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On a High-Speed Hearing Measurement Compensated for Gain for Each Sub-band

Bong-Young Kim [*1], Zhixing Tian [*2], Myung-Jin Bae [*3]

[#] *Soong-Sil University, Department of Information and telecommunication Engineering, Seoul, 06978, Korea*

[1]bykim8@ssu.ac.kr , [2]zhixingT@soongsil.ac.kr, [3] mjbae@ssu.ac.kr

Abstract *— Hearing loss is an inevitable problem for humans. It gradually deteriorates with age. Excessive exposure to noise can cause further deterioration. Because hearing cannot be recovered once damaged, it is important to prevent and slow down the hearing loss. This requires a timely understanding of hearing loss and relevant protective measures. This research proposes a sub-band method that can High-Speed measure hearing damage by itself. This method can be extended to the home without going to the hospital. In this method, by listening to 9 pure tones in sequence, you can detect your hearing impairment at high speed. The frequency gain compensation method is used to define each frequency band's reference critical value, and the cross-band test is used to determine the hearing loss part. The results showed that 1 out of 12 subjects was determined to be suspected of partial hearing loss. It has been confirmed that this experimental method can be judged within 30 seconds with a smartphone, compared to the detection method in the hospital. The detection speed has been greatly improved. It allows more people to learn about their hearing health easily.*

Keywords — *Hearing Test, High-Speed Hearing Measurement, Hearing Loss, Noise Environment, Sub-Band Compensation, Partial Frequency Gain.*

I. INTRODUCTION

As we age, our body functions gradually decline. The body's resistance will weaken, which will increase the risk of illness and increase suffering. The decline in the perception of facial features will greatly reduce people's sense of happiness. Therefore, for a happy life in old age, when you are young, you should pay more attention to protecting the body's health, so regular health checks are essential. In health examinations, we often do not pay attention to hearing loss examinations. Because if people do not feel uncomfortable in the conversation, they think their hearing is healthy. Hearing loss is not as easy to detect as vision loss. So, many times, we have already caused hearing loss without knowing it.[1]

The environment in which modern people live is more likely to cause hearing loss. Urban traffic noise, construction site noise, factory noise, etc., are the main sources of hearing loss. This is because long-term exposure to high volume causes fatigue or damage to the hearing organs, which leads to partial hearing loss. On the other hand, hearing loss is related to people's living habits. For example, excessive use of headphones is also one of the reasons for hearing. Hearing loss is not only related to external noise but also the physiological mechanism of the human body. As the human body ages, the hearing will gradually deteriorate from high-frequency bands. This is different from hearing loss caused by specific noise, which can cause hearing loss in a specific frequency band. In addition, high-frequency noise will accelerate the deterioration of hearing caused by human aging. Since hearing loss cannot be repaired once it is caused, the current focus can only be on prevention, reducing exposure to noise, and reducing noise volume. Regular hearing examinations can help people understand hearing loss in time and help reduce hearing loss. At present, the hearing test methods are too cumbersome and take a lot of time. So, it is common in hospitals, and it has not been widely promoted.[2] [3]

Therefore, this paper proposes a frequency-compensated voice sub-band self-listening measurement method. This is a simple method that can be operated at home. It allows anyone to easily grasp their hearing loss situation and make corresponding measures to create a better sound environment for hearing protection. The first chapter has introduced the causes of hearing loss. In chapter 2 explains the structure of the auditory organs and the characteristics of speech signals. In chapter 3 introduces the existing hearing measurement methods. Chapter 4 explains the voice sub-band self-listening measurement method using each frequency's gain compensation technology in chapter 5, deals with experiments and results, and Chapter 6 conclusions.

II. AUDITORY SYSTEM AND VOICE SIGNAL

A. Auditory System

The sound is transmitted to the brain through the ear structure, and the sound from the outside is collected through the ear cup, passes through the ear canal, and vibrates the eardrum. The vibration of the eardrum is amplified by the ossicles and transmitted to the cochlea. The cochlea transmits according to frequency analysis and transmits them to the brain. The cochlea perceives sound by dividing frequencies. The basement membrane of the cochlea is often curled, resembling a snail shell. The cochlea is full of lymph fluid, which acts as a medium for transmitting sound vibrations. The vestibular membrane and basement membrane are wrapped around the cochlea. There are many auditory nerves under the basement membrane to receive vibrations of different frequencies. The basement membrane acts as a spectrum analyzer. Figure 1 shows the hearing system's three main components, and Figure 2 is a flat cochlear structure model. The cochlea's front end recognizes high-frequency sounds, while the

back end recognizes low-frequency sounds. It is very sensitive to sound vibrations and can detect movements of a few microns of the eardrum. Therefore, very loud sounds can damage hearing cells. [4]

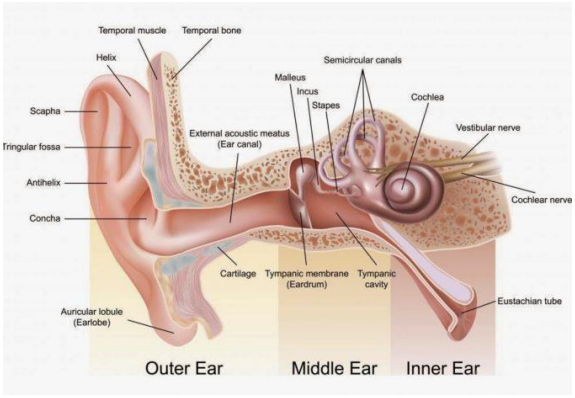

Fig. 1 The structure of the auditory system. [4]

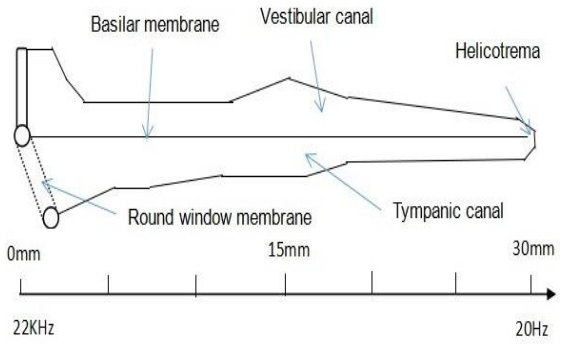

Fig. 2 Flattened cochlea model

B. Voice Signal Characteristics

The human hearing frequency ranges from 20 to 20,000 Hz, but the human voice frequency does not exceed 8000 Hz. The fundamental frequency of vocal cord vibration is lower, with the fundamental male frequency being 50~250Hz and the fundamental female frequency being 120~500Hz. The frequency component of human speech is 200~8000Hz. Sound intensity is the intensity of sound, that is, the magnitude of sound energy. The sound intensity range that human ears can feel is 10^{-16}~$10^{2}\ W/cm^{2}$. If the sound intensity is too low, it will not be heard, and if the sound intensity is too high, it will damage the hearing organs. So, we should pay attention to the impact of sound intensity on health. Moreover, humans have different perceptions of sound intensity at different frequencies. Therefore, to get the same feeling, each frequency's loudness is different, and the equal loudness curve presents a form of high on both sides and low in the middle. people need greater sound intensity to hear low and high frequencies.[5]

Speech is the product of the synthesis of the vocal cords' fundamental frequency and the oral cavity's resonance. According to the sound they want to make, humans control the fundamental frequency by changing the closure of the vocal cords, changing the resonant cavity by changing the opening and closing of the mouth, the shape of the lips, and the position of the tongue, thereby changing the resonance frequency. In the time domain, we can perceive the beginning and end of the speech, and in frequency, we can recognize the meaning of speech. Figure 3 Speech waveform and speech spectrogram in the time domain.[5]

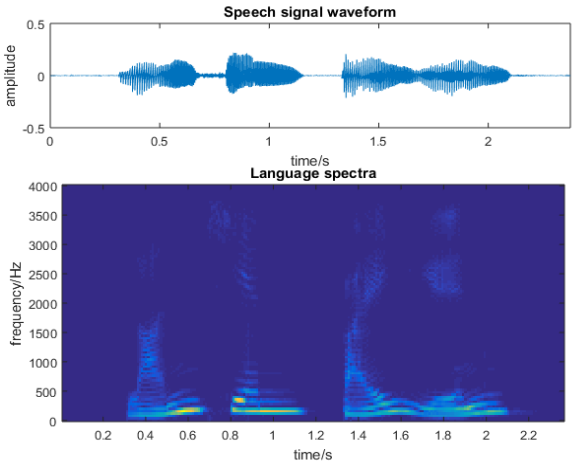

Fig. 3 Speech waveform and spectrogram

III. TRADITIONAL AUDIOMETRY METHODS

Pure tone hearing test is the most common hearing test in hospitals. It is a method of listening to pure tones. The test range is 250~8KHz, and the area is divided into multiple frequency bands. Each frequency band has an audible threshold, which varies according to age. By adjusting the amplitude of the pure tone and playing it several times, each frequency component's auditory ability is determined. When the sound can only be heard above this threshold, it is considered that this frequency has hearing loss. This method is mainly used to detect whether the other party's voice can be heard clearly in daily conversations.

However, it is difficult for people to detect hearing loss initially because even if hearing loss occurs, most of the speech can still be heard. And most hospitals measure hearing, and if talking is possible, judge hearing is normal. The traditional hearing test needs to listen to pure tones, often on different frequency bands, which increases the time cost. [6] [7] [8]

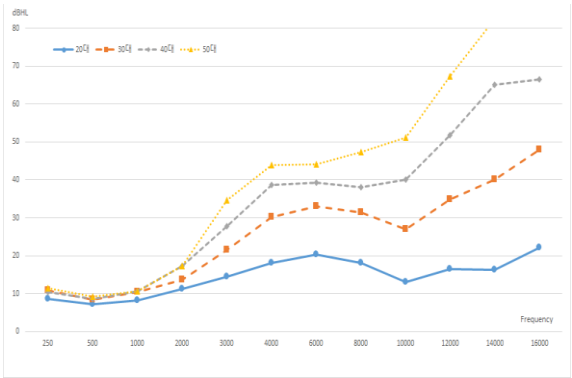

Fig. 4 Average hearing threshold by age group

IV. PRINCIPLES OF BLOOD OXYGEN SATURATION AND PULSE OXIMETRY DETECTION

This paper proposes a self-listening measurement method for each voice sub-band, which speeds up the pure-tone audiometry method's running speed. Figure 4 of the hearing threshold displayed by age group shows that hearing loss caused by aging first occurs at high frequencies. That is the high-frequency hearing is greatly affected by age. As people get older, people's sound perception ability gradually degrades from high frequency to low frequency. The frequency band below 2KHz is less affected by age.[9]

Figure 5 shows the predicted value of identifying pure tones by age group in the speech subband. What is clear here is that with each frequency 20dB as the reference line, for the number of people who can hear the sound, there are 7 for 20 years old, 6 for 30 years old, and 5 for 40 and 50 years old. In other words, even if the hearing is normal, a 40-year-old cannot hear 3Khz, 20dB sound. Therefore, based on each frequency's original 20dB, the high frequency higher than 2Khz is compensated. Therefore, this article uses +15dB/octave to compensate and hear the pure tone level from 2.5 to 8.0 kHz. In this figure, the red line is the hearing threshold after high-frequency weighting. It can be confirmed that the sound level is higher than the hearing threshold of each age group, so it is an audible pure tone level for testers of all ages. [10]

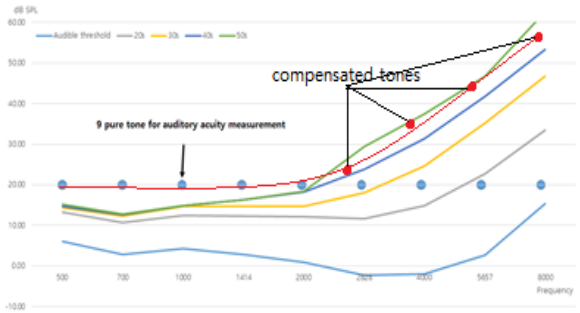

Fig. 5 Expected values of pure tone perception in speech sub-bands by age group

To check this kind of partial hearing loss, splitting and counting the number of sounds shown in Table 1 is used. Divide all 9 pure tones into two detection methods, A and B. The B method takes the pure tone with half the interval, while A moves the pure tone of B back by one, just at the interval of B. [11]

TABLE I. PROPOSED VOICE SUB-BAND PURE TONE ARRANGEMENT

Sound source		500 Hz	700 Hz	1000 Hz	1414 Hz	2000 Hz	2828 Hz	4000 Hz	5657 Hz	8 KHz
Play by 1/2	A			O		O		O		O
	B		O		O		O		O	
Total		O	O	O	O	O	O	O	O	O

If the 20-year-old normal hearing and the partial hearing loss in the 1920s are 3KHz, perform A and B tests according to the method in Table 1. Corresponding to the number of sounds shown in Table 2, you can judge whether the hearing loss is in this frequency band.

TABLE II. ESTIMATED NUMBER OF SOUNDS THAT CAN BE HEARD AT THE AGE OF 20

Sound source		The 20s with normal hearing	The 20s with a partial auditory disturbance at 3KHz
Play by 1/2	A	3	2
	B	3	3

Table 2 shows that according to the number of perceptual sounds of each sound source, it can be used as an index to classify normal hearing and partial hearing loss. If A $\leqslant$ B can be judged as a normal hearing person, but if A > B, because the number of sounds heard by the sound source first is greater than the number of sounds heard after the sound source, it is evaluated as having a hearing impairment. [12]

V. EXPERIMENT AND RESULTS

In this paper, 12 males and females aged 20 to 50 have experimented on the audiometric measurement method of voice subbands. All subjects were recognized as hearing people. The selection criteria for the subjects are that there is no hearing discomfort in normal communication. The test experiment was conducted in a quiet university lecture room. As shown in Table 1, using the audition CC to generate 9 pure tones (500~8KHz) gain compensation at -

15dBFS, the Microsoft Surface Pro6 notebook computer's audio volume is 8%, 4%, and 2% of the total volume. Play all the pure tones under these three-volume levels, respectively, once. The order is that the volume decreases in order.[13]

TABLE III. MEASUREMENT RESULT

Number	Age	Sex	Volume (%)	The number of hearing times for each sound source		Judgment on partial hearing loss
				A	B	O (Yes) or X (No)
1	18	Male	8	4	4	X
			4	4	4	X
			2	4	4	X
2	17	Female	8	4	4	X
			4	4	4	X
			2	4	4	X
3	39	Female	8	4	4	X
			4	4	4	X
			2	4	4	X
4	33	Male	8	4	4	X
			4	4	4	X
			2	4	4	X
5	47	Male	8	4	4	X
			4	3	3	O
			2	3	2	O
6	45	Female	8	4	4	X
			4	4	4	X
			2	4	4	X
7	23	Male	8	4	4	X
			4	4	4	X
			2	4	4	X
8	24	Male	8	4	4	X
			4	4	4	X
			2	4	4	X
9	29	Male	8	4	4	X
			4	4	4	X
			2	4	4	X
10	52	Female	8	4	4	X
			4	4	4	X
			2	3	4	X
11	41	Female	8	4	4	X
			4	4	4	X
			2	4	4	X
12	35	Male	8	4	4	X
			4	4	4	X
			2	3	4	X

Table 3 shows the age, gender, and measurement results of each participant in the experiment. From the measurement results in Table 3, 11 of the 12 subjects judged their hearing to be normal, and 1 was determined to be partially hearing impaired. Due to each age group's hearing threshold characteristics, low-frequency sounds are easy to hear, while high-frequency sounds require longer response time. This situation is more common when the volume is low, even if the hearing is normal. Therefore, when you suspect partial hearing damage, you hear it less often, even if you hear a low-volume pure tone. After the test is completed, the tester's self-judged hearing loss results are compared with the test results. In the end, the results unanimously showed that there was a suspected hearing loss.

VI. CONCLUSION

Studies have found that hearing begins to decline rapidly from 30 to 40-60; there may be discomfort in conversation. This loss becomes more serious with urban noise and excessive use of headphones. Hearing loss is irreversible, so it must be prevented in advance. But the current hearing loss test is too cumbersome. This research proposes a frequency-level compensation method for self-recognized speech hearing impairment to quickly and easily cope with the initial stage of hearing impairment. The suggested

method uses the Mel scale to compensate for the frequency level in the audio sub-band of 0.5KH~8Khz in the arrangement shown in Table 1 to detect partial hearing loss. The experiment results showed that in an experiment involving 12 subjects, one was identified as suspected of partial hearing loss.

Furthermore, after explaining the detection principle to all subjects, the subject's self-judgment results are the same as the actual measurement results. This means that people can do it at home by themselves and quickly get accurate test results after getting such a sound source. Through the spread of the proposed hearing measurement method, prevention and vigilance are made by making it easy to distinguish whether hearing damage has occurred. This will improve people's happiness in life.

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