Urban Exploration Using Audio Scents

Andreas Komninos, Peter Barrie
Glasgow Caledonian University
70 Cowcaddens Rd., Glasgow G4 0BA, UK
[andreas.komninos, peter.barrie]@gcu.ac.uk

Vasilios Stefanis, Athanasios Plessas
University of Patras / RACTI
Rion, Patras, Greece
[stefanis, plessas]@ceid.upatras.gr

ABSTRACT
We describe the design and evaluation of an audio-based mixed reality navigation system that uses the concept of *audio scents* for the implicit guidance of tourists and visitors of urban areas, as an alternative to turn-by-turn guidance systems. A field trial of our prototype uncovers great potential for this type of implicit navigation and is received positively by our participants. We discuss the technical implementation of our prototype, detailed findings from quantitative and subjective evaluation data gathered during the field trial and highlight possible strands for further research and development.

Author Keywords
Audio mixed reality, implicit navigation, urban environments

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous. H.5.2 User Interfaces - Auditory (non-speech) feedback and User-centered design. H.5.5 Sound and Music Computing - systems

General Terms
Design, Experimentation, Human Factors,

INTRODUCTION
Turn-by-turn (TbT) GPS navigation for pedestrians is a technology that many tourists have found to be a valuable aid for navigating unfamiliar urban environments. However the experience of tourism is not just about getting from A to B. Assimilation of the surroundings, sights, sounds and smells is a critical factor in the visit experience. When attention is shifted away from the surroundings (e.g. through close following of turn-by-turn instructions or through constant consultation of a mobile screen), the visitor experience suffers greatly. Krüger et al [1] and Aslan et al. [2] found that turn-by-turn systems often fail to help users assimilate and form an impression of the navigated environment. Seager [3] also discusses many of the challenges in screen-based pedestrian navigation, while Pielot & Boll [4] found that users often feel "bossed around" by the explicit commands issued by TbT systems.

Since visual distraction is the most detrimental factor in a user's visiting experience, researchers have attempted to examine solutions using other interaction modes, such as audio and haptic feedback. Jones et al. [5] and Strachan et al. [6, 7] examined systems that dynamically adapt the music that a user is listening to, in order to guide them in a certain direction, by controlling the left and right audio channel volume. Route finding applications, such as the AudioGPS system [8], Mediascapes [9], Audio Bubbles [10] and Soundcrumbs [11], have used abstract sounds as an auditory beacon to support navigation tasks and guide users to points of interest. These beacons alert users of their proximity to a location of interest through a brief repeating sound such as an Earcon (a structured non-verbal audio message, e.g. a trumpet sound to indicate the discovery of a location), or an Auditory Icon (a familiar sound mapped onto an event to which it clearly relates e.g. water noises to indicate the presence of a river). Auditory beacons are generally presented within proximity and activation zones around the landmarks.

Other applications like the Roaring Navigator [12] estimated the position and orientation of the listener's head by means of a GPS receiver and magnetometer and also used stereo panning to indicate the direction of a navigational goal, i.e. animal sounds, located at the various enclosures in a zoo in both a navigational and an exploratory scenario. Vazquez-Alvarez et al. [13] examined the use of Earcons as auditory landmarks and 3D audio spatialisation, aiming to test the user experience of unguided exploration of an environment populated with multiple simultaneous sound sources. They showed that spatial audio together with Earcons allowed users to explore multiple simultaneous sources and had the added benefit of increasing the level of immersion in the experience. In addition, spatial audio encouraged a more exploratory and playful response to the environment. While these approaches have shown promise, related early work has found that many users are reluctant to use headphones for this type of task [14], citing concerns about being recognised as tourists, or a feeling of isolation from the environment [12]. Additionally, Harma et al. [15] show that 3D audio spatialisation suffers from users' lack of

MobileHCI'12, September 21–24, 2012, San Francisco, CA, USA.

ability to clearly distinguish between front and rear sound placement.

Robinson et al. [16] discussed the concept of navigation by removing turn-by-turn instructions, so as to prompt users to explore, rather than hurry through their surroundings. Their approach helps to minimise the effects of strict TbT audio feedback, using vibrotactile feedback to allow a less restrictive interaction style, in which users point their device towards their navigation goal and appropriate feedback is given through vibration-encoded information from their mobile. A similar concept is also discussed in [17], using multiple track points to guide users using a mobile device, while significant advantages in using a non-visual vibrotactile belt interface for navigation were found in [4].

Further from the aspect of navigation, mobile location-based audio offers excellent opportunities to deliver guided tours, or information relevant to sights for tourists. The Hear & There system [18] was able to determine the location and head position of the user using the information from GPS and a digital compass. This system used "customizable collections of sounds that could be placed in the space" consisting of "a single primary sound, with other audio braided in the periphery". In [19], Reid et al. describe the use of location-based audio in order to provide a mixed reality experience in the form of a play, which is acted out as the user walks through the streets of Bristol. The system was implemented with the use of a PDA with a GPS receiver so that audio could be triggered at appropriate locations, and the user was required to wear headphones. The experience could also be shared with a companion, through the use of headphone splitters. The experience was found to be compelling and immersive for users, though immersion was found to be a transitive state and often delivered in short bursts, due to the continuous interleaving of real and virtual world events. Rowland also recorded positive user experience outcomes from delivering location-based stories to cyclists [20].

The findings of research in mobile aids to assist pedestrian navigation and exploration can be summarised as follows:

- TbT systems deliver performance and security in navigation, but at the detriment of the overall visitor experience.
- Earcons and 3D spatialisation can perform well for navigation but front/back sound placement is not clear to users
- Location-based delivery of audio narratives can provide a very immersive experience
- Users express issues and worries over headphone usage in respect of safety implications and isolation from fellow travellers
- Research has focused on the individual user, with little consideration for the support of tourist groups

FOLLOWING THE TRAILS OF AUDIO SCENTS

To escape the "tyranny" of turn-by-turn navigation, we considered the concept of audio scent trails to encourage exploration in an urban environment while giving a sense of direction and security. Much like a trail of scent that can be picked up by an animal with enhanced olfactory perception, an audio scent is a trail generated artificially by a navigation system that augments a user's perceptive experience with *continuous* (compared to *discrete*) cues for navigating through the environment. Just as the animal following a scent trail is free to explore different directions of travel in order to pick up the scent and able to return to previous locations where the scent was stronger, a pedestrian following an audio scent is encouraged to explore their surroundings in order to figure out where the audio scent is stronger. However, in contrast to the goal-driven animal, for our pedestrian the exploratory experience *is* the goal. The freedom to roam about, albeit within the confines of the safety zone within which users can pick up the audio scent, is the distinguishing feature of our concept and its main advantage in improving a visitor's experience in exploring an urban environment. To illustrate the concept by example, one might split the reviewed literature in three main categories:

1. Navigation systems such as [4-7] and [16,17] appropriate for the type of tourist that simply wants to go from A to B without obeying specific verbal commands,
2. Exploratory systems such as [10-13] appropriate for a tourist that wants to just "roam about" without a clear navigation goal and
3. Audio mixed reality experience systems such as [18-20] appropriate for the delivery of meta-information about an environment without navigation support as a goal.

Our audio scent concept sits somewhere between categories 1 and 2. Our user is a tourist that would like to go from A to B, but is not in a hurry and does not want to just take the shortest route. They want to head towards B and explore along the way until they eventually get to their destination.

The SoNav prototype

We developed a prototype system called SoNav, which can become a promising platform for addressing the issues identified by the preceding survey of the state of the art. SoNav uses 3D spatialised audio on a mobile device to deliver feedback about a user's position compared to a pre-determined path. Our prototype is built on the Android platform and requires a device with a GPS and magnetic compass sensor. Internet connectivity is desirable, as it allows the UI to display local maps (Fig. 1) and dynamically compute a route between any chosen start and end points, but is non-essential - as will be shown below.

The mode of operation is as follows: The user selects a start and end point from a map-interface on their device. A path between selected points is calculated using the Google directions service and is drawn on the map (Fig. 2). Alternatively, a user can load a pre-defined path stored locally on the device. The waypoints of each path are drawn as small orange blobs. Each path is thus divided into appropriate segments, which are later used to determine user distance and azimuth to the path. The user then puts on their headphones, places the phone in their pocket and starts to walk toward their destination and along that path.

As discussed previously, to materialize our concept of an audio scent emanating from the path, we use the following approach: A thread of execution plays back a constant sound (the audio scent) through the user's headphones, which can be music or a looping Auditory icon. At the moment, we use the sound of a couple of people walking in a city environment, which gives a deeply immersive experience, as if the user is walking with a virtual group. This thread utilizes a port of the OpenAL 3D audio library for Android and thus has the ability to control the sound source distance and orientation during playback. A second thread of execution is responsible for updating the user's current position using the device location sensors (A/GPS). A final thread monitors the user's current orientation (magnetic compass).

Figure 1 The SoNav user interface and basic options menu

At every orientation update, we calculate the distance of the user to the nearest segment of the path and also the relative azimuth of the user to that of the nearest path segment, using the magnetic north as reference. This information is then passed to the audio player thread, which is responsible for changing the sound source orientation in such a manner so it would seem to the user that the sound is emanating from the direction of the nearest path segment.

As the user places themselves at different angles to the left or right of the path, the sound shifts in 3D around them to indicate the relative position of the path. Additionally, the further away the user is from the path, the lower the sound volume becomes, giving a sense of moving far away from the path, or, in the case of our prototype, to convey a sense of having veered away from the path. Additionally, multiple sound sources can be placed within the soundscape, to act as virtual sound beacons, perhaps marking the location and direction of a point of interest, or the end point of a route.

Technically, the main differences between the audio scent concept and other exploratory or navigation systems which are based on audio beacons (e.g. [9-13]) is that in lieu of having fixed audio beacons at certain positions, our user experiences a moving beacon (placed on the optimal route). The user does essentially have to travel towards the beacon. As long as they hear it at a constant level from some direction, they are effectively travelling in parallel to it. Hence they can explore by taking alternative routes, without pressure to move towards a certain direction.

To better demonstrate our concept, consider the following simple use case: Our pedestrian is placed away from the path in the position marked by the blue marker in Figure 3 and pointing towards the north-west (as indicated by the pointed end of the marker). In this position, the path is to the user's right at approximately 45 degrees, and as such, the audio balance is shifted mostly (but not fully) towards the right headphone. The user understands that the path they should follow is somewhere to their right, so at the next junction, they take a right turn. As they turn, the sound starts to shift towards their left ear. Given the fact they are now closer to the path, the sound volume becomes higher, indicating their increasing proximity. As the user reaches the position marked by the orange marker, the path is directly to their left, hence the sound shifts to play exclusively in their left headphone.

The user keeps walking until they finally reach the path, in which case the sound equalizes on both ears, as they stand directly on top of the path (actually we do allow a certain radius to account for street and pavement width for this change). Now the user has a choice, whether to turn left or right. Turning left will keep them on the path. A further right turn will gradually take them further away from the path. The sound source will now be behind the user and the sound volume will attenuate as the user walks increasingly further from the path, indicating that they have taken a wrong turn. One might ask, what would have happened if the user had not turned right at the junction after the blue marker but continued straight ahead? This is precisely the point - SoNav leaves the user free to explore an area as they desire, with constant and reassuring feedback given to them at all times, as long as they remain within a certain distance from the path. There is no right or wrong path to follow. The feedback is continuous and there is no need to wait for a turn-by-turn system to recalculate or to issue the next command, which could well not be issued for several hundred meters from the previous one (e.g. walking in a straight line).

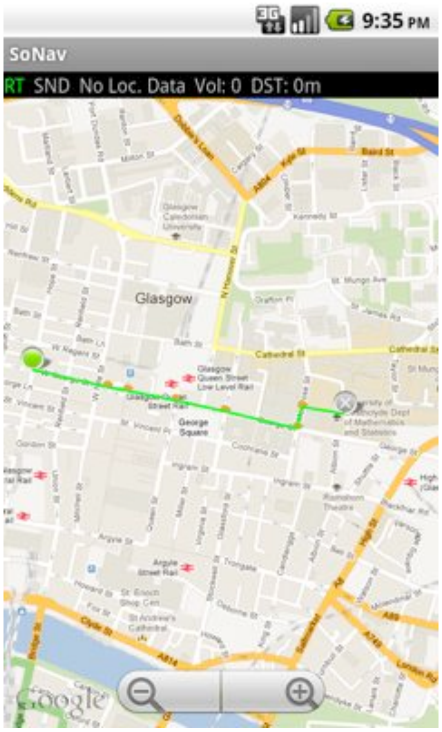


Figure 2 A user has selected a random start (green bubble) and end (grey bubble) point. The route drawn in green is retrieved using the Google directions API

This means that the user can place their focus on the environment without a need to constantly check a screen or interact with the device for instructions. The user can also choose to wear their headphones occasionally, so as to better focus on the environment or interact with their group. Finally, because we use organic city sounds with intermittent volume peaks (e.g. the sound of a walking person's heels) and let external sounds filter through, the user is at much less of a danger while navigating than they would be with a constant isolating sound like music.

USER TRIALS

We were keen to explore the effect of SoNav with real participants, and designed an experiment to navigate an urban environment. We felt that it was important that we carry out our experiment in a realistic environment. Most literature reports on experiments in relatively quiet and safe areas, such as parks, university campuses or quiet parts of town. Since our system is geared towards exploring urban environments, we felt that an experiment in any other setting would detract from our findings. However, using actual tourists for an experiment in a busy urban setting would have been dangerous. We did not want to follow them so as not to interfere with their behaviour; at the same time, we could not afford to have participants getting lost or straying too far from the experiment area. A further factor to consider was that the experiment was carried out in a right-hand driving country, a system which many overseas tourists would be unfamiliar with and would thus require additional attention on the road from them.

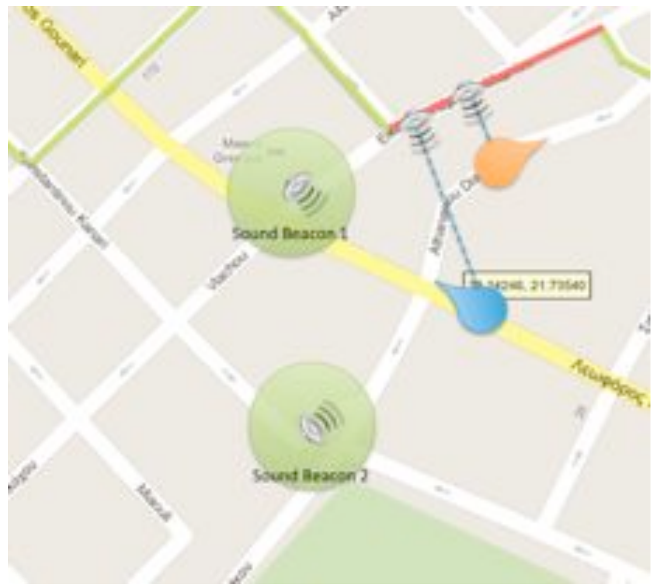


Figure 3. A simplified visualisation of the audio scent principle, auxiliary beacons and their corresponding range

Bearing in mind the safety of participants, we decided to conduct an experiment whereby the participants would be reasonably familiar with the experiment area. To simulate the effect of being a tourist and thus generally unsure of where to go, we asked our participants to navigate to a destination which remained unknown to them for the duration of the experiment. As such, they would be forced to explore the area, in order to discover the actual destination. We recruited a total of 16 participants (15 male, 1 female) with an age range between 18 and 35 (one user being older than 40). Two participants were members of staff in our university in the areas of Audio and Interactive Media while the rest were postgraduate and undergraduate students with varied discipline backgrounds (Computing, Business, Engineering). Most of the participants (9) had made use of a GPS turn-by-turn system in the past while the rest had experienced and understood the function of such systems (e.g. as passengers in cars with such systems in operation), although they had never used one themselves.

Figure 4. The experiment route, starting at a busy railway station and ending at a popular visitor attraction. The shaded area shows the audio scent coverage. The red shaded area shows the coverage of the target audio beacon.

We chose a route for our experiment that was reasonably varied in direction in order to present several decision points for our participants (Fig. 4). The route of our experiment began at the entrance of a busy railway station, right at the heart of the city. In contrast, the end point was a relatively quiet part of town as shown in Fig. 6. This allowed us to explore user behaviour in areas with both heavy traffic and low traffic density. The route was also quite rich in shortcuts that participants could take, including a square and three pedestrian pathways, in order to maximize the possible variability of the routes. Our participants were briefed about the system and its general mode of operation and were informed of the general direction of their destination (just as a local would tend to point a tourist towards the general direction of a destination). We told participants that their route was approximately 5 minutes away by foot if they knew exactly where to go and to take as much time as they liked with their exploration. We also told them to come back to the starting point if they started to feel lost or if they felt the experiment was taking too long.

Each participant was given a mobile device with the route pre-loaded and a pair of in-ear headphones. The device was hung around the participants' neck and kept relatively still by tucking the device into the participants' jackets (Fig. 8). This ensured that the device orientation would remain parallel to the users' body throughout the experiment and thus provide consistent orientation information.

Figure 5. The starting point of our experiment simulated a tourist's arrival at a busy railway station whose entrance is in a noisy heavy traffic area

Figure 6. The end point of the experiment route was in a quiet part of the city and represented a popular visitor attraction

.

Configuration of the prototype

The prototype was configured to produce sound at a radius of 160m from any path segment. We chose this radius as being roughly equivalent to the size of two blocks in the city where the experiment was carried out. Additionally, we set up a "buffer zone" of 12m (typical width of a city street and pavements) around the path where the orientation of the sound was disabled. This was in order to prevent erratic sound shifts as the path runs through the middle of the street and it is not reasonable to provide a directional cue when the participant is on either pavement beside the path. Additionally, we set up a sound beacon at the target at a range of 80m (one average block). The audio scent used for the path was a recording of a woman walking in heels, in an urban environment (Fig. 7). The sound clip contained organic urban sound artefacts in the background, such as the sound of cars driving by or pedestrian random chatter. This sound clip was selected primarily for two reasons. First, the background artefacts were low in volume, and the walking heels sound is effectively represented by short duration volume spikes. This allows external sound to filter through the headphones, even if these are of the in-ear type. This makes the experience both more realistic (enhancing the mixed reality immersion) and safer for the user as they can still hear sounds such as oncoming traffic.

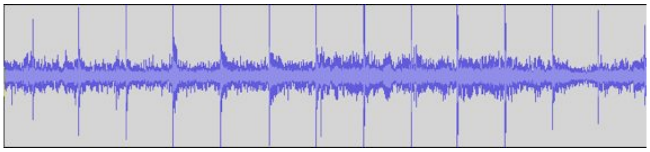


Figure 7. The audio clip used to represent the audio scent. The sound of walking heels (spikes) is clearly distinguishable from the constant background noise (organic urban sounds). This choice gives constant feedback while allowing external sound to filter through, enhancing the mixing of reality.

The target audio beacon was represented by a simple looping music clip, to create the sense that one is arriving a point of interest (just as one can hear the muffled music when heading towards a bar that they intend to go to).

Figure 8. The equipment worn by participants. It consists of an Acer Liquid Metal Android device with integrated GPS & magnetic compass, a soft fabric case, neck strap and in-ear Sony headphones.

We were keen to obtain both qualitative and quantitative data from our users. At the end of the experiment, we asked the participants to fill in a short questionnaire with several limited-option questions and a final open-ended comments box at the end. Our prototype applications also recorded the GPS location of the users during the trial, their speed, bearing, location provider (GPS/Network) and time. In this paper we present an analysis of the GPS location.

FINDINGS

User exploratory behaviour

We used Seth Golub's heat map generator[1] to plot the GPS traces recorded during our experiment. As can be seen from the heat maps produced by the logging of GPS data, the users stayed reasonably close to the route preloaded into the system. In most cases, the participants remained within the zone of the audio scent, with the exception of one person who clearly went outside the zone, realized they were not hearing any sound and return soon after (right side of Figure 9). We note that our users, as a group, explored most of the possible routes to the target. This behaviour is also observable for each individual user, with the average number of route segments visited exceeding the number of route segments laid out by our pre-planned route.

Figure 9. Heat map of all participants' GPS traces. The blue arrow indicates the start point; the black arrow is the end point.

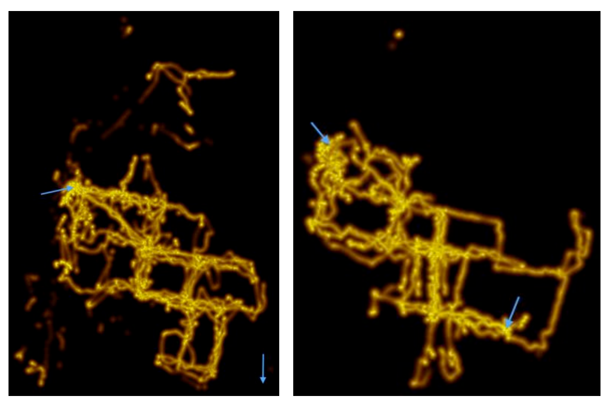


Figure 10. Breakdown of participant GPS traces in failed (left) and successful (right) task completion. The blue arrows denote the start and end points of the route.

Several disconnected islands of GPS traces appear in our heat maps. These are attributable to GPS errors, which are expectable within an urban environment. This highlights a need for our system to "filter out" such erroneous data,

1 http://sethoscope.net/heatmap/ [accessed 10/2/2012]

which in some cases caused erratic jumps in the directional cues given to participants. The participants highlighted this behaviour in their comments, and we can see this explained by the GPS errors (verified from application log files).

Overall, 7 participants managed to navigate to the target destination, while 9 participants failed to find the target. Upon splitting their GPS traces and analysing them separately (Figure 10), it can be seen that failing participants actually got rather close to the target (approximately one block away). Unfortunately, this distance was just out of range for our target beacon (the block preceding the destination was slightly larger than the average block size of 80m). This highlights a need for our system to perhaps offer more help and guided direction near the target destination for users.

The average walking speed in our experiment was 2.313Km/h (1.437mph), indicating a rather leisurely style of walking considering that in the UK, pedestrian crossing traffic light timings are calculated using a standard pedestrian average speed of 4.32Km/h (1.2 m/sec) [21]. This can be attributed to the low stress factor reported by our participants (see qualitative results below) and also the fact that they were mostly exploring, thus the cognitive load of following the audio scent could be an attributing factor to the lowering of their speed.

Figure 11. Heat map of all participants' GPS traces superimposed on the audio scent zone of coverage (shaded grey area), clearly showing the islands of GPS data (errors)

User subjective evaluations

At the end of our experiment, we asked participants to fill in a short questionnaire to capture their subjective evaluation of the prototype. Not all participants agreed to provide a questionnaire response; hence we gathered 14 questionnaires from our 16 participants. We asked a total of 10 questions with pre-defined answers and provided a final comments box for free entry at the end of the questionnaire. The first three questions we asked were related to the participants' sex, age and previous experience with turn-by-turn guidance systems. The remaining seven were focused on the affective impact of SoNav on the participants, in terms of feeling lost, ability to re-gain orientation, overall enjoyment and preference of music vs. the walking sound for navigation. In this paper we shall focus on the responses to the two most interesting questions, starting with the sentiment of participants during use.

This question included a list of 12 experience state descriptions, split equally between positive and negative axes. We note from the participants response that the positive states gathered 31 responses while the negative states gathered 15. Particularly noteworthy is that despite a feeling of being lost and distracted, participants nevertheless felt free, relaxed and having fun, while a sense of exploration was highly present amongst the group of participants.

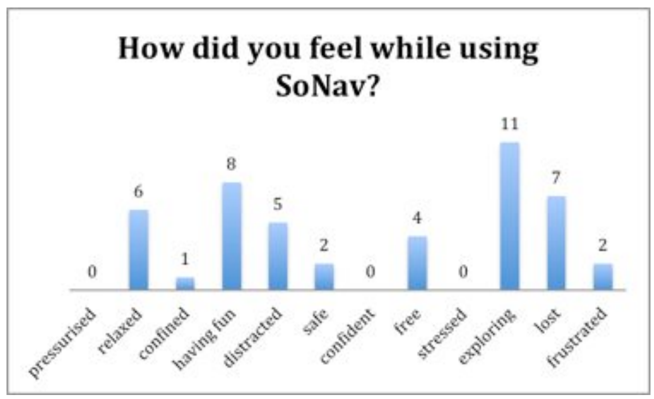
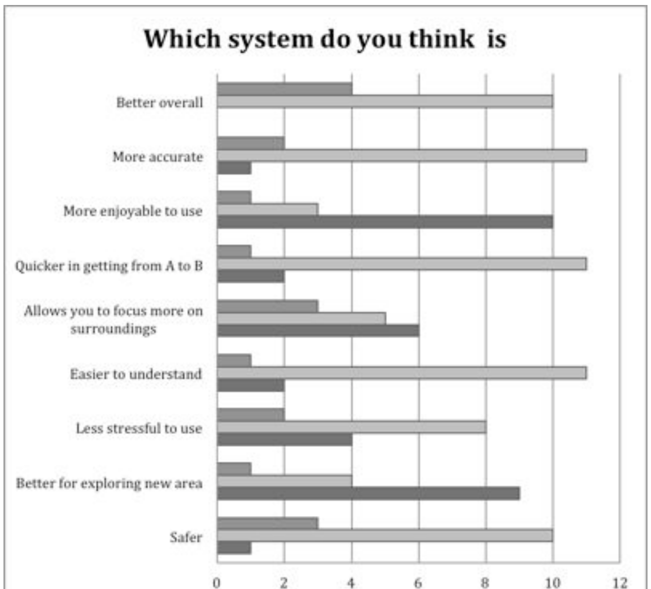


Figure 12. Participants' subjective perception of experience states while using SoNav

We asked our participants to rate our prototype against traditional turn-by-turn systems. In summary, we noted that participants felt that overall a turn-by-turn system was better for guidance in an unfamiliar urban environment, more accurate, able to guide from A to B quicker, being less stressful to use, easier to understand and safer. However, our prototype scored very highly in being more enjoyable to use, allowing a person to focus more on their environments and it was felt that overall it was better for exploring a new area.

We also asked the participants if there were features within the prototype that they would like to be improved or added. Two participants indicated that the addition of a head-mounted digital compass sensor would lead to a more natural searching motion where only the the head (rather than torso) need be rotated to allow the user to sense the target direction. This technique has been utilised by [12] and [13], where the sensing equipment (GPS and magnetometer) was worn on the head of participants (mounted on earcup headphones and a baseball cap respectively). However, in our prototype, we wanted to explore a more realistic solution that would not involve hardware or wearable items not currently available on the market. Three participants indicated that they would welcome some improvement to the directional focus of the audio scents to more clearly indicate target direction. There were also some conflicting requests from participants in relation to audio volume. Although four participants indicated that they would like increased volume in order to overcome ambient noise levels, three of the participants indicated that the audio scent used within the trial (walking with heels sound) actually merged-with and "blurred" the ambient soundscape to the extent that they felt uncertain of the degree of disconnect of the virtual from the external real environment; one participant highlighted this as a potential safety issue. Other uses indicated that a hybrid system, with user-selectable periods of directed turn-by-turn navigation, would instill more confidence in the use of this technology. This is an obvious area for further investigation.

.



	Safer	Better for exploring new area	Less stressful to use	Easier to understand	Allows you to focus more on surroundings	Quicker in getting from A to B	More enjoyable to use	More accurate	Better overall
No Preference	3	1	2	1	3	1	1	2	4
Turn-By-Turn	10	4	8	11	5	11	3	11	10
SoNav	1	9	4	2	6	2	10	1	0

Figure 13. Participants subjective evaluation of SoNav compared to turn-by-turn guidance systems

Two of our users indicated that the system would sometimes provide directional feedback changes at times when they were crossing a street and highlighted this as safety concern, as their attention would be partially diverted from the task of crossing a street to interpreting the new directional cues. Finally, most users reported a general sense of confusion at the start of the experiment, which subsided as they walked nearer the destination. They reported that this was partly due to the high noise levels and traffic caused by buses and heavy car traffic at the starting point. This is a natural observation – any tourist that has ever arrived at a busy station in a new city is often confounded with "arrival stress" [22] which relates to the sudden intake of large volumes of information and a need to orient one's self towards their destination. The increased load of traffic and noise at the starting point added to the uncertaintly of choosing a direction of travel and thus it might be assumed that our system could benefit from deterministic and explicit instructions to get people started on their journey, and revert to implicit navigation shortly afterwards.

The system that we have designed has as a fundamental tenet the use of subtle intervention rather than a directed navigational experience. There is an indication that users may find difficulties in separating the virtual-reality world (the ambient soundscape overlaid with the *walking* or other organic urban audio scents) from the ambient audio reality around them. There are clearly further questions in relation to the following aspects: How merged or separated should reality be from virtual reality? Should we use audio scents that are obviously distinct from the ambient soundscape and would this lead to better separation of real and virtual? Amongst the participants who succeeded in finding the destination, a strong preference for the musical guidance was shown over the walking sound. However, music is a continuous stream of audio which effectively blocks most external sounds, hence is more likely to impact on pedestrian safety. There are clearly design tradeoffs in relation to these that bear further investigation.

CONCLUSIONS AND FURTHER WORK

We developed a prototype that implicitly guides visitors of urban environments towards a destination of their choice. We used the concept of an audio scent that continuously "emanates" from a pre-determined route towards a target. Instead of giving explicit directions to users, our prototype allows them to freely roam while attempting to understand the direction that the audio scent is coming from. In contrast with turn-by-turn guidance systems, our prototype encourages and promotes exploration of the urban environment. It was shown during our trials that participants visited a greater area of a city than the area covered by a pre-determined route. The concept of the audio scent was effective in keeping participants within a certain area, allowing them to explore without straying too far away. While our participants perceived a turn-by-turn system to be more efficient for navigation, they indicated high levels of enjoyment from using our system and felt it would be better for exploring a new area and assimilating as much of their environment as possible.

Our participants highlighted the need for further research along two main axes: Firstly, there is a clear need to investigate the balance of perception between real and virtual in our mixed audio reality system. This is a crucial direction of research, as the safety implications as highlighted by our participants can be significant. A better ability to distinguish real and virtual information might also lead to improved performance in navigation.

Secondly, though there is a strong positive perception of implicit navigation for exploring a new area, it is clear that implicit navigation alone cannot adequately support the needs of tourists in urban environments. A hybrid implicit / turn-by-turn approach, particularly for guiding people during the initial segments of a route, is possibly a better design approach. A hybrid approach that allows a tourist to fall back to turn-by-turn guidance might also increase the perceived levels of safety and stress during the exploration of new environments.

We are also keen to explore new ways of extending our prototype further in order to incorporate spoken narratives alongside the implicit navigation element, and also investigate social and group aspects in navigation, orientation and POI discovery. Our prototype can accommodate the incorporation of sound beacons, to represent points of interest along a route. We are especially interested in examining whether the use of 3D audio can help with points of interest on the vertical axis (e.g. architectural features in tall buildings), as our system currently only uses the horizontal plane (left and right). We are also very keen to investigate the playback of seamlessly integrating context-relevant narratives near beacons, which will serve as both informational and direction-finding clues, thus creating themed navigation experiences. Additionally, looping Earcon or musical layers can be incorporated in the system to give various "feels" to certain areas of the environment (e.g. appropriate music to indicate a dangerous part of the city, or a historic/modern/shopping area of a city). Our prototype can be easily extended to accommodate groups of tourists, by sharing locations of individuals so that one "group" can hear where other groups are in the city, in relation to it. Finally our system can possibly benefit from the integration of data from social media (e.g. Foursquare check-ins) to mine for socially popular locations (e.g. good restaurants) and portray these to the users as they walk along an unfamiliar road.

ACKNOWLEDGMENTS

This work is inspired by early work from S. Strachan and M. Jones to whom we would like to extend special thanks. Additional thanks are extended to M. Dunlop for his feedback and enthusiastic support. Finally we would also like to particularly thank M. Pielot for openly releasing his port of the OpenAL library to the Android platform, without which this work would not have been possible.

REFERENCES

1. Kruger A, Aslan I, Zimmer H The effects of mobile pedestrian navigation systems on the concurrent acquisition of route and survey knowledge. *In: MobileHCI '04, volume 3160 of LNCS. Springer, Berlin , pp 446–450* (2004)
2. Aslan I, Schwalm M, Baus J, Kru¨ger A, Schwartz T Acquisition of spatial knowledge in location aware mobile pedestrian navigation systems. *In: Proceedings of CHI '06, ACM, pp 105–108* (2006)
3. Seager W The usability of map-based applications for pedestrian navigation. *PhD thesis, Nottingham University* (2007)
4. Pielot M., Boll S. C. J. Tactile Wayfinder: Comparison of tactile waypoint navigation with commercial pedestrian navigation systems. *In The Eighth International Conference on Pervasive Computing, Helsinki, Finland* (2010)
5. Jones M, Jones S, Bradley G, Warren N, Bainbridge D, Holmes G ONTRACK: dynamically adapting music playback to support navigation. *Personal & Ubiquitous Computing 12(7):513–525* (2008)
6. Strachan S, Eslambolchilar P, Murray-Smith R, Hughes S, O'Modhrain S gpsTunes: controlling navigation via audio feedback. *In: Proceedings of MobileHCI '05, ACM, pp 275–278* (2005)
7. Strachan S, Murray-Smith R Bearing-based selection in mobile spatial interaction. *Personal & Ubiquitous Computing 13(4):265–280* (2009)
8. Holland S, Morse DR, Gedenryd H AudioGPS: spatial audio navigation with a minimal attention interface. *Personal & Ubiquitous Computing 6(4):253–259* (2002)
9. Cater K, Hull R, O'Hara K, Melamed T, Clayton B The potential of spatialised audio for location based services on mobile devices: Mediascapes. *SAMD: Workshop on Spatialised Audio for Mobile Devices, MobileHCI 2007* (2007)
10. McGookin D, Brewster S, Priego P Audio Bubbles. Employing non-speech audio to support tourist wayfinding. *In: Altinsoy ME, Jekosch U, Brewster S (eds) HAID 2009, LNCS, vol 5763, pp 41–50* (2009)
11. Magnusson C, Breidegard B, Rassmus-Gröhn K Sound- crumbs-Hansel and Gretel in the 21st century. *In: HAID 2009, LNCS. Springer* (2009)
12. Stahl C The roaring navigator: a group guide for the zoo with shared auditory landmark display. *In:*

Proceedings of MobileHCI 2007. ACM Press, New York, pp 282–386 (2007)

13. Vazquez-Alvarez Y., Oakley I., Brewster S. A. Auditory display design for exploration in mobile audio-augmented reality, *Personal & Ubiquitous Computing, Online First* (2011)
14. Borntrager C, Cheverst K, Davies N, Dix A, Friday A, Seitz J Experiments with multi-modal interfaces in a context- aware city guide. *In: MobileHCI '03, volume 2795 of LNCS. Springer, Berlin, pp 116–130* (2003)
15. Härmä A., Jakka J., Tikander M., Karjalainen M., Lokki T., Hiipakka J., Lorho G. Augmented reality audio for mobile and wearable appliances *J. Audio Engineering Society 52: 6. 618-639* (2004)
16. Robinson, S. Matt Jones, John Williamson, Roderick Murray-Smith, Parisa Eslambolchilar and Mads Lindborg Navigation your way: from spontaneous independent exploration to dynamic social journeys. *Personal & Ubiquitous Computing, Online First* (2011).
17. Magnusson, C., Rassmus-Gröhn, K. & Szymczak, D.. Navigation by pointing to GPS locations. *Personal and Ubiquitous Computing Online First* (2011)
18. Rozier J, Karahalios K, Donath J Hear & There: an augmented reality system of linked audio. *In: Proceedings of the international conference on auditory display—ICAD 2000* (2000)
19. Reid, J., Geelhoed, E., Hull, R., Carter, K., Clayton, B. Parallel worlds: Immersion in location-based experiences. *In: CHI 2005, Portland, Oregon, vol. 2, pp. 1733– 1736. ACM Press, New York* (2005)
20. Rowland D., Flintham M., Oppermann L., Marshall J., Chamberlain A., Koleva B., Benford S., Perez C. Ubikequitous computing: designing interactive experiences for cyclists. *In Proceedings of the 11th International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI '09). ACM, New York, NY, USA* (2009)
21. Kennedy J., Sexton B. Literature review of road safety at traffic signals and signalised crossings, *Transport Research Laboratory, ISBN 978-1-84608-859-9* (2009)
22. Cole S. Information needs of the independent traveller on public transport, *Wales Transport Centre ISBN 1-840540-87-7* (2003)

Contribution statement

We present an audio mixed reality prototype for implicit navigation in urban areas. Our trials show that our technique promotes safe exploration of an area while being engaging and pleasant to use.