Development of hearing self-assessment pure tone audiometer

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Abstract—Hearing impaired persons suffer from irreversible damage. Hearing screening test is used to detect hearing- impairment degree in different frequencies for both right and left ears. The conventional audiometer requires an audiologist to perform hearing test process, which causes a burden for the hearing-impaired person in respect of time and cost. The aim of this study is to develop a new portable audiometer for the hearing self-assessment. This portable audiometer consists of a computer, Raspberry pi 3 B+, patient response button and headphone. The sound signal is send to patient via headphones and the patient feeds back the response to the system using the left mouse button. Based on the response of the patient an automatic audiogram is plotted between frequency and intensity, which presents the volume of sound pressure. The results include the audiogram and raw data are saved in CSV files named with the time and date. A familiarization procedure is used to make the hearing-impaired person understands and able to perform the response task. The less time consuming and efficient Hughson Westlake procedure is implemented in the popular Python programming language to obtain the audiogram. The use of the open source Python programming language, help to reduce software development cost.

Keywords—hearing loss, hearing screening test, Hughson Westlake procedure, Familiarization, Python.

I. Introduction

Hearing loss is a frequent chronic disease, which affects adults of all ages. Its pregnancy increases as a function of aging, especially at frequencies above 2000 Hz [1, 2]. According to the World Health Organization, 466 million people in the world have a hearing loss and 75% of these people are from the developing countries [3]. The excessive noise exposure, ageing process, tumors, sickness and ototoxic medication could cause hearing loss in elderly persons. This disease may occurby itself or with tinnitus (ringing in the ears) [4, 5]. Although hearing impairment is not a fatal illness, it can lead to depression, to miscommunication, reduction in functional status and social withdrawals. The treatment of hearing loss could enhance the quality of life of the hearing-impaired elderly person population [6, 7, 8]. A study conducted in the United Kingdom [9], showed that the earlier-identified patients had a higher benefit through many years of using hearing aids than those who wore hearing aids at a later stage of the disease.

As such, a hearing screening test is essential for the early stage of hearing loss to minimize its impacts on the quality of life of the hearing-impaired persons. Hearing level describes the frequency bands centered at 250 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz and 8 kHz. The commonly stated range of human hearing is 20 to 20,000 Hz, although there is some variation between people, essentially at high frequencies.

The audiometer is an instrument by which we can screen the hearing capacity. In the conventional pure tone audiometry (PTA) testing, subjects could respond to the presented pure tone by pressing the patient response button. Currently, the conventional audiometer used by the audiologist in a soundproof booth, still dominates in most clinics. Patients have to go to the clinic to test their hearing, which is not suitable especially for the elderly hearing impairment persons who have difficulty in moving [10]. During the test, the patient needs to wear a sound-isolating headphone, which plays a pure tone for different frequencies, which start from 125 Hz to 8 Hz with varying the intensity level from 0 dB to 110 dB [11]. The intensity level adjusted in a way to reach the hearing threshold level of the patient at specific frequency, if the patient responds, the signal intensity is decremented by 10 dB and otherwise, the intensity is incremented 5 dB. This hearing measured procedure called Hughson Westlake ascending method [12, 13]. Although the conventional audiometers are accurate, they are costly and take a long time.

Due to the rapid development of information and communication technology, recently, several screening audiometer and a portable hearing-test devices have integrated the domain of hearing test with enhanced efficiency and reduced cost implementation [14, 15].
In 2012, Kok Beng Gan and Dhifaf Azeez developed an auto-Kit using a personal computer for hearing screening. However, the use of expensive TDH-49 headphone during the screening process increases thesystem cost [16]. In 2016, Ritu Rani developed a portable audiometer with hardware units, which is connected to the headphone and patient response button. This method has limitation in hearing self- assessment since an audiologist is required to participate in the testing process [17]. In India, Mahalakshmi and Mohanavalli implemented a software application in the LABVIEW programming environment, which recreates the function of a conventional audiometer; with this method, the environmental noise could affect the outcomes [18].

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The present study reported on the development of a self-assessment-hearing test. This study aimed to develop a cost-effective, simple and user-friendly computer-based hearing screening kit that anyone with minimal computer skill could be able to function his or her own hearing screening test. The proposed PTA has the advantages of high portability and low cost. The block schematic for portable audiometer will be described in detail. Process flow is illustrated in section III. Experimental results and discussion are given in section IV. Finally, a conclusion is given in section V.

II. SYSTEM DESIGN

In this project, a hearing impaired person can diagnose his hearing and detect the range of audibility. The block diagram of the proposed portable audiometer is shown in figure 1

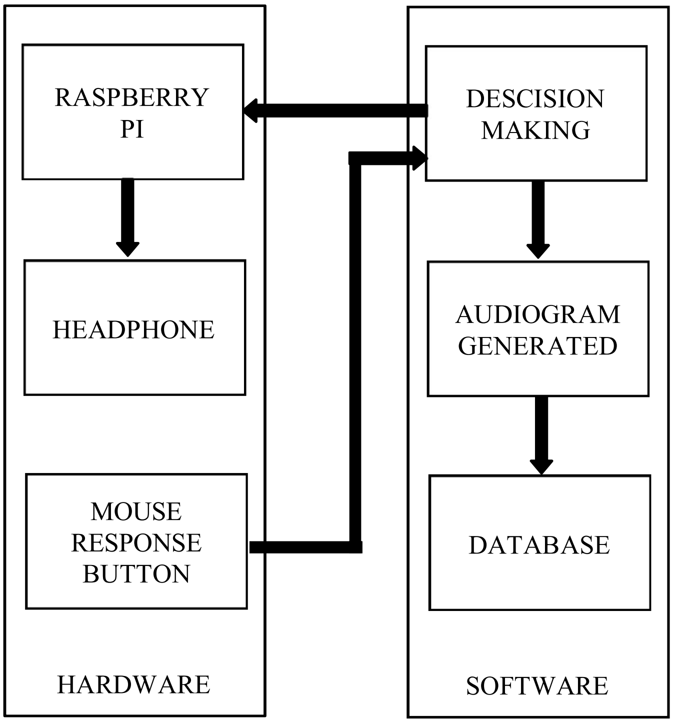

Fig.1. block diagram of portable audiometer

A. Hardware integration

During the development stage, the hardware integration approaches are used to minimize the system cost and fast prototyping. The proposed portable pure tone audiometer consists of Raspberry Pi3 B+ card, a mouse, a headphone as shown in figure 1.

The Raspberry Pi used in this study is an inexpensive card with fully computer features, which runs the Raspbian operating system. It is the 3rd generation Raspberry pi with a 64-bit 1.2GHz quad-core processor. This minicomputer has the essential connection ports that are used to plug peripheral devices as mouse and keyboard. It includes the popular Python programming language, which is the main core language in the Raspbian operating system that enables programmers to develop scripts or program.

The configured ALSA sound card of raspberry pi generates of pure tone in frequency ranges [250 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz, and 8 kHz], which will be the input signal for the circuit. Audio Output 3.5mm jack of the Raspberry pi is connected to HP102BK headphone to deliver the tone to the patient. During the test, subject must use only one earphone to one ear then begin the screening procedure. The hearing test begin automatically with testing the right ear. To avoid the wrong response, proposed portable audiometer used to mask the non-tested ear. If the right ear is tested, left ear is at rest, thus, left ear does not hear any tone. The same process is repeated to test the left ear.

When the hearing impairment person hears the pure tone signal, he will respond through the left mouse button. When pressing the mouse button, an event which presents the left mouse button on down state is send to the python based program on which the frequencies and the intensities are varied automatically which is the principal function of decision making block.

B. Software development

The process of decision-making is implemented in the python environment. The input is taken from the response of patient using the left mouse button and according to the patient response from the values of intensity in dB will be decremented or incremented using the programmed raspberry pi. An audiogram is a graph that illustrates the hearing thresholds, which is the lowest sound that can hear at different frequencies and intensities. The two X and Y axis of the graph represent the frequency measured in Hertz (Hz) and the intensity measured in decibels (dB) respectively. The test is conducted for each ear individually. When the patient hear a tone, the patient will press a left mouse button. Then the hearing thresholds of the patient are displayed in the audiogram. According to patient's response, the audiogram is displayed automatically by the decision-making. The results include the audiogram and raw data are stored in CSV files named with the time and date.

III. PROCESS FLOW

The screening test starts by sending a familiarization tone (i.e., 40 dB at 1000 Hz by default) to one of the hearing-impaired person's ears. Then the automated ascending screening procedure begins if the subject is able to respond to the familiarization tones presented.

A. Familiarization

In priority, the patient should be familiarized with the task before the determination of the thresholds. At the beginning of each new frequency, a pure tone test is presented to the patient with an infinite duration to raise a definite response. In the familiarization process, initially, an audible tone of 1000 Hz at 40 dB is delivered to the test subject. The hearing level of the tone is reduced by 20 dB steps until no response occurs then increased by steps of 10 dB until an answer is given. The tone is repeated at the same level, and the familiarization method is completed if the patient responses are consistent with the tone test presentation, if not it must be repeated again. After the second failure trial, the instruction must be repeated.

After using the familiarization procedure the tester could be sure that the hearing-impaired person understands and able to perform the response task.

For better understanding, the familiarization method is described in the following flowchart shown in figure 4.

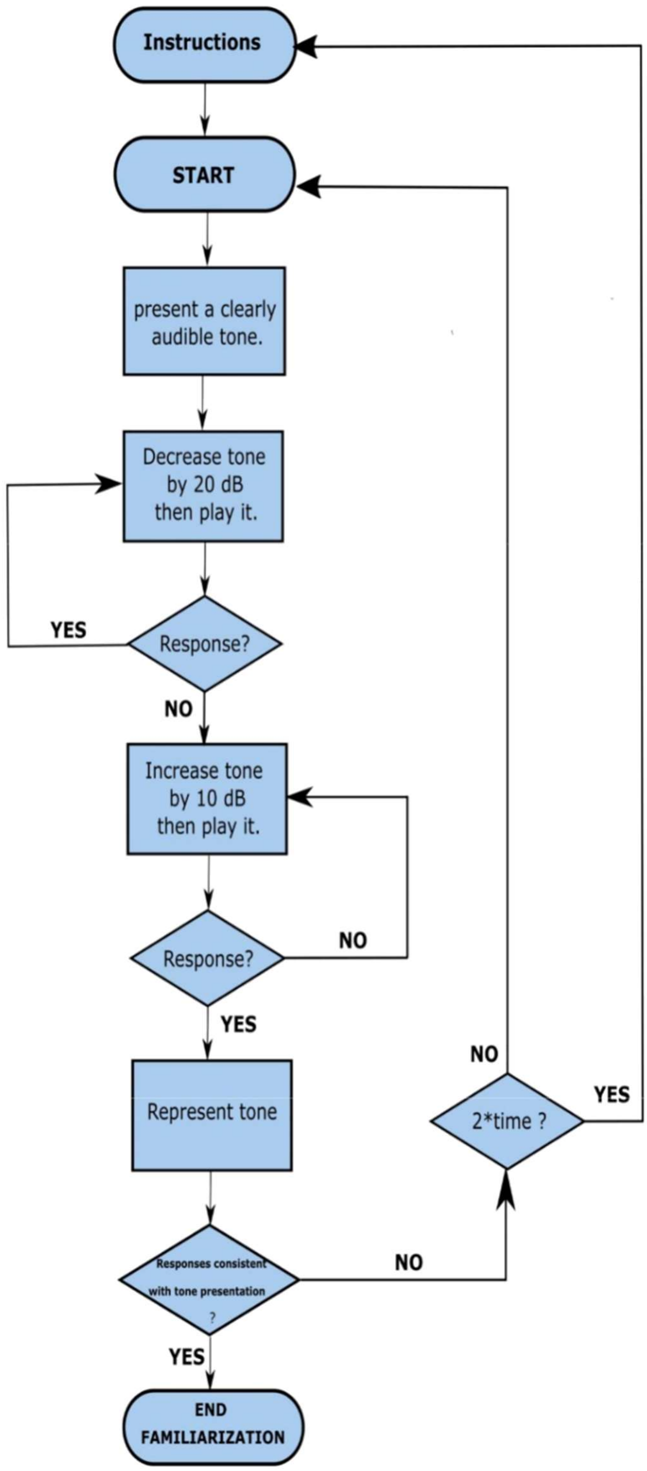

Fig.4. Flowchart of familiarization

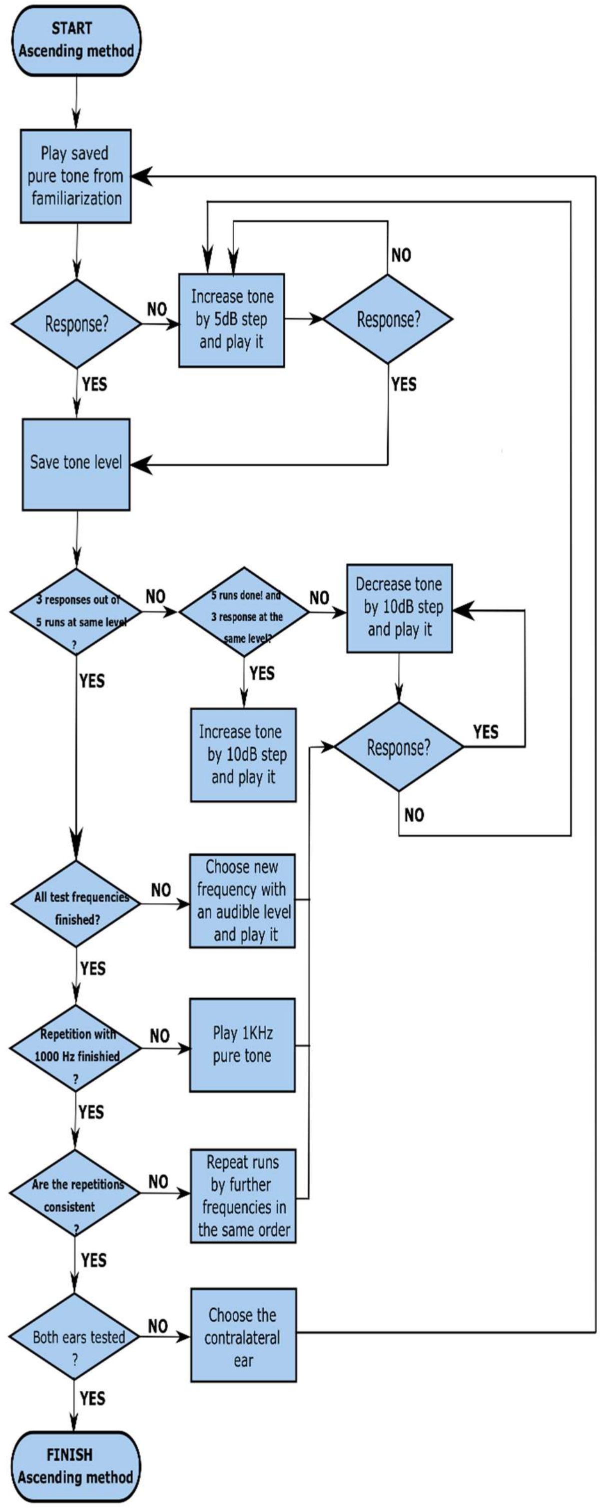

Fig.5.Flowchart of ascending method

B. Ascending method

It is a psychophysical method, which is used to predict hearing thresholds using a conventional audiometer. In the modified Hughson Westlake (HW) procedure shown in figure 5 used in this project, the hearing impairment person is asked to response by tapping the response left button's mouse when the test tone was heard. At the beginning, the saved tone level from the familiarization was played and then increased in 10-

dB steps until the test subject indicated that the signal is heard, then, the level tone is reduced by 10 dB until the test subject no longer answered.
At that point, the intensity of the signal is increased by 5 dB until the test subject answered. Thereafter, the signal is reduced again by 10 dB until the test subject no longer response and then augmented in 5 dB steps until a response is raised. In conclusion, the modified HW is a cycle, which decrease the tone level in 10 dB steps after response, then increase in 5-dB steps until response obtained. This cycle is repeated until two responses are raised at same test signal intensity that is considered as the test subject's threshold

IV. EXPERIMENT AND RESULTS

The implementation of the audiogram to evaluate the hearing loss was successfully implemented in the python environment with the help of computer, a raspberry Pi and headphones as shown in figure 6. The pure tone of different frequencies and intensities are generated by the sound card of raspberry Pi 3 B+. The generated sound is delivered to the headphones of the hearing impairment person. Based on response of the patient, the intensity and the frequency ranges may be increase or decrease. The response of the subject done by the left button mouse is recorded with the python program via raspberry Pi cart. The audiogram is plotted in the python, based on the response of the subject the results include the audiogram and raw data shown in figures 7 and 8 are stored in CSV files named with the time and date.

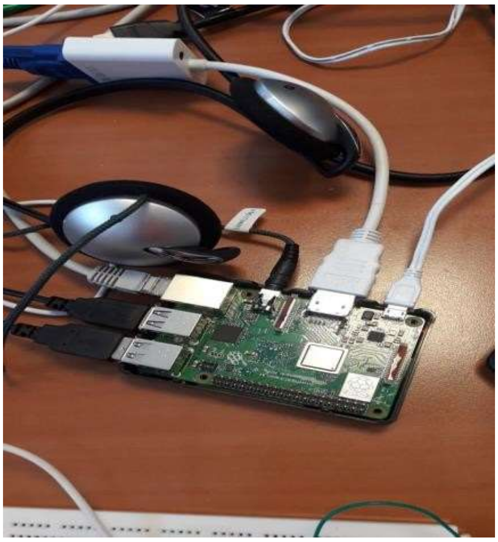

Fig.6. Hardware setup of proposed portable audiometer.

Before starting the audiometric test, hearing impairment person has to understand the following software essential instructions:

1. At the time of presenting a new frequency subject starts a pure tone with an unlimited duration to be familiarized with the presented frequency. The subject has to choose a clearly audible loudness with the arrow keys on the keyboard, when pressing the right arrow, the loudness get higher and the loudness get lower with the left arrow then confirm it by pressing the space key when you feel comfortable with.
2. Subject has to click the left mouse button to begin the hearing test at this frequency.
3. If the subject hears the presented tone, he must click the left mouse button and hold it on as long as the tone is audible for him. Then he releases the left mouse button and wait to receive the next tone presentation.
4. Finally, if the hearing impairment threshold is determinate at this frequency, the procedure starts again from 1. with a new frequency.

	A	B	C
1	Conduction	air	
2	Masking	off	
3	Level/dB	Frequency/Hz	Earside
4	25	1000	right
5	25	1500	right
6	25	2000	right
7	15	3000	right
8	5	4000	right
9	5	6000	right
10	5	8000	right
11	35	750	right
12	30	500	right
13	20	250	right
14	15	125	right
15	20	1000	left
16	15	1500	left
17	25	2000	left
18	10	3000	left
19	5	4000	left
20	5	6000	left
21	0	8000	left
22	25	750	left
23	25	500	left
24	25	250	left
25	5	125	left

Fig.7.The raw data of the hearing threshold in CSV file

From the results values of the hearing threshold stored in the CSV file, the audiogram contains the hearing threshold that is plotted for both right and left ears. The two X and Y-axis of the graph represent the frequency measured in Hertz and the sound intensity measured in decibels (dB) respectively.

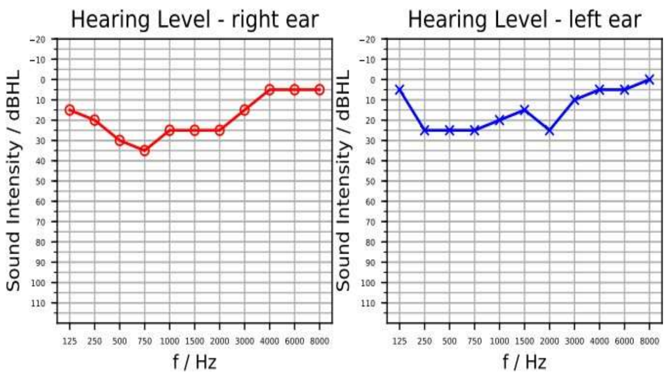

Fig.8. Audiograms of right and left ears

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V. Conclusion

The outcome of this project was the development of a portable audiometer used to diagnose independently and repeatedly hearing loss. The novelty and the strength of this portable tool is the application of information technology in the devices for audiology use. The use of the popular Python programming language makes the system accessible to non-experts and the simplicity of Python will facilitate the integration with other devices. The automated screening procedure implemented in python reduces the operating costs of the system and increases the portability of the hearing screening tool. In addition, the developed audiometer is a hearing self-assessment system and does not require expert to operate. Future developmental work may include implementing Active Noise Cancelling in the headphone to minimize the noise level so that, the hearing test could be performed under better working environment.

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