Posicionamiento de fuente sonora virtual en navegación para personas invidentes

Virtual Sound Source Positioning for Navigation of Visually Impaired

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Resumen

Este artículo describe las opciones de crear un Espacio Acústico Virtual para propósitos de navegación de personas invidentes en un ambiente desconocido. La idea de navegación acústica está basada en el uso de sonidos posicionados virtualmente a través de audífonos, los cuales son presentados al cliente a través de un operador de cámara. Esta propuesta requiere una mirada cercana al efecto de movimiento de la cabeza y habilidad del operador de cámara para guiar al cliente con los estímulos sonoros para evitar los obstáculos existentes. El presente artículo continúa con la anterior investigación, extiende los primeros resultados y sugerencias y descubre nuevos aspectos para ser analizados.

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Palabras clave

Espacio acústico virtual, navegación, invidentes, HRTF, sonorización, seguimiento de cabeza.

Abstract

This paper deals with the options of creating Virtual Acoustic Space for the purposes of navigation of visually impaired people in unknown environment. The idea of acoustic navigation is based on using virtually positioned sounds presented through the headphones, which are performed to the client by camera operator. This proposal requires a closer aim on head motion effect and ability of the camera operator to lead the client by the sounds stimuli avoiding present obstacles. The presented article follows our previous research, extends first results and suggestions, and discovers new aspects necessary to be examined.

Keywords

Virtual acoustic space, navigation, visually impaired, blind, HRTF, sonification, head tracking.

I. Introduction

Last year, our team presented a complex set of suggested tests in [1]. These tests were aimed to discover the theoretical background and find and verify basic concepts of localization and positioning of the virtual sound source. This year, we present further branch of experiments focused especially on localization the sources during the subject movement in space. For our purposes the assistive device and the system described in [2] was used. The system consists of unique glasses equipped with two cameras at the usual place of eyes. New low-cost head tracking system was also established to perform localization experiments with dynamic movements. Three types of experiment were picked up and will be discussed below.

a. *Static Localization Experiment:* In this experiment the virtually positioned sound is presented to the subject in various locations, but all the head motions are not compensated and the absolute source position perception changes while moving.

b. *Static Navigation Experiment:* In this experiment the subject was navigated by the camera device from [2] through an obstacle race in experimental flat. The importance of this experiment lies in practical verification of the navigation options.

c. *Dynamic Localization Experiment:* A new device for tracking the head movements (Head Tracking Sensor) provides the information about relative head position to the source. This alows to compensate the head motion and fix the virtual sound source in an absolute virtual position.

II. Static localization experiment

In this type of experiments the virtually positioned sound is presented to the subject in various locations, taking into account the azimuth plane, but all the head motions are not compensated and the absolute source position perception changes while moving. The subject under the test is placed to the centre of the oval screen and marks perceived source position by a laser pointer, as it is shown in Figure 1. The Image system with two cameras evaluates the position automatically.

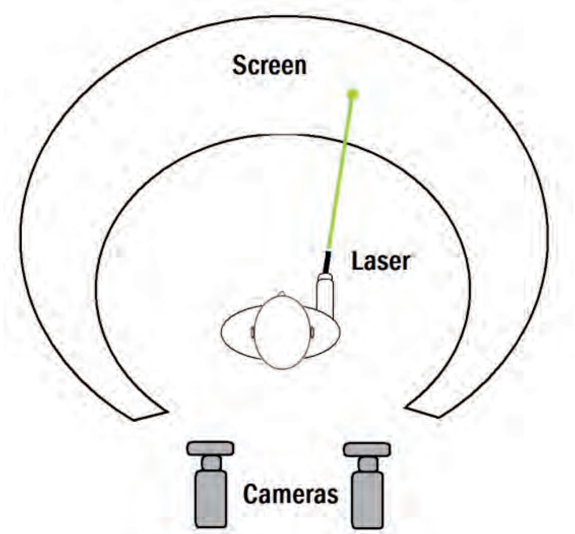

Figure 1. Top view of new set-up for static localization experiments. Subject under the test is placed to the centre of the oval screen and marks perceived source position by laser pointer. Image system with two cameras evaluates the position automatically.

III. Navigation experiment with static positioning

Perceiving virtually positioned sound in constant position of the subject is mostly important for data sonification in static applications e.g. computer interaction with the visually impaired person [5]. But for the purposes of personal navigation in unknown terrain, an experiment assessing the options of static virtual positioning (no head movement compensation) had to be set.

An alpha version of electronic device PERSEUS specified in [2] was used for our experiment. It is an interface between operator who navigates the visually impaired subject. This navigation device is a glasses-based video transmitter and audio receiver, which the tested subject wears, as shown in Figure 2. The operator obtains digital stereoscopic visual information about situation or obstacles in the direction of subject's movement. According to this information the operator uses a pointing device (computer joystick with multiple buttons) to determinate the direction where the subject has to go, specified in [6]. The virtual source in desired location is created and presented to the subject via the integrated headphones and the subject shall follow the perceived direction of the source.

Figure 2. Subject wearing the device PERSEUS with stereoscopic cameras and integrated headphones. Heavy limitation of this device is only 6.5 meters long wired connection between the operator and the subject.

During performing this experiment, our team was continuously finding some limitations, not only of the proposed equipment, but there were also high demands of adding additional information. It was very difficult to design the navigation test because of hard limitation of subject movement due to only 6.5 meters long wired connection between the operator PC set and the alpha prototype of PERSEUS device.

Originally the test was planned to be performed in open space, but finally the location of the test performance was moved into usual empty room with multiple obstacles (chair, camera stand, etc.). The task of the subject was to pass through the obstacle slalom race according to operator's instruction represented via virtually positioned sound. But even in this case another limitation occurred due to lack of information about nearby perimeter around the user.

As can be seen in Figure.3, the spatial range of the operator view is significantly limited to only approximately 45 degrees sector as in horizontal, as in median plane. Therefore, the obstacles in the close range to the subject are invisible to the operator. In case of using the ordinary obstacles as mentioned above, the subject in most cases hit the obstacle, because the operator led the subject to wrong direction not being aware of the obstacle presence. Forcing the subject to permanent looking towards his own toes is inefficient and unacceptable from the application principle point of view.

Figure 3. Operator camera view – the system provides enough information about space farther space in front of the user, but here is no information about obstacles in close distance to the subject (stair, curb, etc.)

Thus in this case the test had to be modified again. This time we focused on assessing orientation by virtually positioned sounds in buildings resp. in rectangular space. The path determined by hall corridors and wall corners can be easily followed from the operator view. Due to the cable length limitation mentioned above, the experiment was moved to model flat in CAT (Assistive Technology Center) in CTU building. This flat is designed for examining assistive devices in everyday life.

The task of the test was to reach the destination (restroom) from the starting point (kitchen) as shown in Figure 4. The operator station was half way. There were 5 subjects with no sight defect participating in the test – 3 of them were novices and 2 were trained before.

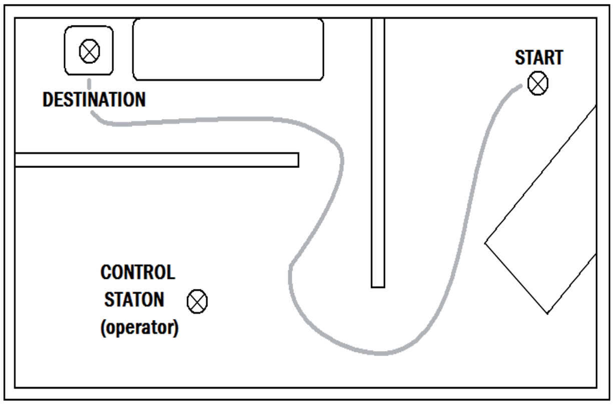

Figure 4. A scheme of the tested path – subject had to make three sharp turnings before reaching the destination.

It is important to notice that even if all the participating subjects are normally sighted, wearing the PERSEUS device completely blindfolded them. There were three sharp turnings on the path from the starting point to destination. Two different positioned stimuli were tested – wideband tone bursts and piano trill. The three non-skilled subjects were in the model flat for the first time, therefore they were not aware of the path shape. A shot from the test performance is shown in Figure 4.

Figure 5. Blindfolded subject wearing navigation system nearly reaching the destination. Wired-base limitation of the system prototype is obvious.

After performing the orientation test, it was difficult to find objective evaluation. Time of the walking and number of hitting obstacles were very subjective-dependent and not predicative. Selected conclusions shall be presented instead.

1. Narrow operator view is not only nuisance in case of lower situated obstacles but also the time when the subject crosses the corner is difficult to identify, therefore collisions sometimes occurs.
2. It is necessary to add some commands to additional joystick buttons such as *stop, forward, back, look around*, etc. There occurred situations, when the subject had to be stopped but there was no option.
3. Important factor is even the time the stimuli is presented to the subject. Rare presence of the stimulus leads to subject confusion, frequent presence becomes annoying.
4. Navigation through the virtually positioned sound also requires well-skilled operator, who can predict the behavior of the subject and also predict the spatial orientation of the obstacles from reduced viewpoint.

Despite all the hidden limitations, which occurred right when the pilot test was performed, all the subjects reported good ability to follow the path by the spatial sound information obtained from the operator. Training of the subject seems to be necessary to carry out in following examinations. In real applications, the combination of such kind of camera-out-audio-in navigation system (aimed on extending navigation range and directing the person) and the usual white cane (important to detecting obstacles in close range) is supposed to provide good orientation ability and independent movement in unknown terrain, as depicted in Figure 5.

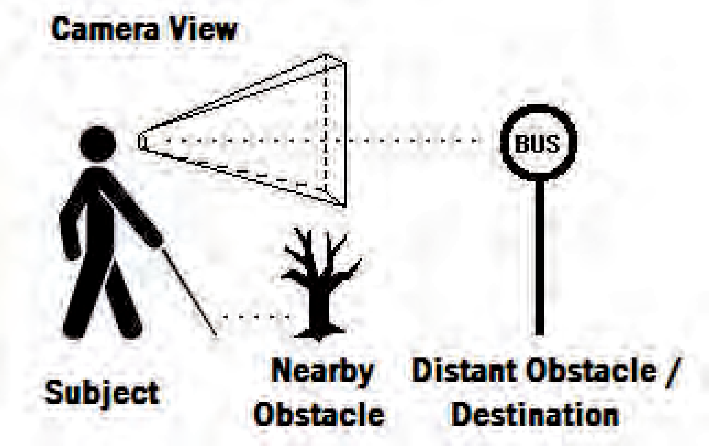

Figure 6. Combination of operator assistance and usual white cane provides as information about distant destinations as information about nearby obstacles

IV. Dynamic localization experiment

Par In previous static localization experiment (Chapter II.), an important factor of sound source localization has been neglected. It concerns the fact the hearing system improves the spatial sound source recognition by small head movements. These small movements significantly improve the localization especially in determining front-back position of the source [7]. When the head movement is neglected, the perceived sound position during headphone reproduction (the positioning method is based on headphone listening) is the same relatively to the listener, but not relatively to the surrounding space what corresponds with real situation. This fact is demonstrated in Figure 6.

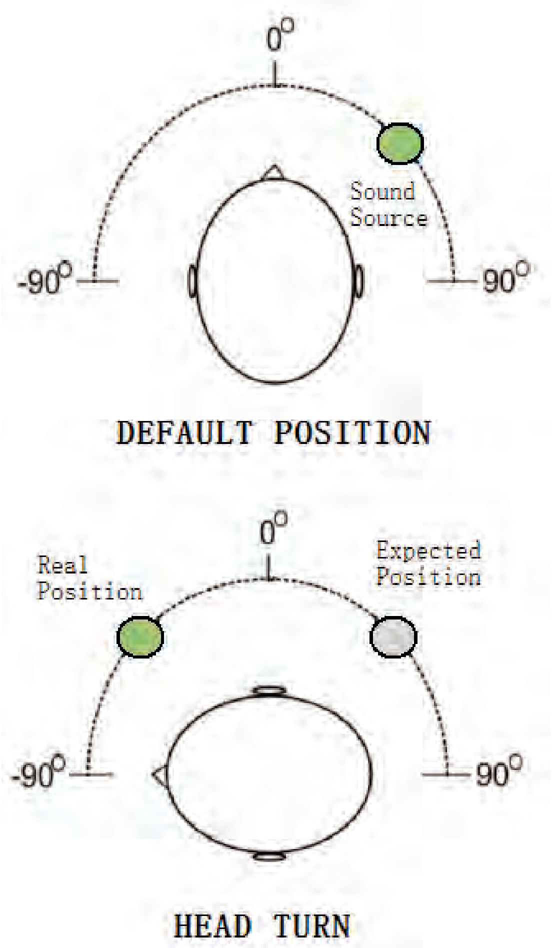

Figure 7. When the head motion is not compensated during headphone reproduction, the virtual sound source position follows the head (green dot position moves) and confusion occurs. A stable sound object position is required (source keeps grey dot position).

For these purposes a Head Tracking system has to be created and set. Such system provides information about absolute head position and, in case of head movement, enables the positioning signal processing to reselect presented virtually positioned stereo signal. For assessing of the impact of head tracking, another experiment was performed. Detailed measuring condition from the psychoacoustical point of view can be found in [8].

This time, the subject was sitting in front of a computer (equipped with standard web-camera), wearing specially modified cap with three triangularly placed LEDs, see Figure 7.

Figure 8. Subject during performing dynamic localization test. Head Tracking for system for head motion compensation consists of cap with LED triangle and computer with web camera.

This cap is part of the *FreeTrack* system solution used in computer games [9]. The *FreetTrack software* analyses the head movement through the web camera according to the LED geometry. As an output it emulates a pointing device (joystick), which is detected by the positioning Matlab program similar to [6]. The test sequence was created using method described in [3]. The test itself was focused on only azimuth plane, the movement in median plane was neglected. Each subject was presented by 24 stimuli situated in various virtual positions as in front of the subject, as behind the subject (the same as in the first test). The results of both localization tests (static and dynamic) are summarized in Table 1.

The efficiency of both methods is assessed by two coefficients. ALE (Average Localization Error) is defined by (1), FBC (Front-Back Confusion) is a mean value of mismatching the front-back position.

$$ALE_{HT|NHT} = \frac{1}{N}\sum_{k=1}^{N}\left|\xi_C - \xi_P\right| \qquad (1)$$

Where ζ_C stands for correct position, ζ_P for perceived position, N is number of presented stimuli. Indexes HT (Head Tracking) and NHT (Non-Head Tracking) define whether the head motions are compensated.

Subject	ALENHT	ALEHT	FBCNHT	FBCHT
1.	39.4	20.7	0.17	0.08
2.	45.0	1.9	0.39	0.00
3.	39.4	28.1	0.21	0.13
4.	42.3	18.2	0.24	0.11
average	41.6	17.2	0.25	0.08

Table 1. Static and dynamic localization test

Static and dynamic localization test was performed to four subject. Indexes ALE and FCB confirm that head motion compensation based on head tracking substantialy improves evaluation of virtual sound source position and reduces front-back confusion. Notice the results of Subject 2 who was able to make only one mistake during the test after short practicing. A disadvantage of proposed system was only 26 degrees posible head move to each side, which could affect the localization precision.

V. Conclusions

This article deals with the issue of virtual sound source positioning for the purposes of acoustic navigation in unknown spaces and extends our research published last year. The proposed methods are extended by the use of prototypes of assistive devices in practice. Three types of pilot experiments, which are supposed the specify further research, are presented. All the proposed experiments examine the virtual sound source localization issue for the navigation purposes from different points of view. Finally, all the findings shall fuse for creating useful and robust system for assisting visually impaired people.

Acknowledgement

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References

[1] D. Štorek, F. Rund, R. Suchan, «Virtual Auditory Space for the Visually Impaired - Experimental Background», In 2011 International Conference on Applied Electronics. Plzeň: Západočeská univerzita v Plzni, 2011, p. 314-318.

[2] S. Vítek, M. Klíma, L. Husník, D. Špirk, «New possibilities for blind people navigation», In 2011 International Conference on Applied Electronics. Plzeň: Západočeská univerzita v Plzni, 2011, p. 405-408.

[3] F. Saturka, «HRTF Synthesis - simplified model of elevation», POSTER 2012 - 16th International Student Conference on Electrical Engineering, Czech Technical University in Prague.

[4] D. Štorek, F. Rund, «Differential Head Related Transfer Function as a New Approach to Virtual Sound Source Positioning», submitted publication for Radioelektronika 2012, Brno, Czech Republic.

[5] G. Wersényi, «Localization a HRTF-based minimum-audible-angle listening test for GUIB applications». In *Electronic Journal «Technical Acoustics»*, 2007.

[6] F. Rund, «Audio Pointer V2 - Joystick & Camera in MATLAB», 19th Annual Conference Proceedings Technical Computing Prague 2011, Prague, p. 1-5.

[7] R. Algazi, C. Aveando, D. Thompson, «CIPIC HRTF Database», in Proc. IEEE WASPAA´01, New Platz, NY, 2001, http://interface.cipic.ucdavis.edu/.

[8] D. Štorek, «Graphical User Interface for Measuring the Just Noticeable Difference in Localization of Virtual Acoustic Sources» 19th Annual Conference Proceedings Technical Computing Prague 2011, Prague, p. 1-5.

[9] Free Track – freeware program to be found on: http://www.free-track.net/english/