INTERNET OF SOUNDS


Luca Turchet


Maximo Cobos


Woon-Seng Gan


Hossein Shokri Ghadikolaei

In recent years, converging research trends in academia and industry have brought the fields of Sound and Music Computing and the Internet of Things (IoT) closer. This convergence has given rise to a new domain — the Internet of Sounds (IoS) — supported by a growing community of researchers. Many of these scholars now collaborate under the IEEE Emerging Technology Initiative on the Internet of Sounds, operating under the guidance of the IEEE Communications Society.

The IoS represents a network of devices capable of sensing, collecting, processing, actuating, and exchanging data to facilitate the communication of sound-related information. It merges two key paradigms: the Internet of Musical Things and the Internet of Audio Things. These respectively address musical and non-musical domains in networked contexts. In the IoS paradigm, diverse devices designed for musical and non-musical tasks interact seamlessly, cooperating with other Internet-connected systems to deliver sound-based services and globally accessible applications.

This Feature Topic (FT) explores the new exciting opportunities and unique challenges within the IoS domain. Following a rigorous selection process, six articles were accepted. Below, we provide a comprehensive summary of these pioneering contributions, showcasing the progress in the state of the art of IoS research.

The first article, "Intelligent Noise Mapping for Smart Cities: Solutions, Trends, and Research Opportunities," by Liu et al., addresses the pressing issue of noise pollution in urban environments, a significant challenge for healthcare and sustainable urban development. The authors begin by offering a critical review of recent advances in intelligent noise mapping. This mapping is an essential emerging tool expected to transform invisible noise problems into visible data, thereby providing a foundation for effective governance. They then present their insights into development trends for intelligent noise mapping for smart cities, followed by identifying key open issues and potential research directions. The relevance of this study lies in its contribution to the development of more effective strategies for mitigating noise pollution and fostering sustainable urban environments.

The second article, "Democratizing Networked Music Performance with an RL-based SD-WAN," by Borgianni et al., explores the use of satellite-based communications to connect geographically dispersed musicians via a networked music performance (NMP) system. The authors leveraged Software Defined Wide Area Network technology combined with reinforcement learning for the integration of a Low Earth Orbit tunnel into an NMP system. The proposed architecture aims to democratize NMP by extending its accessibility to remote areas and individuals lacking access to high-performance networks.

The third article, "Inclusiveness in Remote Music Teaching and Networked Music Performances: Vision, Technological Enablers and Design Strategies," by Rottondi, tackles the challenge of ensuring inclusivity in collaborative music education and practices, conducted via NMP systems. The article first reviews the main technological enablers for designing customized solutions to support the needs of music students and practitioners with visual, auditory, or mobility impairments. Next, it discusses an interdisciplinary design methodology for creating technology-assisted educational activities tailored to individual needs. The author also presents several use cases demonstrating the potential adoption of such solutions. Notably, the article highlights the importance of holistic and multidisciplinary approaches. It emphasizes bringing together expertise from Information and Communication Technologies, pedagogy, psychology, and healthcare to enable inclusiveness in remote music teaching and NMP.

In the fourth article "Designing an Internet of Sounds Sonification System with FM Synthesis Techniques, " Roddy studies the relatively underexplored application of sonification (the representation of data through sound to communicate information) within IoS contexts. The author proposes a formal definition of sonification for the IoS and details the design of a novel system for sonification-enabled IoS networks in smart cities. The article outlines key design considerations and highlights the opportunities and challenges of integrating sonification methods into IoS settings.

In the fifth article, "Evaluating hearables for augmenting TV audio in shared viewing environments," Geary et al. investigate the use of wireless hearables with 'hear-through' transparency features to deliver personalized audio experiences in shared TV viewing scenarios. The authors conducted a listening test to assess how different TV mix contents could be rendered over hearables, with concurrent TV audio perceived over a transparency mode. They evaluated how these setups impacted user preference and dialogue clarity. The results indicated that while users preferred both the full mix and dialogue-focused audio over hearables equally compared to the open-ear TV condition, they favored the hearables-only condition more. Additionally, the study also found improvements in dialogue clarity when the original mix made the dialogue difficult to perceive, emphasizing the need for personal mix control in shared viewing environments.

Finally, the article "Development of Ad Hoc Loudspeaker Arrays using Smart Devices," by Fujita and Villegas, proposes a system using smart devices to create ad hoc loudspeaker arrays for real-time audio spatialization. The system employs a modified "room within a room" spatialization technique, dynamically defining the listening area using the convex hull formed by the loudspeakers. The system utilizes ultra-wideband technology for precise indoor positioning, allowing speakers to move horizontally while maintaining accurate audio spatialization. A user study with 20 participants demonstrated the feasibility of using commercially available smart devices to form flexible loudspeaker arrays, suggesting promising potential for adaptive, user-friendly spatial audio systems.

In conclusion, we have provided an overview of six accepted articles that explore various dimensions of the IoS. The diversity of these contributions reflects the growing academic and industrial interest in this area. Each article offers unique insights into the latest trends and advancements in the IoS field. We hope these articles inspire further research and innovation in this rapidly evolving domain. We also hope that these papers serve as valuable resources for both the IoS communitys and the broader field of IoT, facilitating the exchange of ideas, methodologies, and solutions across multiple research disciplines.

Finally, the Guest Editorial team expresses its sincere gratitude to the authors for their original contributions, and to the reviewers for time and invaluable feedback. We are especially grateful to Editor-in-Chief Rose Qingyang Hu, Associate Editor-in-Chief Gabor Fodor, and Editorial Assistant Tammy Remington for their steadfast support and guidance, which were instrumental in the success of this FT.

Biographies

Luca Turchet (luca.turchet@unitn.it) is an Associate Professor at the Department of Information Engineering and Computer Science of the University of Trento, where he leads the Creative, Intelligent, and Multisensory Interactions Laboratory. He currently serves as an Associate Editor for *IEEE Transactions of Human-Machine Systems*, *IEEE Access*, and the *Journal of the Audio Engineering Society*. He is the Founding Chair of the IEEE Emerging Technology Initiative on the Internet of Sounds, and the General Chair of the IEEE International Symposium on the Internet of Sounds.

Maximo Cobos (maximo.cobos@uv.es) is a Full Professor in the Computer Science Department at the Universitat de València in Spain, where he leads the Signal Processing and Acoustic Technology group. He serves as a Senior Area Editor for *IEEE Signal Processing Letters* and is a member of the EURASIP Technical Area Committee on Acoustic, Speech, and Music Signal Processing, as well as the Technical Committee on Audio Signal Processing of the European Acoustics Association.

Woon-Seng Gan (ewsgan@ntu.edu.sg) is a Professor of Audio Engineering at the School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore. He is serving as a Senior Area Editor for the *IEEE Signal Processing Letters*, and Associate Editor for the *IEEE Signal Processing Magazine*, and the *Journal of the Audio Engineering Society*. He is also a Distinguished Lecturer of the IEEE Signal Processing Society and will become the President of the Asia-Pacific Signal and Information Processing Association (APSIPA) in 2025.

Hossein Shokri Ghadikolaei (hossein.shokri.ghadikolaei@ericsson.com) is Senior Researcher in Ericsson Research, Kista, Sweden. His research focuses on distributed optimization and machine learning in communication networks. His research has received several international awards including the IEEE Communications Society Stephen O. Rice Prize and the Premium Award for the Best Paper in *IET Communications*. He served as an Associate Editor of *IEEE Communications Letters*.