Smartphone-Based Self Hearing Diagnosis using Hearing Aids

Fei Chen, Shuai Wang
School of Microelectronics, Tianjin University
Tianjin, China
chen-fei@tju.edu.cn, wangshuai_36@tju.edu.cn

***Abstract*—As a portable smart device, smartphone has been widely used in the field of hearing diagnosis. It can simplify the diagnostic procedure and provide a simple method for hearing diagnosis. However, smartphone is usually used as an audio source and operate conventional test algorithms, which takes a lot of time. We propose a new method for self-hearing diagnosis based on smartphone, which uses hearing aids as audio sources. A new hearing diagnosis algorithm that we developed running on the smartphone is used to reduce the test time. The test result is output in the form of an audiogram. This method not only solves the limitation of various audio codec chips of smartphone, but also provides a model for the combination of hearing aid fitting and hearing diagnosis based on the smartphone in the future. We evaluated this method on 6 subjects. The evaluated results indicate that the new method is able to be used for self-hearing diagnosis and reduce the test time compared to the conventional hearing diagnosis.**

Keywords—smartphone; self-hearing diagnosis; hearing aids; audiogram

I. INTRODUCTION

There are about 360 million people are suffering from disabled hearing loss in the world, which makes up 5% of the world population. Hearing loss affects their daily life and even leads to psychological disorders, such as sadness and loneliness [1]. Many people begin to pay attention to hearing health. Wearing hearing aids is still the best option to solve hearing problem [2] [3]. However, every patient with hearing loss has different hearing loss. The parameters of hearing aids should be programmed by the audiologists according to the audiogram of the patient. Therefore, the correct results of hearing diagnosis can help patients quickly adapt their hearing aids and get the best hearing effect.

Hearing diagnosis is based on the hearing ability of patients, recording the minimum sound level they heard to form an audiogram at some specific frequencies. Audiologists can judge the hearing loss level according to the audiogram, which provides a basis for adjusting the parameters of the hearing aids. The conventional hearing diagnosis is complex. Patients have to go to a professional hearing organization to complete the hearing diagnosis. The diagnostic procedure is usually carried out in a sound-proof booth, and it is conducted by an audiologist with a technical audiometer [4]. There are six test frequencies are given in the following order: 1000, 2000, 4000, 8000Hz and 500Hz and then 250Hz. The audiologist usually uses a more precise method called up-5-down-10. In this method, the patient needs to wear a professional headphone on his ears. The audiometer first plays a pure-tone with a suitable sound level at 1000 Hz frequency. If this tone can be heard by the patient, the sound level will be reduced by 10 dB HL, or the sound level is increased by 5dB HL at the same frequency. If the patient heard a tone twice in the same sound level, then the level is recorded as the auditory threshold at 1000Hz. For other frequencies, this procedure is the same as that of 1000Hz [5]. Although the conventional hearing diagnosis is accurate, it is inconvenient and takes a long time. Because the audiometer is not portable and the patients need to respond many times in test process.

Smartphone has a powerful operating system and excellent audio codec chip. Many engineers began to apply smartphone in the field of hearing diagnosis [6] [7]. At present, there are two categories of hearing diagnosis based on smartphone. The first is completely based on smartphone, a smartphone plays a pure-tone as an audio source, and meanwhile, it can also guide patients to complete the hearing diagnosis as a control center. This method can lead to deviation due to different hardware of smartphone. The other is using a professional audiometer to play a pure-tone, the smartphone can control audiometer to guide patients to complete the hearing diagnosis. However, it is not portable.

Fig. 1. Comparision between conventional method and our method

In this paper, we propose a method based on smartphone for self-hearing diagnosis, which uses hearing aids as audio sources. The smartphone can communicate with the hearing aids by Bluetooth Low Energy (BLE). As shown in Fig. 1, the patients can complete hearing diagnosis by themselves in their home. The hearing aids play a pure-tone to ensure accurate sound level. This method can solve the portability and accuracy of hearing diagnosis. In order to reduce test time, we utilize the wide-to-thin algorithm to replace up-5-down-10 algorithm for test procedure. We design a smart self-hearing diagnosis system (SSHDS) to implement the method proposed in this paper. In the following chapters, the architecture of SSHDS will be discussed and the evaluation scheme will be given. We proved this system could be used in self-hearing diagnosis. The wide-to-thin algorithm could reduce the test time compared with conventional method.

II. System Design

SSHDS consists of three parts: (1) two hearing aid devices, which plays a pure-tone with different sound levels at different frequencies as an audiometer in this system; (2) a self-hearing diagnosis application running on the Android operating system is developed, which can lead patients to completing the test procedure by themselves; (3) the wide-to-thin algorithm is used to reduce the test time. The block diagram of SSHDS is shown in Fig. 2. The patient needs to wear hearing aids in their ears to hear various tones. The test procedure is controlled by an android smartphone. The wide-to-thin algorithm is executed to control the sound level and frequency. Finally, the test result is displayed using an audiogram on the smartphone.

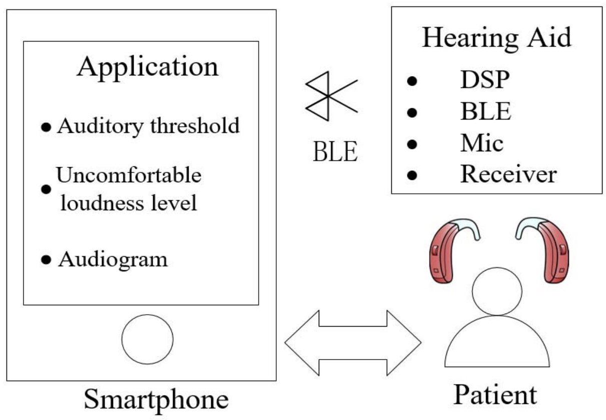

Fig. 2. The block diagram of SSHDS

A. Hearing Aids Design

The structure of hearing aid is shown in Fig. 3. It includes a Digital Signal Processing (DSP) to process the serialized speech signal, two omnidirectional microphones, a receiver, a power circuit and an antenna with a matching circuit. Ezairo 7150SL is used as the DSP, which is produced by ON Semiconductor Company. Ezairo 7150SL is an open programmable DSP and integrates ADC, DAC and NRF51822 wireless System on Chip (SoC) from Nordic Semiconductor. NRF51822 is a BLE component that acts a slave in wireless communication of SSHDS. The hearing aid can be used as a normal hearing aid to amplify the sound in our design. Two microphones are responsible for collecting the sound signal from exterior space to convert into electrical signal. The electrical signal will be serialized by ADC to become digital signal which can be handled by DSP. The DAC converts the processed digital signal to the analog signal to play sound by the receiver. This is a general function for the hearing aid in SSHDS.

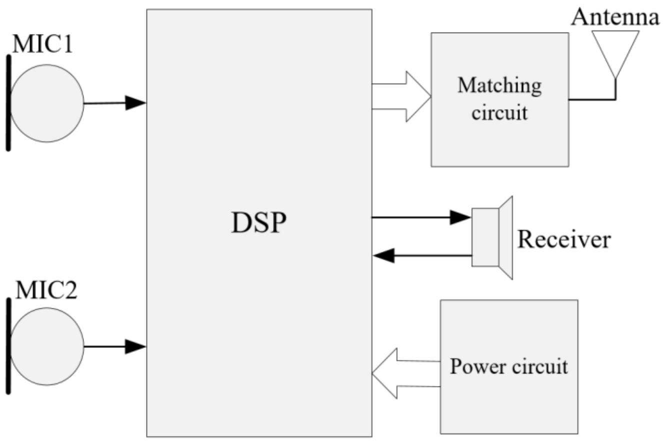

Fig. 3. The structure of hearing aid with Bluetooth Low Energy

$$fs = sample\_frequency \times frequency \quad (1)$$

$$y(n) = A \times sin(2/fs \times \pi \times n) \quad n = 0,1,2\ldots(fs - 1). \quad (2)$$

The hearing aid is mainly used as an audio source in this paper. In order to produce a tone with a specific frequency, the sine wave series must be written to the DSP memory in advance. The sine wave series is calculated as in (1) and (2). The frequency in (1) is the frequency of the tone played by receiver, and it is multiplied by the sampling frequency of the DAC to produce the number of the series fs. The y (n) in (2) is the sample value per point of the sine wave series. It is obtained by a sin wave function multiply with amplitude A in (2). The A is used to calculate the sound level. Finally, the series is transferred to DAC to convert into the analog signal, which is sent to the receiver to play a pure-tone with a specific frequency. The loudness range of pure-tone is from 0dB HL to 110dB HL and frequency range is from 250Hz to 8000Hz. We have calibrated the sound level to ensure accuracy of the pure-tone.

B. Application for SSHDS

The application for SSHDS is developed on Android Studio platform, written by JAVA language. The application can be run on a smartphone equipped with android 4.3 Jelly Bean and above, because the Android operating system begins to support BLE device from API 18. There are ample BLE operating functions in Android API, Such as BLE connections, read and writing. BLE device uses characteristic value to communicate with each other. Some similar characteristics constitute a service. So in this application, some services and characteristics have been customized to send commands between smartphone and hearing aids. The application includes three functions: (1) auditory threshold test based on wide-to-thin algorithm; (2) uncomfortable loudness level test based on simple increasing algorithm; (3) audiogram for the result. Fig. 4 shows the interface of the application.

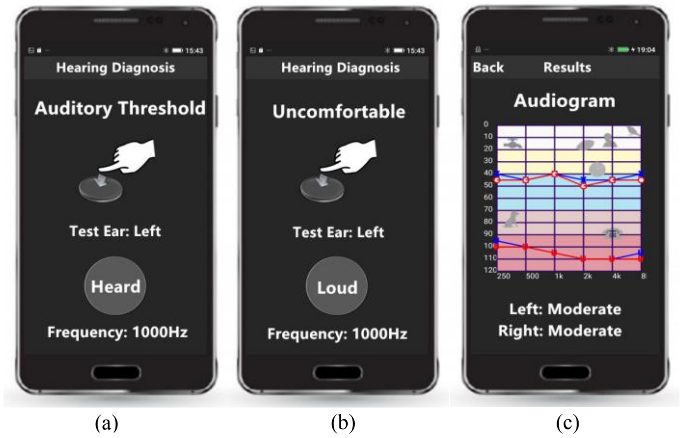

Fig. 4. Interface of the application for SSHDS

In this Application, the BLE of hearing aid can be scanned by the master BLE device on the smartphone. The smartphone will automatically connect this two hearing aids when they are founded and distinguish between the left and the right ear according to the selection operation. The smartphone can send command to the hearing aid via BLE. When the command is received by hearing aid, enter the corresponding program on DSP. Hearing aid will generate a specific pure-tone. The operation of the application is very simple for patients.

1) Auditory threshold test: This process uses the wide-to-thin algorithm to control the tone level and frequency. The wide-to-thin algorithm is described in detail in the next section. As shown in Fig. 4 (a), the patient only need to press “Heard” according to tips when they heard the tone played by hearing aids.

2) Uncomfortable Loudness Level: In this process, the sample increasing algorithm is used. The hearing aid initially plays a 50dB HL tone at 1000Hz. As shown in Fig.4 (b), if the patient feels the tone is uncomfortable, press “Loudness” according to tips, the sound level would be recorded as the uncomfortable loudness level at 1000Hz, otherwise, the sound level would be increased by 5dB HL per second. The process is repeated at other frequencies.

3) Audiogram: After the hearing diagnosis is completed, the application will output the audiogram and calculate hearing loss level. As shown in Fig 4 (c), the red line represents auditory threshold and uncomfortable loudness level of the right ear and the blue one represents auditory threshold and uncomfortable loudness level of the left ear. Patient can visually see their hearing loss level according to different colors in the audiogram.

C. Wide-to-thin algorithm.

The conventional up-5-down-10 algorithm has a long test time. We developed the wide-to-thin algorithm to solve this problem. This new algorithm controls the program of the auditory threshold test. The concept map of this algorithm is shown in Fig. 5. The main idea of the wide-to-thin is to control the playing time, which can avoid the multiple measurements at the same frequency. The algorithm first goes into wide model, the sound level is increased by 5 dB HL every 0.8s to reduce the whole test time. In thin model, the sound level is increased by 5dB HL every 2s to improve accuracy of results.

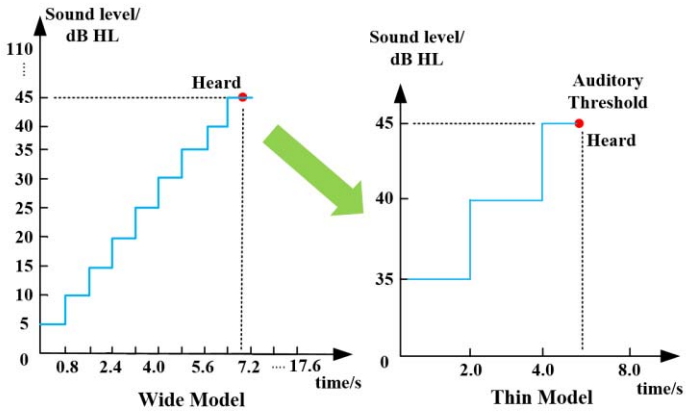

Fig. 5. The concept map of the wide-to-thin algorthim

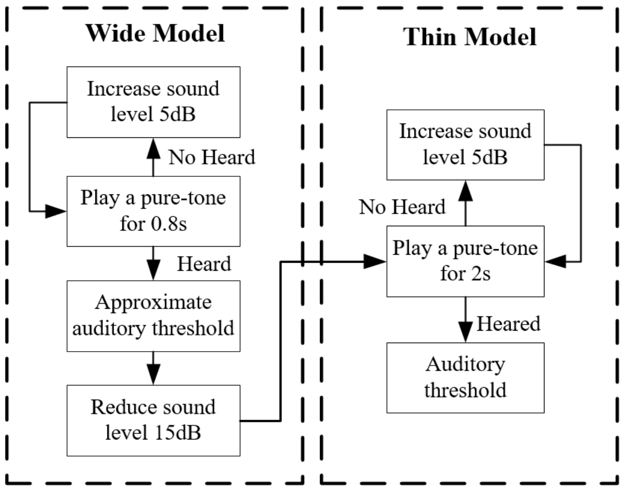

Fig. 6. The flow chart of the wide-to-thin algorthim

The flow chart of this algorithm is shown in Fig. 6. The order of the test frequencies is the same as the conventional as follows: 1000, 2000, 4000, 8000Hz and 500Hz and then 250Hz. The hearing aid initially plays a pure-tone with the 15dB HL at 1000Hz for 0.8 seconds. If the patient does not hear the tone in 0.8s time, the sound level will be increased by 5dB HL to play for 0.8s, which is called the wide model. Otherwise, the sound level will be regarded as the approximate auditory threshold, which will make the program into the thin model. In the thin model, the approximate auditory threshold will be reduced by 15 dB HL as a new sound level to play for 2 seconds. If the patient can hear the tone, the sound level will be recorded as the auditory threshold at 1000Hz, or the sound level will be increased by 5dB HL. This process is repeated at other frequencies. The algorithm can reduce the test time comparing with the conventional method in theory because the patient only needs to respond for two times at each frequency.

III. VERIFCATION Method And Results

In order to verify SSHDS, we invited 6 subjects to participate in the test. Their mean age was 71.2 years with the highest age of 90 years and the lowest age of 25 years. There are 12 ears were tested, with two normal ears, two ears of mild hearing loss, seven ears of moderate hearing loss and one ear of severe hearing loss. These subjects respectively used SSHDS and conventional method to test their auditory threshold in the same environment. In SSHDS test, the subject completed the test by themselves. We calculated the mean test time for different hearing loss and analyzed the test result of the two methods.

A. Comparison of Mean Test Time

The mean test time of SSHDS and conventional method for different hearing loss is shown in Table I. The mean test time for conventional method was 112.3s, whereas SSHDS was 72.5s for mild hearing loss. In the moderate hearing loss, the mean test time for SSHDS was 33.5s less than the mean time of conventional method. In the other two types of hearing loss, the mean test time of SSHDS was also less than the conventional method. So, it can be concluded that SSHDS could reduce the test time for hearing diagnosis.

TABLE I. MEAN TEST TIME OF SSHDS AND CONVENTIONAL METHOD

Hearing Loss	Ear Number	Mean Test Time (s)	
		SSHDS	Conventional Method
Mild	2	72.5	112.3
Moderate	7	136.7	170.2
Severe	1	325.1	367.5
Normal	2	61.5	94.0

B. Difference between SSHDS and Conventional Method

Fig.7 shows the average difference between SSHDS and conventional method for the six subjects. The average differences were 5.5, 5.0, 3.5, 4.0, 3.5, 3.0 dB HL at 250, 500, 1000, 2000, 4000, 8000Hz, respectively. We could see that the average difference at 250Hz is more than 5dB HL. However, the difference was less than 5dB HL at other frequencies. The result was acceptable for self-hearing diagnosis. The pure-tone played by hearing aids was precise, and it could be used for diagnosis.

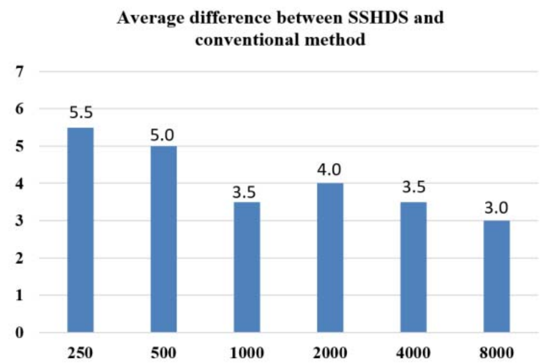

Fig. 7. Average difference between SSHDS and conventional method

TABLE II. DIFFERENCE BETWEEN SSHDS AND CONVENTIONAL METOOD FOR ONE SUBJECT

Method \ Frequency	250	500	1000	2000	4000	8000
SSHDS	30	35	40	35	40	40
Convention	35	30	40	35	40	40

Table II shows the difference between SSHDS and conventional method for a subject. We select left ear of the subject to discuss. We could see that the auditory threshold was different at low frequency (250 and 500 Hz), but that was only 5dB HL. At other frequencies, the auditory threshold was the same for this two methods. The result shows that the SSHDS is viable.

IV. CONCLUSIONS

In this paper, we propose a new method for the self-hearing diagnosis using smartphone. Hearing aids are used as audio sources, which solves portability and ensures the accuracy of the test result. The wide-to-thin algorithm designed by us is effective for reducing test time. The smart self-hearing diagnosis system (SSHDS) is developed to implement the new method. The system design of SSHDS is described in detail in this paper. We verified SSHDS through experiment. The results show the new method can help people with hearing loss complete hearing diagnosis by themselves. In addition, we will add the hearing aid fitting function in the future. The smartphone will calculate the fitting data according to the audiogram and directly send the data to the hearing aids, which will realize the combination of hearing aid self-fitting and self-hearing diagnosis.

REFERENCES

[1] Mielke M, Brueck R. Design and evaluation of a smartphone application for non-speech sound awareness for people with hearing loss [J]. Conf Proc IEEE Eng Med Biol Soc, 2015, 2015:5008-5011.

[2] Einhorn R. Hearing Aid Technology for the 21st Century: A Proposal for Universal Wireless Connectivity and Improved Sound Quality [J]. IEEE Pulse, 2017, 8(2):25-28.

[3] Ganguly A, Reddy C, Hao Y, et al. Improving Sound Localization for Hearing Aid Devices Using Smartphone Assisted Technology[C]. IEEE International Workshop on Signal Processing Systems. IEEE, 2016:165-170.

[4] R. J. Roeser, K. A. Buckley, and G. S. Stickney, “Pure tone test,”in Audiology Diagnosis, 1st ed., R. J. Roeser, M. Valente, and H. Hosford-Dunn, Eds. New York, USA: Thieme, 2000, pp. 227–256.

[5] Fayal Y, Wahiba B, Lotfi B, et al. Computer Audiometer for Hearing Testing[C]. International Conference on Advances in Electronics and Micro-Electronics. IEEE Computer Society, 2008:111-114.

[6] Miah M S, Rubya S, Kabir M F. Assessment of occupational noise induced hearing loss via a smartphone application[C]. International Conference on Software, Knowledge, Information Management and Applications. IEEE, 2015:1-5.

[7] Choi J M, Sohn J, Ku Y, et al. Phoneme-Based Self Hearing Assessment on a Smartphone [J]. IEEE Journal of Biomedical & Health Informatics, 2013, 17(3):526.