Italian Association of Aeronautics and Astronautics
XXVI International Congress
31st August – 3rd September 2021
On-line event hosted by the Tuscany AIDAA Section in Pisa

SPATIAL SOUND SYSTEM TO AID INTERACTIVITY IN A HUMAN CENTRED DESIGN EVALUATION OF AN AIRCRAFT CABIN ENVIRONMENT.

Sandhya Santhosh [1*], Martino C. Moruzzi [1], Francesca De Crescenzio [1], Sara Bagassi[1]
[1] University of Bologna, Department of Industrial Engineering
* sandhya.santhosh2@unibo.it

ABSTRACT

There is a lot of research towards the concept of 3D sound in virtual reality environments. With the incipient growth in the significance of designing more realistic and immersive experiences for a Human Centred Design (HCD) approach, sound perception is believed to add an interactive element in maximizing the human perspective. In this context, the concept of an audio-visual interaction model between a passenger and a crew member in an immersive aircraft cabin environment is studied and presented in this paper. The study focuses on the design and usability of spatial sources as an interactive component in a regional aircraft cabin design for Human in the Loop evaluation. Sound sources are placed among the virtual manikins acting as passengers with the aim of building a realistic virtual environment for the user enacting the role of a crew member. The crew member, while walking through the cabin can orient and identify the position of the sound source inside the immersive Cabin environment. We review the 3D sound approaches and cues for sound spatialization in a virtual environment and propose that audio-visual interactivity aids the immersive Human centred design analysis.

Keywords*:* Spatial Sound, Human Centred Design, Interactivity, Virtual Reality

1 INTRODUCTION

In the last decades the way in which products and interfaces are developed has radically changed from a technology-centred approach, where the focus is on the technology and on the features a product will provide, to User-Centred Design (UCD) or Human Centred Design (HCD) approach, where the focus is on the needs and perceptions of users. Therefore, to design a great experience, one must understand the user's perspective. To this aim, the Human-centred design (HCD) approach is based on the comprehension of the human's point of view in evaluating any design process [1]. In this regard, Virtual Reality (VR) is a valuable means for validating the design by involving users in design reviews before any product is physically manufactured [2].

As known, VR is a discipline focused on creating realistic scenarios artificially allowing these digitally created world to be explored and interacted by human. It has paved its way to several applications such as ergonomics display, aesthetic quality monitoring, data visualization, product evaluation and validation, designing etc., [3]. Examples of VR devices include: CAVE (Cave Automatic Virtual Environment, Passive Stereoscopy Theatre (PST) and Head Mounted Displays (HMD). Fully immersive environments allow users to use hands, eyes and ears same as in the real world.

While the primary sense to be rendered in a VR is vision, the auditory rendering often enhances the feeling of realism and immersion [4]. Moreover, audio rendering is particularly important in the design of those environments in which the comfort of users and their possibility to verbally interact are highly impacted by noise conditions [5]. Sound as an interactive element is believed to provide more natural interface to virtual environments [6]. In particular, sound is an important media for information transmission and the goal of the spatial sound is to design the sound source that needs to be convincing to the listener and enhance the virtual experience. In the aviation sector, sound can be a source of information, like that from the crew or the speakers, or a source of discomfort, like the noise generated during the flight. Moreover, in aviation sound has an important negative effect on the passenger flight experience, so we consider it as a noise. New passenger cabins and aircraft configurations could decrease the noise inside the cabin [7][8]. In order to evaluate the passenger's acceptance of new cabin design in a virtual mockup we have to simulate the related noise footprint. In this way the passenger will experience and evaluate the cabin's comfort not only from an ergonomic and aesthetic way, but also from an auditory and acoustic point of view. Sensory affordances aiming at providing sensory actions such as seeing, hearing and feeling things in an immersive cabin environment are studied and presented in this paper.A spatially localized sound allows one to quickly determine from which particular object the sound is forthcoming [9]. Sound provides important channel of feedback that either can be helpfully redundant to a visual cue making it useful for situational awareness.

In this paper, we outline the concept of spatial sound and field study application to propound that sound can improve user presence by acting as an interactive element using a HMD for immersive environment. A mixed reality device, Microsoft HoloLens2, has been considered to provide the user a "walk through" of an aircraft cabin. The next sections follow the introduction to spatial sound and its physical description.

2 3D SOUND- AN INTERACTIVE ELEMENT

Humans rely on the sense of hearing depending on the distance and direction of the sound or audio when other senses are stalled. Similarly, in immersive environments, spatial audio is used to expand the mixed world experience beyond visual cues. With auditory and visual senses mixed, intuitive nature of interactions are deepened for the user improving the Quality of Experience (QoE) [10]. 3D sound has always been considered as a means to improve the experience, but not for interaction [11]. Schoeffler, Michael, et al have compared the perception of spatial sound in physical and virtual worlds with demonstration through experiments [10]. 3D sound has so far been implemented in various tasks such as selection, navigation, system application and manipulation of virtual artifacts. Designing 3dimensional sound in order to improve the interaction factor depends not only on the audio source but also on properties like direction, distance and other environmental factors [12]. The directional component to spatial sound is termed as "Spatialization" and the sense of distance as "Reverb".

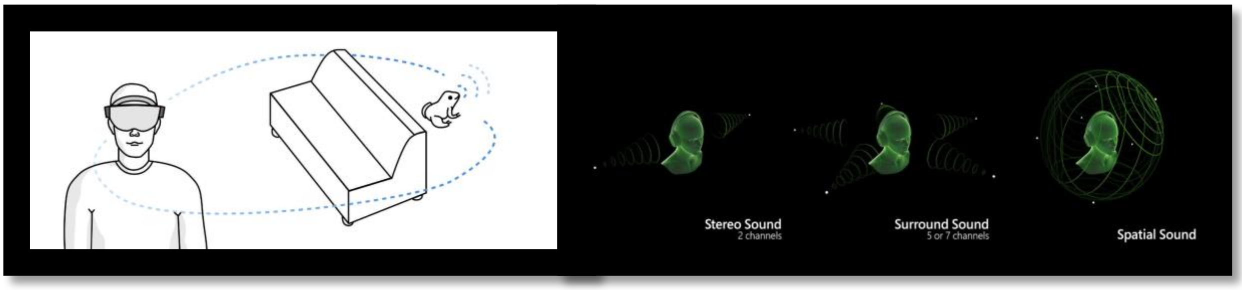

Figure 1 Occlusion of Spatial Sound

For developing spatial sound to a Head Mounted Display, as the Field of View of the device is in front of the viewer and holograms appear in the clear line of sight, it uses Head-Related Transfer (HRTF)-based spatialization to simulate sound coming from distances and directions. HRTF is the most efficient method for realistic spatialization of sound [13]. HRTF determines the virtual sound source and recomputes it by determining the head orientation for the user and thus knowing the distance towards the 3D audio. As the ear shape, ear position and head size are distinctive, HoloLens uses individuals inter pupilary distance to improve spatialization accuracy.

In an aircraft sound comes from many sources and at different intensity levels [14][15]. These sources could generate noise for the passenger, information (as that given by the crew) and also vibrations, which affect the aircraft structure. Sound localisation in real world is simple as panning the loudspeakers but there are some known issues with spatial hearing through auditory displays. Studies conducted on the localisation of virtual sounds usually include virtual objects and not just direction [16]. HRTF encapsulates how sound is modified from original sound source all the way to the ear drums of human. On its way, it is driven through a number of dimensions including occlusion, obstruction, reverb, room reflections and source modelling. All these dimensions are weighed as acoustics which are important to be considered when developing a spatial sound to achieve perceived distance and direction. From a physical point of view [16][17] sound is described as an acoustic wave in a medium (fluid or solid), its propagation is modelled by the wave equation:

$$\frac{\partial^2 p}{\partial t^2} = c^2 \nabla^2 p \tag{1}$$

in which *p* is the acoustic pressure and *c* the speed of sound. An acoustic model (or a vibro-acoustic, aero-acoustic, etc.) must take in account sources and boundary conditions. In our model we define a simple source with direction and distance. The simple kind of source is an omnidirectional pulsating sphere (a monopole). The sound intensity I decrease with the square of the distance r from the source. The power radiated *W* by the acoustic source depends on the sphere's surface:

$$W = 4\pi r^2 I \tag{2}$$

and finally, the acoustic pressure *p*:

$$p^2 = \rho c I = \frac{\rho c W}{4\pi r^2} \tag{3}$$

where c is the speed of sound and ρ the density of the medium. Typically, acoustic source radiation is directional, so directivity factor D_θ is defined as function of the two angular orientations.

In a real environment there are obstructions, walls or other obstacles for the sound waves, which are influenced by the variation of the medium in density and in the speed of sound. Obstacles could be defined as external bodies with a characteristic absorption and reflection coefficients. Inside an aircraft cabin, the seats, the lining panels, the floor and the overheads reflect and absorb the acoustic waves [18]. A complete vibro-acoustic model describes some of these obstacles as boundary conditions or as particular components (porous material, vibro-acoustic interfaces, etc.) [19][20] . The high complexity of a complete acoustic model cannot be real-time described inside a virtual reality system, so previous acoustic analyses must be performed with dedicated software.

Holograms are digital elements and elements such as light and sound pass through them. Thus, designing spatial sound is a gradual process by implementing each salient feature and modelling the acoustics in a fully immersive environment. The following section elaborates the concept of a field study based application model with spatialization and reverb factors of 3D sound embedded to the environment.

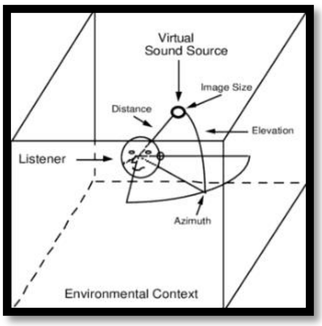

Figure 2 3D Sound in VR

3 CONCEPT OF A FIELD STUDY APPLICATION MODEL

In order to study the concept of spatial sound in VR environment, a field study of human in the loop evaluation for an aircraft cabin has been considered. The 3D model of the aircraft cabin has been derived from the framework of a Horizon 2020 project, the CASTLE (CAbin Systems design Toward passenger welLbEing). CASTLE experiments aim at validating design solutions through the involvement of voluntary participants representing potential users [21][22]. Several aspects of comfort, such as visual comfort, interaction comfort or living space comfort have been measured and used to iteratively validate design solutions. We believe that 3D sound stimulation inside the cabin environment would assist the interaction comfort validation factor by providing the user realism and immersion. It allows by displaying sound sources with spatial properties such as : Directivity, Depth and Reverberation. As an initial step for this paper, distance and directivity property of the spatial sound has been considered.

A regional aircraft cabin environment has to be exported to UNITY 3D software with virtual manikins enacting the roles of passengers placed on the aircraft seats at different seat positions. Similar manikin models are to be considered in order to study the effect of sound localization by the user. Thanks to the mixed reality device, Microsoft HoloLens2, unlike the traditional VR HMD, user here can have the understanding of the physical environment. In this particular scenario, the user enacts the role of a crew member that wears the HoloLens and walks through the cabin aisle. Sound sources from virtual manikins are designed to emerge from all sides (right, left, back and front) and the crew member can identify the location it is emerging from. The HRTF function of the Microsoft HoloLens2 allows the user to orient himself towards the audio source. A pictorial representation of the idea is as presented in Figure 3 and Figure 4.

Figure 3 Virtual environment of Regional Aircraft Cabin with human models as passengers

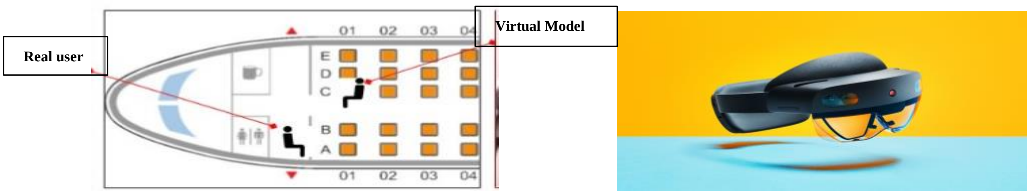

Figure 4 (a) Position of the real user and virtual models in an aircraft cabin, (b) Microsoft HoloLens2

3.1 Model Design

The Immersive Regional aircraft model is planned to be built on a Windows10 PC, Unity version 2019.4 and Visual Studio v16.9. The following procedure is outlined, and not limited to, in building the environment:

- In order to bring the spatialization properties to the environment, an open source cross-platform development kit, Mixed Reality Tool Kit (MRTK) v2.7 can be considered.
- The project to be configured with MRTK and *DefaultHoloLens2ConfigurationProfile* with spatial awareness function enabled in order to provide the real world environmental awareness.
- Choice of Spatializer Plugin has to be made in designing the sound properties to the project. Unity provides a “Microsoft Spatializer” plugin that can be used to avoid large amount of specialized computation using HRTF-based algorithms for HoloLens2.
- A single audio source component is attached to all the virtual manikins placed at different seats inside the cabin environment.
- Add the spatialization feature by coding with C# script attached to the manikins in order to enable the spatialization feature by adjusting the spatial blend property. Volume curve is adjusted to same level for all the models. The C# script includes the reverb factor and the Audio Mixer is configured with SFX Reverb effect with parameters set to adapt to the project.

The model considered for above design only to have the distance and direction effects to the sound in a 3D environment with no physical sound field boundaries.

4 CONCLUSION AND FUTURE WORKS

The conceptual and pre-experimental research design paper outlines the theory of 3D sound in virtual reality environments and proposes spatial sound as an interactive element to HCD evaluation. Spatial sound is an interdisciplinary field dealing with acoustics, signals and human perception. For this research, it is laid to improve comfort validation factor in a aircraft cabin design evaluation. A field study application model of a regional aircraft cabin with virtual manikins enacting the role of passengers embedded with audio sources is provided. The user, in this case, crew member inside the virtual aircraft model can walk through the cabin and orient oneself towards the audio source from passengers and identifies it. The model is believed to bring realism in a VR ambiance for the user and promote natural interface. As an initiation, the sound source has been studied to contain the direction and distance effects for the user to identify it. Building the model as outlined in this paper can however bring challenges to be solved in the path.

The future works can investigate the acoustic wave features of spatial sound in a Virtual Reality environment and design to assess the noise comfort of a passenger inside an aircraft cabin. The VR environment can include complete acoustic features with boundaries designed accordingly.

REFERENCES

[1] De Crescenzio, F., Bagassi, S., Asfaux, S., & Lawson, N. Human centred design and evaluation of cabin interiors for business jet aircraft in virtual reality. *International Journal on Interactive Design and Manufacturing (IJIDeM)*, *13*(2), **761-772** (2019).

[2] Cohen, M., Villegas, J., & Barfield, W. Special issue on spatial sound in virtual, augmented, and mixed-reality environments. *Virtual Reality*, *19*(3), **147-148** (2015).

[3] Berni, A., & Borgianni, Y. Applications of virtual reality in engineering and product design: why, what, how, when and where. *Electronics*, *9*(7), **1064** (2020).

[4] Hohmann, V., Paluch, R., Krueger, M., Meis, M., & Grimm, G. The Virtual Reality Lab: Realization and application of virtual sound environments. *Ear and Hearing*, *41*(Suppl 1), **31S** (2020).

[5] Hartson, R. Cognitive, physical, sensory, and functional affordances in interaction design. *Behaviour & information technology*, *22*(5), **315-338** (2003).

[6] Grani, F., Overholt, D., Erkut, C., Gelineck, S., Triantafyllidis, G., Nordahl, R., & Serafin, S. Spatial sound and multimodal interaction in immersive environments in "*Proceedings of the Audio Mostly 2015 on Interaction With Sound"* (pp. 1-5) (2015).

[7] Vos, R., Geuskens, F. J. J. M. M., & Hoogreef, M. F. M. A new structural design concept for blended wing body cabins in "*53rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference 20th AIAA/ASME/AHS Adaptive Structures Conference 14th AIAA"* (p. 1998) (2012).

[8] Moruzzi, M. C., & Bagassi, S. Preliminary design of a short-medium range windowless aircraft. *International Journal on Interactive Design and Manufacturing (IJIDeM)*, *14*(3), **823-832** (2020).

[9] Schmidt, A., Löllmann, H. W., & Kellermann, W. Acoustic self-awareness of autonomous systems in a world of sounds. *Proceedings of the IEEE*, *108*(7), **1127-1149** (2020).

[10] Schoeffler, M., Gernert, J. L., Neumayer, M., Westphal, S., & Herre, J. On the validity of virtual reality-based auditory experiments: a case study about ratings of the overall listening experience. *Virtual Reality*, *19*(3), **181-200** (2015).

[11] Ortega-Gonza´ lez, V., Garbaya, S., & Merienne, F. D. R. Using 3d sound for providing 3d interaction in virtual environment in "*ASME World Conference on Innovative Virtual Reality"* (Vol. 49088, pp. 311-321) 2010, January.

[12] Xie, B. Spatial Sound-History, Principle, Progress and Challenge. *Chinese Journal of Electronics*, *29*(3), **397-416** (2020).

[13] Usman, M., Kamal, K., Qayyum, R., Akram, S., & Mathavan, S. 3D sound generation using Kinect and HRTF in "*2017 IEEE 2nd International Conference on Signal and Image Processing (ICSIP)*" (pp. 307-310). IEEE (2017, August).

[14] Leylekian, L., Lebrun, M., & Lempereur, P. An overview of aircraft noise reduction technologies. *AerospaceLab*, (6), p-1 (2014).

[15] Strutt, J. W., & Rayleigh, J. W. S. B. *The theory of sound* (Vol. 1). Macmillan (1894).

[16] Sodnik, J., Tomazic, S., Grasset, R., Duenser, A., & Billinghurst, M. Spatial sound localization in an augmented reality environment in "*Proceedings of the 18th Australia conference on computer-human interaction: design: activities, artefacts and environments"* (pp. 111-118) (2006, November).

[17] Bertsch, L., Simons, D. G., & Snellen, M. Aircraft Noise: The major sources, modelling capabilities, and reduction possibilities (2015).

[18] Bies, D. H., Hansen, C. H., & Campbell, R. H. Engineering noise control (1996).

[19] Moruzzi, M. C., Cinefra, M., & Bagassi, S. Vibroacoustic analysis of an innovative windowless cabin with metamaterial trim panels in regional turboprops. *Mechanics of Advanced Materials and Structures*, **1-13** (2019).

[20] Cinefra, M., & Petrone, G. SEA analysis in the cabin of a regional turboprop with metamaterial lining panels. In *AIAA Scitech 2019 Forum* (p. 1806) (2019).

[21] De Crescenzio, F., Bagassi, S., Asfaux, S., & Lawson, N. Human centred design and evaluation of cabin interiors for business jet aircraft in virtual reality. *International Journal on Interactive Design and Manufacturing (IJIDeM)*, *13*(2), **761-772** (2019).

[22] Bagassi, S., Lucchi, F., De Crescenzio, F., & Piastra, S. Design for comfort: aircraft interiors design assessment through a human centered response model approach in "*31st Congress of the International Council of the Aeronautical Sciences, ICAS"* (2018).