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研究課題名（和文）Perceptual constancy in spatial hearing

研究課題名（英文）Perceptual constancy in spatial hearing

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研究成果の概要（和文）：本プロジェクトの内に達成された主な目標は以下に要約される。1）遠距離と近距離で空間音を捕捉し再生するための新数学的方法を定式した。2）頭部伝達関数の集まりを作成できた。3）心理物理学的実験のための仮想環境を構築した。4）ヘッドフォンとヘッドマウントディスプレイ用の没入型内容の集まりを作成できた。5）清華大学とハノーバー医科大学との国際協力は、聴覚脳の計算面を探求するために始めることができた。6）成果を発表するために、ペルーのリマで国際ワークショップが開催された。これは、"サンマルティンデポーレス大学"および "Fundacion Telefonica"と共同で行われた。

研究成果の学術的意義や社会的意義
An important contribution of this project are the tools to render sound sources in the peripersonal space. To foster reproducibility of research and reach the wider community, the contents generated during this project are publicly available at: https://cesardsalvador.github.io/projects.html

研究成果の概要（英文）：The main goals accomplished during this project are summarized as follows. 1) New mathematical methods to capture and reproduce spatial sound at far and near distances were formulated and evaluated. 2) A collection of head-related transfer functions was created. 3) A virtual environment for psychophysical experimentation was assembled. The system captures and reproduces 3D ambisonic audio and 360 video. 4) A collection of immersive contents for headphones and head-mounted displays has been created. 5) The international collaboration with Tsing Hua University and Hannover Medical School has been initiated to explore the computational aspects of the auditory brain. 6) An international workshop has been organized and held in Lima, Peru, to present the achievements of this project. This was done in collaboration with "Universidad de San Martin de Porres" and "Fundacion Telefonica".

研究分野：情報学・人間情報学・知覚情報処理

キーワード：音響情報処理　頭部伝達関数　位相幾何学

１．研究開始当初の背景

Research trends in realistic spatial audio are pursuing the ambitious goal of re-creating the full acoustic world. However, obtaining vast amounts of sensorial information is not always feasible. Recent studies in brain dynamics suggest that the mind have an innate disposition to construct full representations of the world in continuous change by identifying invariant structures in the sensorial information. Following this line of thought, this research aims to identify patterns of invariance along databases of morphological and acoustical measurements related to the external anatomy of ten research participants. Psychophysical experiments are considered to stablish relations between the patterns of invariance identified by the new mathematical models and the perceptual cues involved in sound localization.
Before the starting of this research, the existing mathematical formulations and acoustical data that chracterizes spatial hearing were mainly oriented to treat directions. However, distance dependencies were neglected, specially for sources in the peripersonal space within 1 m from the center of the head. For this reason, this research is mainly oriented to clarify the phenomenon of spatial hearing in the peripersonal space.

２．研究の目的

This research seeks to formulate and evaluate new mathematical models for human spatial hearing to elucidate the phenomena of perceptual constancy involved in sound localization. The understanding of these phenomena is crucial to enable the presentation of spatial sound with high levels of realism and naturalness. This will enable the presentation of spatial sound with high levels of naturalness. The specific aim is to identify patterns of invariance along databases of acoustical measurements related to the external anatomy of individuals.

３．研究の方法

The present research comprised three stages:

- The first stage was avocated to the creation and formulation of a new approach to analyze patterns of invariance in databases of spatial sound information. This stage was mostly theoretical and was assisted by numerical simulations.
- The second stage consited on the generation of a database of morphological and acoustical data related to the anatomical shapes of ten research participants. This stage was assisted by medical services of magnetic resonance imaging to obtain the 3D models of the participants; in addition, numerical solutions to the acoustic wave equation were used to calculate acoustical data.
- The third stage was oriented to the analysis of the database to identify

patterns of invariance that are linked to perceptual constancy cues in spatial hearing. To ensure reproducibility of results, this stage also involved the implementation of an immersive audiovisual environment for perceptual experimentation with the research participants.

４．研究成果

The results of this research are summarized as follows.

- New mathematical methods for the analysis of acoustical data were formulated and evaluated. Special attention was given to distance information. Methods were formulated in abstract domains of representation where it is possible to unmask distance dependencies that are otherwise hardly observed in the natural spatial domain. This achievement constituted a step forward in the research field of spatial sound because the issues related to including distance information were not comprehensively considered in previous research. The results and validations were published in a journal paper.
- A collection of data describing the external anatomy of listeners' heads (morphology), as well as the transmission of sound from a point in space to the listeners' eardrums (acoustical), was created. Near sources (within 1 meter from the head) were specially considered due to their importance when aiming at rendering spatial sound in the peripersonal space with high levels of realism and naturalness. This was a major contribution because existing datasets mainly provide information for far sources (beyond 1 m from the head). To foster the reproducibility of research results and reach the wider community, a sample of the morphological and acoustical dataset has been made publicly available in the project's website.
- An immersive audiovisual system for psychophysical experimentation was assembled; its components are a microphone array, a 360 camera, a pair of headphones and a head-mounted display. The system captures and reproduces 3D ambisonic audio and 360 video. Ambisonic audio facilitates the digital tracking of head movements, which is important to increase the sense of presence during reproduction. A collection of immersive contents for headphones and head-mounted displays has been created and made publicly available in the project's website. The contents have been captured in anechoic and natural environments, and are intended to be use on subjective tests in future extensions of this project.
- The international collaboration with Tsing Hua University and Hannover Medical School has been initiated to explore the computational aspects of the brain processes that are involved in auditory tasks such as the localization, identification, and selective attention to sound sources.
- The dataset of near-distance HRTFs developed in this project has also been used in psychophysical experiments of auditory attention along distance. This

has been done in collaboration with colleagues of a different project.

- An international workshop has been organized and held in Lima, Peru, to present the achievements of this project. This was done in collaboration with "Universidad de San Martin de Porres" and "Fundacion Telefonica". The language of the event was Spanish. All activities and materials are publicly available in the project's website.

５．主な発表論文等

〔雑誌論文〕（計 1 件）

(1) C. D. Salvador, S. Sakamoto, J. Treviño, and Y. Suzuki, "Boundary matching filters for spherical microphone and loudspeaker arrays," IEEE/ACM Trans. Audio, Speech, Language Process., vol. 26, no. 3, pp. 461-474, Mar. 2018. Peer-reviewed publication.
Available at: https://doi.org/10.1109/TASLP.2017.2778562

〔学会発表〕（計 4 件）

(1) C. D. Salvador, R. Teraoka, Y.-W. Liu, M. Sato, A. Kral, and S. Sakamoto, "Computational models of the auditory brain," 6th Int. Symp. Brainware LSI, Sendai, Japan, March 2019.
Available at:
https://cesardsalvador.github.io/doc/salvador_2019_auditory_brain.pdf

(2) C. D. Salvador, S. Sakamoto, J. Treviño, and Y. Suzuki, "Enhancing binaural reconstruction from rigid circular microphone array recordings by using virtual microphones," Proc. Audio Eng. Soc. Int. Conf. Audio for Virtual and Augmented Reality, Redmond, WA, USA, August 2018.
Avaiable at: http://www.aes.org/e-lib/browse.cfm?elib=19669

(3) C. D. Salvador, S. Sakamoto, J. Treviño, and Y. Suzuki, "Dataset of near-distance head-related transfer functions calculated using the boundary element method," Proc. Audio Eng. Soc. Int. Conf. Spatial Reproduction -Aesthetics and Science-, Tokyo, Japan, August 2018.
Available at: http://www.aes.org/e-lib/browse.cfm?elib=19602

(4) C. D. Salvador, S. Sakamoto, J. Treviño, and Y. Suzuki, "Enhancing the binaural synthesis from spherical microphone array recordings by using virtual microphones," IEICE Tech. Rep., vol. 117, no. 328, pp. 61-66, The New Zealand/Japan Joint Research Meeting on Psychological & Physiological Acoustics and Electroacoustics, Auckland, New Zealand, Nov. 2017.
Available at: https://www.ieice.org/ken/paper/201711307bYy/eng/

〔その他〕

ホームページ等

- Project website: https://cesardsalvador.github.io/projects.html
- Dataset of near-distance HRTFs: https://cesardsalvador.github.io/download.html
- International workshop (in Spanish): https://cesardsalvador.github.io/a3d/

６．研究組織

(1)研究分担者