Three-Dimensional Evaluation of the Cochlea Using Terahertz Near-Field Imaging

Luwei Zheng[1], Takeshi Fujita[2], Akinobu Kakigi[2], Hironaru Murakami[1,3], Masayoshi Tonouchi[4], Niu Zhengya[5], and Kazunori Serita[5]

[1] Institute of Laser Engineering, The University of Osaka, [2] Department of Otolaryngology-Head and Neck Surgery, Graduate School of Medicine, Kobe University, [3] Department of Electrical, Electronic and Computer Engineering, Fukui University of Technology, [4] Research Institute for Interdisciplinary Science, Okayama University, [5] Graduate School of Information, Production, and Systems, Waseda University
E-mail: k_serita@aoni.waseda.jp

1. Introduction

Hearing impairment and loss are widespread conditions that impact a significant portion of the global population, greatly diminishing both communication abilities and overall quality of life [1]. These auditory issues are most commonly associated dysfunctions within the cochlea of the inner ear [2-4]. Achieving non-destructive imaging of the cochlea's internal structure with adequate spatial resolution remains a significant challenge. To address this, we successfully conducted the first non-destructive terahertz (THz) imaging of a mouse cochlea using a THz near-field point source microscope capable of micro-scale resolution [5,6]. High-accuracy three-dimensional (3D) THz time-of-flight (ToF) imaging and reconstruction were also demonstrated. This advancement lays the groundwork for future medical diagnostic applications, particularly in the early detection and evaluation of hearing-related disorders.

2. Method

The methodology employed in this study for 3D terahertz (THz) imaging and structural reconstruction of the cochlea involves three main stages: (1) two-dimensional (2D) data acquisition, (2) structural information extraction, and (3) 3D reconstruction. First, 2D time-domain THz images were obtained at various delay time points using a scanning point-source THz imaging system combined with the time-of-flight (ToF) technique. Second, an unsupervised machine learning algorithm—k-means clustering—was applied to classify the 2D THz images into distinct subgroups, enabling the separation of structural and non-structural regions. Finally, using the extracted structural data, a 3D point cloud was generated, and a 3D surface mesh was reconstructed through the Poisson surface reconstruction method. This approach demonstrates high reliability and flexibility, making it applicable to 3D reconstruction of a wide range of biological tissues.

3. Results

Fig. 1 shows the reconstructed 3D results, including 3D point cloud and surface mesh data. Fig. 1(a) and 1(b) show the 3D point cloud and surface mesh results, respectively. Fig. 1(c) shows a cross-sectional view of the 3D surface results shown in Fig. 1(b). The internal structure of the cochlea was easily and clearly observable, as indicated by the arrows in Figs. 1(b) and 1(c). Fig. 1(d) shows the bottom view of the reconstructed 3D surface mesh cochlea. The results demonstrate that the interior and exterior features of the cochlea can be successfully and clearly visualized.

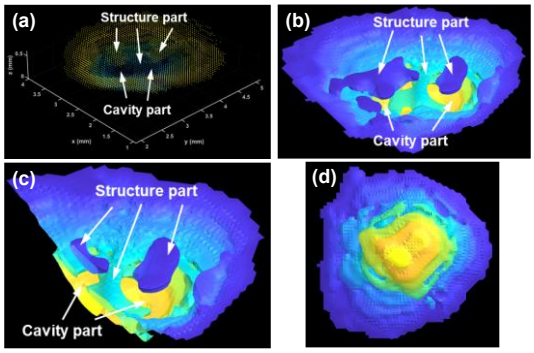

Figure 1 3D point cloud and surface mesh reconstruction.

4. Conclusions

In this study, we successfully visualized the internal structure of a mouse cochlea using terahertz (THz) near-field imaging with a micrometer-scale point source generated by laser irradiation (~20 μm spot size). The cochlea was placed on a GaAs substrate for effective imaging. 2D THz time-domain images were captured at various delay times, providing depth-resolved structural information. By applying the time-of-flight (ToF) principle, temporal data were converted into depth profiles. Structural features were extracted using *k*-means clustering, enabling 3D reconstruction through point cloud generation and Poisson surface meshing. This approach marks the first 3D THz imaging of cochlear structures and shows great potential for high-resolution imaging of biological tissues and early diagnosis of related diseases. Image analysis for achieving higher resolution and more detailed measurement results are presented.

Acknowledgements

This work is partially supported by the Japan Science and Technology Agency FOREST program (JPMJFR2029 and JPMJFR215F), the Japan Society for the Promotion of Science KAKENHI (JP23K22820, JP23H00184, and JP25K01294), and the China Scholarship Council (Grant No. 202206170007).

References

[1] S. G. Kujawa and M. C, Hear. Res. **330** (2015) 191–199.
[2] L. F. Corns *et al.*, Nat. Commun. **9** (2018) 4015
[3] Z. Wu *et al.*, Nat. Neurosci. *20* (2017) 24–33.
[4] P. Delmas *et al.*, Cell *155* (2013) 278-284.
[5] K. Serita *et al.*, Opt. Express 20 (2012) 12959-12965.
[6] L. Zheng *et al.*, Optica 12 (2025) 437-445.