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A Bimodal Navigation System for Pedestrians using Visual and Auditory Displays

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Abstract

A Bimodal Navigation System for Pedestrians using Visual and Auditory Displays

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In this study, we designed and implemented a bimodal navigation system using visual and auditory display. The auditory display gives information about the orientation of a destination to users to enhance their spatial knowledge acquisition. The distinction of this system compared to existing ones is that it uses the moving sound source as the auditory display. To investigate the performance of human sound azimuthal localization using the moving sound source, we tested the sound localization on the horizontal plane using the moving sound source and the stationary one. The results showed that the performance with the moving sound source is more accurate and the difference of the accuracy between the moving sound source and the stationary one is statistically significant.

We evaluated our system in a user study with four participants. Most users gave positive feedbacks on two main features of our system. They favored the auditory cues because it clearly indicated the orientation to the destination. The issue was front-back confusion that had been shown during sound localization. It has to be improved in future works.

Keywords : navigation, spatial knowledge, orientation sense, multimodal interface, sound localization

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1. INTRODUCTION

There have been several efforts to suggest efficient navigation systems for pedestrians. For instance, most pedestrian navigation systems adopted a route planner which provides the shortest route to the destination. However, it does not always provide the most efficient modal for pedestrians, especially for the ones in an urban environment, due to difficulty in seeing a wide angle view in urban streets surrounded by skyscrapers, so the wayfinding based on landmarks, one of the typical ways of spatial knowledge acquisition[29], becomes difficult to be used successfully. Several navigation systems utilized direct turn-by-turn instructions similar to car navigations. However, the route suggested by navigation systems can be blocked due to a construction or other unexpected events. Also, key landmarks used to indicate the turns can often disappear, especially when they are commercial businesses like local restaurants or banks.

Pielot and Boll discussed some issues which make direct turn-by-turn instructions unsuitable for existing pedestrian navigation[21]. The turn-by-turn way navigation systems focus on providing the most efficient route to a destination using various algorithms. For example, in the study of Wang et al., the campus navigation system provides 5 different routes to the destination by user's request as shortest, sheltered, lighted, crowded, and less climbing ways[39].

However in many cases, pedestrians, especially tourists in the city, do not need to find the shortest route. In Brown and Rourier's ethnographic study on city tourists for designing new navigation, tourists usually use a map to locate or orient themselves as heading in a 'roughly correct' direction and enjoy exploring an unfamiliar city[3].

The aim of this study is to design and implement the novel navigation system suitable for pedestrians in an urban environment by giving more intuitive orientation cue that could indicate the destination.

1.1 Multimodal interface for navigation system

Visual information is not the only or the best way to get spatial knowledge acquisition. It is more intuitive and effective to integrate multisensory input like sight, hearing, touch, smell, and taste. According to Rieser's study[25], it is possible to get spatial knowledge only from other sensory information for exploring areas. For instance, the visually impaired and the blind are able to have enough spatial ability. Sossinski argued that most blind mathematicians were working on the geometry by obtaining spatial ability through their sense of touch and hearing. He also said that sighted people could get misconceptions of three-dimensional space because they depend on two-dimensional projection of space onto the retina[8].

Exploring strange surroundings using a traditional pictorial map could be a cognitive overload to users. People who are navigating to the destination need to recognize his/her orientation and position within the area, and also need to be able to predict change of relationship between him/herself and environments when they change their direction of movement. Safety is another important consideration. A pedestrian who is concentrating on a map and walking in roadways might be in danger due to the lack of attention to surroundings. Many pedestrian navigation systems suggest alternative solution to lighten cognitive burden and enable an intuitive spatial perception to solve these issues. In this field, the auditory or tactile display is usually used as the alternative.

This study attempts to suggest a navigation system which is giving intuitive orientation indicator using bimodal display, focusing on visual and auditory one, for pedestrians in an urban environment.

The distinction of the proposed system compared to existing systems is that the moving sound is used as auditory cues for orientation of the destination. In R. Näätänen's study and others, spatial differences of sound source can elicit selective attention of human brain[16, 28]. According to the result of behavioral experiments, moving sound could be separated faster than other concurrent sounds by human brain because the mismatch negativity (MMN) which is generated by human brain’s automatic detection of a sound location changes has shorter latency than other change such as frequency. So users could perceive spatial information of the auditory cue without cognitive overload. In our proposed system, outstanding performance of orientation is exploited via moving sound as the auditory cues.

In the study of Thorndyke and his colleagues, they focused on the differences between spatial knowledge acquisition from a map and navigation experience[34]. According to the result, the map experience could be better on judgments of relative location and the straight-lined distances between objects and the navigation experience could be better on orienting oneself with expectation of unseen objects and estimating route distances. The presented system attempts to draw richer spatial knowledge acquisition from the use of a map, wandering(navigation) and auditory aid experience evenly.

2. RELATED WORK

Several navigation systems used other sensorial displays like auditory or tactile displays rather than the visual one for enhancing spatial knowledge acquisition of users. The approach of such systems could be interpreted as the augmented reality display for experiencing areas focused on the specific purpose like a museum tour using earcons or auditory landmarks[11, 19, 30 31], but this part will be limited its scope to the general navigation system focused on suggesting alternatives to visual displays, especially ones using non-speech sound.

AudioGPS[7], the work of Holland and his colleagues is one of the first attempts to build the auditory navigation system for sighted users. It gives direction and distance information to the destination to users via non-speech spatial auditory sound. Spatial panning of sound is used to encode the information of correct direction, and Geiger counter metaphor is used to encode the information of distance to destination. Several researches have suggested using auditory cues, many of which are designed for the visually impaired users[10, 37]. SWAN project[43] was an extensive auditory navigation that gives the route and the contextual information of surroundings for the visually impaired through 3D spatial sound. It provided speech sound as the instruction of the route and earcons as descriptions of current environments.

Some navigation systems tried to give more immersive and enjoyable experience to users using music[9, 40]. gpsTunes[33] is using music to which a user wants to listen to indicate distance and orientation of the destination through spatial sound. This solution has additional purpose of giving some pleasure to the user via musical experience as well as giving position information at the same time. Eyesound[44] is similar to the previous systems, but it runs as direction instruction system. When a user reaches to a fork, the music provides direction instruction via spatial sound.

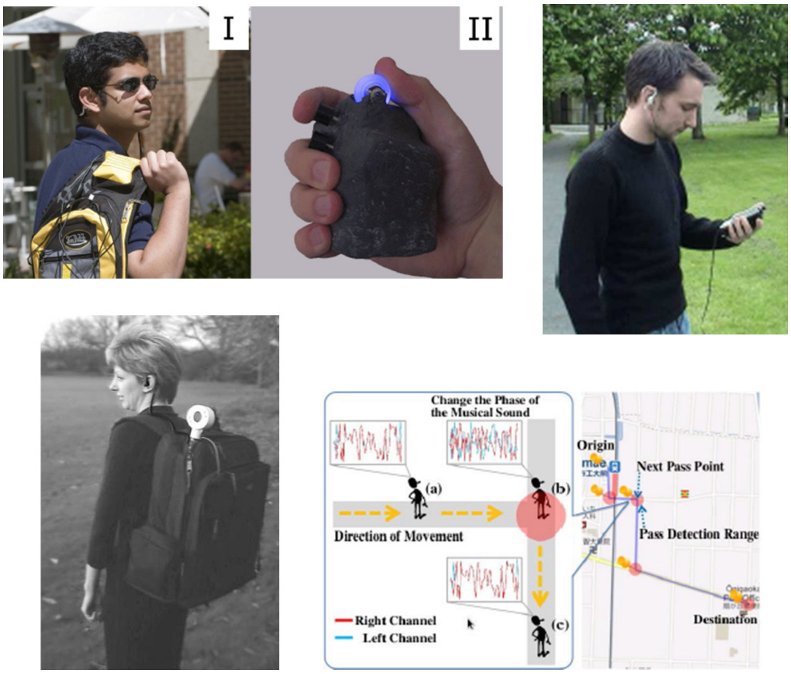


Figure 1. Existing auditory navigation systems. (Upper left) SWAN project using audio-only display and tactile input. (Upper right) gpsTunes using 3D spatial music sound in user's own device (Lower left) AudioGPS using encoded auditory cues for sighted people (Lower right) Eyesound using musical sound to give instructions of direction.

There are various navigation systems using tactile display, too. But most systems of this kind usually give direct instruction due to its' own limitation. Unlike other tactile navigations which can give only forward/backward/left/right instructions, PocketNavigator[22] runs as digital compass on the mobile vibrator device. In PocketNavigator, the mobile device in user's pocket keeps informing about distance and direction to the next waypoint through vibration. The authors called it “the tactile compass”. But it still gives instructions to follow only the specific route to user. Similar projects are using tactile display to provide route information to users[2, 6, 23, 26, 35].

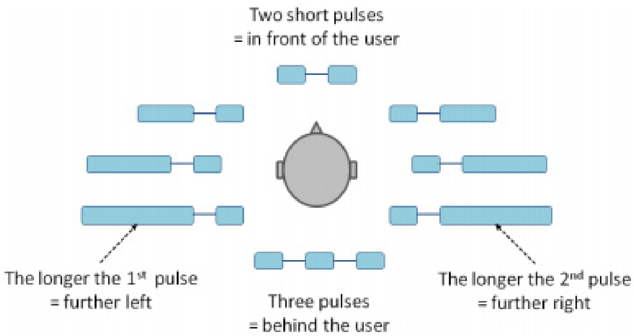


Figure 2. The distance and direction encoding of PocketNavigator [22].

3. MOVING SOUND SOURCE

Studies on sound localization from the stationary source have been done in diverse academic fields. Starting in the early 1900s, researchers in psychophysics began to investigate human perception of sound localization. Lord Rayleigh[24] firstly noticed about the sound localization by binaural cues. He provided the Duplex theory which explains time differences between the sound reaching two ears (ITDs) and differences in sound level reaching two ears (ILDs) for the ability of human sound localization. Spectral cues are also considered as another main factor in these days[14]. After Rayleigh's study, most studies on localization in the horizontal plane have done with a focus on the frequency characteristic of the sound stimuli using loudspeakers[12, 27, 32]. The performance of sound localization could be enhanced via repeated training with feedback of subject's responses[15, 45, 46]. Sound localization accuracy have been shown to be higher in the condition with sight[1, 38]. Some researchers investigated the accuracy of sound direction identification of bilateral cochlear implants users[17, 36]. Regarding spatial sound synthesize, sound localization experiment under the free-field condition and the headphone condition is noticed to some researches[42]. The Localization using non-individualized Head-Related-Transfer-Function (HRTF) is another issue in this area[41]. Researches regarding human perception of the moving sound source are mainly focusing on the minimum audible movement angle (MAMA)[4, 20].

Despite series of sound localization experiments, the performance with the sound moving above a listener's head has never been investigated earlier. In this study, prior to design auditory display of the presented navigation system, psychoacoustic experiments were performed to compare the human sound azimuthal localization performance between the moving sound source and the stationary one.

3.1 Method

Sixteen young adults, with ages ranging from 19 to 33 (M = 25.88) participated in the experiment as paid volunteers. All had normal hearing with no history of hearing problems of any kind. None of the subjects had any previous experience in psychoacoustic experiments.

The experiment was carried out in a quiet classroom. A participant sat in a turning chair and wore a headphone with orientation sensor. The experiment consisted of 2 session, the moving sound source test session and the stationary one, and each session had 20 tests. The test was designed as a within-subject comparison and counter-balanced to prevent the learning effects. The participants were allowed to review instructions and conduct trial tests until they felt comfortable with the procedure. A calibration of the orientation sensor was done before every tests.

An android smartphone was used to generate and control the presentation of stimuli. The sound stimuli were played over the headphone as a participant pressed the start button. Each participant was asked to try to figure out the azimuthal location of sound source by rotating their head in the only horizontal dimension. In most previous psychoacoustical experiments, participants' moving of head is not allowed for exact measuring of human auditory localization performance. However, the goal of this experiment is to compare the sound azimuthal localization performance between two types of sound source in the auditory navigation system, so we allowed user's head movement as the natural user behavior. when they thought they found the direction of sound source, they responded where the most likely indicated target direction was by selecting one of twelve buttons on the computer screen. The reaction time and the judged location are recorded as the log file. Figure 3 shows a participant who ran the test and a user interface of the electronic answer sheet.

The basic stimulus was a repeated bell-like sound. The stimuli lasted for 20sec, and the sound could be replayed if needed. The azimuthal direction of sound source was distributed from 0' to 330' at intervals of 30' and randomly picked in the experiment design process before the test. The stimulus was generated as non-individualized HRTF spatial sound using OpenAL on the android application. More specific stimulus description is in the next section.

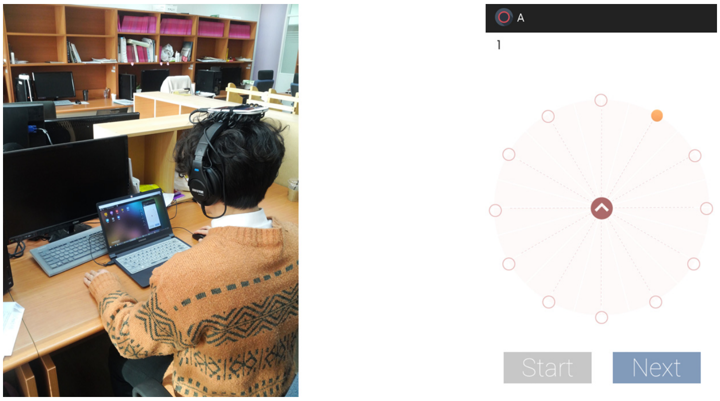
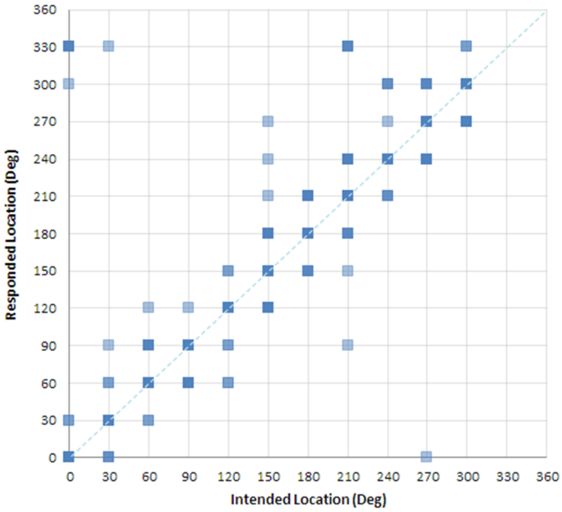


Figure 3. Auditory Experiments Scene (Left) An user who is running the test (Right) User Interface of the electronic answer sheet. Participants select one button as a direction of the sound source among 12 buttons.

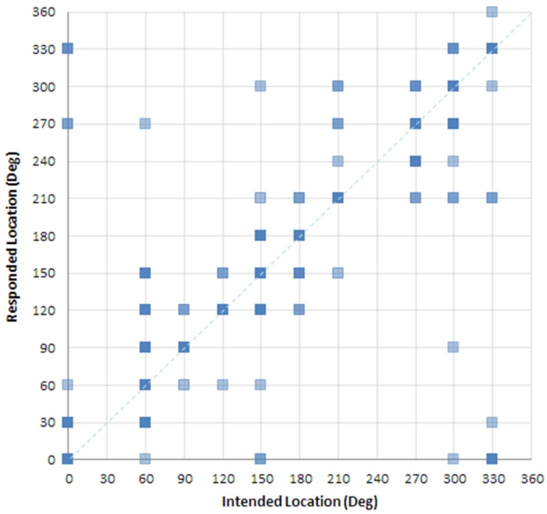
3.2 Results

In this experiment, only the relation between intended and responded azimuthal location on the horizontal plane was measured. So the spherical statistics for the 3-dimensional sound localization experiment was not applied to analyze results of this experiment.

The azimuthal localization responses of all participants to the moving sound source are shown in Figure 4 (Upper) and responses to the stationary sound source are shown in Figure 4 (Lower). In these plots, the intended sound location appears on the x-axis and the responses appears on the y-axis. There were individual differences in sound localization performance as can be seen in figures. Response data from one user was discarded because his experiment was ran in unstable situation. The group mean and standard deviations of responded sound azimuthal localization from intended locations are shown in Figure 5. All stimuli were randomly picked, so some angles did not appeared in the stimuli sets. As shown in the figures, accuracy of the sound localization was better under the moving sound stimuli condition. The mean values of responses from the moving sound were almost similar with intended values, but the mean values of responses from the stationary sound were different from intended values.

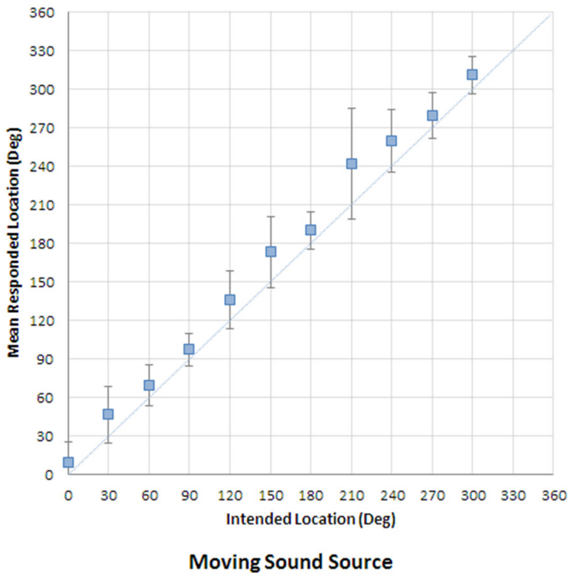


Moving Sound Source



Stationary Sound Source

Figure 4. Responded azimuthal location of experiments. (Upper) Responded locations of moving sound source. (Lower) Responded locations of stationary sound source.



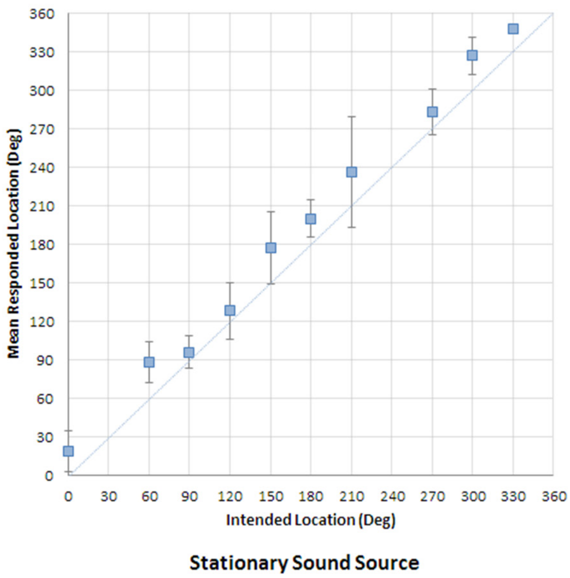


Figure 5. Group means and standard deviations of each responded location. (Upper) The results of the moving sound source. (Lower) The results of the stationary sound source.

The mean error of sound azimuthal localization responses was 14.13° (*SD* = 23.31) for the moving sound and 21.7° (*SD* = 29.75) for the stationary sound. Paired sample T-test analysis shows that the difference between two types of stimuli was statistically highly significant (N = 600, $p < .001$). These results could not be simply compared with earlier studies because there are many differences among them, such as a device (headphone/ loudspeaker), an interval degree of stimulus (15°~33°), or an answering method (forced-choice/ free-answer). For more elaborate evaluation of performance, the root mean square (RMS) of responses was calculated. The RMS error was 27.28° (*SD* = 11.35) for the moving sound and 37.75° (*SD* = 11.54) for the stationary sound. These results also shows that the difference of RMS error between two types of stimuli was statistically highly significant ($p < .01$).

The mean reaction time of sound azimuthal localization responses was 18.30 sec (N = 300, *SD* = 8.89) for the moving sound and 16.21 sec (N = 300, *SD* = 8.21) for the stationary sound. The difference was statistically significant ($p < .005$). By user behavior observation during the experiments, participants tend to delay their judgement of the moving sound until the sound passed above their head, so longer time was needed.

In short, sound localization on the horizontal plane with the moving sound is more accurate than with the stationary sound, but it takes more time to make a judgement. Based on these results, the navigation system with the moving sound display might provide more accurate cue for the spatial perception to users.

4. SYSTEM DESIGN

4.1 Overview

The navigation system is comprised of 5 components such as a map, an user state marker, a destination marker, an orientation guide as an visual cues of orientation, and an auditory cue using spatial sound with HRTF. The interface of the proposed system is shown in Figure 6. To enhance the user's awareness of their orientation and the spatial relation with environments, the proposed system adopts two key features besides an user state marker which shows the user's current location and heading.

4.2 Auditory Cue

An auditory cue informs about the orientation of the destination as a first feature. In this system, the auditory cues provide information of direction for which a user have to head for. When a user tap a target marker, the tinkling sound moves from the opposite side of a target with the user an origin to the destination. This auditory cue gives not information of distance but of orientation. For user's accurate processing of sound localization, the auditory cue is realized as spatial sound containing binaural cues, through using OpenAL(Open Audio Library) on Android OS.

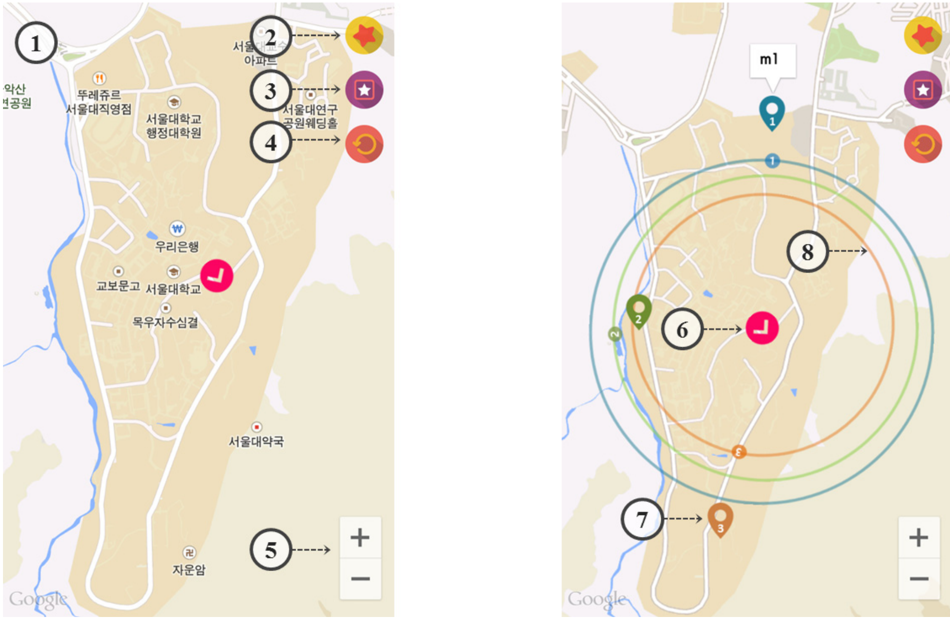


Figure 6. User interface components of the proposed system. (1) a map, (2) a button to add markers, (3) a button to add the orientation guides (4) a button to change mapview, (5) buttons to zoom in/out the map, (6) an user state marker, indicate current user state such as location and heading, (7) destination markers, user can locate markers through long press on the map, (8) the orientation guides which indicate orientation of each destination.

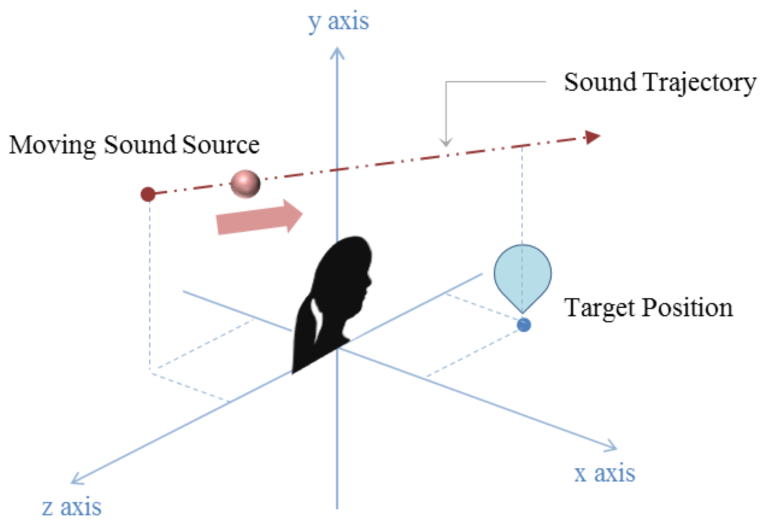


Figure 7. Moving sound trajectory. The user as a listener is place on the origin and looking at the direction of -z axis. The sound starts the opposite point of target position and moves to the target position, above the user's head. The moving sound lasts for 13 seconds.

4.3 Orientation Guide

An orientation guide as the second visually informative feature indicates the macroscopic orientation of a destination via a circle-shape indicator surrounding the user state marker. When users have difficulty to find the way, they usually zoom in the navigation map. In that case, the current position and the destination position could not be visible at the same time. This make it harder to find the route when a user uses the map without route planner. The orientation guide always can show the orientation of the final destination regardless of map scales on the mobile device, so user can see the big picture of the route by being aware of the expected direction.

The map view has 3 modes, the plane view, the tilted view, and the rotating view as in Figure 8. In the plane view and the tilted view the map is fixed as north at the top and in the rotating view, user can see the map in egocentric way. The rotating view could not be zoomed in or changed the tilted angles because it only has to be used for reference, not the main view.

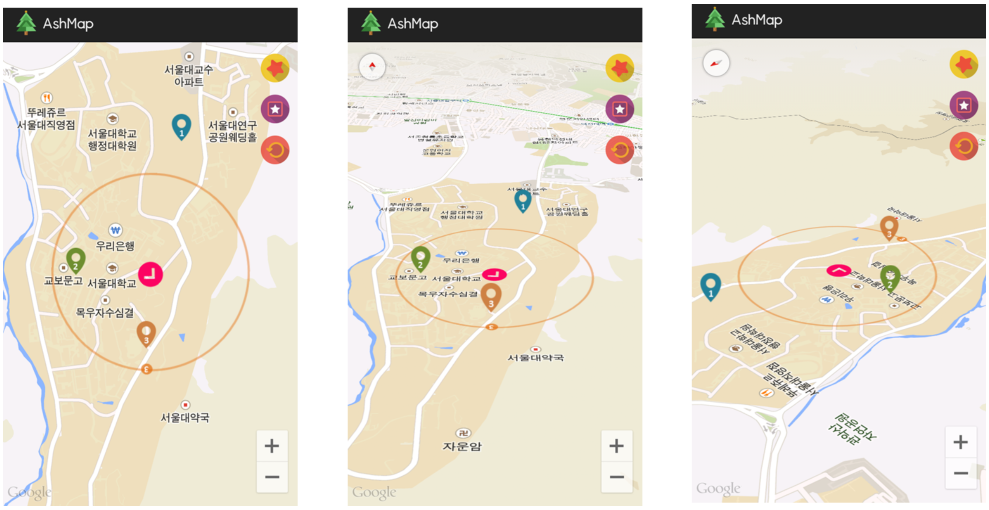


Figure 8. Map view modes of the proposed system. (Left) Plain view. The navigation screen is able to be zoomed in or out and be rotated by users' control. (Middle) Tilted view. In this mode, user's viewpoint moves up in the air, and buildings are shown as 2.5D object. But in this region, 2.5D graphic is not supported by Google. (Right) Rotating view as egocentric view. In this system this view is not able to be zoomed in or out because the main purpose of this system is to observe user's orientation awareness supported by other features.

5. IMPLEMENTATION

The prototype is developed as an Android application. Most Android devices are including various sensors for the electronic navigation system such as GPS module and magnetometer. Also, most pedestrians have experienced the navigation system of the mobile device, this prototype of android application could give similar experience they used to use.

Figure 9 shows the architecture of the proposed navigation system. A mobile device provides information of current location and orientation using its GPS, an orientation sensor and network information. The navigation system on a mobile device provides spatial information to users via its bimodal interface. The user gets spatial information through visual and auditory input and perceives the surrounding space.

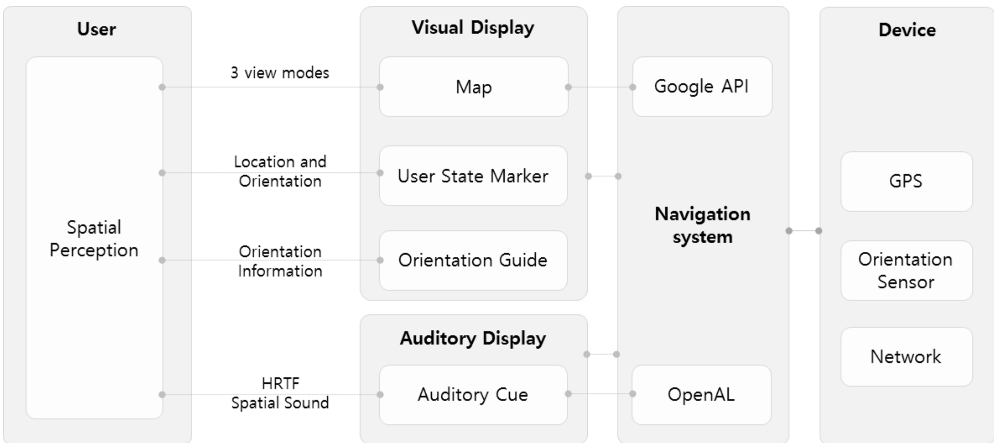


Figure 9. System architecture includes device and user.

3D spatial sound system is using OpenAL library for sound localization through binaural cues as Interaural time differences(ITD) and Interaural level differences(ILD). The localization of sound is just considered in the horizontal plane so spatial sound generation depends on the user's yaw, rotation around the vertical (z) axis. Figure 10 shows the auditory cues of a destination which lies at front-left side and in front of the user.

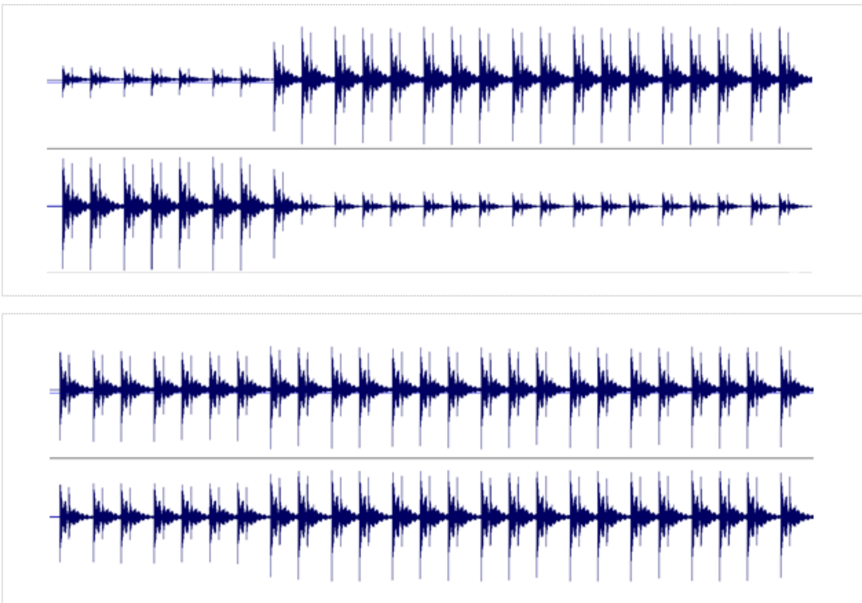


Figure 10. Sound wave of auditory cues. (Upper) The sound wave from the destination located at front-left side of a user. (Lower) The sound wave from the destination located in front of a user. The volume of sound gets slightly bigger at user's position.

For spatial sound synthesizing which is reacting to user head movement, the proto-design of this system included Arduino magnetometer module placed on user's head. But the processing of the third party orientation signal makes delay of the entire system, so finally this system is using the orientation sensor of the Android device's own. Heller studied on the behavior of the user who trace the source of artificial sound in the virtual sound environment[5]. In this study, the relative angles of the head to the body, the device to the body, and the head to the device are generally slight (lower than 4') but it involves some delays between the head-turn and the body/device-turn in the headphone-wearing condition except in the case of first head-turn to the sound source. In present system, a user could recognize the orientation of sound turning within 180 degree unlike 360 degree of Heller's experiments, so using the magnetometer of the smartphone device could be more acceptable. In the future works, this assumption should be demonstrated.

6. EVALUATION

In studies on the multimodal navigation system there are no consensus criteria for evaluation. It is quite hard to measure the performance of navigation system with a quantitative analysis because of users' individual differences such as walking speed, and an innate sense of spatial knowledge acquisition, so in this paper the evaluation of the present system took a qualitative approach, as the user test. The user test was conducted to shed light on some questions about the presented system.

1. *Is this system really helpful to users to find destinations?*

2. *How users control this system to find the way to get to destination?*

6.1 Design of User Test

The test took place in the campus of Seoul National University. Four Participants (3 women, 1 man) aged from 25 to 33 without any problem with sight, hearing and mobility took part in the test. All the participants were never been in this place and have previous experience of using the smartphone navigation.

The Navigation system runs on the Samsung Galaxy III device with Android JellyBean (v.4.3.1). All users wore the stereo headphone (SHURE SHR440) for auditory cues.

Figure 11. User test tasks. (Left) The first view of the application given to users at the start of the main test. (Right) The starting point and three target positions of the user test.

All the participants were trained enough to use this system in the tutorial before the main test. In the main test, they were requested to get to 3 destination overall which are marked on the map as Figure 11. For tracking users' location and heading information, both informations are saved in the log file. After starting, users moved freely and spoke aloud about their feelings or thoughts for 'think aloud'. The experimenter accompanied participants for recording and safety. The post-interview was taken after the main test session to access users' subjective impression of this system.

6.2 Result

All participants succeeded to get all destinations without a significant disorientation. The mean time to complete the task was 25min 30sec. But as mentioned above, completion time does not matter because there are individual differences between each participants. The traces and the behaviour patterns of each user could give us more important implications.

Use patterns of the auditory cues in this navigation system is shown as 2 types. The first type of user followed the auditory cues in whole navigation to find the destination. They played the sound as they starts the test, and kept on play the auditory cues of target position until they got to the destination.

> *"I think I can get to destination by following only this sound, It was unexpectedly easier to follow the move of sound than I thought" (User 1)*

A noticeable observation is that the user didn't play auditory cues in the section which has shown smooth mobility, and kept on playing auditory cues in the section where the user seems to be lost. Expecially, this user played the auditory cues almost every time the direction of the move is changed.

> *"I lost my orientation when I was confused in the forked road like just now. I will just follow the sound" (User 3)*

The second type of user did not play the auditory cues so much. This user used only the visual map to get closer to the target, and used the auditory cues to find accurate target position when he/she got near to the destination. This user also used the auditory cues when the direction of move was changed.

> *"I prefer to wander to find the target when I lost rather than to look the map standing up. It makes me more confused to find my position and orientation in the map. But this sound are less confusing than the visual map." (User 2)*

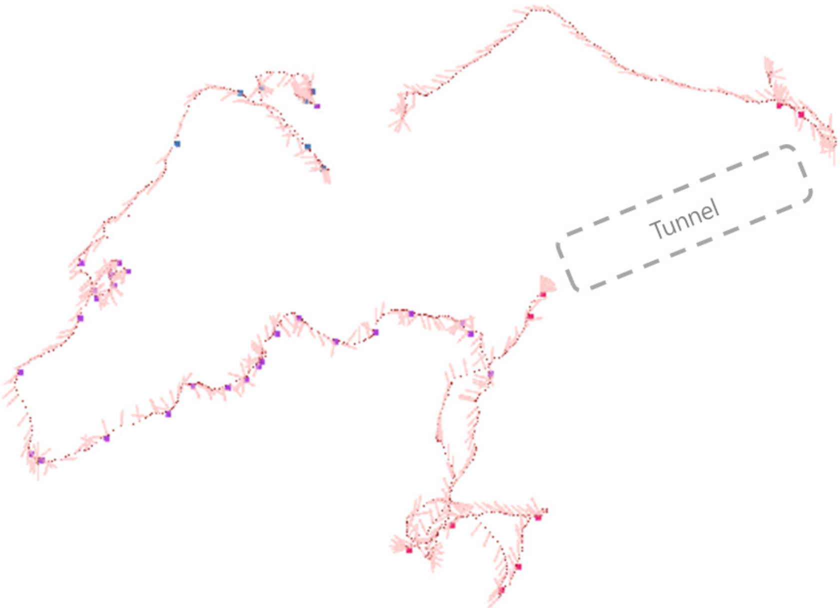


Figure 12. Traces of location and heading of an user. Tiny red dots are locations of the user recorded every 800ms, the pink line indicates the user's heading in every 2.4sec. The big blue dot indicates playing of auditory cues of the first target location. The big purple dot means the second target and the big red dot means the third target.

Figure 13. Traces of another user. All indicators are same as above one.

6.3 Discussion

Users have positive opinions of this system overall. In post-interviews of the main test, they give positive scores to the auditory cues and the orientation guide in nine-level Likert-scale questions. The result of Likert-scale is in the Figure 14. More detailed descriptions are below.

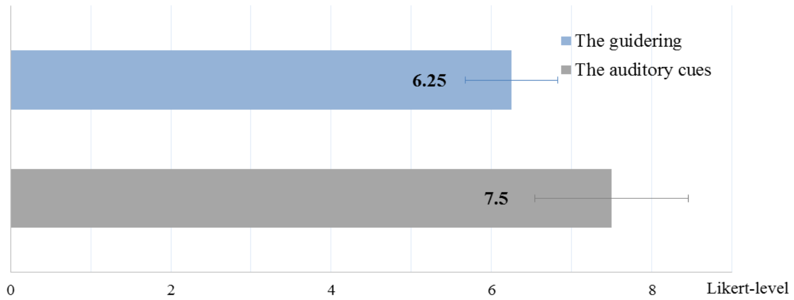


Figure 14. Likert-scale results of two main features in the post-interview. Both of the features got positive scores from users. More specified comments are described as below.

6.3.1 Auditory Cue as Moving Sound

User gave positive feedback overall on the auditory cues. All participants have never used the navigation with any auditory cues. Most users felt a bit confused at first, but shortly got used to this system.

“I think that a novice needs to get used to this sound. I was confused when I heard the sound at firstly hear the sound because the sound was moving. But now I feel I could get to my destination by following this sound." (User 4)

"I like that the sound is moving, because I can recognize the direction of moving of this sound easily. Even though I had some difficulties to find the direction of sound, I could figure out it soon after the sound moved to opposite side of original one." (User 1)

Some comments described the weakness of the auditory cues. Three users found some difficulties with figuring out whether the sound is moving forward or backward of the user.

> *"I could easily figure out whether the sound is moving to the left or right side of me. but it was quite hard to find out whether the sound is moving forward or backward of me so I had to turn around largely to find the direction." (User 3)*

The minimum cues to distinguish whether the sound comes from the front or back of the user is implemented in the OpenAL using binaural effect. Basically the sound coming from backward is a little smaller than the sound coming from forward as shown in Figure 10. But this difference is so subtle that all users cannot notice it. This part have to be improved in the future works.

6.3.2 Orientation Guide

This feature also got positive feedbacks also, but less favored by users than the auditory cues. The main attraction is that orientation guide is always visible regardless of map scale, so user can establish the relation between the orientation of her/himself and the destination whenever they turn around.

Most users thought that the orientation guide is not key feature but an additional supplementary.

"This orientation ring surely give me the rough information of the orientation of the destination always. It's always visible when I zoom in the map, but if I want to listen to the auditory cue of the destination, I have to find the marker anyway so it does little part when I use this system." (User 3)

6.3.3 Overall

Overall, two features of this navigation system could be useful and helpful to pedestrians but there are still several points to be improved. The primary issue is solving the front-back confusing problems via more powerful binaural evidences.

A following comment is shows both pros and cons of this system.

"I think that I could take a roundabout way to the destination by just following the sound, particularly when I reached a fork. So I think I have to check the map sometimes even if I am satisfied with this system. But it's quite convenient that there is no need to concentrate on the map throughout the wandering." (User 1)

7. CONCLUSION AND FUTURE WORK

In this study, I presented the bimodal navigation system using the visual information through a pictorial map and the orientation guide, and the auditory cues through a spatial moving sound which is generated by HRTF for enhancing pedestrians' orientation sense to navigate to a destination. This system gives information of the relation between the user and the destination or the environment surrounding the user.

This system is designed for pedestrians especially who wandering in dynamic urban environment with a purpose of touring. With support of two features of this system, users will not lost their spatial state and the way to the final destination without cognitive overload to translate the pictorial map and could enjoy wandering in the city.

To investigate the performance of sound localization accuracy using the moving sound source, we ran experiments with 16 participants. The result showed that the moving sound could give more accurate information of direction to users rather than the stationary one which have been used in existing auditory navigation system.

According to the user test on the new navigation system, we could find some advantages and weaknesses of this system. Users could be helped to recognize their orientational relation to the environment, and they could find the direction to which they have to go to reach their destinations without excessive cognitive overload to know their spatial state especially via the HRTF auditory cues.

The auditory cues give the orientation information of a destination, user could easily recognize the direction of a destination which is placed in left or right side of the user. But there is a considerable front/back confusion problem caused by non-individualized HRTF, so it has to be improved via enhancing the binaural sound solution.

Another issue is still safety. The user wearing a headphone could be insulated ambient sound. In the future work, the audio device has to be replaced with devices like a bone conduction headphone that allow the user to hear ambient sound better.

An evaluation of presented system compared to existing auditory navigation systems for pedestrians have to be conducted. In that process the comparative pros and cons of this system to existing systems will be figured out.

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국문 초록

시각 및 청각 디스플레이를 통한 보행자용 바이모달 네비게이션

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본 연구는 시각과 청각 디스플레이를 통한 보행자용 바이모달 네비게이션 시스템을 고안하고 구현하였다. 청각 디스플레이는 목적지의 방향정보를 기존 방식보다 좀 더 직관적으로 제공함으로서 사용자의 공간정보 획득을 보조한다. 이를 위해 본 연구에서는 기존 방식과 달리 이동하는 음원을 청각 디스플레이의 요소로 사용하였다. 이동하는 음원의 방향정보 전달력을 검증하기 위해, 16명의 실험참여자를 대상으로 이동하는 음원과 정지된 음원에서 발생하는 소리를 들려주고 그 방향을 지목하게 한 결과 이동하는 음원에서의 소리를 통해 판단된 방향인식이 더욱 높은 정확도를 보였고, 이러한 통계적 차이는 유의한 것으로 나타났다.

구현된 네비게이션 시스템은 4명의 사용자를 대상으로 사용자 테스트를 하였다. 사용자들은 대체로 본 시스템의 두가지 주요 기능에 대해 긍정적인 반응을 보였으며, 특히 청각 디스플레이를 통해 목적지의 방향을 명확하게 알 수 있어 좋다고 평가하였다. 그러나 인위적으로 발생된 spatial sound의 문제점인 front-back confusion 문제가 발생하는 경향이 있었고, 향후 작업에서 이러한 부분이 더욱 개선되어야 할 것이다.

주요어 : 네비게이션, 공간 지각, 방향 지각, 멀티모달 인터페이스, 음향 정위
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