様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９　（共通）

科研費
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研究課題名（和文）"Two Ears Are Better Than One: Towards the Development of a Real-Time Crosstalk Cancellation System Based on Bone Conduction

研究課題名（英文）"Two Ears Are Better Than One": Towards the Development of a Real-Time Crosstalk Cancellation System Based on Bone Conduction

研究代表者

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交付決定額（研究期間全体）：（直接経費）　　2,900,000円

研究成果の概要（和文）：骨伝導補聴器におけるクロストークは、特に音源定位の精度に影響を及ぼします。我々の研究では、マストイドに配置した加速度計と、適応型FxLMSアルゴリズムを活用してこの問題に対処し、クロストークを効果的にキャンセルする技術を開発しました。実験結果から、この技術は純音聴力閾値を改善し、蝸牛におけるクロストークの減少を実現することが示唆されました。リアルタイム実装により、このアプローチの実用性が実証されました。さらに、側方化タスクとの組み合わせによって、より精密な蝸牛へのクロストークキャンセルが可能となります。これらの革新は、骨伝導補聴器を向上させるための重要な一歩です。

研究成果の学術的意義や社会的意義
Our research demonstrates the potential to reduce crosstalk in bone conduction (BC) devices, a crucial step towards improved binaural hearing. While not yet fully realized, it shows promise for enhancing binaural perception in future BC device applications.

研究成果の概要（英文）：Crosstalk in bone conduction (BC) hearing devices presents a challenge by transmitting sound to the unintended ear, affecting binaural hearing benefits such as sound localization. Our research tackles this by developing a method to cancel crosstalk at an accelerometer on the mastoid via an adaptive FxLMS algorithm to generate an anti-crosstalk signal, aiming for the cancellation effect to extend to the cochlea. Despite mastoid cancellation, testing with pure-tone hearing thresholds indicated successful crosstalk reduction, as participants experienced lower thresholds in noise, suggesting effective cancellation. We further advanced our solution by implementing it in real-time, demonstrating practical applicability. Additionally, we explored combining this with lateralization tasks to refine crosstalk cancellation directly at the cochlea, aiming for a more targeted and effective approach. This series of innovations marks a significant step forward in improving BC hearing devices.

研究分野：Hearing Sciences, Acoustical Engineering

キーワード：Hearing　Bone Conduction　Crosstalk　Cancellation　Bone Transducer

１．研究開始当初の背景

Bone conduction (BC) devices are an innovative hearing solution that transmits sound through skull vibrations, bypassing the outer and middle ear. Despite their benefits, these devices face a challenge known as "crosstalk," where sound intended for one ear is also heard by the other, as depicted in Fig. 1. This crosstalk phenomenon can diminish the advantages of binaural hearing, such as accurate sound localization, which is crucial for understanding speech in complex environments.

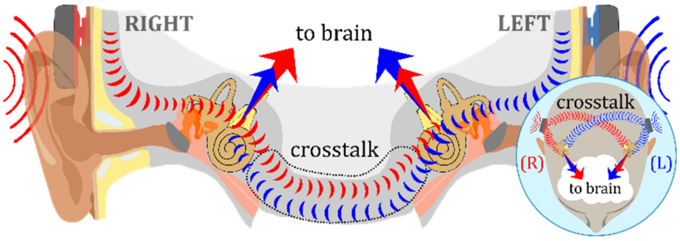

Figure 1: BC hearing and "crosstalk," illustrating how sound from BC transducers can reach both cochleae, possibly hindering the central auditory system's use of binaural cues.

Studies have shown that users of BC devices can generally localize sounds within a 30 to 45-degree range (Snik *et al.*, 1998). However, difficulties arise with sounds from extreme angles and in distinguishing speech from background noise, particularly when they come from different directions (J Wang *et al.*, 2024). A Cochlear™ survey found that only 6% of individuals with bilateral hearing loss use two BC hearing devices, compared to 70% who use traditional hearing aids (Cochlear™, 2018). This preference and the challenges highlighted in research point to crosstalk as a significant concern and an area needed for improvement.

Having recognized "crosstalk" as a significant challenge in BC technology, our project focuses on exploring potential solutions. We are particularly interested in the feasibility of applying crosstalk cancellation methods, traditionally utilized in two-loudspeaker systems to create binaural sounds, to the human head. By utilizing existing techniques in a new context, we seek to minimize crosstalk, potentially enhancing BC device performance.

２．研究の目的

The purpose of this project is to find a solution to the crosstalk challenge in BC devices. We aim to investigate if crosstalk cancellation, successful in two-loudspeaker setups, can be innovatively applied to BC systems, specifically targeting the unique acoustic environment of the human head. Our primary goal is to validate the feasibility of this approach in reducing crosstalk within BC devices.

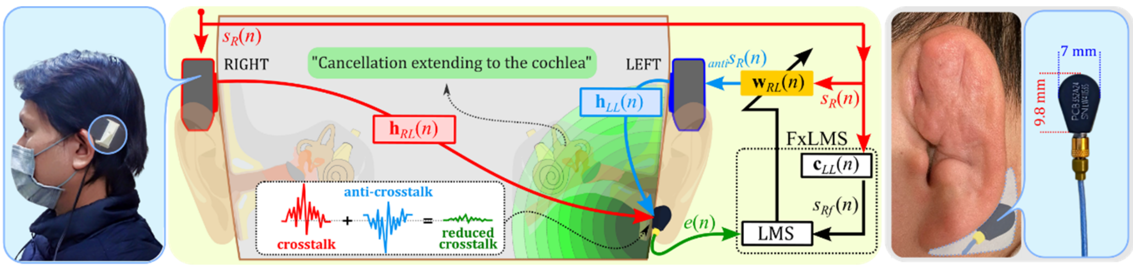

Figure 2: An accelerometer on the mastoid serves as the target site for cancellation, where the FxLMS algorithm adjusts the signals from two bone transducers to achieve cancellation at this location, aiming to extend the cancellation effect to the cochlea.

３．研究の方法

In our approach to crosstalk cancellation, we use techniques from two-loudspeaker systems that require a reference point near the intended cancellation area. Direct cochlear access in humans being impractical, we opt for a practical approach by placing an accelerometer on the mastoid, as shown in Fig. 2, aiming for crosstalk cancellation at this accessible site to indirectly benefit the cochlea. The core of our method involves the Filtered-X Least Mean Square (FxLMS) algorithm. This algorithm dynamically adjusts the signals to the bone transducers, targeting crosstalk reduction at the mastoid with the hope of extending these benefits to the cochlea within the inner ear. To verify whether the crosstalk cancellation effect reaches the cochlea, we conduct hearing threshold tests, which serve as an important indicator of the method's effectiveness.

４．研究成果

(1) Real-Time Unilateral Crosstalk Cancellation

Building on the setup depicted in Fig. 2, where an accelerometer on the mastoid targets crosstalk cancellation via the FxLMS algorithm, we have successfully implemented this in real-time. At the core of our system is the *Bela Mini*, a single-board Linux computer designed for low latency audio processing (below 1 ms). As shown in Fig. 3, the *Bela Mini* used is equipped with a simple GUI for device control, featuring a central button that activates the cancellation feature.

A demonstration of our system's effectiveness is captured in a demo video, the link to which is provided in the caption of Fig. 3. The video clearly shows how signals from BC transducers are designed to cancel each other out at the mastoid accelerometer. Achieving a latency of about 1.65 ms, dependent on the buffer size, this implementation underscores the practicality of real-time crosstalk cancellation.

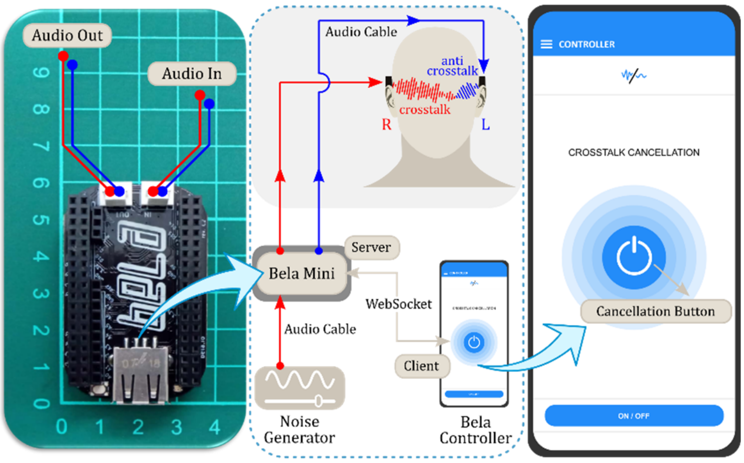

Figure 3: The *Bela Mini* embedded audio platform, showcasing a real-time unilateral cancellation system with a user-friendly GUI for controlling the device. See the system in action here: https://youtu.be/SY15300dORE.

(2) Crosstalk Reduction at the Accelerometer

In this part of our study, we focused on quantifying crosstalk cancellation at the mastoid accelerometer using the setup described in Fig. 2. We conducted experiments on seven subjects with normal hearing, employing white noise filtered between 224-1122 Hz as the crosstalk signal. The crosstalk cancellation (CTC) filter, derived from the FxLMS algorithm, was used to generate an anti-crosstalk signal. Each subject was exposed to the crosstalk signal both with and without the anti-signal, allowing us to assess the crosstalk reduction, which is shown in Fig. 4. Our findings were significant, demonstrating a crosstalk reduction of over 10 dB across all subjects within the 250 to 1000 Hz frequency range. The average reduction across frequencies was measured at 15.9 dB.

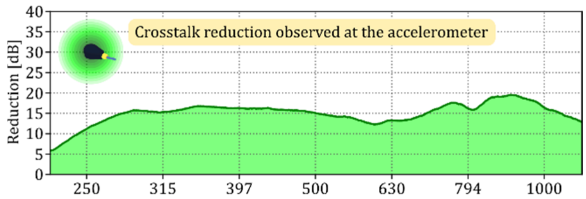

Figure 4: Crosstalk reduction in dB at the accelerometer located on the mastoid.

(3) Hearing Thresholds: With and Without Cancellation

In assessing the efficacy of our approach, we conducted hearing threshold measurements at low frequencies (250 to 1000 Hz), with the results presented in Fig. 5. The data clearly illustrates that thresholds with crosstalk cancellation (represented in green) are consistently lower than those without cancellation (depicted in red), indicating that the cancellation effect successfully extends to the cochlea. Statistically significant reductions were found at 250, 315, and 397 Hz, indicating a stronger cancellation effect at these frequencies. However, as the frequency increases, the difference between green and red thresholds narrows, highlighting a present limitation in cancellation efficacy. Despite this, the observed improvements form a solid basis for future work to enhance crosstalk cancellation effectiveness more broadly.

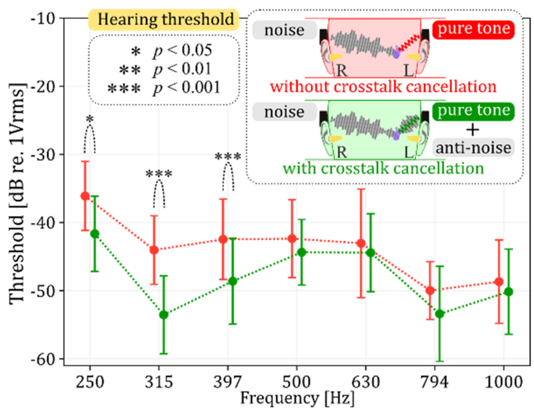

Figure 5: Hearing thresholds: comparing crosstalk cancellation effects.

5．主な発表論文等

〔雑誌論文〕　計1件（うち査読付論文　1件／うち国際共著　1件／うちオープンアクセス　1件）

1．著者名 Irwansyah、Otsuka Sho、Nakagawa Seiji	4．巻 11
2．論文標題 Unilateral crosstalk cancellation via bone conduction: Methods and evaluation	5．発行年 2023年
3．雑誌名 MethodsX	6．最初と最後の頁 102394～102394
掲載論文のDOI（デジタルオブジェクト識別子） 10.1016/j.mex.2023.102394	査読の有無 有
オープンアクセス オープンアクセスとしている（また、その予定である）	国際共著 該当する

〔学会発表〕　計12件（うち招待講演　0件／うち国際学会　5件）

1．発表者名 Irwansyah, Sho Otsuka, Seiji Nakagawa
2．発表標題 Unilateral Crosstalk Cancellation in Bone Conduction Using an Accelerometer Placed at the Mastoid
3．学会等名 日本音響学会2022年秋季研究発表会
4．発表年 2022年

1．発表者名 Irwansyah, Sho Otsuka, Seiji Nakagawa
2．発表標題 Effects of in-ear-sensor type on bone-conduction-based crosstalk cancellation: an assessment by tone reception thresholds
3．学会等名 The 24th International Congress on Acoustics (ICA) 2022（国際学会）
4．発表年 2022年

1．発表者名 Irwansyah, Sho Otsuka, Seiji Nakagawa
2．発表標題 Towards Real-Time Crosstalk Cancellation for Application in Bone Conduction Hearing Devices
3．学会等名 日本生体医工学会関東支部 若手研究者発表会 2022
4．発表年 2022年

1．発表者名 Irwansyah, Sho Otsuka, Seiji Nakagawa
2．発表標題 Real-Time Implementation of Unilateral Crosstalk Cancellation Based on Bone Conduction
3．学会等名 The IEEE 41st International Conference on Consumer Electronics (ICCE)（国際学会）
4．発表年 2023年

1．発表者名 Irwansyah, 大塚 翔, 中川 誠司
2．発表標題 骨伝導の聞こえの改善を目指したクロストーク・キャンセリング手法の開発
3．学会等名 第62回日本生体医工学会大会
4．発表年 2023年

1．発表者名 Irwansyah, Sho Otsuka, Seiji Nakagawa
2．発表標題 Cancelling Crosstalk Sound in Bone Conduction Hearing: An Accelerometer-Based Approach
3．学会等名 The 45th Int. Conf. of the IEEE Eng. in Medicine and Biology Society（国際学会）
4．発表年 2023年

1．発表者名 Irwansyah, Sho Otsuka, Seiji Nakagawa
2．発表標題 FxLMS and Lateralization: A Combined Strategy for Crosstalk Cancellation in Bone Conduction
3．学会等名 The 52th International Congress and Expo on Noise Control Engineering (INTER-NOISE)（国際学会）
4．発表年 2023年

１．発表者名
Irwansyah, Sho Otsuka, Seiji Nakagawa

２．発表標題
Crosstalk Cancellation in Bone Conduction Hearing: Human vs. Ballistic Dummy Head Study

３．学会等名
ライフエンジニアリング部門シンポジウム2023

４．発表年
2023年

１．発表者名
Irwansyah, Akane Tamura, Sho Otsuka, Seiji Nakagawa

２．発表標題
Comparing Sound Propagation in Silicone Pinna Models: The Effect of Vibrator Positioning

３．学会等名
日本音響学会2023年秋季研究発表会

４．発表年
2023年

１．発表者名
Irwansyah, Sho Otsuka, Seiji Nakagawa

２．発表標題
Towards Optimized Crosstalk Cancellation in Bone Conduction: An In-depth Exploration of FxLMS and Lateralization

３．学会等名
日本音響学会2023年秋季研究発表会

４．発表年
2023年

１．発表者名
Irwansyah, Sho Otsuka, Seiji Nakagawa

２．発表標題
Exploring the Impact of Pinna Hardness and Vibrator Placement on Bone Conduction Through the Pinna

３．学会等名
The 44th Symposium on UltraSonic Electronics（国際学会）

４．発表年
2023年

１．発表者名 Irwansyah, Sho Otsuka, Seiji Nakagawa
２．発表標題 Evaluating Cartilage Conduction: A Comparative Study of Sound Transmission in Artificial and Human Pinnas
３．学会等名 日本音響学会2024年春季研究発表会
４．発表年 2024年

〔図書〕　計0件

〔産業財産権〕

〔その他〕

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６．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考

７．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

８．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関