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2pPPb32. Communication aid utilizing bone-conducted sound via teeth by means of mouthpiece form actuator

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Since bone-conducted sound is conveyed to cochlea directly, without passing through eardrum, it is audible even for hard-of-hearing people whose inner ears are still normal. In this study, we utilize bone-conducted sound via teeth so as to support sound communication. We implemented a bone-conducted actuator on teeth, while actuators of prevalent hearing aids are attached to mastoid, forehead or jaw in general. Teeth convey sound excitation more easily, because they are bare bones, not covered with skin. Our communication aid is made in the form of mouthpiece with a dental material, and it can be readily put on and taken off from a tooth. Using this actuator, we attempted to record vibrations of teeth when a subject produces a sound. In addition, we carried out experiments regarding sound lateralization of bone-conducted sound via teeth with this actuator. The result shows that examinees can perceive right and left using bone-conducted sound via teeth. The aim of this study is to suggest a new communication aid system not only for hard-of-hearing people but also for the robust.

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INTRODUCTION

Since the bone-conducted sound vibration through a skull is conveyed to cochlea directly, without passing through eardrum, it is audible even for hard-of-hearing people whose inner ears are still normal. Nowadays, the technology using bone-conducted sound is applied to headset for mobile phone, headphone for listening to music, hearing aid, etc.

Many studies on bone-conducted sound have been conducted in the past. Békésy has presented how people feel when bone-conducted sound through a skull is heard [1]. Moreover, McBride has conducted measurement of finding locations where are highly sensitive to bone conduction auditory signal reception on skull and reported that locations showing relatively good effectiveness of bone conduction transmission are the mastoid, vertex and temple [2]. However, this experiment was not carried out for teeth.

On bone conduction via teeth, Weinkove gives details on sound transmission through teeth as a way to heighten auditory perception [3]. It is also a well-known fact that Beethoven, who had suffered from defective hearing, heard a sound with a vibration through a tact that he holds between his tooth. Although bone-conducted actuator is usually attached to mastoid or antilobium, a tooth can propagate sound vibration to cochlea efficiently since a tooth is deemed as bare bone. Measurement of bone-conduction sensitivity through teeth has been presented by Dahlin and Stenfelt [4][5]. However, the measurement method of threshold via teeth has not yet been established.

Besides these researches, not only hearing bone-conducted sound through teeth but also extracting the vibration of a tooth has been surveyed. Ikehata reported that a tooth vibration can be extracted with acceleration pickup and converted to speech signal [6]. Saiki also showed that teeth vibration can be picked up utilizing MEMS acceleration sensor [7]. Furthermore, Yanagisawa has presented relatively good positions on the head setting acceleration vibration transducer when bone-conducted sound is recorded [8]. He showed that teeth are relatively good location extracting bone-conducted sound, and the bone-conduction sound via teeth has high articulation score when normal listeners hear the recorded bone-conducted sounds through teeth with their ears as air-conducted sound.

In this paper, consideration of communication aid system focused on bone-conducted sound via teeth is investigated. Our aim is to use bone-conducted sound via teeth readily for a new communication aid system, not only for hard-of-hearing people but also for the robust. We have experimented recording and hearing bone-conducted sound via teeth utilizing mouthpiece form actuator with dental material. In recording experiment, we also carried out experiment to extract sound vibration through teeth when a subject produces a sound. Furthermore, unwiring the mouthpiece actuator was considered. In hearing experiment, sound localization experiment was conducted. According to the results of these experiments, we suggest a new communication aid system by means of bone-conducted sound through teeth.

COMMUNICATION AID USING BONE-CONDUCTED SOUND VIA TEETH

Bone conduction Actuator for teeth

Communication aid system utilizing bone-conducted sound via teeth has been developed. Recently, hearing aid which transfers sound signal vibration to teeth has been developed by Sonitus Medical [9]. The bone-conducted device, called the SoundBite hearing system, is put on teeth. However, this device is only attached to one side of teeth, and there has been no device applied to either side of teeth.

We have suggested a communication aid system with bone-conducted sound through teeth [10][11][12]. Figure 1 shows the actuator which people can hear a sound signal vibration through teeth with biting. The actuator includes giant magnetostrictive material (GMM) inside a coil. Sound signal is inputted into the coil around GMM, and magnetic field is generated around GMM by signal current. Using two same actuators, people can recognize lateralization by voltage difference presented to these actuators. However, there is a problem that people have difficulty in speaking when the actuator is used.

For resolving this problem, a mouthpiece form actuator was produced with dental material as shown in Fig. 2. The actuator has an advantage that it just fits the mold of each subject's teeth. The actuator has two vibrators using piezoelectric device (25 mm in long, 10 mm in width and 0.1 mm in thick). When the actuator is put on subject's teeth, two piezoelectric devices are located on each side of second bicuspid and first molar tooth on upper jaw.

We measured frequency characteristic of the actuator using Laser Doppler Vibrometer. When this experiment was conducted, time stretched pulse signal is utilized as input signal to the actuator

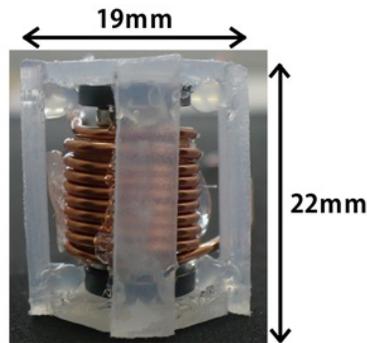


FIGURE 1. Biting type actuator. The giant magnetostrictive material, ETREMA Terfenol-D is used. The material around wire is EVA resin which is unharful for human.

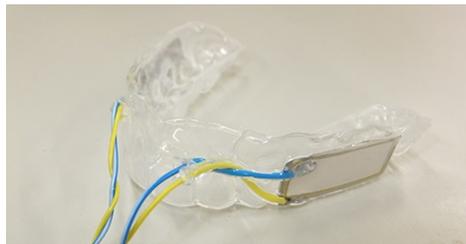


FIGURE 2. Mouthpiece form actuator. The piezoelectric device, Thrive OMR251005-U-210, is used. It is laminated by dental material formed teeth mark.

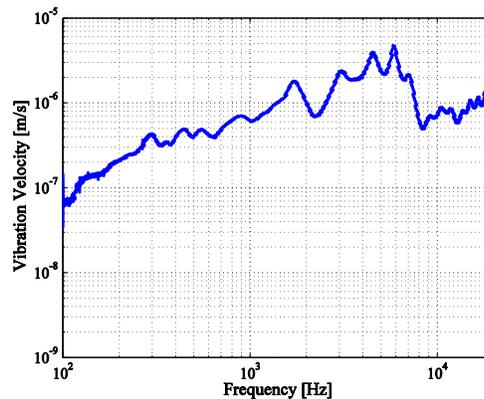


FIGURE 3. Frequency characteristic of mouthpiece form actuator. This is measured by Laser Doppler Vibrometer (Polytec OFV-505 and OFV-5000). X-axis is frequency and Y-axis is vibration velocity.

and input voltage was 1V. Figure 3 shows the frequency characteristic. It is clear that the actuator has a slow vibration velocity below range of 2000Hz and tends to be a fast vibration velocity between 2000Hz and 7000Hz.

Perception of bone-conducted sound via teeth

We have conducted the experiment to observe the perception of hearing bone-conducted sound via teeth. In this experiment, we measured the threshold when bone-conducted sound through teeth is heard. Sinusoidal waves at 1/3 octave frequency intervals from 400Hz to 16000Hz were used as stimulus sounds. A subject wears earplug in order to prevent hearing air-conducted sound during the experiment. Figure 4 shows the threshold we measured. It can be seen that relative voltage level is comparatively low between 1000Hz and 4000Hz. A subject cannot recognize the presented sound below 400Hz and above 16000Hz.

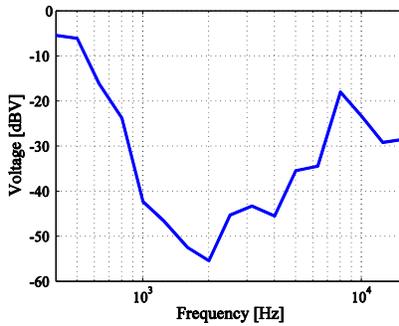


FIGURE 4. Threshold. X-axis is frequency and Y-axis is relative voltage level that reference voltage is 1.0V.

Recording sound via teeth

Recording bone-conducted sound via teeth has been conducted by means of the same mouthpiece form actuator as a microphone. Piezoelectric device also picks up teeth vibration during phonation. Extracted vibration converted to electrical signal is inputted to audio interface (Mackie ONYX Blackbird) to record. Figure 5 shows the waveform of extracted teeth vibration when a subject pronounces “a” and “sakana”. According to Fig. 5, the waveform includes few noise components. The speech spectrograms are presented in Fig. 6. A comparison of Fig. 6 (a) and (b) shows that frequency components of three Japanese consonants, such as “s”, “k” and “n”, are contained as well as recording air-conducted sound.

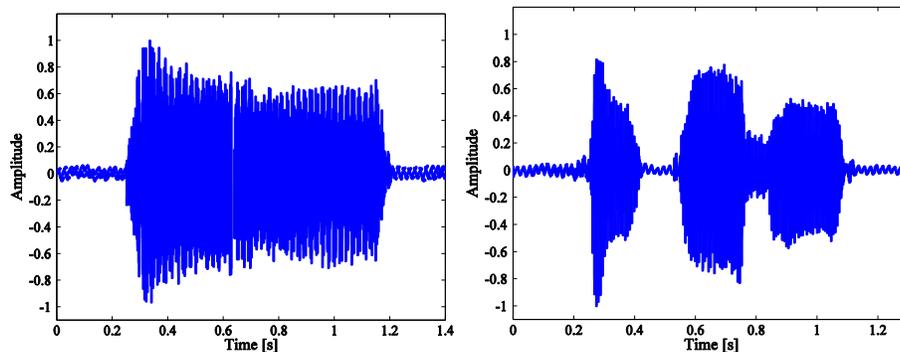


FIGURE 5. Waveform of “a” at left and “sakana” at right.

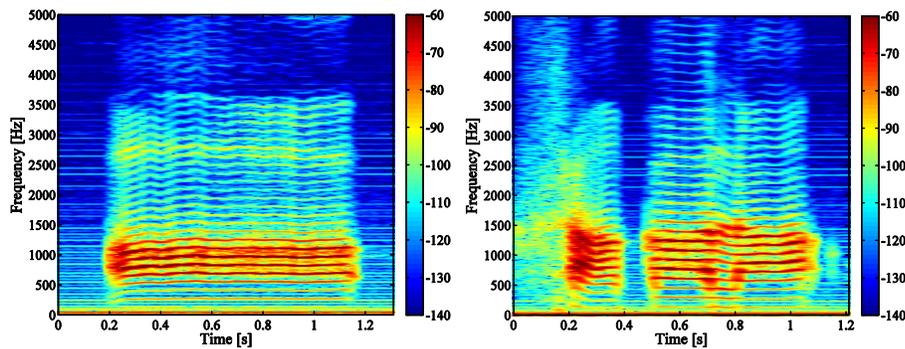


FIGURE 6. Spectrogram of “a” at left and “sakana” at right. The color bar shows relative voltage level. The reference voltage is 1.0V.

Wireless actuator with telecoil

The experimental production of wireless actuator has been performed. Figure 7 shows the wireless system with electromagnetic induction, called hearing loop, and the prototyped actuator is shown in Fig. 8. Hearing loop system has the feature that people wearing hearing aid with T-mode, which picks up magnetic field including sound signal by using telecoil, can hear sound clearly compared to M-mode, which picks up sound using microphone equipped with hearing aid. The prototype of actuator is equipped with telecoil (Knowles 5300) to pick up magnetic field. Received sound signal by means of telecoil is amplified by Op. Amp. In this way, the actuator with receiving equipment can be miniaturized and set in oral cavity.

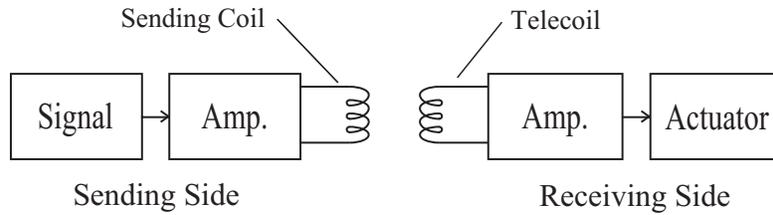


FIGURE 7. Wireless system with electromagnetic induction.

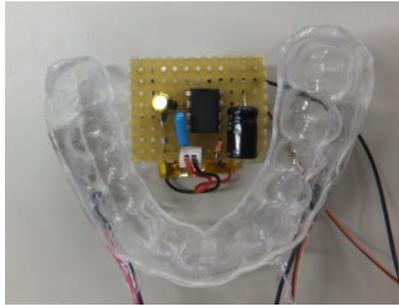


FIGURE 8. Prototype of wireless actuator. The wireless circuit equipped with telecoil is small enough to set in oral cavity.

SOUND LATERALIZATION EXPERIMENT

Sound lateralization experiment utilizing mouthpiece form actuator has been carried out in order to observe whether people can recognize the direction when they hear sounds through their teeth. We basically build up a perception of sound lateralization based on interaural differences of level, time, or phase. In this experiment, level difference of voltage, i.e. interaural level difference (ILD), is presented to piezoelectric device on each side. We used seven numbers as shown in Table 1 and present stimulus sound corresponding to seven numbers to a subject.

Voltage corresponding to seven numbers was presented to a subject. Table 1 shows voltage corresponding to seven stimuli. Presented voltages on each side are determined as

$$V_L = \frac{\sqrt{2}(6-x)}{\sqrt{(6-x)^2 + x^2}} \quad \text{and} \quad V_R = \frac{\sqrt{2}x}{\sqrt{(6-x)^2 + x^2}}, \quad (1)$$

where V_L is voltage presented on left side, V_R is voltage presented on right side and x is the number corresponding to seven stimuli. From Eq. (1),

$$\left(\frac{V_L}{\sqrt{2}}\right)^2 + \left(\frac{V_R}{\sqrt{2}}\right)^2 = 1. \quad (2)$$

From Eq. (2) and Fig. 9, the sum of squares composed voltage on each side is constant. The drive force of piezoelectric device

$$F = 10 \log_{10} \left(\frac{V^2}{V_o^2} \right), \quad (3)$$

where V is input voltage to device and V_o is reference voltage. We use 1.0 V as V_o .

In this experiment, we used speech and white noise as the presented signals, and sampling rate is 44100Hz. The experimental process is as follows:

- Step 1: A subject adjusts volume levels of each actuator as a subject feels same sound level.
- Step 2: As reference signal, the signal corresponding to number 3 is presented to a subject.
- Step 3: An experimenter presents some signal which a subject should answer with hearing.
- Step 4: After hearing, a subject answers the perceived direction in Fig.10.
- Step 5: These steps from 2 to 4 is repeated seven times in all.

We repeated these processes 8 times in all. Both an experimenter and a subject don't know the number corresponding to a presented signal. In addition, a subject wears earplug in order to prevent hearing air-conducted sound during the experiment.

Figure 11 shows the results of the experiments, which (a) is for speech and (b) is for white noise. From Fig. 11 (a), it is clear that the perceived direction is dispersed, but it could be made that a subject can perceive the direction roughly with hearing bone-conducted sound through teeth. On the other hand, Fig. 11 (b) describes that a subject can perceive the direction of presented white noise signal accurately.

Accurate perception with white noise is attributed to the signal with wide frequency range components. Akiyama describes that lateralization of air-conducted sound is enhanced with the sound including wide frequency range components [13]. From this consideration, it is thought that lateralization with bone-conducted sound via teeth can be recognized as with using air-conducted sound.

TABLE 1. Presented voltage in this experiment.

Number (x)	V_L	V_R
0	1.42	0.00
1	1.39	0.28
2	1.26	0.63
3	1.00	1.00
4	0.63	1.26
5	0.28	1.39
6	0.00	1.42

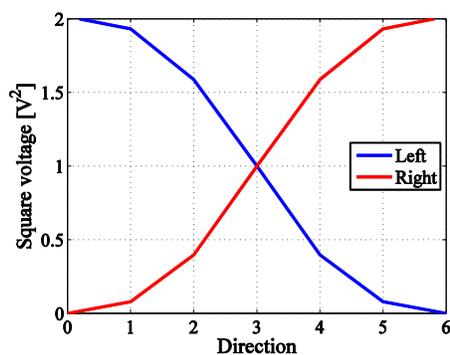


FIGURE 9. Square voltage corresponding to the seven direction.

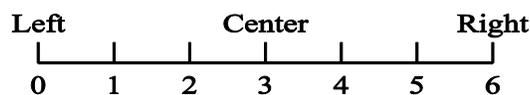


FIGURE 10. Seven directions numbered from 0 to 6, such as leftmost is 0, 3 at the middle and rightmost is 6.

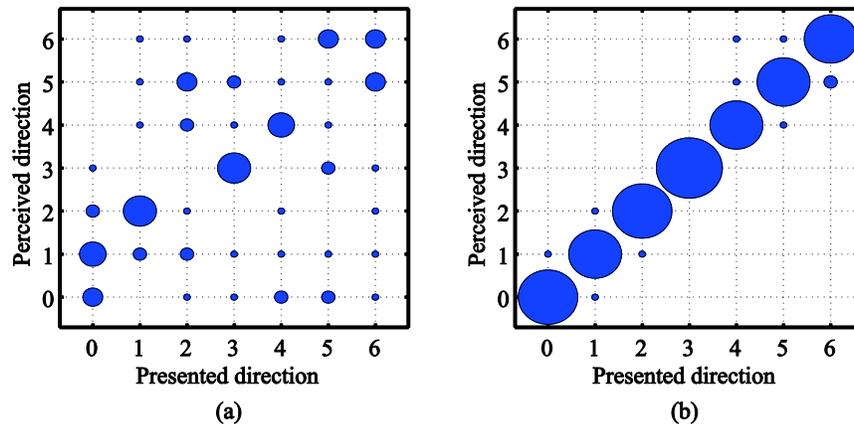


FIGURE 11. Results of sound lateralization experiment. (a) is for speech and (b) is for white noise. X-axis is the number of presented signal. Y-axis is the number of perceived direction. The size of circle is relative to quantities of responses.

CONCLUSIONS

Communication aid focused on using bone-conducted-sound via teeth is proposed. The prototype of actuator is produced and the experiments have been conducted to confirm if utilizing bone-conducted sound through teeth is useful as communication aid. In the measurement of extracting teeth vibration, teeth vibration can be converted to sound signal using the mouthpiece actuator. The prototype of wireless actuator equipped with telecoil is also produced. Using the prototype product, it can be applied to hearing loop system as same as T-mode for hearing aid. In addition, sound lateralization experiment shows that a subject can recognize right and left by means of bone-conducted sound via teeth. It is clear from the experiment with white noise to perceive lateralization accurately. In the future, we will aim to achieve the practical use of this system.

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REFERENCES

1. G. V. Békésy, "Vibration of the head in a sound field and its role in hearing by bone conduction", *J. Acoust. Soc. Am.* **20**, 743-760 (1978).
2. M. McBride, T. Letowski, and P. Tran, "Bone conduction reception: Head sensitivity mapping," *Ergonomics*, **51**, 702-718 (2008).
3. R. Weinkove, "Aids to Hearing", <http://www.medicalindexing.co.uk/rob/hearing/hearing.htm> (Last viewed 19 Jan. 2013.)
4. G. C. Dahlin, F. G. Allen, and E.W. Collard, "Bone-conduction thresholds of human teeth," *J. Acoust. Soc. Am.* **53**, 1434-1437 (1973).
5. Stefan P. Y. Stenfelt, and Bo E.V. Hakansson, "Sensitivity to bone-conducted sound: excitation of the mastoid vs the teeth," *Scandinavian Audiology*, **28**, 190-198 (1999).
6. M. Ikehata, T. Saito, Y. Takahashi, Y. Oikawa, J. Kurosawa, T. Ono, and Y. Yamasaki, "Development of Communication Aid by measurement in the oral cavity. - estimation of transfer characteristic by vibration and shape measurement -," *Proc. Spring Meet. Acoust. Soc. Jpn.*, 503-504 (2005.3), (in Japanese).
7. T. Saiki, Y. Takizawa, T. Hashizume, K. Higuchi, T. Fujita, and K. Maenaka, "Utterance Detection by Intraoral Acceleration Sensor," *IEEJ Trans. EIS*, **131**, 826-832 (2011), (in Japanese).
8. T. Yanagisawa, and K. Furihata, "Pickup of Speech Signal by Utilization of Vibration Transducer under High Ambient Noise," *J. Acoust. Soc. Jpn.* **31**, 213-220 (1975), (in Japanese).
9. R. J. Miller, "It's time we listened to our teeth: The Soundbite hearing system," *American Journal of Orthodontics and Dentofacial Orthopedics*, **138**, 666-669 (2010).
10. M. Muramatsu, Y. Oikawa, Y. Yamasaki, J. Kurosawa, "Communication Aid Using the Actuator for Bone Conduction via Teeth," *IEICE Trans. Fundamentals (Japanese Edition)* Vol. J95-A, No.7, 623-630 (2012), (in Japanese).
11. M. Muramatsu, J. Kurosawa, Y. Oikawa, Y. Yamasaki, "Communication aid by bone conduction via teeth," *Proc. Autumn Meet. Acoust. Soc. Jpn.*, 1533-1534 (2011.9), (in Japanese).

12. M. Muramatsu, J. Kurosawa, Y. Oikawa, Y. Yamasaki, "Direction sense and audibility characteristics when bone conducted sound via teeth is presented," *Proc. Autumn Meet. Acoust. Soc. Jpn.* , 471-472 (2012.9), (in Japanese).
13. M. Akiyama, H. Hokari, S. Shimada, "Study of stimuli for sound localization test – Comparison of the duration time of pink noise and white noise," IEICE technical report, **EA2003-83**, 37-47 (2003), (in Japanese).