BINAURAL SOUND ANALYSIS AND SPATIAL LOCALIZATION FOR THE VISUALLY IMPAIRED PEOPLE

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ABSTRACT

The blind people face serious difficulties concerning exclusion from working activities, lack of social involvement and having a sedentary lifestyle. The blind individuals can, however, enhance their life quality by using powerful and effective assistive devices that would help them to perform navigational and orientation tasks and to build a rich mental representation of the environment. An assistive system for the visually impaired people needs to fulfill certain usability requirements, such as to be wearable and affordable and to provide a large quantity of information as efficiently as possible in order to give the user a natural-like perception of the settings. The purpose of our research is to develop an assistive device for the blind people, based on alternative sensory modalities, such as hearing (by encoding the visual information into sound) and touch (by providing additional information through vibrations and other haptic cues). This paper presents the results achieved so far in our research, concerning the sonification and training techniques that will be applied for the development of the proposed assistive system.

KEYWORDS

3D sound, training, HRTF, virtual auditory display, haptic, blind people.

1. INTRODUCTION

In the scientific community, there have been significant attempts to develop information systems that would assist the blind people to accomplish different activities, such as navigating open or closed environments, gain spatial awareness or build a solid cognitive representation of the settings. There are several systems that enable the visually impaired people to use the computer, public transportation or to navigate in unknown environments. However, very few of them provide a high degree of independence and feasibility, as they fail in allowing the blind users to develop orientation and mobility skills and to navigate safely under unfamiliar circumstances [1] [2] [3]. Nowadays, due to the advances in computer technology, medicine and neuroscience, we believe that the development of a cost-effective, wearable and powerful assistive system that would replace sight by another sense can turn to be a realistic approach towards improving the life quality of the visually impaired people.

2. THE PROPOSED ASSISTIVE DEVICE

The system we intend to develop aims to provide a rich, continuous, real-time visual reconstruction of the environment that will be delivered to the user through spatialized 3D sounds and vibration cues. Thus, our device will offer a complex perception of the surrounding space, by emphasizing in particular the characteristics and dynamics of the objects and events that are of significant interest for the user. The data acquisition module will continuously scan the environment, acquiring real-time depth and color information that will be further processed, resulting in a set of relevant 3D objects. The next step consists in creating a spatial acoustic 3D model that would define the location and features of the target objects, based on a sonification technique that would employ 3D sounds, earcons, auditory icons, speech and by adjusting the physical parameters of the sound, such as pitch, amplitude and timings between two consecutive stimuli [4].

This research is oriented towards improving the blind people's spatial hearing resolution through perceptual feedback based training, multimodal sensorial adaptation (visual, auditory and haptic) and procedural learning [5] [6]. For this, we performed a series of experiments with both sighted and visually impaired subjects, in order to study and compare the level of spatial auditory performance they can achieve as a result of training. The theoretical and practical results obtained in my research will be used for creating an effective strategy for improving the sound localization accuracy of the visually impaired people (in respect with the development of a sensory substitution device aimed to provide a rich representation of the environment) and for designing audio games that are targeted for both the blind community and for the sighted players who want to try an alternative type of games [7] [8].

3. TRAINING THE SOUND LOCALIZATION SKILLS OF THE VISUALLY IMPAIRED PEOPLE

In this chapter, we intend to describe a strategy towards improving the sound localization accuracy of the blind and visually impaired people. This strategy is based on perceptual training and sensorial adaptation to 3D sounds synthesized with non-individualized Head Related Transfer Functions (HRTF). The HRTFs are a response that defines how the ear perceives a sound originating from a particular location in space [9]. They significantly depend on the anatomical features of the human body, such as size and shape of the pinna (the external ear), head and torso. These specific differences do not permit the use of the same HRTFs for all the listeners, as they would conduct to large localization errors and to an ambiguous acoustic perception [10]. Unfortunately, the use of individualized HRTFs in sound localization experiments or in virtual auditory environments is a very difficult task, due to the highly demanding measurement technique (it can take up to several hours to record the transfer characteristics for all the possible positions in the horizontal and in the vertical plane) that is tedious and tiring for both the subject and the experimenter [11]. Individualized HRTFs would conduct to a perfect virtual-reality auditory system but, as they are difficult to be obtained, most of the virtual auditory displays employ generic or non-individualized HRTF filters that lead to a decreased sound localization accuracy [12].

Our approach is built upon perceptual feedback based training, as a practical and effective solution towards improving the spatial auditory resolution in virtual acoustic systems and audio games. Thus, we developed a learning procedure aimed to help the visually impaired subjects to adapt to auditory cues that are different from their own by using haptic, visual (in the case of the subjects who have a higher degree of residual vision left) and acoustic feedback. Moreover, our training strategy intends to help the users recalibrate their spatial acoustic representation in unfamiliar virtual environments and to enhance their orientation and mobility abilities in navigational audio games or 3D sound based electronic travel systems. The proposed sound localization experiment has as main goal to improve the precision angular accuracy and to reduce the incidence of reversal errors (front-back and back-front confusions, situation in which the listener perceives the sound as originating from the opposite plane across the interaural axis – the axis that passes through the ears, dividing the horizontal space into the frontal and rear hemifields). As the rate of front-back confusions is relatively high when the listeners are exposed to 3D binaural sounds generated from non-individualized HRTFs, we considered devising a method for creating 3D audio stimuli that would enable the subjects to differentiate between the sources located in the front and in the back planes. Thus, we combined white and pink noise in varying proportions, according to the direction of the sound source in space, so that at 0 degrees to the front the listener perceived 100% white noise and 0% pink noise, at 90 degrees (to the left) and 270 degrees (to the right), the percentages of white and pink noise were equal (50%-50%), while at 180 degrees (to the back), the listeners could hear only pink noise. This spectral coloration of the sound helped the users to differentiate between the sound sources situated in the back and in the front, by creating a mental association (acquired as a result of the training process) between the spectral profile of the sound and the correct direction of its source.

Our experiment consisted of a pre-test, a training and a test session. In the pre-test and in the post-test sessions, the nine visually impaired listeners were required to listen to 3D sounds and to identify the location of a hidden target. The sonification technique was based on the inverse proportional encoding of distance, so that as the user got nearer to the target, the intensity of the sound increased and, on the other hand, when he got farther, the volume decreased until complete silence (outside the auditory area). During the training session, the subjects were asked to listen to a series of auditory stimuli and to indicate (using the conventional hour hand of the clock) the perceived direction of the sound. After the experimenter introduced the subjects' choice, they were offered instant haptic, auditory and visual feedback. The auditory feedback consisted in playing again the target sound over headphones.

On the other hand, the haptic feedback was provided through a series of vibrations on a haptic belt (that the listeners were required to wear on their heads) which were perceived from the same direction as the sound source. In addition to this, the visual feedback was offered graphically on the screen (for the subjects who had a higher degree of residual vision) – the subject's choice was colored in red, while the correct direction of the sound was colored in green (Fig. 1). In this way, the visually impaired subjects benefitted from various sensory perceptual experiences that allowed them to effectively create an association between the acoustic perception of the stimuli and the correct direction of the sound (Fig. 2).

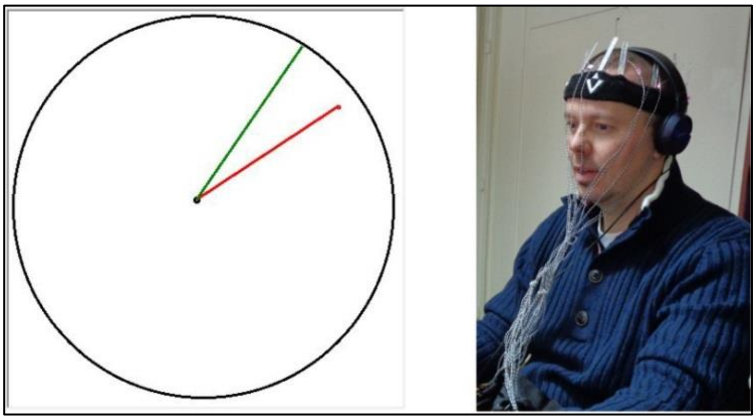

Figure 1. Visual (left) and haptic (right) feedback during the training session

Figure 2. Visually impaired subject and the experimenter during the haptic training session

The results of our experiment demonstrated that the visually impaired subjects succeeded to achieve a rapid adjustment of the auditory system in response to 3D sounds synthesized from non-individualized HRTFs, due to the crossmodal interaction between the auditory, visual and haptic senses. In addition to this, they improved their spatial auditory abilities, by reducing the front-back confusion rate and angular precision errors between the pre-test to the post-test session of the experiment, as a result of the training procedure. The adaptation process was rapid, demonstrating that the learning effect was enhanced by other cognitive mechanism, such as attention and focus. Moreover, the visually impaired users enhanced their spatial auditory resolution, navigational and orientation skills and decision-making abilities.

As a result, we can conclude that that training plays a fundamental role for auditory adaptation to altered hearing conditions and that a rapid adaptation of the auditory system to non-individualized HRTFs is possible through a spatial map recalibration with multimodal sensory associations. The proposed model can be considered an effective training tool for the future development of audio-only games or for the design of the assistive device aiming to provide a rich representation of the environment that will be delivered to the end-users through 3D binaural sounds and haptic cues.

3. CONCLUSIONS

To sum up, our paper briefly presented the results obtained so far in our research that is focused on developing an assistive device for the visually impaired people. Thus, we succeeded in developing a sound localization training strategy based on auditory and haptic feedback that significantly enhanced the spatial auditory resolution of the nine visually impaired subjects who participated in the experiment.

The results of the post-test session proved that the subjects have been able to use 3D binaural sounds as the only means for navigating in the virtual auditory environment. In addition to this, they improved their spatial auditory resolution, sound localization accuracy, orientation and mobility skills and directional decision-making abilities.

In conclusion, the proposed approach can be considered a useful training and rehabilitation tool for the future development of audio-only games or for the design of an assistive device for the blind people. Our research will continue by designing a navigational audio game (with hierarchical levels of difficulty), using the same sonification method as in the previous applications. Moreover, we intend to increase the duration of the training session and to make some non-invasive BCI EEG measurements for studying the subjects' neuroplasticity during the practice of the game. The results that will be obtained will be integrated into a training procedure for using the auditory sensory substitution device which will be developed in the next 2 years and for designing other audio games that will be available on an online platform dedicated to both the blind and the sighted players.

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