ABSTRACT
This paper introduces DarkVR, a virtual environment designed to give the blind experience to sighted people. In DarkVR, people can explore two different environments, relying completely on hearing. Thereby, DarkVR provides not only a fun challenge, it also helps to raise awareness for the problems of visually impaired in an engaging manner. To give the best 3D audio experience, state-of-the-art sound engines are combined with head tracking to let the sounds appear static in a 3D space. A preliminary user-study with 6 subjects showed the potential and future challenges to make DarkVR a success.

Categories and Subject Descriptors
H.5.2 [Information Interfaces and Presentation]: User Interfaces—auditory feedback

Keywords
Virtual reality, 3D audio, blind, dialogue in the dark

1. INTRODUCTION
The project aims to create a virtual reality environment without visual cues and without substituting visual cues by auditory cues (e.g. playing the sound of a creaking door when you stand right in front of a door). The aim of the project is to create and experience a virtual world as close as possible to how non-sighted people would experience the real world. Therefore, two virtual worlds were created that can be explored relying on hearing only.

The state-of-the-art 3D audio engine FMOD\(^3\) was combined with magnetic head-tracking in order to let the sounds appear static in 3D, independent of head movement. To further assist navigation, the user can use a virtual cane which provides auditory feedback when hitting objects in the virtual environment. Figure 1 shows the system in use.

The remainder of the paper is structured as follows: Section 2 briefly reviews related work. The whole system is then introduced in section 3. The design of the user study is described in section 4, followed by the evaluation of the results. Section 6 concludes the paper with a discussion of the results and future work.

2. RELATED WORK
This work is most closely related to the Dialogue in the Dark project\(^2\). Dialogue in the Dark is an exhibition which lets sighted people experience the world of visually impaired and, thereby, raises awareness for the problems non-sighted are faced everyday while navigate through the world. Since the created environments are replicas build in an indoor space, the scenarios that can be rebuild are very limited. A virtual reality can help bringing the blindness-experience to scenarios that are too expensive to rebuild (e.g. navigating through an entire city) or too dangerous (e.g. due to traffic).

The work is also related to video games for blinds. Video games for blinds can be roughly classified into two categories: (1) games, which were initially designed for blinds, and (2) games which have been made accessible to blinds. Games of the first category often either use a combination of

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**Figure 1:** The DarkVR system. User experiencing the zoo environment blindfolded completely relying on hearing.
The keyboard and the trackers is processed and compiled into the continue game loop. During each cycle, user input through graph is loaded from a 3D model file, the program runs in a method that allows for head motion relative to the body. Once the scene graph is shown in figure 3. It is worth noting that different levels of abstraction. Audio cues are the least abstract way of replacing visuals with audio. Audio cues are sounds that an object would make in the real world (e.g. footsteps of a walking person). Auditory Icons or ear cons are sounds which are associated with an object, even though the object would not make this sound in the current situation (e.g. playing the sound of a creaking door when you stand in front of it, even if the door is not moving). Sonification is used to translate physical properties of an object into sound. These sounds are usually artificial. Properties like pitch or frequency are used to represent other properties like distance.

In contrast to the many attempts to making a virtual world accessible for the blinds, this project aims to create an experience which is as close as possible to the real experience of blindness. Therefore, accessibility methods like auditory icons/ear cons and sonifications are not used on purpose. Instead, the user navigates through the world relying on 3D binaural audio and devices like a virtual long cane or a virtual GPS localizer. DarkVR, therefore, does not only give the possibility to experience blindness, it also gives the possibility to try out imaginary devices that might help blinds in the future to navigate and orientate in the real world.

3. IMPLEMENTATION

DarkVR is a virtual environment that simulates the perception of the world of visually impaired. An overview of the setup is shown in figure 2. The system consists of a laptop, a magnetic field source, two trackers (one for the head and one for the virtual cane), headphones, and a sleep mask or a scarf. The world is also visualized in 3D in order to enable other people to provide assistance to the user.

This section describes the implementation of DarkVR. First, the design of the software is briefly introduces, followed by the design of the soundscape. This section concludes with a description of how virtual worlds can be modeled followed by a brief description of two examples environments: a zoo and an apartment.

3.1 Software Design

3.1.1 Overview

The software builds upon OpenSceneGraph[7], a high level 3D graphics library based on OpenGl[8]. All 3D models of the world, the avatar, the cane, and various 3D sound sources are organized in a scene graph. The basic structure of the scene graph is shown in figure 3. It is worth noting that the body is further divided into the main body part (Body Node) and the head part (Head Node). This division allows for head motion relative to the body. Once the scene graph is loaded from a 3D model file, the program runs in a continuous game loop. During each cycle, user input through the keyboard and the trackers is processed and compiled into scene graph and soundscape modification.

3.1.2 Tracker calibration

In order to ease the use of the system, the head tracker can be attached to any location on the head. The head tracker is than automatically calibrated when the system starts. Therefore, the head has to be in a normal position looking straight when the system starts. The initial tracker position and orientation at the start of the system is later used to calculate the head movement relative to the initial position.

Since the position of the cane tracker relative to the cane is fixed, this tracker does not need to be calibrated every time the system starts. In order to be independent of the placement of the magnetic field source, the position of the cane relative to the body is normalized using the initial head position.

3.1.3 Controls

The avatar can be moved using the keyboard. The basic hotkeys are summarized in table 1. The user can choose between two different rotation modes: discrete and continuous. In discrete mode, the user rotates around a certain amount (e.g. 45°) when hitting a rotation key. The user has to release and press again the key in order to further rotate. In order to avoid collision while rotating, the avatar is shaped like a cylinder. This makes navigation easier, once the user has hit a wall.

The virtual cane can be controlled with the wooden wand. The virtual cane obeys the full range of 6 degrees of freedom.

3.2 Sound Design

The first part of DarkVR’s sound engine is a wrapper around the FMOD Sound System[9], which is used to output 3D spatial audio. FMOD provides realistic 3D audio using head-related transfer functions (HRTFs). It also calculates realistic audio occlusion using the 3D geometric model of the world. Therefore, 3D models described by the scene graph scene graph the sound engine is a wrapper around the FMOD Sound System, which is used to output 3D spatial audio. FMOD provides realistic 3D audio using head-related transfer functions (HRTFs). It also calculates realistic audio occlusion using the 3D geometric model of the world. Therefore, 3D models described by the scene graph
are translated to FMOD's internal geometry representation.

The second part of the sound engine is a powerful sound event manager, which queues and triggers randomized sound events. The time between two events is drawn from a uniform distribution. The time minimum and maximum delay between two occurrences can be specified individually for every sound event.

The sound engine also handles triggered sound events that are the result of the interaction of the avatar or the cane with the world. When the avatar moves, a footstep sound is played which depends on the material of the ground under the avatar. A collision of the cane with the world triggers a sound as well, which depends on the material of the hit object.

3.3 World Design

The 3D world can be modelled using any 3D modelling program that can output 3D models in a format that can be read with OpenSceneGraph. The models of the first prototype were created using SketchUp 3D and exported as COLLADA 3D models. Since most modelling programs are not made for sound design, sounds are modelled as 3D objects, too. Sound source properties (e.g. the audio file name, the minimum distance, or the volume) and audio material properties (like wooden, grass, water, . . .) are encoded in the name of the object. The two created worlds from a bird’s-eye view are shown in figure 4.

3.3.1 The Zoo

The terrain of the zoo is a remodelling of parts of the Zoo Leipzig[13]. The placement of animals are arbitrary. The zoo features different birds, elephants, tigers, monkeys, hippopotamus, sea lions, and frogs, with 3 to 7 different sounds per animal. The ground is made of 5 different materials (parkway, grass, hollow wood, stone, and water). Each material comes with a distinctive footstep and cane hit sound.

3.3.2 The Apartment

The apartment consists of 8 different rooms and a basic outer iour. Different ground or floor types are carpet, concrete, linoleum, tiles, and grass. Some rooms have a sound attached to it. There is one room with a playing radio that can be heard throughout the apartment. Rooms can not be identified by the ground material alone since some rooms share the same flooring. E.g. the bathroom and the kitchen are both tiled but the fridge is only audible in the kitchen.

4. STUDY DESIGN

The objective of study was to evaluate if the use of the program can raise awareness for the problems of visually impaired. Therefore, a questionnaire was used to assess the awareness before and after the subjects had solved a few tasks within DarkVR.

4.1 Participants

The test group of the user study consisted of 6 participants (5 male, 1 female) in the age between 20 and 40 years. All of them were familiar with computer games in general. None of them had experience with visually impaired people.

4.2 Study Procedure

After a short introduction, each participant had the chance to get familiar with the control of the program. Therefore, they were asked to move freely in the zoo without the blindfold and to get familiar with different footstep and cane hit sounds. Then, the participants were asked to put on the blindfold.

The first task was to follow a trail in the zoo. This task required to listen to footstep sounds in order to detect when the avatar leaves the trail and to use the cane in order to distinguish a bend to the right from a bend to the left. The second task was to find the elephants in the zoo and to identify one more animal. The subjects were allowed to move freely in the zoo without having to stay on the trail. “Looking around” was helpful in order to localize sounds better in 3D.

The last task took place in the apartment. In contrast to the zoo scene, the rotation mode was changed to discrete, which simplifies the navigation in mainly orthogonal environments. In the first step, the participants were guided through the apartment with simple voice commands from the tester. They were also told in which room they are in. After the introduction, the participants were guided into different rooms and they were asked to tell, in which room
they are in. The performance of the subjects in all three tasks was not measured. They were merely used to let the subjects experience the virtual environment in a more challenging setting.

4.3 The Questionnaire

The questionnaire was divided into three parts: personal information, questions that were to be completed before and after the experiment. In both parts, subjects were asked to rate the difficulty of the following tasks for visually impaired on a 5 level scale: “crossing a street”, “walking in a park”, “navigating in an unknown apartment”, and “navigating in a known apartment”. They were also asked to imagine, which other tasks might be difficult for visually impaired. A second set of questions was used to identify the importance of several cues for the navigation.

5. RESULTS

The usability of the program was rated as easy and intuitive by all subjects. Difficulties to solve other tasks are hence mainly caused by the lack of visual feedback. The quality of the implementation (e.g. localization of 3D sounds) was rated as good by most participants.

In order to measure if the use of the program can raise the awareness of the problems of visually impaired, the rated difficulty for certain tasks before and after the experiment were compared. The result of the comparison is shown in figure 5. Most tasks were rated more difficult after the experiment by most subjects. However, the variation between subjects is too high to conclude that the increase in rated difficulty is statistically significant. The “navigation in an unknown apartment” task was even rated easier after the experiment. A possible explanation for this result is, that the task might have been too simple. In previous tests, the navigation in the apartment without help was perceived as being too difficult. Therefore, the participants were guided throughout the entire task using voice commands, which might have decreased the difficulty too much.

4 of 6 subjects have identified more difficult tasks for visually impaired after the experiment. While some of them are directly related to the newly gained experience (e.g. subject 4 answered after the experiment, that it is difficult for visually impaired to operate technical equipment like computers), others could also be explained by the fact, that the participants merely had more time to think about potential problems.

The last questions were posed to help improving future version of the program. Therefore, the subjects were asked which cues they think are important for navigation. Most subjects agreed that force-feedback of the cane and vibration of the cane on different ground would be very helpful.

Figure 4: The two created environments from the bird’s-eye view. Small blocks in the zoo represent the different animals.

Figure 5: Change of rated difficulty on a 5 level scale of the following tasks: (1) “crossing a street”, (2) “walking in a park”, (3) “navigating in an unknown apartment”, and (4) “navigating in a known apartment”. The standard deviation is indicated by the error bars. The standard deviation is too large to detect a significant increase in the rated difficulty.
6. DISCUSSION AND FUTURE WORK

The evaluation of the user study has revealed that even though it is still unclear, if DarkVR can help to increase awareness for the problems of visually impaired, the approach bears some potential. However, auditory cues alone are not sufficient to facilitate a satisfying navigation in an unknown environment without visual cues. I anticipate that the use of 6 degree force-feedback devices like the PHAN-TOM\[9\], will greatly increase the possibility to navigate freely without too much assistance, in order to provide a more realistic blind experience. The enables the implementation of more realistic scenarios which are better suited to raise awareness of the problems of visually impaired.

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8. REFERENCES