold light is generated in the 3D scene based on the cloudy weather at that time. For this system to work, by-minute weather forecast is required.

4 EVALUATION

Agile development with biweekly subject testing was implemented early on in the development process. Two distinct subject groups were identified: handheld mobile device and gaming domain experts, as well as casual users with limited gaming experience. The development process followed established guidelines for AR evaluation, as presented in prior research [14, 15]. We utilized evaluation methods such as the think-aloud technique or heuristic evaluation primarily focused on assessing the usability of the system. For each new prototype, we conducted usability tests to compare a new interaction technique in terms of user efficiency and accuracy, as well as to study subject behavior and interaction during GUI design, movement through the interactive map and utilization of the AAR features, including both the main gameplay and the AAR SoundScape Generator. The analysis of each evaluation was based on observations, notes and discussions with the participants.

While experts were able to comprehend the assigned tasks without requiring assistance, casual users consistently requested help at various stages. The usability of the GUI was improved by rectifying the difficulty in reading text, implementing an instruction system and incorporating both visual and auditory feedback in response to players' actions. As different users followed varying paths within the AAR experience, the observation of these paths facilitated quality assurance.

5 CONCLUSION

Our paper introduces an novel AAR experience that utilizes cutting-edge gamification techniques, non-linear storytelling, precise AR visualization and spatial audio to promote the cultural heritage of Ancient Kydonia's CH in the bustling city of Chania, Crete. By incorporating immersive visual and virtual auditory content, our multimodal AAR experience offers a unique and exciting way for audiences to explore and interact with the city's archaeological sites and history. Our research adds to the growing body of knowledge on AAR, aimed at designing engaging interactive experiences in outdoor settings. Additional on-site evaluation of the proposed AAR experience will enhance our understanding of the potential of AAR as a tool for engaging audiences in novel and exciting ways. Future work could include a technical implementation of filtering as well as correlating auditory input to adjust the auditory output volume.

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