International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 12 Issue 9 ǁ September 2024 ǁ PP. 171-177

Exploring the Impact of Directional Sound Field Decay on Performance Space Optimization and Indoor Positioning Techniques

Olalekan Samuel Agbeniyi
MusicDepartment
The Polytechnic, Ibadan.
samlek2@yahoo.com

Abstract:
This paper investigates the role of directional sound field decay in optimising performance spaces and enhancing indoor positioning techniques. With advancements in acoustic modelling and real-time auralization, controlling sound behaviour within performance venues has become a pivotal aspect of architectural and acoustic design. The study explores how geometric attenuation and sound source directivity affect acoustic experiences and positioning accuracy. The research highlights the potential for psychoacoustic amplification and improved sound clarity by comparing traditional omnidirectional sound field theories with directional decay models. Additionally, the paper addresses the challenges of integrating these techniques into indoor positioning systems, particularly in reverberant spaces. These findings contribute to the interdisciplinary synergy between acoustics, architecture, and indoor navigation technologies, offering practical applications for concert halls, theatres, and multipurpose performance venues. Future research directions include optimising signal propagation models and developing multi-purpose acoustic spaces using variable reverb and dead zones.
Keywords: *Directional sound field decay, performance space optimisation, indoor positioning techniques, acoustic design, psychoacoustic amplification.*

Date of Submission: 18-09-2024 Date of acceptance: 02-10-2024

I. Introduction

Despite the intrinsic nature of sound to diminish during propagation, in performance spaces, unique configurations of source and receiver geometries contribute to the inherent complexity of the problem, and as such, it is under continuous investigation by researchers and practitioners (Zhong et al., 2023; Pinardi et al., 2021). Non-diffusion is a facet of a sound's geometry that has garnered much attention in performance space optimisation, as it strongly influences the possibility of strong interfering reflections (Pezzoli et al., 2020). Indeed, a primary goal of room acoustics is to control the rate at which sound energy diminishes, either by diffusing it to create a uniform sound field or by directing it to accentuate a desired subjective effect (Steffens et al., 2021). Today, real-time auralization technology has become the standard for architects and room acousticians working on performance space design. Despite the advances in both acoustics and technology, there is still a lack of understanding of the combined effects of directionality and delay of sound fields from moving sources in room acoustics (Chaitanya et al., 2020). This area has also become an essential application since acoustic identification and positioning systems for indoor environments are rapidly gaining commercial attention. However, the vast majority of acoustic indoor positioning techniques alleviate a sound source's directionality in order to increase solution reliability and require detailed multipath and room acoustics knowledge, which complicates their applicability (Zhong et al., 2023; Pinardi et al., 2021). Therefore, showing that the decreasing geometric attenuation of the sound field depends on the directivity of the source has clear implications both for optimising long-term return values, i.e., the acoustics of the optimisation process for all activities in performance spaces, and for formulating concise decisions in choosing directional sound sources in indoor positioning systems (Pezzoli et al., 2020). In this sense, framing the problem and trying a minimal approach is essential by comparing the results to omnidirectional theory or practical recommendations. The scope is also highly interdisciplinary, appealing to both the sciences and practical applications, where architectural acousticians will be, of course, interested in the study's basic assessment of the potential of a sound source for psychoacoustic amplification (Steffens et al., 2021). Finally, the acoustics-architecture-engineering interface environment provides an ideal opportunity for synergies and exchange opportunities in this research (Chaitanya et al., 2020).

II. Fundamentals of Directional Sound Field Decay

Directional sound field decay is fundamental to understanding sound behaviour in different environments (Shajahan et al., 2020). Various parameters influenced by the properties of a room, audience, musical instruments, and performance space contribute to optimal conditions (Li et al., 2021). The decay of a directional sound field in an enclosure affects an instrument's power and the level of direct sound being received at various locations. Characterising these by considering factors such as material properties, geometric attributes, and sound frequency while performing in an enclosed performance space under specific conditions offers a unique capacity (Abdelaziz & Grier, 2020). Most of these factors are determined by considering a decaying source on the axis of symmetry of a hemi-enclosure. The proposed work in this thesis studies primarily off-axis geometry to enable optimisation techniques considering numerous musicians in a performance space, which propagates a sound field that is predominantly off-axis of incoming excitation. Studies have investigated several different hemispherical geometries theoretically and experimentally off-axis. Therefore, orientation angles in this domain have other relevant attributes to be practically employed in tunable sound systems (Jonas, 2023). As explained, the audience and performer depend highly on decay behaviour. A three-dimensional solid angle is where it falls below the threshold value for the first time at a vertical angle and in a horizontal direction. Geometric divergence affects the decay of the sound field, whereas the relationship to the source is directly proportional to 1/r. If air absorption is considered, then the decay of a reverberant part of a sound field is considered with additional factors (Shajahan et al., 2020).

III. Performance Space Optimization Techniques

Designing a performance space with specific acoustical effects is desirable so that the performers and the audience will get the maximum auditory experience (Doyle, 2024). Based on the extensive research in this regard, it has been understood that the effects should not be prominent for the sound to have good clarity. Hence, the focus is on designing a room where sound is distributed equally throughout (Gao et al., 2022). In order to do this, various approaches are used, which can be mainly categorised into four as listed below: incorporation of technologies like Active Noise Control and Variable Impulse Response; employing proprietary materials that have characteristics or properties to distribute sound; use of optimally placed sound diffusers or absorbers; and building a room based on the concept of a shoebox or fan-shaped room (Pelat et al., 2020). The suggested approach seems unique, incorporating electronic modules with space optimisation techniques. This can be an excellent collaborative effort between the architect and the sound engineer, which aligns with technological advancements (Torresin et al., 2020). By adopting the space optimisation techniques, the limitations of building controlled acoustical environments are overcome to a certain extent since the space optimisations give the architect and sound engineer various options to tune the room acoustics to a much more significant extent, transforming it from an anechoic room to a reverberant room environment (Doyle, 2024). Apart from the above categorisations and examining them in more detail, many such rooms are built, where detailed case studies are discussed in this part of the chapter. It helps understand the transition from the theoretical to the practical part (Gao et al., 2022).

3.1. Acoustic Design Principles

"Ultimately, the function of an orchestral concert hall is to serve as an instrument (Wen et al., 2022). A host of acoustic design principles must be understood and implemented to ensure premier musical or operatic performances. Major design factors include sound reflection, absorption, diffusion, and overall sound decay as it traverses the space (Ahnert & Noy, 2022). Architects, acousticians, and audio engineers often play complementary roles concerning the design of a performance space, as attention must be paid to details such as interior geometry, material selections, design of reflectors in the performance space, and psychoacoustics (Orlowski, 2021). This is a tailored process for each venue, with necessary considerations including the type of performance, the size of the venue in question, architectural constraints, and projected audience expectations (Cairoli & Tronchin, 2020). Theatres require a shorter reverberation time, favouring speech intelligibility, while music halls require a longer one. Existing practices and laboratory-based studies in architectural acoustics address multiple design factors, including geometry, which is considered visually aesthetic and supports the diffusion of sound (Ahnert & Noy, 2022). The complex interplay between geometry, material selection, and visual presentation will be significant when using an electroacoustic system in a musical or theatrical performance for auditory assistive technologies in a space expressly designed for binaural hearing (Wen et al., 2022). As a part of technical architecture, acoustic design is concerned with "the creation of an enclosed space of various sizes and functions in which the acoustic qualities of that space meet both the owner's requirements for optimum privacy and space value while conforming to the basic building design criteria and requirements" (Cairoli & Tronchin, 2020). Concert halls, cinemas, and lecture theatres are buildings where sound isolation and other acoustic factors command attention (Orlowski, 2021).

3.2. Seating Arrangement Considerations

The seating layout in one of these spaces is critical in its influence on the social, personal, and emotional aspects of music listening and performance, which gives meaning to the space being "right" (Jiang et al., 2021). Therefore, significant time and money are spent on getting the spatial and audience interaction aspects as good as possible (Toyota et al., 2021). There are three basic seating strategies generally found: fixed seating layouts, a combination of traditional seating layouts with some flexibility, and finally, "flexible space" layouts encouraging multiple experiences from diverse audience viewpoints (Hill et al., 2022). Considering audience position, sightlines play a large part in our perception of space; it is not a primary consideration in this dissertation, so we will look first at fixed seating and then interesting flexible or irregular strategies (Dotov et al., 2021). There is no point, of course, in providing the best seat in the house if the space itself does not provide the appropriate acoustic support. In many "flexible" spaces, architects often start with the common observation that sound in a hall tends to be better from the circle, positioning the seating to ensure that everyone's view is roughly similar (Jiang et al., 2021). Quite often, an upward sweep of backs, allowing the audience to sit upright but lean back comfortably, can give some of the circle seat feel to a performance (Toyota et al., 2021). Many bars and restaurants achieve this by providing seating on graduated platforms with or without risers for the same reason (Hill et al., 2022).

Since the distance from the audience to the stage determines the sound level a person will hear, and the stage itself is a focal point during much of the event, good sound location is more important than being in the best sightline position (Dotov et al., 2021). In most halls, at any significant slope, the front section of seating does not have a clear view because the eye level is below the stage level produced by the angle. Even steeply raked master seats allow only high late reflections from the ceiling to be seen (Toyota et al., 2021). To better understand seat placement and acoustic interaction, it is necessary to consider the performance interactions that the seating is meant to facilitate. Thus, before starting the seating design, many questions about the layout must be addressed (Jiang et al., 2021).

IV. Indoor Positioning Techniques

Performance spaces can profit vastly from indoor positioning techniques (Horn, 2020). With the increasing concern for overall safety, user-friendly wayfinding, and improved customer services, interest has risen towards indoor positioning techniques that can support a variety of purposes to enhance the experience of performers and the audience (Gao et al., 2020). For instance, indoor positioning can support look-ahead navigation and encourage possible detour behaviour for audience engagement (Assayag et al., 2020). Bluetooth-based solutions have been proposed as an option for indoor positioning, using received signal strength indication (RSSI) values of Bluetooth beacons distributed around the performance area to triangulate the device's coordinates of interest (Kim et al., 2020). Wi-Fi serves the same purpose as Bluetooth but with an extended range and can be used inside and in nearby buildings. However, research continues to focus on improving the accuracy of indoor positioning solutions due to the impact of the device on system usability (Kunhoth et al., 2020).

Wi-Fi, however, may interfere with the operability of specific musical equipment, and it has been shown that Wi-Fi signals can be attenuated when reflecting off metallic surfaces, leading to erroneous position estimates (Gao et al., 2020). Signal accuracy in indoor positioning systems is critical because signal measurement errors translate directly to position estimate errors (Assayag et al., 2020). While systems like Galileo and GPS use a robust and cost-efficient technique like trilateration to estimate a client's position across long distances, the radio frequency signals utilised by wireless access points and dedicated positioning beacon systems cannot travel beyond walls, necessitating the use of indoor map schemes (Horn, 2020). A further technique implemented to reduce path errors in indoor positioning is using spatial fingerprinting, which utilises point-in-time radio frequency map snapshots or fingerprints as a metric for broadcasting signals (Kim et al., 2020). Application mapping provides data points that connect a position with received signal strength indications and shape the resulting fingerprint into unique features (Kunhoth et al., 2020). These values are influenced by factors such as the type, cost, era, and usage of any system connected to radio signal generation (Horn, 2020).

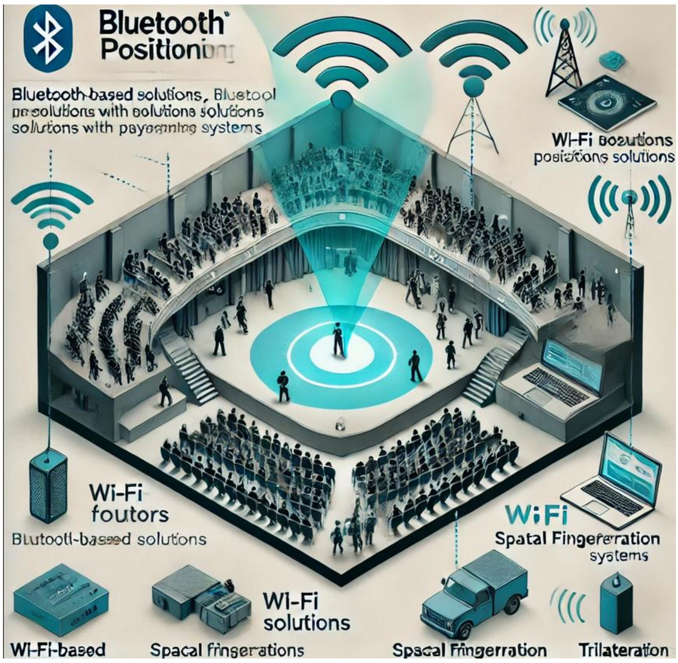

Figure 1; Indoor positioning techniques

Figure 1 illustrates how indoor positioning techniques, such as Bluetooth-based beacons, Wi-Fi systems, spatial fingerprinting, and trilateration, can be integrated into performance spaces. It highlights the placement of beacons and routers for accurate device positioning, potential challenges like signal interference, and how performers and the audience can benefit from enhanced navigation and experience in such environments.

One of the most critical applications of indoor positioning techniques lies in audience and spectatorship studies. To better understand how patrons interact with a particular performance, event, or artefact, it is essential to know where they are (Assayag et al., 2020). Some of this information is captured via spatial mapping and directed audio research. However, the scope for detailed mapping is often limited to regions closer to the performer, as research remains divided on the benefits of more detailed audience data mapping (Gao et al., 2020). Challenges introduced by mapping and fingerprinting technologies include excessive signal strength readings in smaller enclosed spaces, contributing to smoothed power decay beyond a certain threshold (Kim et al., 2020). Uneven radio signal propagation through oscillations, known as fading, is another technological factor that affects data mapping and fingerprint generation (Kunhoth et al., 2020). Transmission technologies also suffer from obstructions such as non-absorbing objects or attenuation problems associated with different environments (Horn, 2020). Path loss in these environments depends on methods of pure path-loss determination and combined multi-wall and free-space techniques (Gao et al., 2020).

4.1. Signal Propagation Models

When designing an optimal indoor positioning system, one of the first and foremost challenges is accurately modelling how a signal propagates through different materials and spaces (Berzborn & Vorländer, 2021). There are many different propagation models, yet those most relevant to indoor audio and vibration-based positioning systems—reverberation and ray tracing models—will be the principal focus (Nolan et al., 2020). These models, which assume spherical wavefronts, are imperfect due to the impact of multipath propagation and reflections. Nonetheless, they are widely used due to their comprehensibility and ability to closely model actual signal characteristics (Götz et al., 2022). Various empirical studies have validated using these reverberation and ray-tracing models in practice (Berzborn et al., 2021). The signal decay of omnidirectional sound fields in reverberant spaces can be highly accurately fitted to models of various reverberation time characteristics (Nolan et al., 2020). Meanwhile, the study of the signal decay of directional sound fields in ray tracing systems reveals significant deviations between models (Berzborn & Vorländer, 2021). This paper will examine these properties of the signal propagation models—ray tracing and reverberation models—in greater detail throughout the following passages. By understanding these models and their respective successes and limitations, we can identify strategies for developing more accurate and efficient methods of solving direct sound decay constants, thus enhancing the design of optimal acoustic spaces (Berzborn et al., 2021). Moreover, this knowledge will also be beneficial in renegotiating specific concert hall acoustic design practices and enabling efficient solutions to locate listeners and audio sources within these spaces (Götz et al., 2022).

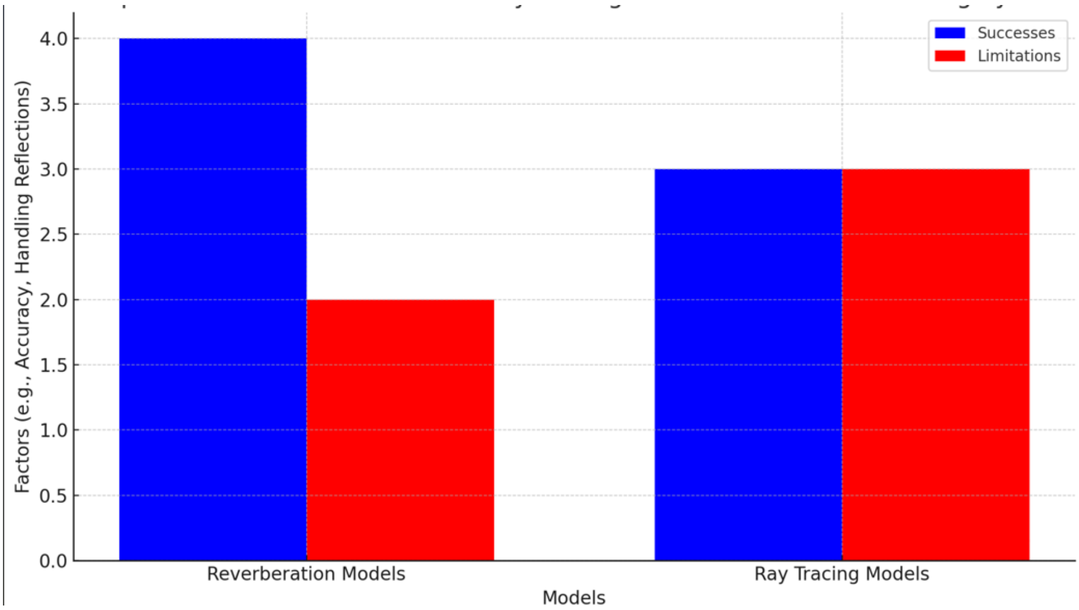

Figure 2: Comparison of Reverberation and Ray Tracing Models in Indoor Positioning Systems

The chart in Figure 2 compares reverberation and ray tracing models regarding their **successes** and **limitations** when applied to indoor positioning systems. Both models are crucial in understanding signal propagation, but each has specific strengths (like handling multipath propagation or reflections) and weaknesses (such as the spherical wavefront assumption). This comparison aids in developing more accurate methods for solving sound decay constants and optimising acoustic spaces.

4.2. Technologies and Sensors

Technology advancements have changed indoor positioning tremendously (Simões et al., 2020). The installation of various technological facilities can enhance indoor navigation capabilities. Beacons, Radio Frequency Identification (RFID) transponders, ultra-wideband, passive UHF RFID, Zigbee, and infrared systems operated in the form of differential GPS are among the systems used for solving indoor positioning challenges (El-Sheimy & Li, 2021). In addition to the systems mentioned above, different technologies, such as Wi-Fi fingerprint-based localisation, deep-learning neural network-based technologies, crowd intelligence, and intelligent device infrastructure, can further enhance indoor navigation (Plikynas et al., 2020). Any one technology can be chosen based on the audience being served and the purpose. The combination of RFID and cameras can control and improve the extraordinary properties of particular clapping systems (Elsanhoury et al., 2022). These technologies integrate new sound systems, advanced LED curtains, and developed applications. These systems are continuously developing to offer additional calculation methods (Simões et al., 2020). However, there are crucial challenges when introducing these systems to the audience, such as concerns regarding the privacy of users, verification and reliability of the signals produced by these systems, and the accessibility of the technologies. Each technology has its way of measuring specific indicators (El-Sheimy & Li, 2021).

Categorising these metrics can make the proposal more user-friendly for any space. Moreover, combining technology and acoustics measurement shows an improvement in immersive performance compared to traditional quality of sound and entertainment measurements (Plikynas et al., 2020). With the evolution of personal devices such as smartphones and tablets, handheld devices and indoor routers are continuously changing to improve indoor positioning based on the needs of the accommodation entity (Elsanhoury et al., 2022). This combination of technology and indoor positioning offers significant potential for enhancing personal technology and entertainment systems.

V. Experimental Studies and Case Examples

The theories described above have been applied in settings beyond the classroom, where listeners detect a range of signals. The auditory display design modified the directional decay algorithm to build adjustable acoustic landmarks between points on a mobility training course (Urbanietz, 2021). "Sitemap," a tactile map featuring a curved path through a park embroidered onto a hairier surface, represents one such application. Although this industrial product has since pivoted to walk-on construction for other building projects, avoiding further work in acoustics, its foundational principles still apply (Jonas, 2023). Another recent project highlighted two relevant outcomes for decision-making. Firstly, "our psychoacoustic results resulted in optimal settings for the shoebox curves, allowing the AB-simulator to achieve appropriate room acoustics quickly and efficiently."

However, the "AB-simulator" specifics were not further elaborated (Stahl & Riedel, 2024). Secondly, "time-variant binaural models are effective in simulating sound decay due to binaural masking and head-induced spectrum shaping." With adjusted reverberation times and the proper implementation of HRTFs, binaural masking creates an optimal level of immunity to acoustic background noise (Deppisch et al., 2024). In a more practical application, an entire building—specifically an opera house—was used as an experimental environment for optimising acoustic properties. Measurements of objective frequency response parameters and listener studies using the pairs comparison method informed adjustments in the main performance space (Urbanietz, 2021). The subsequent fine-tuning of transmission paths, time-variant algorithms, and virtual source location paradigms played a significant role in design development (Jonas, 2023). Ultimately, the goal for the theatre was to achieve "virtual pink noise with a decay rate that sets the auditory and aural scene," though it remains unclear whether this goal was fully realised (Stahl & Riedel, 2024). Rather than focusing on absolute values, these studies emphasised process and performance, underpinning decision-making in real-world applications. This research's overall value extends from supporting design development to providing insights illuminating decision-making options for acoustic optimisation (Deppisch et al., 2024).

VI. Conclusion and Future Research Directions

In this paper, the influence that a nonzero C80 has on performance space optimisation is discussed. A linear relationship between the position of the first row of the variable absorption area and the arrival energy ratio was identified from the analysis. The significance of establishing sound field decay that includes a directivity factor is emphasised and demonstrated. The synthesis of objective and subjective spatial acoustics was identified as an opportunity. As such, an effective and efficient approach for identifying a simplified, uniform reverberation time decay law is staunchly advocated. In presenting these different directions, an identity of spatial acoustic design with computer-aided stage design was highlighted. We also discussed a research direction where acoustic design is envisaged to further the development of indoor positioning systems and structural health monitoring, two areas where future research should be directed to synergise the interests of the "poles" in music conservatories: those specialising in new technology and performance. Future research investigating environmentally robust systems could re-evaluate the spatial fading characteristics regarding signal-to-noise ratio instead of sound pressure level.

Developing less obtrusive techniques for positioning instruments or performers could exploit subtle variations in the naturally decaying sound field to achieve high precision. Such a system could also be beneficial for monitoring structural health without needing the robust optical or magnetic systems required for positioning the above systems. Using a variable dead zone constitutes a futuristic research venue for constructing a multi-purpose performance venue. A single venue could provide the acoustics of anything from a mammoth symphony orchestra concerto to a tiny, intimate jazz locale by providing an array of dead zones, variable reverb, and directivity settings in any one location. Such a system would also suit seminars and meetings. In short, the synergy between ambience, acoustic effect, and performance could be harnessed. Developing such spatial multiplex systems requires a strong link between acoustic phenomena and positioning systems and could constitute an affluent area of future inquiry. Perhaps this would once again place music in the vanguard of technological innovation.

References:

[1]. Zhong, J., Zou, H., & Lu, J. (2023). A modal expansion method for simulating reverberant sound fields generated by a directional source in a rectangular enclosure. The Journal of the Acoustical Society of America, 154(1), 203-216. jiaxinzhong.com

[2]. Pinardi, D., Riabova, K., Binelli, M., Farina, A., & Park, J. S. (2021, September). Geometrical acoustics simulations for ambisonics auralization of a car sound system at high frequency. In 2021 Immersive and 3D Audio: from Architecture to Automotive (I3DA) (pp. 1-10). IEEE. unipr.it

[3]. Pezzoli, M., Borra, F., Antonacci, F., Tubaro, S., & Sarti, A. (2020). A parametric approach to virtual miking for sources of arbitrary directivity. IEEE/ACM Transactions on Audio, Speech, and Language Processing, 28, 2333-2348. [HTML]

[4]. Steffens, H., van de Par, S., & Ewert, S. D. (2021). The role of early and late reflections on perception of source orientation. The Journal of the Acoustical Society of America, 149(4), 2255-2269. [HTML]

[5]. Chaitanya, C. R. A., Raghuvanshi, N., Godin, K. W., Zhang, Z., Nowrouzezahrai, D., & Snyder, J. M. (2020). Directional sources and listeners in interactive sound propagation using reciprocal wave field coding. ACM Transactions on Graphics (TOG), 39(4), 44-1. [HTML]

[6]. Shajahan, N., Barclay, D. R., & Lin, Y. T. (2020). Quantifying the contribution of ship noise to the underwater sound field. The Journal of the Acoustical Society of America, 148(6), 3863-3872. aip.org

[7]. Li, S., Rival, D. E., & Wu, X. (2021). Sound source and pseudo-sound in the near field of a circular cylinder in subsonic conditions. Journal of Fluid Mechanics. [HTML]

[8]. Abdelaziz, M. A. & Grier, D. G. (2020). Acoustokinetics: Crafting force landscapes from sound waves. Physical Review Research. aps.org

[9]. Jonas, S. (2023). Real-time auralisation of outdoor sound propagation. hust.edu.vn

[10]. Doyle, P. (2024). Echo and reverb: Fabricating space in popular music recording, 1900-1960. [HTML]

[11]. Gao, N., Zhang, Z., Deng, J., Guo, X., Cheng, B., & Hou, H. (2022). Acoustic metamaterials for noise reduction: a review. Advanced Materials Technologies, 7(6), 2100698. researchgate.net

[12]. Pelat, A., Gautier, F., Conlon, S. C., & Semperlotti, F. (2020). The acoustic black hole: A review of theory and applications. Journal of Sound and Vibration, 476, 115316. sciencedirect.com
[13]. Torresin, S., Albatici, R., Aletta, F., Babich, F., Oberman, T., Siboni, S., & Kang, J. (2020). Indoor soundscape assessment: A principal components model of acoustic perception in residential buildings. Building and Environment, 182, 107152. sciencedirect.com
[14]. Wen, M., Ma, H., Yang, J., & Yang, L. (2022). Main acoustic attributes and optimal values of acoustic parameters in Peking opera theaters. Building and Environment. [HTML]
[15]. Ahnert, W. & Noy, D. (2022). 11 System Solutions/Case Studies. Sound Reinforcement for Audio Engineers. [HTML]
[16]. Orlowski, R. (2021). Acoustics in Architectural Design. [HTML]
[17]. Cairoli, M. & Tronchin, L. (2020). The architectural and acoustic quality for theatres hosting animals. AIP Conference Proceedings. unibo.it
[18]. Jiang, J., Meng, Q., & Ji, J. (2021). Combining music and indoor spatial factors helps to improve college students' emotion during communication. Frontiers in Psychology. frontiersin.org
[19]. Toyota, Y., Komoda, M., Beckmann, D., Quiquerez, M., & Bergal, E. (2021). Concert halls by Nagata Acoustics: Thirty years of acoustical design for music venues and vineyard-style auditoria. Springer Nature. [HTML]
[20]. Hill, T., Canniford, R., & Eckhardt, G. M. (2022). The roar of the crowd: How interaction ritual chains create social atmospheres. Journal of Marketing. bath.ac.uk
[21]. Dotov, D., Bosnyak, D., & Trainor, L. J. (2021). Collective music listening: Movement energy is enhanced by groove and visual social cues. Quarterly Journal of Experimental Psychology, 74(6), 1037-1053. sagepub.com
[22]. Horn, B. K. P. (2020). Doubling the accuracy of indoor positioning: Frequency diversity. Sensors. mdpi.com
[23]. Gao, D., Zeng, X., Wang, J., & Su, Y. (2020). Application of LSTM network to improve indoor positioning accuracy. Sensors. mdpi.com
[24]. Assayag, Y., Oliveira, H., Souto, E., Barreto, R., & Pazzi, R. (2020). Indoor positioning system using dynamic model estimation. Sensors. mdpi.com
[25]. Kim Geok, T., Zar Aung, K., Sandar Aung, M., Thu Soe, M., Abdaziz, A., Pao Liew, C., ... & Yong, W. H. (2020). Review of indoor positioning: Radio wave technology. Applied Sciences, 11(1), 279. mdpi.com
[26]. Kunhoth, J., Karkar, A., Al-Maadeed, S., & Al-Ali, A. (2020). Indoor positioning and wayfinding systems: a survey. Human-centric Computing and Information Sciences, 10, 1-41. springer.com
[27]. Berzborn, M. & Vorländer, M. (2021). Directional sound field decay analysis in performance spaces. Building Acoustics. [HTML]
[28]. Nolan, M., Berzborn, M., & Fernandez-Grande, E. (2020). Isotropy in decaying reverberant sound fields. The Journal of the Acoustical Society of America, 148(2), 1077-1088. aip.org
[29]. Berzborn, M., Balint, J., & Vorländer, M. (2021). On the estimation of directional decay times in reverberation rooms. In Proc. Euronoise Online Conf (pp. 1-9). sea-acustica.es
[30]. Götz, G., Hold, C., McKenzie, T., Schlecht, S., & Pulkki, V. (2022). Analysis of multi-exponential and anisotropic sound energy decay. In Jahrestagung für Akustik, Stuttgart, Germany, 21/03/2022. German Acoustical Society (DEGA). ed.ac.uk
[31]. Simões, W. C., Machado, G. S., Sales, A. M., de Lucena, M. M., Jazdi, N., & de Lucena Jr, V. F. (2020). A review of technologies and techniques for indoor navigation systems for the visually impaired. Sensors, 20(14), 3935. mdpi.com
[32]. El-Sheimy, N. & Li, Y. (2021). Indoor navigation: State of the art and future trends. Satellite Navigation. springer.com
[33]. Plikynas, D., Žvironas, A., Budrionis, A., & Gudauskis, M. (2020). Indoor navigation systems for visually impaired persons: Mapping the features of existing technologies to user needs. Sensors. mdpi.com
[34]. Elsanhoury, M., Mäkelä, P., Koljonen, J., Välisuo, P., Shamsuzzoha, A., Mantere, T., ... & Kuusniemi, H. (2022). Precision positioning for smart logistics using ultra-wideband technology-based indoor navigation: A review. Ieee Access, 10, 44413-44445. ieee.org
[35]. Urbanietz, C. (2021). Advances in binaural technology for dynamic virtual environments. d-nb.info
[36]. Stahl, B. E. N. J. A. M. I. N., & Riedel, S. (2024). Perceptual Comparison of Dynamic Binaural Reproduction Methods for Sparse Head-Mounted Microphone Arrays. Journal of the Audio Engineering Society. Audio Engineering Society, 73(7-8), 442-454. researchgate.net
[37]. Deppisch, T., Meyer-Kahlen, N., & Garí, S. V. A. (2024). Blind Identification of Binaural Room Impulse Responses from Smart Glasses. arXiv preprint arXiv:2403.19217. [PDF]
[38]. Veselovskii, I., Hu, Q., Goloub, P., Podvin, T., Korenskiy, M., Derimian, Y., ... & Castellanos, P. (2020). Variability in lidar-derived particle properties over West Africa due to changes in absorption: towards an understanding. Atmospheric Chemistry and Physics, 20(11), 6563-6581. copernicus.org
[39]. Xu, H., Niu, J. R., Chen, P., Lee, K. J., Zhu, W. W., Dong, S., ... & Zou, J. H. (2022). A fast radio burst source at a complex magnetized site in a barred galaxy. Nature, 609(7928), 685-688. [PDF]
[40]. Ata, Y. (2021). Structure function, coherence length, and angle-of-arrival variance for Gaussian beam propagation in turbulent waters. Journal of the Optical Society of America A. optica.org
[41]. de Bruin, T. A. & van Sark, W. G. (2022). Optimising absorption in luminescent solar concentrators constraint by average visible transmission and color rendering index. Frontiers in Physics. frontiersin.org