VIRTUAL AUDITORY SPACE FOR VISUALLY IMPAIRED – METHODS FOR TESTING VIRTUAL SOUND SOURCE LOCALIZATION

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ABSTRACT

This article deals with issue of virtual sound source positioning for the purposes of acoustic navigation in unknown spaces and extends our research published last year. Navigation experiment was based on using PERSEUS assistive device. No appropriate standards in the field of performing subjective localization a navigation tests can be found. Our methods of design and evaluation of the listening and navigation tests are proposed and discussed. The following text is considered as an overview with references to our previous articles, which contain more detailed info.

1. INTRODUCTION

A huge increase of multimedia applications in last years pervaded even the area of assistive technology – the specific multimedia field, which purpose is to help people with various sense impairment. Our multimedia research group is dealing with this technology. One of our aim is to figure out how to effectively navigate blind persons in unknown natural environment (e.g. streets, public transport, shopping centers, etc.). In the beginning, our team presented a complex set of suggested tests [1]. These tests were created to discover the theoretical background and verify basic concepts of localization and positioning of the virtual sound source.

The next steps led to using PERSEUS device [2] (the device itself is described briefly in following chapter) for navigation in the indoor environment. After performing first pilot tests with this tool in real space, several problems occurred. There were no available standards how to design, perform, assess, and evaluate the listening tests focused on precision of localization of virtual sound sources and ability to be navigated by these 3D sounds. Methods for testing sufficiency of the positioning algorithm in static and dynamic conditions are discussed below. The limited success of navigation by PERSEUS device is also discussed.

2. PERSEUS ASSISIVE DEVICE

People with visual impairment are usually depended on help of other people (e.g. police officers) when they find themselves in unusual or unexpected situation. These situation may occur for instance when road work or parked car appear on ordinary well-known path. Thus the visually impaired person is finally stucked. The main purpose of PERSEUS (Personal Assistant for Blind User) device is to enable independent navigation of blind subject via an operator in such situations. PERSEUS is stereoscopic video transmitter and stereo audio receiver which can be considered as an interface between subject to be assisted and the operator. The system consists of unique glasses-based form equipped with two cameras at the usual place of eyes. The main idea of its use is as follows: The operator is called on demand. After activating the device the operator obtains digital stereoscopic visual information about situation or obstacles in the direction of subject's movement. This enables the operator to perceive the depth of the space in 3D representation. According to this information the operator uses a pointing device (e.g. computer joystick with multiple buttons) to define the direction where the subject has to go. The action of the operator sends virtually positioned stimuli to headphones of the device. Joystick-based communication with the interface is described in [3]. The subject can subsequently follow the direction of the presented stimulus to avoid the obstacles or to successfully reach the destination. Our research group suggested and developed a prototype of PERSEUS device, which is shown "in action" on live subject in Fig 1. Strong limitation of the prototype is only 6.5 meters long wired connection between the operator and the subject (will be discussed below). The system is planned to be completely wireless.

Figure 1. Subject wearing PERSEUS device with stereoscopic cameras and integrated headphones.

PERSEUS uses a bank of pre-positioned stimuli of different characters (white noise, speech, piano trill, etc.), which are selected from a data matrix according to operator's joystick action. The positioned stimuli are stored directly in the memory of the device with reasonable resolution (e.g. 5 degrees in horizontal plane) and each subject can have his own set. The concept is independent on stimuli and the method of positioning. It depends on the user's preferences (the user can also have more data sets, for various environments). The device is not limited only to positioning methods, user can prefer e.g. verbal marks. Therefore, there is no need to solve real-time processing for positioning. It shall be mentioned here exists a demand not to use directly operator's voice instructions in order to avoid distraction of the subject or to disturb concentration.

The software for the device was firstly implemented in MATLAB for testing purposes [3]. Real-time testing of the system, including head-tracking (correction of azimuth due to head movements) is provided by pure data implementation and also DSP version (SoundArt Chameleon device). For now, the subject-operator interface for the test performance is running under MATLAB system with 2D signal from one camera only. View of the operator is shown in Fig. 2. The camera being used provides approximately 45° sector as in horizontal, as in median plane.

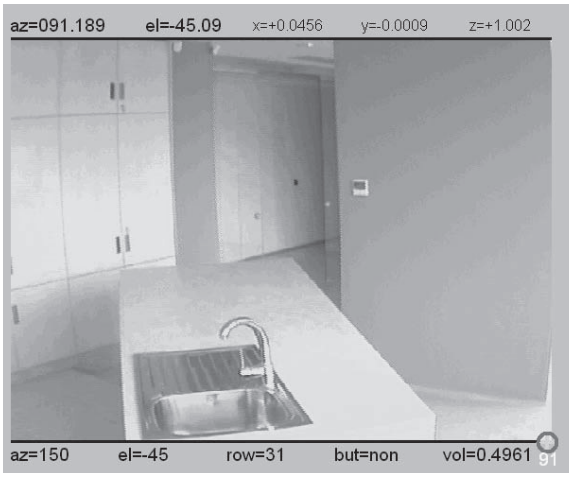

Figure 2. Operator camera view – the system provides enough information about farther space in front of the user, but here is no information about obstacles in close range.

In order to provide sufficient assistive tool in the final run, a need of exploration in two individual branches occur. It is important to deal with following.

- How to obtain well-positioned stimuli? Which positioning method is the best one? How to test it?
- How to assess efficiency of the tool? How to arrange communication between the subject and the operator without direct speech? How to test it?

These aspects of selecting, creating and evaluating of selected methods are discussed in the following chapters.

3. LOCALIZATION TESTS

Creating of virtually positioned sounds for our assistive system is based on processing the signal to be positioned by HRTF (Head-Related Transfer Function). All the stimuli are considered to be presented via headphones i.e. stereo system with two-channel independent sound distribution. The HRTF data is obtained either from our own measurements [4] or publicly available databases e.g. [5]. There is also an effort to implement and update already existing algorithms for synthesizing HRTF [6] or to create new algorithms for virtual positioning, such as Differential HRTF [7]. Personalization of an existing HRTF set is also in aim of our research, can be found in [8].

Localization tests can be divided into two groups. It depends whether the sound stimuli being presented to the listener responds to the listener's head movements or not. Both groups are briefly described below.

3.1. Static localization test

Static localization concerns arrangement, when the head movements of the subject are not compensated. When subject moves his/her head, when the stimuli is presented (via headphones), the absolute position of the perceived sound in space changes, but the position related to the listener's head is still the same. This phenomenon does not correspond to moving round sound sources in real situations. However, this phenomenon can be utilized in setting new methods for testing sufficiency of positioning methods. Our method, which is proposed in [9], is based on comparing position of real and virtual source. Real source - the reference - is placed directly in front of the listener, as shown in Fig. 3. As the next step the subject is presented by stimuli with virtual position. The task is to turn the head until the two sources overlaps in perception. The angle of the subject's (head) rotation finally corresponds to presented position of the virtual source.

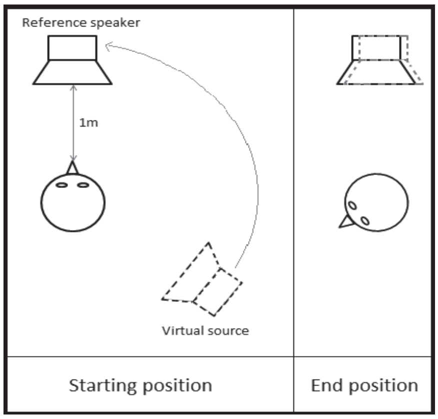

Figure 3. Diagram showing the test procedure. The starting position with the reference speaker in front of the subject and the virtual source at an azimuth that is unknown to the subject. The end position after the subject has rotated such that the reference speaker and the virtual source are at the same perceived position [9].

The first results from experiments using this method is shown in Fig. 4 below. The biggest localization error is well perceptible for back positions of the stimuli.

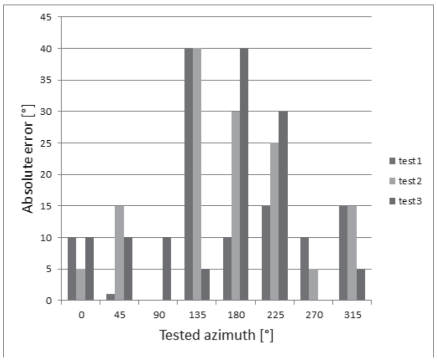

Figure 4. Bar chart showing the absolute localization error of the test subject during each of 3 test runs [9]

This method provides good results and subjects are more comfortable with understanding and completing the task. Previous approach using MATLAB GUI for testing the results [10] was finally considered as insufficient because answering the test's task was not intuitive.

3.2. Dynamic localization test

In real acoustic environment all sound sources change its position of subject's perception, when the subject moves. For example – imagine an arbitrary sound source placed directly in front of the listener. The source is perceived front. When the listener turns his head clockwise for 90°, the source is finally perceived in front of the left ear. Therefore, the absolute position of the sound source is preserved.

This can be achieved by compensation (i.e. correction) of the virtual source position by head-tracking system. Such system captures head movement and its output information is used to correct position of the virtual source. This method was implemented and verified in MATLAB, more information can be found in [11]. Implementation of this system is currently tested in Pure Data with external head-tracking based on MIDI protocol communication. This method is very useful for testing externalization or front-back confusion of selected positioning method.

4. TESTING OF NAVIGATION

In order to verify possibilities of practical use of virtual positioning, navigation test with subjects using PERSEUS was arranged. Due to cable limitation of the device the experiment was situated to rectangular model flat in CAT (Center of Assistive Technology) in CTU buildings. This artificial flat is designed for examining assistive devices in everyday life. Task of each subject was to follow a path across the flat according to operator's instructions presented by virtually positioned sounds and reach the destination. It was necessary to avoid obstacles and pass safely round corners and walls. Scheme of the flat platform with marked path is shown in Fig. 5.

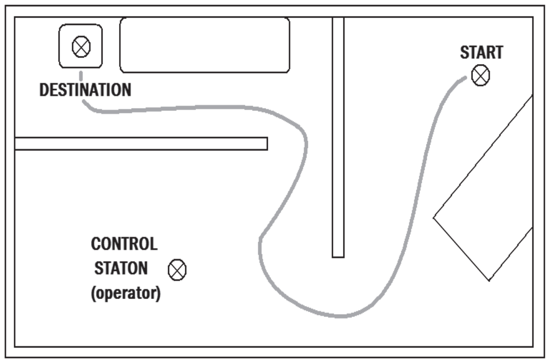

Figure 5. A scheme of the tested path – subject had to make three sharp turnings before reaching the destination.

Subject were divided into two groups according to the fact whether they are familiar or unfamiliar with the flat arrangement. During performance of this experiment, our team was continuously finding some limitations. As shown in Fig. 2 the spatial range of the operator view is significantly limited. Therefore, obstacles in close range to the subject are invisible to the operator and collisions sometimes occurred. Another limitation was passing flat corners. When the subject crosses the corners, it is difficult to identify whether he/she has already passed the corner or not and if it is safe to make sharp turn and continue. Forcing the subject to permanent looking around in order to extend operator's view is inefficient and unacceptable from the application principle point of view. It is also necessary to add some extra commands to additional joystick buttons (*stop*, *forward*, *back*, *look around*, etc.). There occurred situations, when the subject had to be stopped but there was no option. Important problem to solve is also the length of stimuli presence in headphones. Rare presence of the stimuli leads to subject's confusion, frequent presence becomes annoying soon. 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.

Figure 6. Blindfolded subject wearing navigation system nearly reaching the destination. Wired-base limitation of the system prototype is obvious.

After performing the orientation test on several subjects, it was found very difficult to find any objective method for evaluation of the test. Raw walking time and number of hitting obstacles were very subjective-dependent and not predicative. Essentially the only significant factors were the ability of reaching the destination and comfort of the subject. Despite all the hidden limitations, which occurred during the pilot test, most of the subjects reported good ability to follow the path according to the spatial sound information obtained from the operator. Training of the subjects 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 commonly used white cane (for discerning close-range obstacles) can provide sufficient results for medium distances e.g. searching for bus stops, as briefly suggested in Fig. 7.

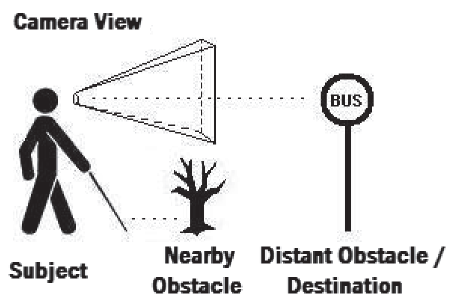

Figure 7. Combination of operator assistance and usual white cane provides as information about distant destinations as information about nearby obstacles.

5. CONCLUSIONS

This article introduces experiments focused on ability of navigation of visually impaired persons in space via virtually positioned sounds presented through subject-operator interface. This issue consists of multiple side quests to be solved (see references). The most important is methodology of testing efficiency of virtual positioning and methodology of navigation experiments. New method for testing precision of virtual source localization was introduced in Section 3. This method provides good results within the meaning of participation of the subject. For more details of this method see [9]. Our team arranged and performed pilot navigation experiment with PERSEUS device. Base of the experiment is described in Section 4. Several problems (e.g. stimuli presence, corner detection, additional commands for the subject, etc.) occurred after experiment performance. The problems are discussed in the same section. Methods of testing navigation in real environment have to be improved permanently step-by-step as there is no available standard. In further work it is necessary to propose and design complete form of communication between operator and the subject, which will be able to provide enough sufficient instruction for independent movement.

6. ACKNOWLEDGMENT

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