From Backpack to Handheld: The Recent Trajectory of Personal Location Aware Spatial Audio

Author:
Mariette, Nicholas

Publication details:
Proceedings of Perth DAC 2007 The 7th International Digital Arts and Culture Conference: The Future of Digital Media Culture.
1-74067-537-1 (ISBN)

Event details:
7th International Digital Arts and Culture Conference
Perth, Australia

Publication Date:
2007

DOI:
https://doi.org/10.26190/unsworks/763

From Backpack to Handheld: The Recent Trajectory of Personal Location Aware Spatial Audio

Nick Mariette
School of Computer Science and Engineering
University of New South Wales
Sydney, Australia
nickm@cse.unsw.edu.au

ABSTRACT

Personal location-sensitive spatial audio describes an electronic medium within the concept of *locative (audio) media*, inclusive of the physically realistic medium of *audio augmented reality*. These concepts describe both systems and the particular forms of resultant media in which a mobile user of the system receives audio content relative to their location in the world. Since the early 1990s, various projects have been created based on such ideas, and since then, advancement of the technology has taken the inevitable route of miniaturisation, integration and convergence with other mobile audio communication technologies. Early systems were implemented using backpacks or roll-around cases to hold components, while current systems tend to use hand-held computing devices. This progression has arrived at a point where the medium can come closer to fully realising its full potential, however, successful implementations now rely on perceptual optimisation and creative application of the technology.

Keywords

Audio Augmented Reality, Binaural Spatial Audio, Locative Media, Geographic Navigation Satellite Systems (GNSS), Geographic Positioning System (GPS)

1. INTRODUCTION

Personal location-sensitive spatial audio (PLASA) is a term I introduce to describe a new digital audio medium in which a mobile user receives a synthetic spatial soundscape, presented on headphones, in relation to their position in the world. The concept is essentially a form of mobile audio augmented reality (AR), as well as a specific instance of spatial audio-based *locative media*. PLASA enables the augmentation of real visible objects in an outdoors environment with sounds spatialised in two or three dimensions, so the sounds seem to emanate from the objects themselves. The user can traverse this *soundscape* by walking around in the world and turning their head to listen closer to directional sounds.

Any PLASA system requires particular components for several essential functions. First, the system requires sensors to measure the user's position and head orientation (e.g., a GPS receiver and a head-mounted digital compass). Secondly, it requires a local or remote system to render the location-specific spatial audio (e.g. a portable computer such as a handheld personal digital assistant [PDA]; or a remote server). For remote rendering, a wireless communications link must be available to transmit user position and orientation to the server and audio back to user. The final necessary component is a portable user device to output the spatial audio to headphones (e.g. a PDA or wireless headphones).

Loomis et al (1993) first conceived a basic PLASA system, the *Personal Guidance System*, intended as a navigational aid for the visually impaired "using a bulky prototype carried in a backpack" [1]. In the late 1990s, several art and engineering research projects implemented PLASA systems housed in backpacks or roll-around cases, ran on laptop computers. These included Hear&There [2] by Rozier et al (2000) at the MIT Media Lab Sociable Media Group, where users could add to a collection of location-based "audio imprints" in a campus courtyard, and Sonic Landscapes [3] by Helyer (1999-2001), a sound art project that augmented a heritage graveyard in Sydney.

More recently, advances in consumer portable computing and position-sensing technologies enable cheaper, increasingly sophisticated, compact and lightweight systems for presenting audio AR. To date, several projects have implemented locative audio on PDAs or other handheld devices, for example *Tactical Sound Garden* [4] (2004-2007), an open-source software platform that allows participants with WiFi-enabled mobile devices to "plant sounds within a positional audio environment". However, very few projects or systems have incorporated all the elements of PLASA or audio AR by including spatial audio affected by both head orientation and body position.

Static spatial audio synthesis benefits from a quite mature body of scientific research on human sound localisation for subjects seated in a room, with minimal visual stimulus. In comparison, effective PLASA presentation is informed by relatively little investigation of the perceptual effects of interaction via body position, multi-modal stimuli (with spatial audio presented in relation to real visible objects), or technological limitations such as latency and accuracy in relation to user movements. Further PLASA system advances may be possible after evaluating how user perception of system output is affected by system design choices and unique perceptual factors of the medium.

This paper discusses the recent and near-future trajectory of research in personal location-aware spatial audio systems through description of a current art/science PLASA project and associated perceptual evaluation research.

2. PLASA, AUGMENTED REALITY AND LOCATIVE AUDIO

Personal location-sensitive spatial audio describes a specific mode of presenting sonic material to a mobile individual, where content is spatialised in relation to the user's position in the world. The term PLASA is introduced to supplement the concept of audio AR presentation with other modes of spatial audio presentation that are not based on simulating physical reality. The concept of audio AR can be understood as overlaying the real visual and/or acoustic environment with a synthetic environment of sound objects positioned in relation to the real world. It is also entirely possible to present location-sensitive spatial audio that does not simulate a real possibility, for example, by simulating a swarm of abstract sounds distributed in multiple directions. PLASA encompasses both possibilities, as illustrated in Figure 1.

PLASA, in turn, can also be understood as a specialised form of *locative media* – a burgeoning term referring to the concept of presenting mobile users with electronic media relating to their location. Thus, *locative audio* is the presentation of any electronically delivered sound in relation to personal spatial context, without necessarily specifying how the sound relates to location or how it is processed. Whereas audio AR intends to simulate realistic positional sound sources using correct physical acoustical modeling, PLASA requires sound spatialisation, as opposed to other forms such as typical mono or stereo sound. While this distinction may seem trivial, the perceptual effect is potentially quite different, by affecting subconscious spatial perception, as well as higher-level cognition such as language semantics processing.

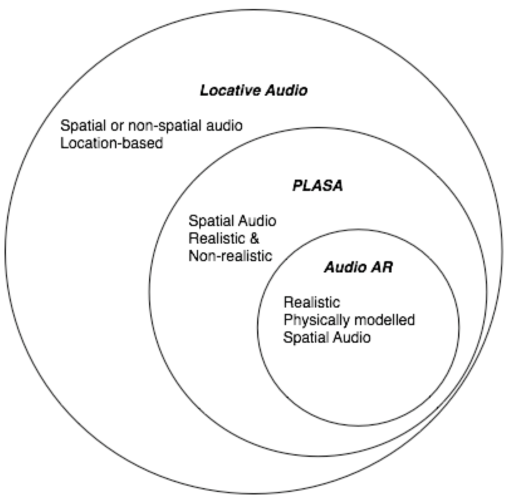

Figure 1 – categorisation of locative audio, PLASA and audio AR.

2.1 PLASA System Components

A PLASA system for outdoor use must perform a particular set of functions, listed below. Functions are performed locally on the mobile user's device, on a centralised server, or distributed among one or many mobile devices and/or servers. The basic system functionality is to present the user with binaural spatial sound via headphones, where audio content can change in relation to the user's spatial context (position and head orientation). Custom software such as that developed for Syren (a prior Audio Nomad project) [5] enables the authoring of location-based audio content. In order to provide this functionality, the following five broad capabilities must exist in the system:

1. Ability to regularly derive the current *position* of the user's head, with adequate range, accuracy and update rate;
2. Ability to regularly derive the current *orientation* of the user's head, with adequate range, accuracy and update rate;
3. Ability to regularly query the content database, using the current spatial context to extract relevant content;
4. Ability to play back the relevant audio content and render it as binaural spatial sound, correct for the user's current spatial context;
5. Finally, the rendered audio must be received and played back on headphones;

The sole capability required on the client device is the playback of rendered audio. All other system functions can be performed remotely. In practical implementations of PLASA systems, many or all functions occur locally on the mobile device, as shown in the system diagram, Figure 2.

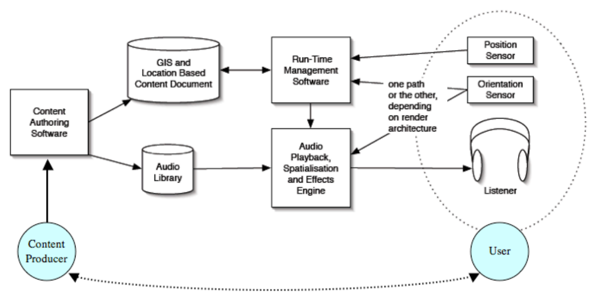

Figure 2 – PLASA system diagram, showing user-local system in dotted line, with other local or remote components.

2.2 Applications

Applications of PLASA systems include location-sensitive sound art events such as *Syren* [5], whereby individual audience members can experience a sonic re-contextualisation of a place in the world via spatial soundscape augmentation of visible landmarks. Another relevant application is self-directed spatial audio tours (for example, in cities or at important heritage sites [6]), where PLASA adds the element of virtual reality to the functionality of the familiar gallery-style audio tour device. This provides the opportunity to shift the mode of user interaction from one of manual engagement to a more natural situation driven by user position, allowing new treatment of content design as ambient information. Navigational assistance for the visually impaired [1] is another possible application (given high accuracy system components), whereby directions and other audio information about proximate points of interest could be spatialised to apparently emanate from the direction of relevant landmarks, guiding the user towards their chosen destination. Other possibilities include spatialised two-way communication systems [7], or entertainment systems including audio AR gaming [8].

3. AUDIO NOMAD

Audio Nomad is a collaboration between artist Dr. Nigel Helyer (Sonic Objects; Sonic Architecture) and the University of New South Wales: Dr. Daniel Woo of the Human Computer Interaction Lab and Prof. Chris Rizos of the Satellite Navigation and Positioning Lab. Jointly supported by the Australian Research Council and the Australia Council for the Arts, under the

"Synapse" scheme facilitating art/science collaborations, the project is a three-year research and development programme into the creative and technological potentials of location-sensitive audio. Audio Nomad is concerned with developing personal location-aware spatial audio artworks that are best classified as existing somewhere between locative media and augmented reality. Artworks produced enable users to experience a virtual audio world situated as an overlay upon the real world. Two-dimensional audio spatialisation simulates realistic sound sources, with non-spatialised sounds also used as location-based content. Conceptually, sound is used to reveal information or create a particular aesthetic, and is typically composed using a combination of oral histories, archival audio, site-specific historical information, field recordings and music.

Audio Nomad is focused on deploying two main production forms. The first is a ship-based system that presents location-sensitive spatial audio to a group audience via a multi-channel speaker array, enclosing a space that allows surrounding scenery to be viewed. Sounds are presented so they emanate from the direction of visual landmarks and regions, with volume that increases as distance decreases. Two versions of the ship-based work have been deployed: *Syren,* presented at the 2004 International Symposium on Electronic Art (ISEA) on the Baltic Sea; and *Syren for Port Jackson*, presented on Sydney Harbour in March 2006, in conjunction with the conference: New Constellations: Art, Science and Society, at the Sydney Museum of Contemporary Art. The second form presents situated spatial audio for individual mobile users, adjusting the content and spatialisation in real time according to user position and head orientation. This pedestrian system is being tested on University of New South Wales grounds as *Campus Navigator* and may be deployed as *Virtual Wall* tracing the path where the Berlin Wall once stood, through central Berlin.

For the pedestrian system, the hardware platform currently employs a handheld computer using an integrated GPS receiver, with head-mounted antenna and digital compass to determine the user's current position and orientation. *Campus Navigator* will provide an artistic location-based audio guide for the University of New South Wales campus, as an initial trial of the solution for a handheld platform. *Virtual Wall* is an audio AR artwork proposed for Berlin Mitte [9]. The project will trace the physical course of the now absent Berlin Wall through the predominantly re-built city centre with a complex location sensitive soundscape composed from a mixture of historical material (oral histories and public speeches) with fictional audio narratives, music and ambient effects.

4. PLASA SYSTEMS TRAJECTORY TO DATE

To present, many different PLASA systems have been developed, each taking their own direction forward from the prior art, leaving a winding route of technology development and many signposts towards the future of social, location-based technology on mobile networked devices. A concurrent development factor is the drive towards the use of lighter, smaller and cheaper hardware systems that will enable the emergence of innovative prototypes for future artworks and popular products alike.

The concept and term *audio augmented reality* was proposed at least as early as 1993 by Cohen et al. [10], as a static system (for a seated user) that demonstrated a synthetically spatialised telephone ring, seeming to come from a real phone, with head-tracking to enable the simulation to adjust relative to user head-turns, so as to remain stationary relative to the world reference frame. Further to the static AR concept, which requires head-orientation sensors, is the concept of mobile AR which enables the user to move their body in space, requiring position sensors to locate the user – either in a room or outdoors.

In 1993, even before the completion in early 1994 of the 24 satellite constellation for the Global Positioning System (GPS), Loomis et al. at the University of California, Santa Barbara, proposed using GPS position tracking in the *Personal Guidance System (UCSB PGS)* for the visually impaired, presenting a virtual acoustic display of sound beacons externalised within the auditory space of the traveler [1]. Audio guidance consists of text-to-speech spatialised to navigation waypoint locations retrieved from a geographic information system (GIS) database. The UCSB PGS has been continuously developed from its conception to present, with recent research focused on the effectiveness of spatial audio navigation versus other guidance modes such as spatial language. Inevitably, the physical system has also developed as new technologies became available, from the original cumbersome backpack configuration to a lighter setup of shoulder bags (Figure 3), which is representative of PLASA systems in general. Although the UCSB PGS was not conceived as an audio AR system as such, it is a good example both of PLASA and audio AR.

Figure 3 - Personal Guidance System, by Loomis et al. Left: the system in 1993; middle and right: the system in 2003 [11]

In 1994, Cohen identified GPS as an appropriate positioning technology for audio AR applications, with a design for a GPS Personal Guidance System, although no system was built [12]. At this early stage, he even made a visionary concluding statement that "further synergetic effects are obtained by eventual leverage off emerging ubiquity of telecommunication networks (more bandwidth [like high-fidelity audio]) and GIS (geographic information system) databases, accessing terrain or street data". Present day PLASA/audio-AR systems are yet to fully realise the potential of these technological synergies as relatively few system implementations have been developed. Great scope remains for future novel applications of the resultant locative (spatial) audio medium.

Around the same time in the early 1990s, not long after consumer handheld GPS receivers became available, artists began to utilise GPS in a multitude of ways. Early GPS art explored the implications of the technology and its capability to record position traces of movements in the world. For example, Fujihata's *Field Works* series (1992-1994) used GPS data to deform topological data, creating digital images such as *Impressing Velocity*, depicting an ascent and descent of Mt Fuji [13], and Kurghan produced images such as the letters “MUSEU” recorded using a handheld GPS receiver in 1995 [14].

A more pertinent example of GPS art is *Sound Mapping* by Mott & Sosnin [15] (1997), one of the earliest GPS art works using audio as the predominant feature. In *Sound Mapping*, the urban landscape is used as the foundation of a real-time musical composition responding to the GPS-tracked movements of the participants. The system consists of multiple roll-around cases, each containing a microcontroller, radio transmitter, batteries and loudspeakers, with a hub case that in addition, contains a laptop computer and GPS receiver. *Sound Mapping* can be considered as a locative audio work, but not an example of PLASA.

GPS and spatial audio projects have appeared in Helyer’s sound art pieces for several years prior to Audio Nomad. Helyer and Rizos worked together in 1999 when Helyer, as artist in residence at Lake Technology in Sydney, developed *Sonic Landscapes* – a mobile audio AR experience presented in St. Stephens graveyard in Newtown, Australia [3]. As listeners walked through the graveyard they could hear spatialised sounds emerge from landmarks in a realistic manner, for example, audio relating to the graves’ occupants. Dynamic content, such as a plane flying overhead and a ghost that followed the listener were other elements in the artwork. This was achieved using spatial audio rendering technologies developed by Lake Technology. The hardware consisted of a backpack-mounted notebook computer, a GPS with external antenna, and a head-mounted digital compass attached to stereo headphones, as shown in Figure 4.

Figure 4 - Sonic Landscapes (1999, Helyer and Lake Technology)

Hear&There is an outdoors audio augmented reality system using GPS for position tracking, developed in 2000 by the Sociable Media Group at MIT Media Lab [2] (Figure 5). Enabling users to annotate a courtyard space with “audio imprints”, subsequent users were able to discover these imprints, allowing users to participate in both generating and receiving of audio content. The *Hear&There* system is comprised of headphones, a PalmPilot (that provides a graphical user interface for mobile content authoring), a laptop computer (for spatial audio rendering), and a bulky “high-accuracy” GPS receiver and batteries, with the heavy or bulky components mounted on a luggage cart. Rozier et al. discuss the potential of the authoring system they prototyped, with sounds placed as circles on a plan of the area to be annotated. A minimal mobile authoring tool allows users to record new content in-situ, or a more extensive server-based authoring tool can be used to edit and preview content in the studio. Ideas such as these all foreshadow the potential of the PLASA medium in a present/near-future world of converged, high-bandwidth telecommunications offering innovative new social locative applications.

Figure 5 - Hear&There (2000, Rozier et al.). Left: the user system; right: software interface screenshot, showing sound placements.

A Walk in the Wired Woods is an interactive art installation by Hewlett-Packard Labs in Bristol [16], in which a photographic exhibition of woodland views was augmented with location-sensitive music, narration and field recording elements presented on headphones (Figure 6). While the sound was only stereo, interaction was via body position and head orientation. Lower requirements of stereo playback, rather than spatial audio, enabled the physical size of the system hardware to be reduced to a small shoulder bag containing a wireless networked PocketPC handheld computer. This device interfaced with an externally installed location-sensing infrastructure, which calculated and logged the user’s position and played back audio fetched from the remote servers. The gallery installation received several hundred visitors, most of whom reported having a positive, immersive experience. According to user surveys, they often considered their experience to be greater than the sum of the aural and visual components alone.

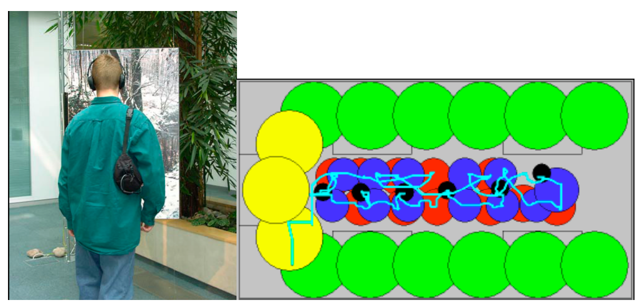

Figure 6 - A Walk in the Wired Woods (2002, Hull et al.). Left: the user system; right: audio content circles and a trace of one user’s path.

AudioGPS [17] (Figure 7) is another laptop and GPS, backpack-based PLASA system, “designed to allow mobile computer users to carry out a location task while their eyes, hands or attention are otherwise engaged”. Innovations of this system include alternative representations of spatial information relating to direction and distance, supplementing audio spatialization. For example, different musical tones and timbres were used for directions, and regularity of pulses (like a Geiger counter), were used to represent distance. Preliminary tests showed that GPS was not responsive enough to cope with rapid direction changes (under 10 seconds in frequency), and confirmed that users could discern directions to an angular resolution of an eighth of a circle. The fact that *AudioGPS* used additional, non-spatial sonification of navigation information suggests that audio spatialisation alone may not impart clear, precise spatial information, and contributes to evidence that the PLASA medium could benefit from further perceptual evaluation and optimisation.

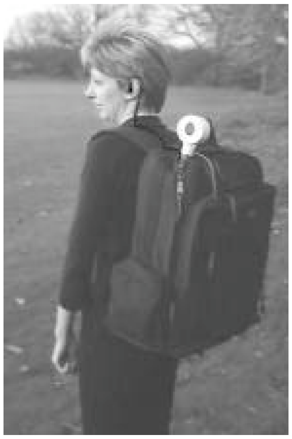

Figure 7 - AudioGPS (Holland et al., 2002).

LISTEN (2001-2003) is an interdisciplinary multi-institutional audio AR project, probably the most sophisticated of its kind to date. Using remote server-based spatial audio rendering, radio frequency positioning with decimetre accuracy and user devices consisting of only wireless headphones and tracking transmitters [18], it was deployed in several public installations including two art gallery exhibitions and a commercial motor show (see Figure 8). One paper describes possible "perceptual devices" (strategies) for creating coherence between visual and aural content using semantic, spatial and temporal relationships [19]. This alludes to the effective communicative and creative potential of the PLASA medium especially with such high-resolution spatial interactive control. In this case, the synthetic spatial audio might be so well controlled as to react like a pliable, three-dimensional, sculptural form of sonic material, if only the authoring system allowed for equally accurate and sophisticated specification of how the sound might shift at each possible position and orientation of the user's head. It is not difficult to imagine many future implementation possibilities in interactive spatial sound or music composition for such an accurate medium.

Figure 8 - LISTEN (2000-2003, Eckel et al.). Left: the user system; right: a trace of a user's path through a gallery application.

In addition to the previously mentioned projects, numerous others have implemented a variety of position-based personal audio systems, though often without the full range of features, namely outdoor, mobile, audio-only (non-visual) AR, with complete interaction via both position and head orientation. Other works of note are pedestrian, locative audio artworks implemented by Perry et al. in *Invisible Ideas* [20] (2002), and Knowlton et al in *34 North, 118 West* [21] (2002). *Invisible Ideas* is a collaborative, site-specific, non-spatialised audio-visual work set in the Boston Public Garden and runs on a GPS-equipped Pocket PC handheld computer. *34 North, 118 West* uses site-specific, non-spatialised audio presented in the streets of Los Angeles, telling a story about the history of the local railroad network. Another outdoors PLASA project is *Tactical Sound Garden*, which was installed at the 2006 International Symposium on Electronic Arts, San Jose [22], and uses GPS and relative position, but without head-turn interaction. These innovative artworks utilise the most portable practical hardware of their time, and generally place more focus on application than on precision of spatial audio and user movement interaction. This approach positions them closer to the locative audio end of the PLASA spectrum than to audio AR.

Throughout the reviewed projects and research several themes emerge. The first theme is the inevitable shrinking of technology – akin to the iPod's trajectory to the present Shuffle model, barely large enough to house its own physical interface – yet no doubt with ever-expanding technological specifications such as storage space. Other themes include the impressive and relatively unrealised potential for innovative applications for spatially interactive, perceptually optimal, synthetic two-dimensional or three-dimensional sound. In addition, the potential for networked, social applications of this technology. Perhaps most importantly, these projects suggest the value of spatial audio over plain mono or stereo, allowing the sonic medium to impart information not only semantically or aesthetically, but directly through spatial perception, thus employing increased perceptual bandwidth, enabling greater performance for applications such as navigation. At this point in the emergence of the PLASA medium, an important step to be considered is the perceptual optimisation through subjective evaluation.

5. PRESENT PLASA, LIMITATIONS AND PERCEPTUAL EVALUATION

Within the Audio Nomad project, the author's present research is focused on evaluating the perception of spatial audio in the augmented reality situation, particularly where the user is mobile, outdoors, and interacting with the sound by body position as well as head orientation. In some cases, this includes real visual stimuli intended to coincide with the synthetic spatial audio stimuli. A series of experiments have been undertaken to study differences between spatial audio perception of this new PLASA/audio-AR medium, and static spatial audio, which is already well supported by significant studies in prior laboratory-based perceptual experiments.

In all experiments, the hardware system used is one capable of running a powerful, full-fledged PLASA system, although it should be noted that software for each experiment is custom built for the specific purpose of implementation and control of the experiment. The first experiment in the series validated a novel, outdoors experimental methodology that required participants to walk and align auditory images from synthetic stimuli with real visible objects [23]. The second experiment studied the mitigation by body-interaction of a particular spatial localisation problem known as front-back confusions, whereby the listener incorrectly perceives the location of a spatialised sound to be behind them when it should be in-front (or vice-versa). Current experiments address further advantages and unique factors of perceiving synthetic spatialised audio by outdoors interaction via body position and head orientation, in an environment of multi-sensory stimuli.

For each experiment, participants wore and carried a system comprised of: a set of headphones, a position-tracking system mounted at the centre back of the waist and a portable computer running custom experiment software displaying a graphical user interface (Figure 9). The main purpose of the software was to render sound stimuli in real-time, while logging participants' positions and responses.

The positioning system, a Honeywell DRM-III [24], combines an inertial navigation system (INS), a GPS receiver, pedometer, digital compass and barometric altimeter – where each can be individually activated/deactivated – with optional Kalman filtering and a serial RS232 interface. Stated INS position accuracy is 2-5% of distance traveled and the digital compass is accurate to within one degree.

Other equipment included Sennheiser HD485 headphones (an economical, open backed, circumaural design) and a Sony Vaio VGN-U71 touch-screen handheld computer with a Pentium M processor, running Windows XP Service Pack 2. The DRM-III interfaced to the Vaio with a Keyspan USB-Serial interface. Current experiments including head-orientation add a serial-interfaced Intersense InertiaCube-3 tracker mounted on the headphone band.

Figure 9 – The author's system for perceptual experiments of audio AR. Left: participant in motion during a test; right: the position tracker device clipped on the participant's belt.

These experiments also seek to understand how various limitations of PLASA/audio-AR systems affect the afforded perceptual quality of the system. Technological system limitations include the need to make the user device portable, lightweight, affordable and self-contained, which in turn limits computation power and spatial audio rendering quality. As a result, the user perceives sound locations with reduced directional accuracy, there is a greater incidence of front-back confusions as well as externalisation errors – where the sound seems to originate inside the user's head, rather than outside at the intended distance.

Other technological limitations are user position/orientation sensor accuracy and latency (time) before this data affects the spatial audio output. Accuracy contributes to sound source position and direction errors relative to the user; latency has a more complex effect, leading to increased localisation errors for brief sounds or slower localisation for longer sounds [25].

Human limitations include inevitable issues with *generalised* binaural spatial audio synthesis (for headphones), which works by filtering sound using *non-individual* models or measurements of the external ears. For most applications, including Audio Nomad, models/measurements specific to each individual user are impossible, so a generalised measurement tends to be used. Unfortunately, generalised synthesis leads to the same localisation errors as those described above, caused by limiting rendering quality [26]. Other limitations come from *psychoacoustic* phenomena, for example, the effect of visual stimuli co-present with aural stimuli has been identified to produce the "ventriloquist effect" [27], where the visual biases the auditory image – this could be either advantageous or detrimental, given different situations. Another human factor is interaction by self-motion: perception/action coupling, which has complex effects. Listener motion with inaccurate distance perception can make static sounds seem to move, or can cause false perception of moving sound trajectories [28].

6. FUTURE PLASA

Various potential capabilities of future PLASA systems and the medium itself have already been indicated by many of the projects reviewed earlier in this paper. The overall theme of the shrinking and convergence of supporting technologies, particularly in relation to the required hardware, will prevail. Other themes including social capabilities (such as user-generated content), networked systems (for example, streaming audio from a remote server) and high resolution tracking plus spatial audio rendering capability will enable a fluid, architectonic spatial sound medium. In addition, perceptually optimal systems informed by subjective evaluation of the unique factors of multimodal, positional interaction with spatial audio will increase in importance.

An indication of future hardware platforms is now visible with the many current or impending products that incorporate partial or complete capabilities providing mass-market support for innovative new PLASA applications. Witness Apple's powerful multi-network capable iPhone, running an embedded personal computing operating system or recently released Nokia GPS-equipped phones. Witness the USA's Enhanced 911 (E911) emergency services phone number ruling that requires mobile phones to be capable of locating themselves within a 100m radius: it could be imagined that incorporation of a significantly more accurate GPS receiver would enable other location-based services. Witness wearable products such as the Nike/iPod collaboration that incorporates (not-quite) locative interaction between your running shoe and portable music player. Even the humble 3rd Generation (3G) mobile phone standard enables high-speed data connections that could potentially stream hi-fi spatial audio from a server. The list goes on with seemingly endless new devices converging mobile, wireless-networked computing platforms with a degree of location-finding capability.

Notable research projects are also emerging, heralding the potential breadth of PLASA enabled applications. Layla et al's Mobile Music Technology workshops [29], for example, extend Tanaka's Malleable Mobile Music [30] describing the concept of mobile music making based on mobile, wirelessly networked, social technology, that takes music-making "beyond portability". This can potentially be achieved by enabling "location [to] become a sensor input to music making". Such a concept easily extends from the suggested mobile, "social remixing" of music one step further, to become *locative*, social remixing of *spatialised* sound that not only relates to place, but more importantly embodies a new (augmented audio reality) place. Yet another example, Vawter's *Ambient Addition* [31], is a novel device similar to a standard portable music player, that remixes immediate environmental sounds, captured via onboard microphones, generating music from the (captured) surrounding noises. This work tends to suggest a potential future form and purpose for the PLASA medium, where portable music devices remix your music (or your friends' compositions) according to your location, but independent of time. The result being your personal ambient addition might be available for replay by others after the original source (environmental) sounds have disappeared.

7. CONCLUSION

Presently, the necessary technologies for personal location aware spatial audio (PLASA) and mobile audio AR systems are rapidly improving in speed, affordability, size and weight, while concurrently, an increasing number of systems are being implemented. These systems have advanced in the last decade from backpack-sized to handheld implementations, with further improvement soon to be based on perceptual evaluation of unique factors of the new PLASA medium. One present technical objective should be optimisation of the perceptual performance afforded by the system design and available, practical component specifications. It is envisaged that considerable scope exists for the creative application and increased perceptual quality of spatial audio afforded by evaluation research and advancing technology, particularly when high-resolution positioning is available. The state of the art is approaching a new convergence with concepts from social applications (developed in other product areas), such as user-created content and social remix capabilities. Advancement is also occurring with emerging locative media applications and general advances in mobile phone technology. In essence, the future of the PLASA medium as an intersection between spatial audio and general locative and social media is ever expansive.

8. ACKNOWLEDGMENTS

This research took place in conjunction with the Audio Nomad project, lead by Dr. Daniel Woo, Dr. Nigel Helyer and Prof. Chris Rizos, supported by an Australian Research Council Linkage Project (LP0348394) in conjunction with the Australia Council for the Arts as part of the Synapse Initiative.

9. REFERENCES

[1] Loomis, J.M. "*Personal Guidance System for the Visually Impaired using GPS, GIS, and VR Technologies.*" in *VR Conference*. 1993. California State University, Northridge.

[2] Rozier, J., K. Karahalios, and J. Donath. "*Hear & There: An Augmented Reality System of Linked Audio.*" in *ICAD 2000, Atlanta, Georgia, April 2000.* 2000.

[3] Helyer, N., *Sonic Landscapes*. 1999-2001: Sydney, Australia.

[4] Shepard, M. (2004-2006) *Tactical Sound Garden [TSG] Toolkit*. 4

[5] Woo, D., et al., "*Syren - A Ship Based Location-Aware Audio Experience,*" Journal of global positioning systems. Int. Assoc. of Chinese Professionals in GPS, 2005. 4(1-2): p. 41-47.

[6] Node. *Node | World Leader in Location Based Media*. [cited 2007 12 February 2007]; Available from: http://www.nodeexplore.com/.

[7] Kan, A., et al., *Mobile Spatial Audio Communication System* in *Tenth Meeting of the International Conference on Auditory Display*. 2004: Sydney, Australia.

[8] Röber, N. and M. Masuch, *Leaving The Screen. New Perspectives In Audio-Only Gaming* in *Eleventh Meeting of the International Conference on Auditory Display*. 2005: Limerick, Ireland.

[9] Helyer, N., D. Woo, and C. Rizos. *Virtual Wall*. 2006 [cited 18th October 2006]; Available from: http://www.audionomad.com/projects/vwall.phtml.

[10] Cohen, M., S. Aoki, and N. Koizumi. "*Augmented Audio Reality: Telepresence/AR Hybrid Acoustic Environments.*" in *IEEE International Workshop on Robot and Human Communication*. 1993.

[11] Loomis, J. *UCSB Personal Guidance System*. 2006 [cited 2007 4 March]; Available from: http://www.geog.ucsb.edu/pgs/multimedia.htm.

[12] Cohen, M. "*Augmented Audio Reality: Design for a Spatial Sound GPS PGS.*" in *Center on Disabilities Virtual Reality Conference*. 1994. California State University, Northridge

[13] Fujihata, M., *Field-Works Projects*. 1992.

[14] Kurgan, L., *You Are Here: Museu*. 1995.

[15] Mott, I. and J. Sosnin. "*Sound Mapping: an assertion of place.*" in *Interface*. 1997.

[16] Hull, R., J. Reid, and A. Kidd, *Experience Design in Ubiquitous Computing*. 2002, Client and Media Systems Laboratory, HP Laboratories Bristol: Bristol.

[17] Holland, S., D.R. Morse, and H. Gedenryd, "*AudioGPS: spatial audio in a minimal attention interface,*" Personal and Ubiquitous Computing, 2002. Volume 6(Issue 4): p. 253 - 259.

[18] Eckel, G. "*Immersive Audio-Augmented Environments - The LISTEN Project.*" in *5th Int. Conf. on Information Visualization (IV2001)*. 2001. Los Alamitos, CA, USA.

[19] Goßmann, J. "*Connecting Virtual Sound and Physical Space in Audio-Augmented Environments.*" in *10th Int. Conf. on Auditory Display*. 2004. Sydney, Australia.

[20] Perry, B. (2002) *The Invisible Ideas Project: Using Mobile Devices, Macromedia Flash, and Global Positioning Systems*.

[21] Knowlton, J., N. Spellman, and J. Hight, *34 North, 118 West*. 2002: Los Angeles.

[22] Shepard, M. (2004) *Tactical Sound Garden [TSG] Toolkit*. 4

[23] Mariette, N. "*A Novel Sound Localization Experiment for Mobile Audio Augmented Reality Applications.*" in *16th International Conference on Artificial Reality and Tele-existence*. 2006. Hangzhou, China: Springer, Berlin/Heidelberg.

[24] Point Research, *DRM-III OEM Dead Reckoning Module for Personnel Positioning*. 2002: Fountain Valley, California.

[25] Brungart, D.S., et al. "*The Interaction Between Head-Tracker Latency, Source Duration, And Response Time In The Localization Of Virtual Sound Sources.*" in *Int. Conf. on Auditory Display*. 2004. Sydney, Australia.

[26] Møller, H., et al., "*Binaural Technique: Do We Need Individual Recordings?,*" Journal of the Audio Engineering Society, 1996. 44(6): p. 451-469.

[27] Choe, C.S., et al., "*The "ventriloquist effect": Visual dominance or response bias?,*" Perception and Psychophysics, 1975. 18: p. 18, 55-60.

[28] Loomis, J.M., *Some Research Issues In Spatial Hearing*, in *IEEE Workshop, Applications of Signal Processing to Audio and Acoustics*. 1995: New Paltz, NY, USA.

[29] Gaye, L., et al., *Mobile music technology: report on an emerging community*, in *Proceedings of the 2006 conference on*

New interfaces for musical expression. 2006, IRCAM Centre Pompidou: Paris, France.
[30] Tanaka, A., *Malleable Mobile Music*, in *The Sixth International Conference on Ubiquitous Computing*. 2004: Nottingham, England.
[31] Vawter, N., *Ambient Addition: How to Turn Urban Noise Into Music*, in *Program in Media Arts and Sciences*. 2006, Massachusetts Institute of Technology: Massachusetts.