3P5-33

Proceedings of Symposium on Ultrasonic Electronics, Vol. 34 (2013) pp. 555-556
20-22 November, 2013

Propagation Characteristics of the Bone-conducted Ultrasound in the Living Human Head: Estimation of the Propagation Delay by Instantaneous Frequency Analysis

骨導超音波の頭部内伝搬特性 - 瞬時周波数解析による伝搬遅延特性の推定

Takuya Hotehama[1†], and Seiji Nakagawa[1] ([1] Health Research Institute, National Institute of Advanced Industrial Science and Technology (AIST))
保手浜　拓也 [1‡]，中川誠司 [1] ([1]独立行政法人産業技術総合研究所　健康工学研究部門)

1. Introduction

An ultrasound with frequency above 20 kHz (up to about 100 kHz) can be heard via bone-conduction (BC)1). This “audible” ultrasound through BC is referred to as the bone-conducted ultrasound (BCU). Since BCU can be perceived not only by normal hearing but also by severe hearing impaired2), a novel hearing aid (bone-conducted ultrasonic hearing aid, BCUHA) is being developped for profoundly hearing impaired3).

The perception mechanisms of BCU, however, have still unclear. For the better understanding of the perception mechanisms of BCU, various approach have been made: estimation of the propagation process of BCU in the head by using computer simulations or actual measurements is one of these approaches. In the previous studies, we estimated the propagation velocity of BCU in a living human head as approximately 300 m/s by using the pattern of acoustic interference of simultaneous bilateral excitation4). Further, we estimated the characteristics of the propagation delay of ultrasonic sinusoidal pulse by using across-frequency phase disturbance of the acceleration responses5). In this method, however, it was difficult to detect the precise delay of paths if there are frequency dispersion in the transmission pathways. On the other hand, the existance of frequency dispersion of the propagation delay could be useful information for identification of the pathway and the mode.

As for accurate detection of the propagation delay and its frequency dispersion, an instantaneous frequency (IF) analysis6) would be an effective since a phase interference caused by a multipath propagation system in the responses for sinusoidal input signal gives rise to changes in the IF. Thus, in the present study, we tried to observe characteristics of the propagation delay and its frequency dependency using the IF analysis.

2. Measurements

2.1 Methods

The experimental setup is shown in **Fig.1**. Ultrasonic pulse as excitation signals were 10-wave sinusoids with frequencies from 28 kHz to 32 kHz in 100-Hz steps. The ultrasonic pulse were presented via vibrators (Murata Manufacturing MA40E7S) placed over the left and right mastoid processes and the forehead. The excitation signals were synthesized digitally by a PC at a sampling frequency of 800 kHz, generated through a 16 bit DA converter (National Instruments, PXI-6120). The acceleration responses were measured using accelerometers (Ono Sokki NP3211) placed inside the left and right ear canals. The acceleration responses at the left and right ears were obtained simultaneously each for the left, the right or the forehead excitation.

2.2 Instantaneous Frequency Analysis

The IF analyses were applied on the transient responses of the sinusoidal ultrasonic pulses. The instantaneous phase as a function of time is represented as:

$$\phi_f(t) = \tan^{-1}\frac{x_{hf}(t)}{x_f(t)}, \tag{1}$$

where $x_f(t)$ is the response signal for the excitation frequency, *f*, and $x_{hf}(t)$ is the Hilbert transform signal of $x_{hf}(t)$. The IF signal as a function of time for *f*, $IF_f(t)$, is obtained as the time derivative of $\phi_f(t)$ as :

$$IF_f(t) = \frac{1}{2\pi}\frac{d\phi_f(t)}{dt}. \tag{2}$$

Then, the normalized IF is obtained as time-frequency function normalized by the excitation frequency *f*:

$$nIF(t,f) = \frac{IF_f(t)}{f}. \tag{3}$$

2.3 Results and discussion

As examples of the results, superposed wave

E-mail: t-hotehama@aist.go.jp

forms of the transient acceleration responses (A), a time-frequency responses map (B), and a normalized IF (C) are shown in **Figs.2** (for left-side excitation recorded at the left ear (ipsilateral side)) and **3** (for left-side excitation recorded at the right ear (contralateral side)).

As for the ipsilateral response (**Fig.2**), the first arrival component was reached about 15 μs with no frequency dependency. After the first wave arrival, prominent arrival components were not observed, but there were some local change in the $nIF(t,f)$ (e.g. 32 kHz at 730 μs).

As for the contralateral response (**Fig.3**), the first and the second components were arrived at about 90 and 160 μs, respectively, with no frequency dependence. On the other hand, at the subsequent part, changes in the $nIF(t,f)$ with frequency dependence were observed. These parts could be due to the transmission of vibration mode with frequency dispersion, such as the bending wave.

4. Conclusions

Measurements of the acceleration responses for ultrasonic sinusoidal pulse as input signals in the human head were performed, and the IF analysis was applied for these acceleration responses. As results, the frequency dependencies of the propagation delay characteristics were observed in the contralateral transmission.

As future work, we will try to develop a method to estimate the exact pathways and the vibration modes of the contralateral transmission based on the delay time and its frequency dispersion of the propagation.

Acknowledgment

This research was supported by the Funding Program for Next-Generation World-Leading Researchers provided by the Cabinet Office, Government of Japan.

References

1. R. Pumphrey: Nature. **166** (1950) 571.
2. M.L. Lenhardt, R. Skellett, P. Wang, A.M. Clarke: Science. **253** (1991) 82-85.
3. S. Nakagawa, Y. Okamoto, Y. Fujisaka: Trans. Jpn. Soc. Med. Bio. Eng. **44** (2006), 184-189.
4. T. Hotehama, S. Nakagawa: Jpn. J. Appl. Phys. **51** (2012) 07GF21.
5. T. Hotehama, S. Nakagawa: Proc. USE2012, **33** (2012) 191-192.
6. R.O. Tachibana, Y. Nagatani: Proc. USE2011, **32** (2011) 415-416.

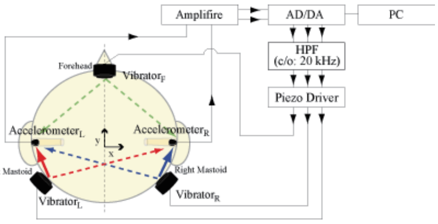

Fig. 1. Experimental set-up for the measurement of the propagation characteristics of BCU in a human head.

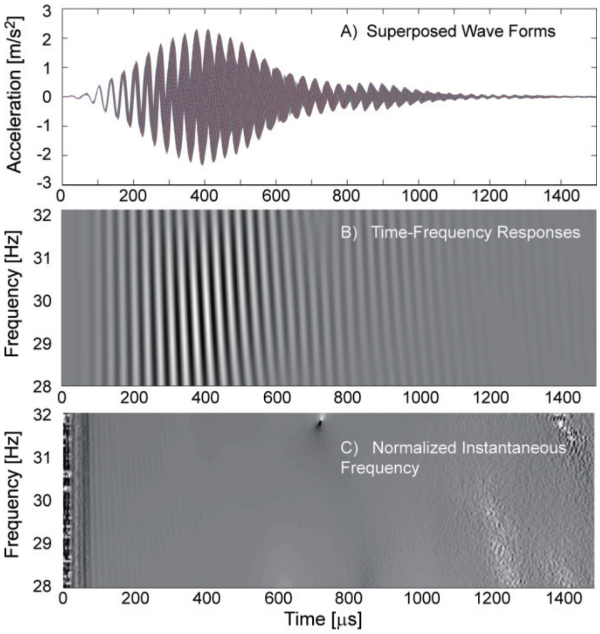

Fig. 2. Responses for left-side excitation received at the left ear (ipsilateral side): Superposed wave forms (A), a time-frequency responses map (B), and a normalized IF (C).

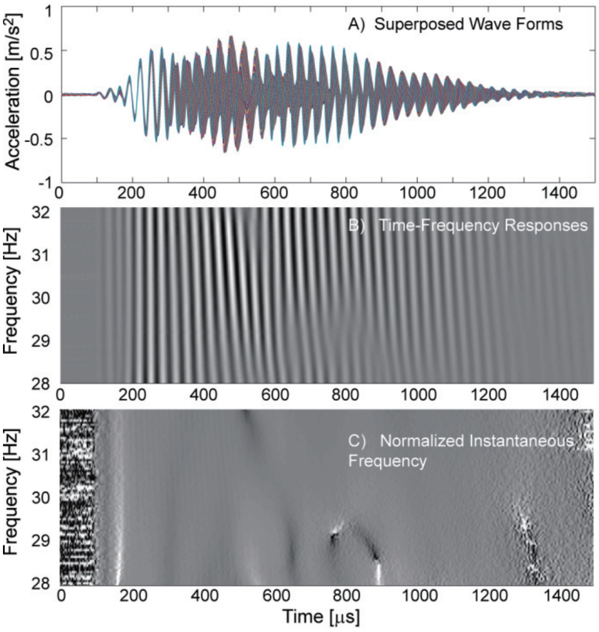

Fig. 3. Responses for left-side excitation received at the right ear (contralateral side).