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Development of "MobileAudiometer" for Screening using Mobile Phones

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Abstract— **As we age, the functions of our body and sensory organs deteriorate. Diagnosis of hearing problems tends to be delayed and people put off wearing hearing aids as they are not aware of the deterioration and get used to paying little attention to their hearing difficulty. Adaptation of sound is necessary because sound quality perceived with hearing aids differs from that of normal sound. Detection of hearing problems at an earlier stage is important. An audiometer that can screen persons with hearing loss easily at an early stage is necessary. In this paper, a prototype of the simple audiometer as the audiometer classified into type 4 for screening/monitoring purposes regulated in IEC standards, proposed in the previous research, is developed on the mobile phone by Java application program and ringing tones of mobile phones. The functions and performance of the prototype are verified along IEC standards.**

Keywords— **Audiometer, mobile phones, screening**

I. Introduction

As we age, body functions and sensory organs deteriorate. In general, the deterioration in hearing capability starts in the 20s. Even though the high frequency components over 1 kHz are necessary to listen to voices clearly, the deterioration with aging in the pure tone hearing ability becomes prominent above 2 kHz over 50 years old.

Adaptation is highly effective at an early stage of slight hearing loss accordingly the detection of hearing problems at an earlier stage is important. On the other hand, hearing loss progresses gradually. People delay wearing hearing aids because they are not aware of the deterioration progress and get used to living with hearing difficulties. For these reasons, audiometers are necessary which can easily screen persons with hearing loss progressing at an early stage. It is inefficient to make precise audiometric tests for all senior citizens and pre-senior citizens. The test should screen the persons efficiently and economically.

In this paper, using a prototype of the simple audiometer for the screening purposes has been developed on the mobile phone, which is the latest model with improved function of Java application program and ringing tones quality. The functions and performance of the prototype are verified along International Electrotechnical Commission (IEC) standards to examine the realisability of the simple audiometer using regular mobile phones. Especially, for screening purposes, only the air conduction pure tone audiometric test method is considered. Hereafter in this paper, it will be referred to as MobileAudiometer since the simple audiometer is implemented by using a mobile phone which has convenient mobility.

II. Design concept

A. Audiometer requirements

The standard of the audiometer is provided by IEC. The standard consists of two parts for pure-tone audiometers *(IEC 60645-1 2001-06)* and for speech audiometers. *IEC 60645-1 2001-06* specifies general requirements for audiometers and particular requirements for pure-tone audiometers designed for use in determining hearing threshold levels, such as the signal source, the signal level adjustment, and transducers (earphone and bone vibrator). It is also preferable for the simple audiometry for screening purposes proposed in this paper to conform to this standard.

Audiometers having air conduction and bone conduction audiometric test are classified into three types: type 1 for advanced clinical/research, type 2 for clinical, and type 3 for basic diagnostic purposes. In this paper, as the audiometer for screening/monitoring purposes, the audiometer classified into type 4 is adopted for air conduction audiometric tests, and the function and performance of the proposed simple audiometer are examined with respect to each requirement of the following IEC standard.

However the supra-aural earphones positioned over the ear are used in general as a transducer of an air conduction audiometry, an insert earphone is adopted instead of the supra-aural earphones in considering the use with a mobile phone, isolation form the outer ambient noise.

In the following sections, the realisability of the simple audiometer MobileAudiometer proposed in this subsection is examined, after the function, the test frequency, the reproduced sound pressure level, and the harmonics distortions are verified based on the type 4 audiometer of the IEC standards.

B. Proposed audiometer

The proposed system [1] is composed of three main parts as follows: a server computer connected with the Internet which distributes program of audiometry service, an electronic hearing database corresponding to electronic patient record systems in hospitals, and a mobile phone

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which operates the program of audiometry service. A virtual audiometer is realized by downloading the program from the server computer to the mobile phone. After the test results are saved temporarily in the memory of the mobile phone, the data is managed as an electronic hearing database by uploading to the server computer through the Internet.

The components between the system block diagrams of the mobile audio LSI in mobile phones and of audiometers [2] are compared beforehand, as shown Figure 1. There is a close similarity between components, for example, the frequency modulation oscillator relates to the sine wave generator, the ADPCM (Adaptive Differential Pulse Code Modulation) oscillator to the external sound source and masking noise generator, the digital volume to the attenuator, keypad to response device, Java application program to the computer-controlled procedure controller, and liquid crystal display to response monitoring display for tester and audiogram chart.

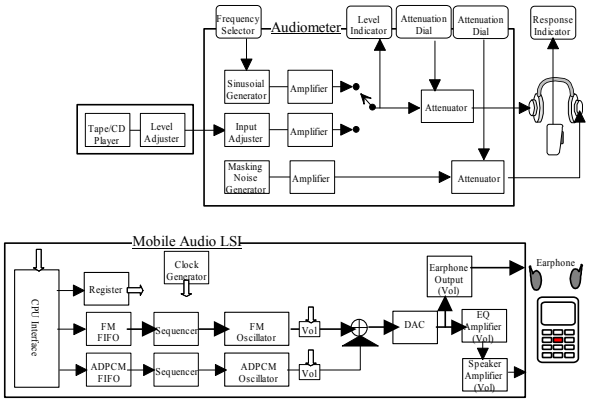


Fig.1 Comparison of audiometer and LSI for ringing tone

As for control of audiometric test sequences, a Java program for the mobile phone is used to develop the application program for it. As for test tones, the frequency modulation oscillator of mobile audio LSI and the function of original ringing tones built into the mobile phone are used. As for presentation of the test tones, the test tones are presented with the insert earphone inserted into the external auditory canal. The way to fit the speaker of the mobile phone close to the ear pinna can not present a fixed sound pressure level. The supraaural and circumaural earphones make the possible air and bone conduction to the other nontested ear. So masking noise is needed to mask the conduction sound to the non-test ear which affects audiometric test. In contrast, insert earphones can reduce the conduction and the use of masking noise. For this reason, an insert earphone is adopted.

III. Function and Performance Verification

A. Test tones

The parameters of the test tone to make a pure tone are adjusted by using the function of original ringing tones. The ringing tones are made by modulating the sine wave with the proper envelope by the frequency modulation oscillator and combining the modulating operators in two or more steps. Various kinds of ringing tones can be produced by changing the parameters [3] of ringing tone and the combination of operators, as shown in Figure 2. Here, the parallel connection mode (OP2) which consists of two modulation operators is adopted to make a test pure tone easily. The two operators' amplitude parameters were put at the same settings, such as durable envelope, no modulation, and no vibrato, as shown in Figure 2.

			Settled (N504i)
FQ	Effect Frequency	0:1.9Hz 1:4.2Hz 2:6.1Hz 3:7.2Hz	0
FB	Feedback	0～7	0
AL	Algorithm	16Chord:1～2, 8Chord:3～6	OP2
ML	Multiple	0～12:0～12 14:15	4
EN	Envelope	0:Decay 1:Durable	1
SU	Sustain	0:OFF 1:ON	0
KR	Key Scale Rate	1～2	2
KL	Key Scale Level	0～3	0
TL	Total Level	0～63	63
AR	Attack Rate	0(slow)～14(fast)	13
DR	Decay Rate	1(slow)～16(fast)	1
SL	Sustain Level	1～16	16
RR	Release Rate	1～16	11
WF	Waveform function	1～8(1:sinusoidal)	1
VI	Vibrato	0～4(0:OFF)	0
AM	Amplitude Modulation	0～4(0:OFF)	0

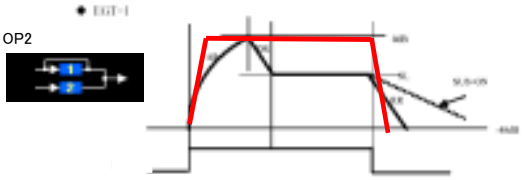


Fig.2 Parameters of ringing tone

As the test tone meets the IEC standard of *"Tone switching"*, the parameters of ringing tones were adjusted appropriately by checking the shape of amplitude, rising, and falling by digital oscilloscope, and the frequency components by FFT analyzer. The adjusted test tones were saved into i-melody format file. Figure 2 shows the settings of the test tone parameters used in this experiment.

B. Test tone measurements

A mobile phone, Docomo N504i model, was used to verify the performance of the test tones. In general, the speaker for the telephone call and the speaker for the ringing tones are equipped on a mobile phone separately. The insert earphone reproduces all of the ringing tones, the telephone call, and the alarm tone of arrival message.

The output sound pressure level from the insert earphone was measured as the sound field characteristic of the test tone by using the dummy head which had the ear simulator. Dummy head (BK4128), microphone preamplifier (BK2669), measuring amplifier (BK2636), and analyzer (Dell Co. PC・PowerEdge300S, NI Co. Data Acquisition

board PCI-6031E, and NI Co. LabVIEW) were used as the measuring equipment. Short-Time Fourier Transform analysis is used for frequency analysis with sampling rate of 40kHz, analysis window of 2048 points length (25.6ms) and Hanning. VI module of LabVIEW was used for the analysis of harmonic distortions. The characteristics of insert earphone (audio-technica Co. ATT-77S) are impedance of 32Ω, the frequency range of 100Hz-20 kHz, and maximum output sound pressure level of 105dB (at the maximum input of 40mW).

C. Frequency accuracy

Table 1 shows the required frequencies of the test tone and the actual frequencies reproduced by the ringing tone of the mobile phone. The ringing tones can reproduce the frequencies only along the music scale. The frequency of the test tones were settled within the tolerance of 2%. The frequency fluctuation in the time domain was constant within 1Hz which is the resolution of the STFT analysis. The results satisfied the permissible error of type 4 audiometer. Moreover, the unwanted obstruction sound also satisfied the regulation when the ringing tone reproduction was off.

TABLE 1
FREQUENCIES OF RINGING TONE

Frequency [Hz]	Type 4 Permissible(±2%)		Frequencies of ringing tones [Hz]		
	Maximum	Minimum			
250	245	255	B3	246	○
500	490	510	B4	493	○
1000	980	1020	B5	986	○
2000	1960	2040	B6	1974	○
3000	2940	3060	F6	2959	○
4000	3920	4080	B7	3950	○
6000	5880	6120	F7	5915	○
8000	7840	8160	B8	7893	○

D. Accuracy of sound pressure level

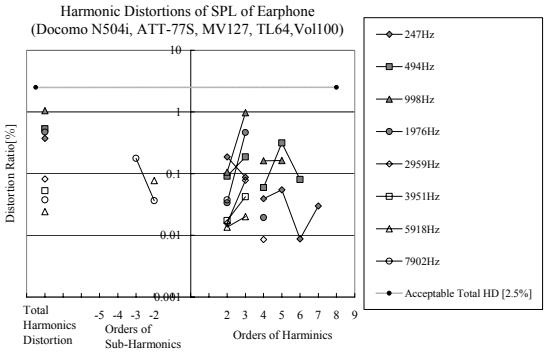
The relationships among the sound pressure level in the insert earphone, and the ringing tone parameters concerning the amplitude, and the output voltage were examined for the verification.

The minimum hearing level of 0 dBHL was reproduced on each frequency by utilizing both parameters of TL and MV. The maximum output hearing levels at the frequencies of 500 Hz to 8 kHz satisfied the required range of 0 to 60 dBHL. The maximum hearing level at 250 Hz satisfied 70 dBHL. The output voltage level could obtain a dynamic range of 83 dB by operating the both of TL and MV parameters as for the intensity.

As for calibration of level, the reference equivalent threshold sound pressure level for each frequency should be matched in consideration of the measured maximum hearing level. In the development of MobileAudiometer, the MV parameter is adopted for the calibration.

E. Total harmonic distortion

The harmonic distortion of the ringing tone at the maximum reproducible sound pressure level was verified according to standard IEC. Figure 4 shows an analytical result of the harmonic distortions of the test tone at the insert earphone. There are data which can not be displayed on the graph. This means the data are so small that they are not on the scale. The harmonic distortions satisfied IEC standards.



IV. MOBILEAUDIOMETER DEVELOPMENT

A. MobileAudiometer algorithm

In this paper, the test algorithm of the computer-controlled audiometer was adopted to develop an audiometer where a test subject tests him/herself without a qualified tester. An ascending method was adopted as a presentation method of the test tones. The test begins when the start button is pushed, and the test instruction is displayed in the liquid crystal display of the mobile phone by the characters. The test subject inserts the insert earphone into his right ear canal according to the instructions. The test sequence continues in order of 1k, 2k, 3k, 4k, 6k, 8k, 1k, 500, and 250Hz.

When the former test results exist in the server computer, the results are referenced to set initial levels of test tones automatically to save the test time. After the subject confirms the test tone of the sufficient intensity which evokes a definite response, the test tone level is lowered so that no response occurs. Next, the level is increased in steps of 5dB every second, the level which can be heard first is assumed to be the hearing threshold level. When there is no response even though the maximum reproducible sound pressure level is presented, it is assumed to be the scale out. When the minimum sound pressure level can be heard, the level is assumed to be the hearing threshold. When one ear has been tested, the other ear is tested according to the instructions.

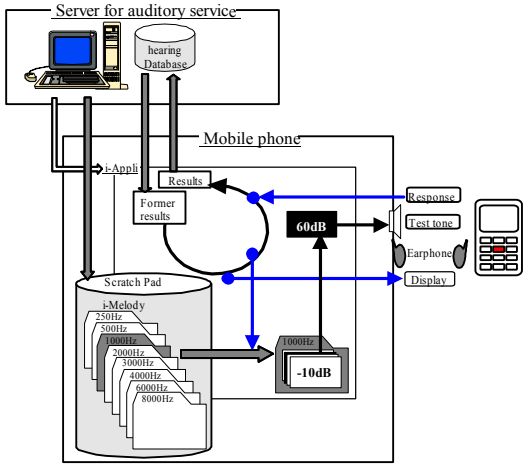


Fig.5 Algorithm of i-Appli for controller

B. MobileAudiometer prototype

The test tones are made from the possible minimum to maximum sound pressure level by steps of 5 dB and saved into i-melody format files. The test tones of each frequency from 250 Hz to 8 kHz were packed into each virtual folder. In the test, after one of the frequency folders was selected, the test tone corresponding to the test hearing level was presented sequentially by the i-Appli program.

The hearing threshold level was calibrated by adjusting the MV parameter by Java program based on the relationship between the sound pressure level of the test tones and the parameters measured in the third section so that the reference equivalent threshold sound pressure level for each frequency corresponded.

The keypad buttons of the mobile phone can be used as a response device to the test tone as the computer-controlled self response device for the subject. In the case of a computer-controlled test, the level of the test tone is selected automatically according to the subject's response by the keypad. The data of the results are temporarily saved in the memory of the mobile phone, and after the test has finished the display shows the pure tone audiogram. Figure 6 shows an example of the test result audiogram.

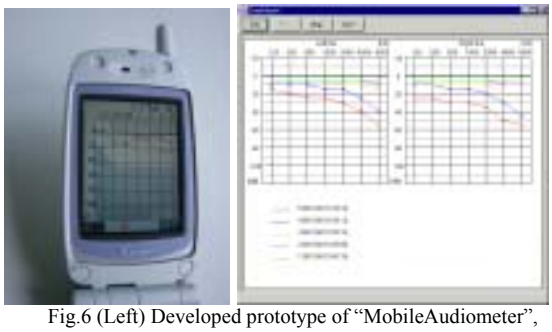


Fig.6 (Left) Developed prototype of "MobileAudiometer", (Right) Prototype of electrical patient record for hearing ability on server.

V. DISCUSSION

The features and the advantages of the proposed MobileAudiometer are summarized below. The frequency modulation oscillator for the ringing tone was used as a test tone generator, but the telephone call was not. If the audiometer were achieved by using voice call of the fixed telephone, the influence of the noise contaminated over the telephone network and the level fluctuation are significant problems. It is the same in the case of the mobile phone. The proposed system can reproduce test tones of consistent and high quality because of the low noise and high accuracy of the ringing tones using the frequency modulation oscillator built-into the mobile phone.

With the proposed mobile audiometery, there is easiness that users can get an audiometer whenever and wherever it is necessary. Since it is not a device specified only for an audiometry and is always carried with him as a telephone. It is likely this device will spread to the home like the clinical thermometer, because the audiometer can be constructed cheaply and easily using a mobile phone. It enables users to test their hearing ability by themselves anytime and anywhere they need. As a result, the increased opportunity of screening helps early detection of hearing impairment.

The system is suitable for periodic test to accumulate test results. It helps making the electronic database of senior citizen's hearing characteristic for the assessment of hearing impairment because the test results are managed easily in the server computer which is connected via the Internet. The test time can be shortened so as not to tire the test subject by initializing a test based on the past audiometry results in the database.

VI. CONCLUSION

In this paper, a prototype of the audiometer for screening purposes named "MobileAudiometer" was developed using the ringing tones and Java program of the mobile phone. The MobileAudiometer was examined as a regulated audiometer by verifying the function and the performance in terms of IEC standard. The results showed that there was the practicable possibility of mobile phones being applied to a simple audiometry for screening use.

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