THE WALKING GAME: A FRAMEWORK FOR EVALUATING SONIFICATION METHODS IN BLIND NAVIGATION

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ABSTRACT

To overcome the existing limitations in the design and evaluation of reproducible sonification methods, a framework that allows for the formal comparison of sonification methods is presented. This platform is defined within the context of SonEX (Sonification Evaluation eXchange), a community-based environment that enables the definition and evaluation of standardized tasks, supporting open science standards and reproducible research. The proposed framework provides a virtual environment for a blind navigation task where subjects must guide an avatar to a target point avoiding obstacles using only auditory cues. Researchers submitting their algorithms for evaluation interface with the platform receiving information about the position and properties of the obstacles and sonify this information using their proposed algorithm. In order to find the most effective sonification method, the performance of the algorithms submitted by different researchers can be then statistically evaluated and compared in terms of both objective (number of collisions and execution time) and subjective measures (user ratings). The architecture and interface of this framework are described. This framework will be used during the sonification hack day that will be celebrated together with the 4th Interactive Sonification (ISon 2013) Workshop at Fraunhofer IIS in Erlangen, Germany. In order to promote reproducible research, the framework will be made publicly available.

1. INTRODUCTION

Sonification and Auditory Display research takes place in a community that builds upon a wide range of disciplines, from physics to signal processing and musicology. Application examples range from auditory displays in assistive technology for visually impaired people to data exploration and industrial process monitoring [1]. Auditory Displays are systems that transform data into sound and present this information to the human user using an interface to allow the user to interact with the sound synthesis process. This transformation of data into sound is called sonification, which can be defined as the systematic data-dependent generation of sound in a way that reflects objective properties of the input data [2]. The aim of Auditory Displays and Sonification is to exploit, among other capabilities, the ability of our powerful auditory sense to interpret sounds using multiple layers of understanding, perceive multiple auditory objects, turn our focus of attention to particular objects and learn and improve the discrimination of auditory stimuli.

The use of sonification for navigation, visual substitution and obstacle avoidance is of great importance in auditory display research for its potential application to assistive technology for the visually impaired and other eyes-free applications. The aim of this technology is to deliver location-based information to support eyes-free navigation through sound [3, 4, 5]. However this is a challenging task as described in [6]. The first challenge is to design a meaningful auditory display that is able to communicate relevant aspects of complex visual scenes efficiently as sound. A large number of possibilities to represent information of physical obstacles as sound objects exist and selecting the most appropriate is not a trivial problem. The perception of sonifications is highly influenced by psychoacoustic factors which impact the localization of objects. Particularly in long-term and frequent use, aesthetics is another important factor. The resulting sound must be accurate in terms of the location-based information communicated but it has to be also attractive to the user.

Multiple sonification methods for visual substitution, navigation and obstacle avoidance can be found in the literature [6]. In general, these methods scan the space to look for potential obstacles and synthesize the position or other properties of the scene using different sound rendering modes. These modes include depth scanning [3], radar and shockwave modes [4]. There are also approaches where a non-blind external operator that analyses the received image and traces the direction to be followed [5]. The sonification algorithms used to synthesize the sound are based on Parameter-Mapping [7] and Model-based sonification techniques [8].

Despite all this work, a robust evaluation and scientific comparison of the effectiveness of the sonification methods used in assistive technology is often neglected by auditory display researchers. Note that we center our discussion about the sonification algorithm itself, the transform used to render the sound from the data, and not the whole auditory display [2] which is obviously more difficult to evaluate. In the Auditory Display community, the decisions about the selection of the sonification method and its corresponding parameters are made based on the subjective decision of the researcher in most of the cases. Also, sonification algorithms are not usually compared with state-of-the-art techniques as shown in [9]. One of the main reasons is that sonification research is, in many cases, not reproducible [10], either because either the software or the database is not available. In some other cases the sonification method is not described with enough details to repeat the experiments. As a consequence, sonification researchers do not have baseline methods for comparison and we are not able to assess which sonification algorithm is the most effective for assistive technology tasks and advance and build our systems based on each others work.

To overcome the existing limitations in the design and evaluation of sonification methods, we present in this paper a framework that allows for the formal comparison of sonification methods for navigation and obstacle avoidance. The architecture of and interface of this framework are described. The *Walking Game* platform provides a virtual environment where subjects must guide an avatar to a target point avoiding obstacles and barriers as fast and accurate as possible using only auditory cues. Researchers receive information about the position and properties of the obstacles the avatar faces and sonify this information using their proposed algorithm. In order to find the most effective sonification method, the performance of the algorithms proposed by the different researchers can be then statistically evaluated and compared in terms of both objective (number of collisions and execution time) and subjective measures (user ratings). In order to allow the formal comparison of the candidate methods with future competitor sonification algorithms, we follow the guidelines for reproducible sonification introduced in the SonEX (Sonification Evaluation eXchange) environment introduced in [9]. SonEX allows the definition of standardized sonification tasks and corresponding evaluation measures to benchmark algorithms, and the *Walking Game* is a first task example.

The framework described in this paper will be used during the sonification hack day that will be celebrated together with the 4th Interactive Sonification (ISon) Workshop at Fraunhofer IIS in Erlangen, Germany. Researchers participating in this hack day will submit their sonification algorithm for blind navigation and a formal evaluation of the performance of the proposed algorithms will be carried out. Algorithm benchmarking is a common practice in many research communities and it contributes to the development of new and very competitive methods as can be seen in the Music Information Retrieval (MIR) community [11]. In the context of the International Community on Auditory Displays (ICAD), several competitions have been run. However, these contests were focused on the aesthetics of the task instead of an objective measurable objective and the databases and software have not been released [9]. On the contrary, our aim is to formalize the proposed job as a task to be run with every ISon or ICAD conference to challenge researchers, compare their results and advance on the development of proper sonification methods. This work constitutes a first approach and many other tasks could be defined following SonEX [9] to enable for reproducible research within the Auditory Display community.

The outline of the paper is as follows. Section 2 describes the *Walking Game* framework in terms of its architecture and interface. Then, Section 3 describes how the task will be defined, the structure of the hack day and how sonification methods will be evaluated. And finally, conclusions and future work are presented in Section 4.

2. SYSTEM DESCRIPTION

The framework described in this paper defines the first evaluation task for reproducible sonification within the context of SonEX [9]. Researchers will submit their sonification algorithms and a formal and scientific evaluation of different sonification methods will be carried out. Although the task focus on blind navigation, the ideas described in this work can be easily extended to other research problems in the context of sonification as, for example, data exploration, auditory graphs or biofeedback.

The system that has been developed provides a virtual environment where subjects must guide an avatar to a target point using only auditory cues. The virtual space is visually presented to the test user together with the sonification of the scene. For the first runs, the players may move the avatar in an audiovisual condition, allowing them to understand how sound and situation relate. Yet after some iterations (with always changing obstacles, targets and initial avatar location), lights go off and the avatar must be guided using the auditory information alone[1]. Researchers that submit their algorithm for evaluation receive information about the position and properties of the obstacles the avatar faces and sonify this information using the proposed algorithm. In order to find the most effective sonification method, the performance of the different algorithms will be then statistically evaluated and compared.

Since this constitutes our first approach to reproducible sonification in the context of SonEX [9], the setup of the system has been simplified. The sound is displayed using stereo headphones and the avatar is controlled using the cursor keys in a keyboard. More advanced interfaces such as handheld smartphones equipped with a compass module could be defined in the future. In addition, the avatar moves in a computer-based space where the position of obstacles and barriers are known and multiple scenarios are generated by placing obstacles in different positions. The benefit of this approach is that we avoid annotating the position of obstacles and using scene image segmentation algorithms if, for example, real video images were used, providing us with a very controlled experiment. In the future, we could also consider the definition of other similar subtasks where, instead of using a virtual model space, a database of real images or videos could be used.

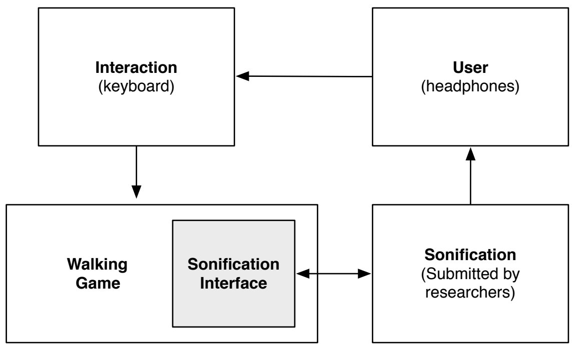

Figure 1: Block diagram of the proposed system. Researchers submit their sonification algorithms for evaluation.

Figure 1 shows a simplified block diagram of the proposed system. The main elements of the system are the *Walking Game*, the *Sonification* method and the *User* that evaluates the sonification method. The *Walking Game* block constitutes the core of the system and implements the virtual environment previously introduced. The system is made freely available to foster reproducible research and the description of the architecture of the system is im-

[1] A video example will be included in the final version.

portant to allow for the implementation of new and extended functionalities by the community. The *Sonification* block is the one in charge of synthesizing the sound given the information about the position of the avatar and obstacles. This *Sonification* module is developed by researchers submitting algorithms for evaluation. Information describing the scene is sent from the *Walking Game* module to the *Sonification* module using a predefined set of OSC (Open Sound Control) commands [12]. This OSC interface allows sonification researchers to develop their sound rendering algorithms independently of the specific implementation details of the proposed *Walking Game*. Finally, the user directs the avatar using a keyboard and the audio feedback provided by the sonification system and the virtual environment is updated according to this interaction.

2.1. System architecture

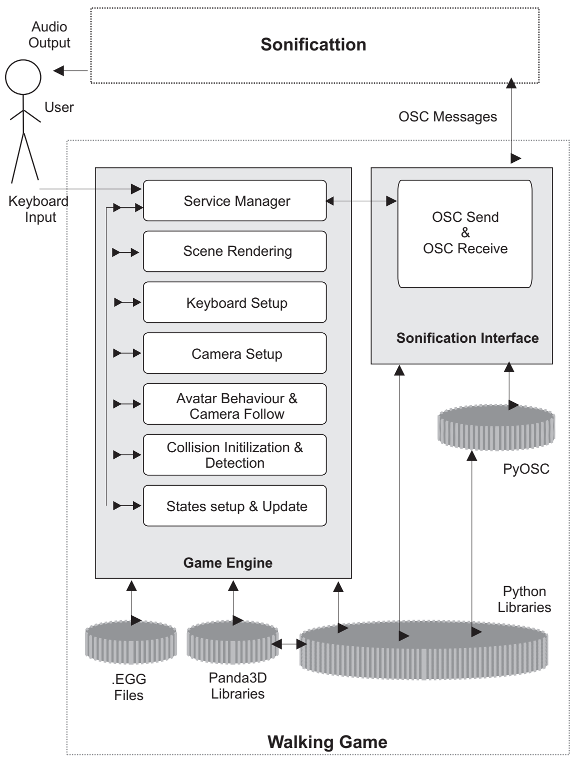

Figure 2: System architecture of the proposed system. The *Sonification Interface* provides a platform independent way of communication with the system using OSC commands.

Figure 2 shows a more detailed description of the different subsystems and libraries that have been used for implementing the *Walking Game*. The subsystems are shown in light gray and the software libraries in dark gray. As it can be seen, the system has been developed in Python using Panda3D libraries for rendering the 3D virtual environment [13] and pyOSC, which is a Python implementation of the OSC (Open Sound Control) protocol [12], for sending the data to the sonification algorithms. Panda3D is a 3D game engine for 3D rendering and game development for Python and C++ programs. It is basically a C++ library with a set of Python bindings. One of the advantages of Panda3D is that it is Open Source and free for any purpose, including commercial ventures, thanks to its liberal license. OSC is a protocol for communication among computers, sound synthesizers, and other multimedia devices that is optimized for modern networking technology. This OSC-implementation uses the UDP/IP protocol for sending and receiving packets of the data information to be sonified.

The *game engine* shown in Figure 2 refers to the game-specific code which deals with scene rendering, keyboard input processing, collision detection, avatar behavior and camera control. The modules that constitute the *game engine* are the following:

- *Service manager*: it is responsible for co-ordination between modules and also between the blocks *game engine* and *sonification interface*.
- *Scene rendering*: this module loads the scene, in this case a room environment. It is also responsible to load the avatar and a predefined start location. This module has information about the type and size of the obstacles and room dimensions which are potential sonification variables. All this information is read from a number of Egg files. Egg files are used by Panda3D to describe many properties of a scene: simple geometry, including special effects and collision surfaces, characters including skeletons, morphs, and multiple-joint assignments, and character animation tables
- *Keyboard setup*: this module enables receiving controls from cursor keys. This module makes the platform interactive with respect to the end user.
- *Camera setup*: the camera is one of the most important elements in a 3D game. It acts as the players eyes, letting them see the game world from different points of view. This module is responsible for the camera setup.
- *Avatar behavior and Camera follow*: this consists of several modules which establish the Walking, Turning and Pause action of the avatar. These actions are controlled by the keyboard input. The camera follows changes in the view point of the avatar. It is also coupled with collision detection. This module has updated information of the position of the avatar, the relative position of the obstacles and orientation of the avatar with respect to camera view. These again form potential sonification variables.
- *Collision initialization and Detection*: this module is responsible for creating an invisible collision sphere over the avatar and the obstacles in the room environment. It is also responsible to detect the collision between avatar and obstacles on avatar's action. This module has information of collision occurrence and also the number of collisions. This can be used for sonification as well as evaluation.
- *States setup and update*: this module creates the states for game flow and hence defines the beginning or start states. Each of the states is updated based on avatar's actions and collision detection. These state update also keeps track of the time which can be used for evaluation purposes.

The *sonification interface* block shown in Figure 2 defines a system-independent interface for the sonification synthesis process. The *sonification interface* communicates with the *service manager* of the *game engine* to get access to the variables describing the virtual scene and actions of the avatar. This information include the initial and current position of the avatar, the updated relative position of the obstacles, the angles and orientation of the avatar with respect to the camera view and collision occurrence but it can be easily extended to any other piece of data useful for sonification. This information is updated with every action of the avatar and sent to the sonification algorithms using an OSC interface. The definition of this interface allows researchers to get information about the virtual environment and the state and current position of the avatar and synthesize sound for blind navigation independently of the specific details of the proposed framework, the programming language selected and the sonification approach implemented.

2.2. Sonification Interface Description

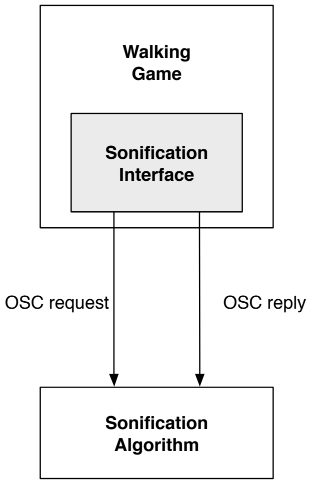

Figure 3: OSC-based sonification interface.

The software interface for communicating sonification methods with the task is shown in Figure 3. In order to make the sonification algorithm independent of the implementation details of this system, the proposed interface follows a client/server architecture. In this case, the walking game acts as a server for the sonification algorithms sending information about the virtual environment and the position and state of the avatar under the request of the sonification algorithm. The structure of the OSC massages exchanged between the sonification algorithms and the system is made of a command and an optional data field,

<*/address/command data*>

where *address* represents the OSC address of the SonEX task server (the *walking game* system) or the sonification algorithm client.

To be able to communicate with the defined SonEX task, the sonification algorithm has to first register as a client for the task sending a *register* OSC command to the task server,

</SonEX/walking_game/*register sonification-method network-address*>

where *sonification-method* is the OSC address of the sonification method itself and the *network-address* specifies the network address of the sonification system. Then, the *walking game* task server establishes communication with the sonification algorithm [2] and both client and server are ready to exchange information about the state of the virtual environment and the interaction of the user with the system.

[2]Using the pyOSC library for this purpose.

The server task sends the location of the Egg configuration file that describes the virtual environment using a *configuration* command addressed to the *sonification-method* as:

<*/sonification-method/cofiguration configuration_path*>.

This information includes the geometry, texture and positions of the obstacles. The sonification researcher can then decide to either interpret this Egg configuration file or ask the server for a list of all the obstacles in the virtual environment,

</SonEX/walking_game/*list-obstacles*>.

The task server then returns the identification name of all the objects,

<*/sonification-method/ object_id ... object_id*>.

With this object identification name *object_id*, the sonification method can ask for the properties of the object,

</SonEX/walking_game/*object_id/properties*>,

receiving its corresponding position and size,

<*/sonification-method/ object_id/properties position size*>.

The target destination of the avatar can be also requested to the task server as,

</SonEX/walking_game/*target-position/position*>

receiving the corresponding position in,

<*/sonification-method/target-position/position x y z*>.

Finally, the sonification method should be ready to receive the position of the avatar to sonify the virtual space in,

<*/sonification-method/ avatar/position x y z*>.

A document with the list of all possible OSC commands will be also made publicly available as a reference for the sonification researchers.

2.3. User Interface

The user that evaluates the different sonification algorithms is essentially the subject who plays the game. The sound is displayed using stereo headphones and users actually control their avatar using a keyboard.

The user interact with the system in two different modes, training and test. During training the user goes through two procedures. First, the user is allowed to play with eyes open to get familiar with the game itself. The user is expected to understand the aim of the game, keyboard controls and aesthetics of the game such as avatar speed, orientation, obstacles etc. Second the user is blindfolded and allowed to play the game based on auditory feedback from sonification. Here the user is expected to get familiar with the auditory feedback signals provided by the signification algorithms in sync with keyboard controls.

Once the training is done the user evaluates the sonification algorithm in a test mode. This is essentially the same as the second procedure described for the training mode. However this time the evaluation is considered. The user is expected to complete the objective of the game solely with the aid of auditory feedback signal.

3. THE WALKING GAME AS A SONEX TASK DURING THE ISON 2013

We will use the *walking game* during a hack day at the ISon 2013. Algorithms will be developed by sonification researchers and evaluated by subjects. Results will be analyzed and presented after the hack day, during the ISon 2013 workshop.

In this Section the *walking game* will be defined in the context of a SonEX task [9]. Also, the structure of the hack day and the method for analyzing the performance of the sonification methods will be briefly described.

3.1. A SonEX Task

SonEX (Sonification Evaluation eXchange) is a community-based environment that enables the definition and evaluation of standardized tasks, supporting open science standards and reproducible research. Thus, the *walking game* can be considered to be a SonEX task. For that, task participants must agree on the aim of the task, agree on the data model, interface and performance measures.

Following the workflow guidelines defined for SonEX in [9], a call of interest for the navigation sonification tasks will be submitted to the ISon 2013 community after the notification of paper acceptance. We aim at having at least 5 sonification researchers participating in the hack day. Then, the potential participants should slightly redefine the ideas and performance measures for the task using a discussion forum previous to the hack day that will take place in December. The objective of the task has been defined in Section 2 but it might be slightly modified by the participants. In addition, we propose to evaluate sonification methods in terms of the total time for getting the avatar to the goal position, the number of obstacle collisions and the subjective preference of the users. However, other measures proposed by the participants will be discussed and considered. These performance measures will be evaluated independently but also in terms of a weighted average to reduce the manifold features onto a single quality function as proposed in [14]. The participants should also discuss the characteristics of the virtual environment such as the number of obstacles, size, random placement and number of tests. Finally, the sonification interface proposed in Section 2.2 should be discussed. The interface can be easily extended depending on the requirements of the participants.

3.2. Hack Day

One of the challenges in this hack day is to allow sonification researchers to use their own setup, programming language and operating system. For that reason, the *walking game* will be distributed and installed in the system of each of the researchers. This is possible since the proposed framework runs in Python, which is a cross-platform programming language.

Researchers will have around 4 hours to work in their sonification algorithm on the first day of the ISon 2013 Workshop. In the following 4 hours, the submitted algorithms will be evaluated by the attendees of the ISon conference. The subjects will basically play the game described in Section 2 and their results in terms of the time spent for completing the task, number of collisions and a rate which indicates the subjective aesthetic quality of the sonification will be saved.

Each submission will be evaluated in different sessions. The evaluation of each of the submissions will not take more than 20 minutes per user (including test and training) in order to have enough time to evaluate all the submissions. Also we will recruit at least 10 subjects for evaluating the submissions and be able to statistically analyze the results.

3.3. Performance Analysis

To compare the different systems, the statistical significant difference on the mean values of the different performance measures will be checked. We will use an analysis of variance test (ANOVA) [15] and a multiple comparison procedure [16]. A multiple comparison procedure is useful to compare the mean of several groups and determine which pairs of means are significantly different. A pairwise comparison could lead to spurious statistical difference appearances due to the large number of pairs to be compared. To overcome this situation, multiple comparison methods provide an upper bound on the probability that any comparison will be incorrectly declared significant. A significance level of 5% is chosen to declare the difference statistically meaningful. This value is commonly used in hypothesis testing. For a more detailed analysis, box plots showing the median and 25^{th} and 75^{th} percentiles will be also presented.

The submitted sonification algorithms will be classified according to their performance. As discussed in [9], we are aware that the proposed evaluation does not reflect the details of a real system and that small factors change results when implementing a real auditory display. Still, we believe that this information can be used for discarding algorithms.

Finally, results and submissions will be presented in the oral session of the ISon 2013 Workshop and posted online. We will encourage people participating in the hack day to share their code to promote reproducible sonification research and we will publish the code of the methods participating in the hack day online when possible.

4. CONCLUSIONS AND FUTURE WORK

A software framework that allows for the formal comparison of sonification methods is presented in this paper. The platform is defined within the context of SonEX (Sonification Evaluation eXchange), a community-based environment that enables the definition and evaluation of standardized tasks, supporting open science standards and reproducible research. The architecture and interface of the proposed framework are described. The *walking game* platform provides a virtual environment for blind navigation where test subjects must guide an avatar to a target point avoiding obstacles using only auditory cues. Sonification researchers receive information about the position and properties of the obstacles through a number of OSC (Open Sound Control) commands and sonify this information using their proposed algorithm.

The framework will be used during the sonification hack day that will be celebrated together with the 4th Interactive Sonification (ISon 2013) Workshop at Fraunhofer IIS in Erlangen, Germany. The proposed system has been defined within the context of SonEX. First a call of interest for participating in the hack day will be done. Then, the potential participant will redefine the ideas of the task and will agree on the performance measures to be used. The database and the sonification interface has been already defined in this system. To find the most effective sonification method, the performance of the different algorithms will be statistically evaluated and compared during the hack day and results will be published the day after the hack day, during the ISon 2013 workshop oral session. The platform will be made publicly available to promote reproducible research.

The present work serves as first example of SonEX task for interactive sonification researchers. The task is simple but ambitious since we plan to develop, evaluate and compare a number of sonification algorithms during our hack day. Still, this is a very interesting experiment where participants will explore how to develop reproducible sonification research for a formal analysis and comparison of algorithms.

As future work, we plan to extend SonEX to other tasks such as data exploration or biofeedback. These evaluation tasks could be promoted and run every year during the ICAD conference. This would allow the ICAD community to build upon each others work and invest more time developing new methods and combining with the existing techniques than recreating existing methods. Also, a web interface could be implemented for the definition, submission evaluation and comparison of sonification methods. This requires a lot of resources and first, the agreement and support of the ICAD community.

To allow for each researcher to use its own sound synthesis setup, the *walking game* has to be installed and evaluated in the system of the sonification researchers. However, this makes the evaluation process more difficult since subjects must evaluate each sonification algorithm on the machine of the researcher. A further improvement will be to develop an online server for the navigation tasks. The task will be run on a server and researchers would stream the synthesize audio to the subjects who could potentially access the game using a web interface and evaluate the task remotely. In this case, we would have to deal with other problems as, for example, delay in real time sonifications. Another approach would be to limit the programming languages, libraries and operating systems to be used by sonification researchers or to install any required library and system on the server. All these points must be discussed and agreed.

We believe SonEX could be a strong driver of research, encouraging the Auditory Display community to clearly define tasks, research goals and standardized evaluation measures that enable formal and statistically based state-of-the-art comparison of algorithms. Therefore, to arrive at the best possible definition of tasks, standards and evaluation methods, we invite you to share your opinions, ideas, data and methods during this ISon workshop. We look forward to a fruitful discussion.

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