Implementation of 3D Sound Effects for Museums Using Raspberry Pi and Home Theatre System

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Abstract. In recent years, museums are exploring digital and computer technologies to enhance visitor experience and for that purpose a variety of systems for creating 3D sound effects for museums have been implemented. The growth of the performance of low-cost minicomputers leads to the issue of their integration with home theatre systems for simple implementation of 3D sound effects. This paper presents one solution for implementing 3D sound effects for auditory illusions immersive experiences in museums using the Raspberry Pi minicomputer and a home theatre system with 5.1 surround sound. With this solution it is possible to create a museum visitor detector via Raspberry Pi that uses motion detection to trigger 3D sound playing on a home theatre system. The solution was experimentally tested developing an audio system called “Auditory Illusions for Concentration Camp Museums”. The system was developed to enrich the exhibition in the Red Cross Second World War Concentration Camp Museum in the city of Niš, Serbia.

Keywords: auditory illusions, virtual reality, 3D sound effects, concentration camp museum, Raspberry Pi, visitor detector, PIR motion sensor, IR transceiver, home theatre system, 5.1 surround sound

1 Introduction

Sound effects are used as a feedback mechanism when users interact with many of their everyday devices, such as mobile phones, cars, toys, and robots. Sound effects become an essential part of the user experience. In virtual reality applications, 3D sound effects can either be environmental or background, or relate directly to the visualization. Background 3D sound effects can be used to create a certain feeling for the user [1], [2].

These effects are also used for attracting and keeping attention of visitors to the exhibits of a museum. The sources of these effects are often integrated with the corresponding objects to enable a realistic 3D soundscape around the visitors. For an immersive virtual reality experience a 3D soundscape needs to be created. Therefore, a 3D sound reproduction system capable of positioning sound sources anywhere in the 3D space is required. 3D sound must provide a high level of fidelity and accuracy, also create the environmental context of the acoustic environment. For any 3D sound reproduction system used in virtual reality applications, there is an additional requirement. The system must interact with the visitors so that the synchronization between the sound and the visitors must be implemented [1], [2].

Home theatre systems today can integrate in a standard manner with multimedia data types (pictures, video, animations, audio) and allow their presentation by any other multimedia device. Quality home theatre systems can cost less than some high-end 5.1 or 7.1 surround sound system, but ultimately they are more about saving space than saving money. Integrations of various home theatre systems for producing background 3D sound effects in virtual reality immersive experiences become very important for many cultural applications like tourism.

Furthermore, Raspberry Pi mini-computer has a number of uses in museums, particularly in small museums that do not have a computer network or IT staff. Nowadays, this mini-computer provides useful features like media shows, menus, sensor triggered events, and a Power Point-like presentation viewer. It displays videos, audio tracks, images, and text messages. Raspberry Pi can be configured to start up automatically when power is attached. It is powerful enough to run full screen high-definition video with high settings. It also can be controlled by buttons or sensors or may run continuously, and shut down on the press of the button [3].

In this paper, it is focused on application of Raspberry Pi in museums for triggering realistic 3D sound effects playing on home theatre system. With this application it was created a museum visitors detector that uses motion detection to trigger 3D audio file with 5.1 surround sounds playing on a home theatre system via the Raspberry Pi, (PIR) motion sensor and IR transceiver for sending infrared commands to the home theatre system.

The solution was experimentally tested by developing an audio system called “Auditory Illusions for Concentration Camp Museums”. For that purpose, the process of producing immersive background 3D sound effects for the concentration camp museums can be divided into three different stages. In the first stage, audio effects which can be natural or synthetic audio are created. In the second stage, the propagation of the sound emitted from the sound sources is modeled and in the last stage a multichannel 3D sound is produced. This solution also enables users to easily create a low cost special-purpose background 3D sound effects for museums.

The solution was developed to improve the exibition of data and artefacts in the Second World War Red Cross concentration camp museum in the city of Niš, Serbia. The system is aimed at supporting the digital and computer technologies to enhance visitor experience in a museum setting. Such an implementation of 3D sound effects for auditory illusions immersive experiences is also supported by the last few years campaign for learning in museums and galleries.

The paper is organized as follows. Section 2 shortly introduces 3D sound effects and 5.1 surround system. In section 3, the Raspberry Pi mini-computer and some of its accessories relevant for the subject of this paper are presented. In Section 4, the proposed solution for the implementation of 3D sound effects for museums using Raspberry Pi and home theatre system is described. Features of the proposed implementation were experimentally tested in Section 5. Section 6 offers some concluding remarks and directions for future work.

2 3D Sound Effects and 5.1 Surround System

3D sound effects are sound effects that are produced using stereo speakers, surround-sound speakers, speaker-arrays, or headphones to create the illusion of sounds from different locations. Creation of these effects requires appropriate positioning of speakers in the 3D space, eg. left or right, above or below, front or behind the listener [4]. A 3D sound effect is simply altering how the sound is played, to give an illusion that they are happening in 3D space [5]. For example, a sound of crash is not just an crash in the 3D space, but the listener can tell where exactly the crash happened. These effects make possible listeners to feel much more involved in the 3D space. Listeners feel like the sound is coming from all around them, rather than from just the pair of speakers [5].

In general, 3D sound experience was almost as effective as its visual counterpart. In distinction to visual experiences, 3D sound experiences are not bundled to the size of the displays and can be calibrated to present a "360-degree" sound experience [6]. Furthermore, in visual experiences the listener can look in any direction, and may not pay attention when something happened. But using a 3D sound enforces listeners to focus their attention in the direction of source of the sound, similar to live performances that are used in the theater [6]. One of the biggest challenges for design of 3D sound experiences is auditory navigation of listeners where points of interest are placed in an immersive 3D environment.

3D sound effects are initially developed in the early 1990s for PC and video game consoles. They were used to render the movement of walls, doors and objects in the 3D space. Later, 3D sound has also been used in creation of music and video arts. It has been explored as a musical tool by a many musicians and various software systems have been developed for creation of 3D audio.

3D sound, which constitutes an extension of stereophony, provides full spatial immersion by using reverberation and reflection [7]. The most typical 3D sound system is Dolby 5.1 surround system.

The 5.1 surround system is the common name for six channel surround sound multichannel audio systems [8]. It is presently the most commonly used techniques in cinemas and home theaters. It uses five full bandwidth channels and one low-frequency effects channel (the "point one") [8]. The 5.1 is also the standard surround sound audio component of digital broadcast and music [8].

The 5.1 surround systems speaker configuration have three front speaker channels (left, right and center) and two speaker channels (left and right), and a subwoofer speaker. The most common speaker configuration for 5.1 used for 3D sound reproduction in the virtual room is depicted in Fig 1. Note that the subwoofer speaker can be placed anywhere in the room on the floor if possible.

Most known software application for editing sounds support creation of 5.1 surround sound. Some software application give rich capabilities than others but all applications can give you the ability to mix your project audio tracks in 5.1 surround sound and deliver 5.1 audio files. The first step in creating a 5.1 surround sound mix is setup of the properties for 5.1 sound at the beginning of a new project. These software applications are used to position a sound in a surround field using multichannel panner with audio tracks. For a visual demonstration, Fig 2. presents a screenshot of the example of the six audio tracks for creating 5.1 surround sound mix [9].

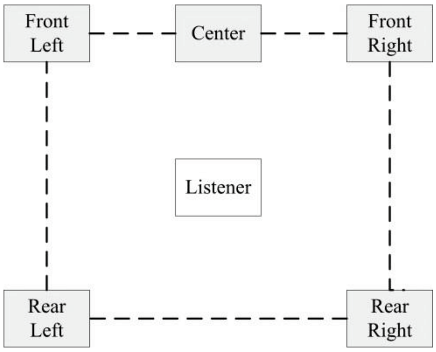

Fig. 1. The most common speaker configuration for 5.1 surround sound

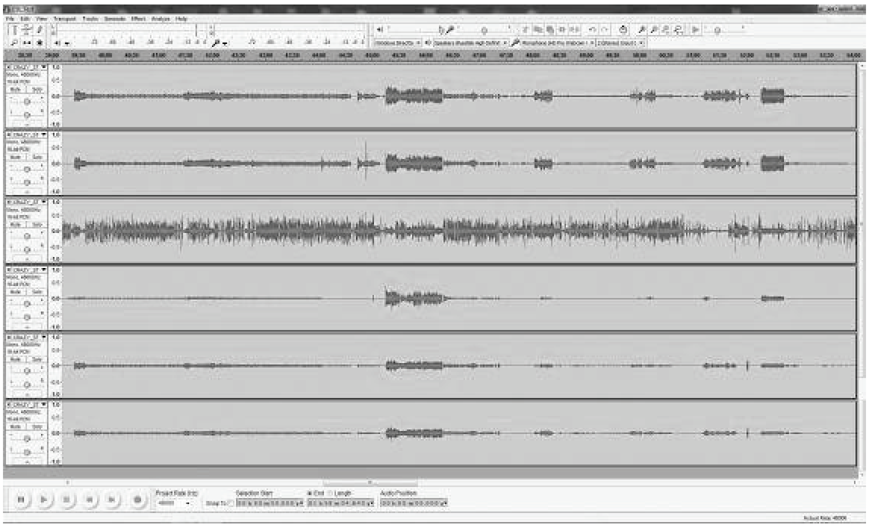

Fig. 2. Example of six audio tracks for creating 5.1 surround sound mix [9]

The upper two audio tracks are the left and right front speakers, the next two audio tracks are the center and subwoofer channels, while the last two tracks are left and right rear speakers.

3 Raspberry Pi, PIR Motion Sensor and IR transceiver

The Raspberry Pi is an inexpensive mini-computer in the size of a cigarette pack makes it very useful for a number of tasks. It can be plugged into a standard computer monitor or TV, and uses a standard computer keyboards, mouses and other accessories. This mini-computer is a fun device with the intention of promoting and exploring basic computing and software/programming languages, like Scratch and Python, to people of all ages. The Raspberry Pi can necessarily do everything that traditional desktop computers can do, like web browsing, playing audio and video, word processing, game playing, etc. [3].

The Raspberry Pi has the ability to interact with devices that are attached to it and can been used in various electronics projects, like controlled robots, parent detectors, weather stations, media center for TV and radio station. Schools and universities have taken part in a competition for innovative projects created using a Raspberry Pi [10].

It cost only around 20 euros and package include a circuit board with a CPU, graphics processor, memory module and several pins and ports with open ability to be adapted and manipulated. An example of the diagram for Raspberry Pi Model B is shown in the Fig. 3 [11].

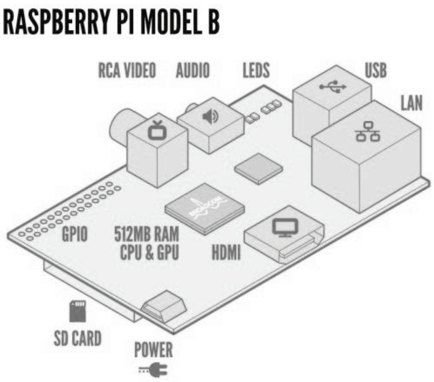

Fig. 3. The Diagram for Raspberry Pi Model B [11]

A Raspberry Pi is so small that it can easily be hidden, making it ideal for secretly detecting visitors to showrooms (like in museums). There are so many inspirations for Raspberry Pi projects and one of the most interesting and useful is the motion detecting systems. There are several approaches for building a motion detecting system for the Raspberry Pi and in this project it was used "Raspberry Pi Learning Resources" [12] that offered a wealth of ideas and suggestions.

In this project, we are going to be using a Passive Infrared (PIR) motion sensor. Infrared lights are not visible to the human eye, but they can be detected by the electronics inside one of these sensors. Any object moving through the room will disturb the infrared light wavelengths, and will cause a change to be noticed by the PIR sensor. They are low power and low cost, pretty rugged, have a wide lens range, and are easy to interface with Raspberry Pi [13]. Note that PIR sensors don't have indication of how many people are around or how close they are to the sensor [13]. After connection of the PIR sensor to pin 4 of the Raspberry Pi, there is need to write program using Python programming language which will detect when the PIR senses movement. Detailed information about connection of PIR sensor and Python script can be found online [12].

There are many devices that use infrared remote controls - TV's, DVD players, cameras, power sockets [14]. So getting a Raspberry Pi to be able to send remote control signals opens up many possibilities for projects [14]. Note that turning a Raspberry Pi into an IR transceiver looks like an interesting academic project and the final result can be used as a versatile replacement for a humble remote control [15]. The most obvious advantage of using a Raspberry Pi-based IR remote control is that you can program it via scripts [15]. You can also add some clever functionality on top. For example, you can write a simple program that makes it possible to access and control all home devices.

Although IR LED can be connected directly to GPIO pins on the Raspberry Pi, the LED's output signal will be too weak, and the IR transmitter will have a very limited range. A simple transistor circuit can solves the problem by amplifying the current output from a pin and thus increasing the IR LED's signal strength. Detailed information about connection of IR LED and corresponding scripts can be found online [14].

Connecting the USB IR Transceiver in an USB port on the Raspberry Pi means that we can easy create an interface to control these devices. USB IR transceiver is a standard USB device that can transmit the infrared codes supported by LIRC. LIRC (Linux Infrared remote control) is an open source package that allows users to receive and send infrared signals with a Linux-based computer system [16]. Using LIRC, this device can communicate with most home electronics and their associated remote controls. For example, the FLIRC USB transceiver dongle allows the use of any remote control with your Raspberry Pi [17]. The device can be configured on desktop PC and then simply connected into Raspberry Pi for a perfect transmitting and receiving IR signals. FLIRC learns from any remote control, not caring about different vendor protocols [17].

Another (not expensive) solution to use IR remotes would be the RemotePi Board [18], which does not take an USB port and can switch the power of the Raspberry Pi as well.

4 Implementation of 3D Sound Effects for Museums

This section describes a simple solution that can be used in implementation of 3D sound effects gives us the audio illusion for attracting and keeping visitors to the exhibits of a museum. The solution is created by using the 3D audio file with 5.1 surround sound playing on home theatre system controlled by the Raspberry Pi.

Raspberry Pi was chosen as the controller because it is easy to connect, to setup, to interfaces with peripherals, and it has general purpose inputs and outputs for connecting to basic electronic components like buttons, sensors, and lights. In this solution PIR motion sensor and IR transceiver are connected to the Raspberry Pi at the same time. For a more permanent implementation, it can be used some 5.1 surround home theatre system with USB input and remote control. The schematic of solution is shown in Fig. 4.

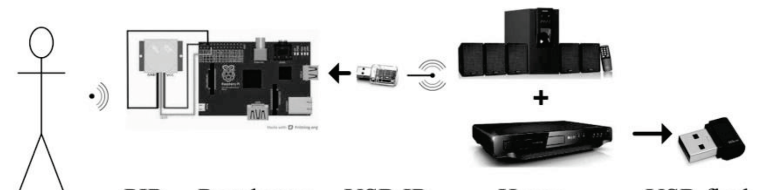

Fig. 4. The schematic of solution for implementation of 3D sound effects for museums

Setting up the Raspberry Pi configuration is easy. The Python script within Raspberry Pi monitors the PIR sensor. If motion is detected, it sends IR command to the home theatre system via USB IR transceiver. When motion is detected, the home theatre system receive IR codes for power on and for start playing 5.1 surround audio file stored on USB flash memory (previously attached to home theatre system). The information of 3D sound effects can be stored in just 6 regular audio tracks (or more for higher-order audio experiences) creating surround 5.1 sound.

In 5.1 surround 3D audio recordings, all the computation and 3D-ness happens in visitors' brain without the recording having a 3D model or any idea what 3D is. With enough speakers on walls, it can be create an actual 3D point cloud of the audio illusions. Or it can be used a light-speakers to capture how all the audio waves look from all the locations within some space. Both those audio options aren't really viable solutions for virtual reality immersive experiences in museums just yet, but 5.1 surround sound is good enough to make visitors brain pleased.

5 Experimental Results

The proposed solution for implementation of 3D sound effects for museums was experimentally tested developing an audio system called "Auditory Illusions for Concentration Camp Museums". The solution was developed to improve the presentation of data and artifacts in the museums and enables novel approaches to presentations. The system was developed to provide support to Second World War Red Cross concentration camp museum, Niš, The system allows visitors to Red Cross concentration camp museum to fathom the pain and suffering of prisoners. In this way, this concentration camp museums can better present the cultural and historical content and attract a larger number of visitors.

The basic principle on which the system is based is a 5.1 surround audio technique known as 3D sound effects. 3D sound technique is an illusion technique used in cinemas, theatres, and homes, described in previous section.

Audio effects are creating using software Sony Vegas Pro [16] for mixing 5.1 surround sound. Fig 5. presents a screenshot of this software for mixing of the three audio tracks for creating 3D audio effects for showroom of Red Cross concentration camp museum.

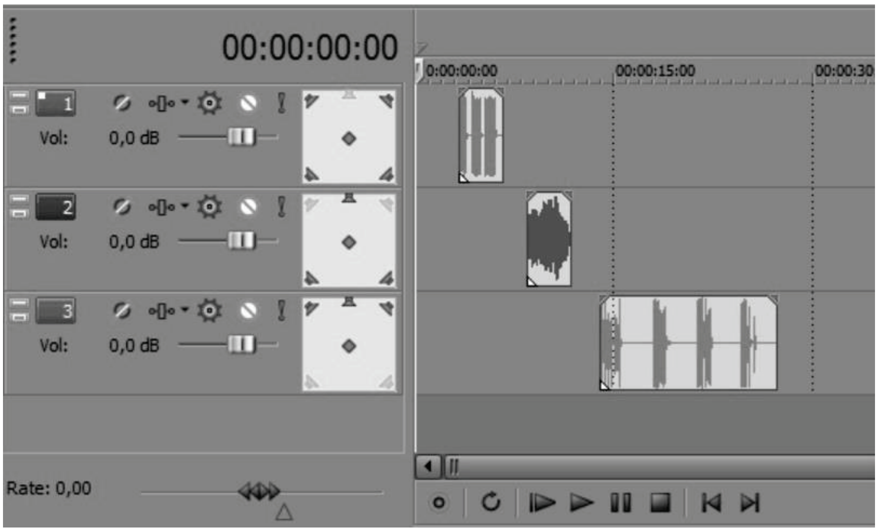

Fig. 5. Mixing of the three audio tracks for creating 3D audio effects for showroom of Red Cross concentration camp museum

The first upper audio track is sound of man groaning (set for the center speaker), the second audio track is sound of man whimpering (set for the left and right front speakers), while the last audio track is sound of German shepherd dog (set for the left and right rear speakers). All audio tracks are downloaded from internet from various available databases of sound effects. As the result of processing audio tracks is 5.1 audio file using MP3 Surround file audio coding format. MP3 Surround is an extension of MP3 for multi-channel audio support including 5.1 surround. This 5.1 audio file must be stored to USB flash memory and attached to DVD player of home theatre system. Note that DVD player of home theatre audio system must support reproduction of MP3 Surround files.

The speaker configuration for showroom of Red Cross concentration camp museum is depicted in Fig 6. Note that Raspberry Pi PIR sensor must be hidden somewhere in front of entrance of showroom. Subwoofer speaker must be hidden placed on the floor. DVD player of home theatre system must be IR visible to Raspberry Pi and all speakers on the walls must be camouflaged.

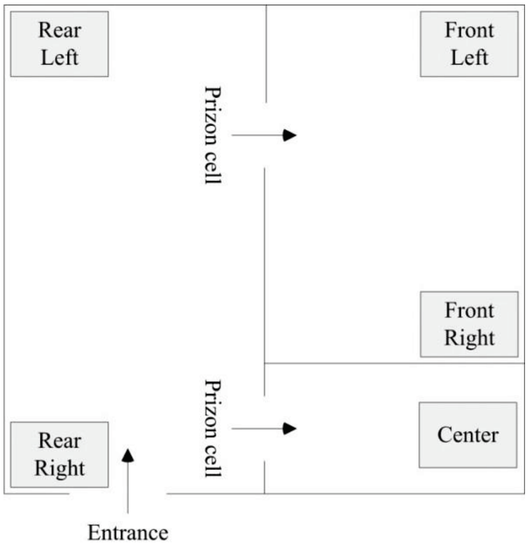

Fig. 6. The speaker configuration for showroom of Red Cross concentration camp museum

6 Conclusion

Stereo sound gives us the illusion of a 3D audio from exactly one perspective, but does not provide the information how the sound looks if position in the 3D space is changed. 3D sound effects tell us what the sounds like from any other locations in the space. 3D sound effects are widely used in various institutions. 5.1 surround audio is perfect for 3D sound effects for museums.

Increasingly, museums have experienced budget cuts and reducing the available staff in response to the recent economic downturn. Consequently, this paper describes a solution for chip and simple implementation of 3D sound effects for auditory illusions immersive experiences in museums using Raspberry Pi mini-computer and home theatre system with 5.1 surround sound. The Raspberry Pi solutions and home theatre systems are often hailed for their incredibly cheap price. Other solutions are available, but for some of these systems, the additional peripherals that are required can quickly amplify the cost.

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