HEARING LOSS ASSESSMENT AND ANALYSIS OF HEARING IMPAIRED SUBJECTS USING A FACILE AUDIOMETRIC TECHNIQUE

S. Rajkumar[1], S. Muttan[2], V. Jaya[3] and S. S. Vignesh[3]
[1]Department of Electronics and Communication Engineering, Kings Engineering College, Chennai, India
[2]Department of Electronics and Communication Engineering, Anna University, Chennai, India
[3]Madras Medical College and Rajiv Gandhi Government Hospital, Chennai, India
E-Mail: srk1670@yahoo.com

ABSTRACT

The objective of the work is to design and develop an expert system embedded in a computer to assess the hearing loss of an individual, and also for the subsequent analysis of the audiometric test results. 256 subjects (176 male, 80 female) were tested with the proposed system, and also with the standard conventional audiometer for proof of validation, and the test results were analyzed. The sensitivity of the proposed audiometer is 93.8%, and its specificity is 82.2%, which proves that the proposed system has more sensitivity in determining the hearing loss. The proposed system was tested and it has a high positive predictive value of 92.2%, a Negative predictive value of 85.7% and an accuracy of 90.2%. The Pearson's correlation coefficient was calculated, between the value of the pure tone average obtained in both modalities ($R2 = 0.884$, $p < 0.001$); it proves an almost linear relation between them. The system was rated for its performance by the calculated values of accuracy, sensitivity, and other statistical parameters with the analysis of the test results. Because of its high sensitivity and simplicity, it can be used for mass screening to identify the level of hearing.

Keywords: audiometer, hearing impaired, audiogram, hearing loss, pure tone average.

1. INTRODUCTION

The World Health Organization (WHO) survey indicated that more than 4% of the world's population agonizes from hearing loss; of this, two-thirds are living in developing countries [1-3]. The studies with school children in south India, Nigeria, and Kenya indicated that, the prevalence of hearing impairment is more among children in developing countries and proper solutions have to be provided to them at the earliest to get productive benefits [4-7]. Continuous exposure to noise is one important reason that causes the deterioration in the hearing level. During our life time, all of us are always exposed to different kinds of noise. Noise induced hearing loss popularly known as NIHL is caused by the destruction of the hair cells in the inner ear. Because our outer and middle ear transmits frequencies near 4 kHz very efficiently, hair cells that are tuned to frequencies close to 4 kHz are particularly vulnerable to the damage caused by noise. During the course of our life, a progressive down fall in the value of the measured hearing threshold occurs, in all the frequency signals used in air conduction (AC) and bone conduction (BC). Aging is the next important cause of a hearing defect. In general, the deterioration in hearing capability starts as early as at the age of 20. If both are present in an individual's case, then the probability of hearing loss is more. Around one third of the hearing problems are due to hereditary factors. The easiest solution to overcome the hearing impairment is to wear a hearing aid. The hearing impaired patients are normally unaware of the deterioration in hearing level, and delay wearing hearing aids [8-10]. Predicting the hearing loss at an early stage will give better satisfaction among the hearing aid users, and further deterioration can also be avoided. Though the modern day's audiometers are suited for testing the hearing loss, they are specific and highly technical. They are also costly and may not be available in every clinic. But, because of the rapid increase in the hearing impairment percentage, and for hearing loss prevention, audiometric tests have necessarily to be done at home, in primary health centers, and also in workplaces, where the workers are exposed to high noise [11-15]. The potential advantages of computer-based audiometers is that they can be designed with automatic screening procedures for audiological investigations, and not require specialized training to perform the screening. Moreover, the use of computerized methods can make the recording of data and quality assurance monitoring of screening programme activities easier, as well as facilitate telemedical applications. Though some research is on in the field of designing computer based audiometers, they have some drawbacks. They are not exactly replicates of the conventional audiometer, not having storage capacity, not analyzing the test results, and their cost also a major concern. The present work considered all these factors before designing the proposed system, one suitable and which caters all to these needs of mankind [16-21].

2. MATERIAL AND METHODS

2.1. System operation

To start with, the pure tone audiogram test, which encompasses the air conduction test and bone conduction test, has to be conducted. The pure tone signals generated using Matlab for different octave frequencies, starting from 125 Hz to 8 kHz are shown in Figure-1 a-b are fed through the head phones connected to the system. The

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amplitude of the sine wave can be calculated using the ensuing formulae given in equation 1 and 2 were incorporated in the program. In the case of personal computer the sound card used has the impedance of 600Ω universally and hence for a load impedance of 600Ω, the reference voltage is 0.7746V. The value of dB ranges from -10 dB to 110 dB.

$$\text{A in dB} = 20 * \log\left[\frac{\text{Sinewave voltage (V)}}{\text{Reference voltage (Vo)}}\right] \text{--- (1)}$$

$$\text{RMS value of the Sinewave} = \text{Reference voltage} * 10^{A/20} - (2)$$

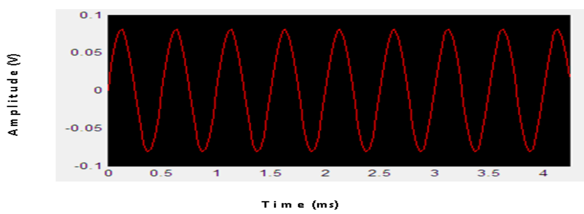

Figure-1(a). Pure tone test signal of 2000 Hz.

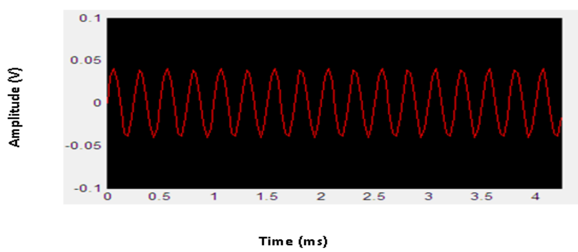

Figure-1(b). Pure tone test signal of 4000 Hz.
Figure-1(a-b). Result of pure test tone signals.

The ensuing steps have to be tailed in sequence to perform the air conduction test.

Step-1: Initially 1000 Hz signal at 40dB level is presented through the headphones to the subject. If it is perceived by the subject, then it has to be responded, by accepting the 'Yes' option.

Step-2: If the subject is not able to hear the tone, then he/she has to press the 'No" option. The magnitude of the test tone is raised in steps of 10 dB automatically, till it is heard.

Step-3: Once it is heard then signal level is decreased in steps of 10 dB till the patient does not hear the tone and accepts the 'No' option.

Step-4: Then the tone is again increased by 10 dB. If the patient hears the tone, then it is decreased by 5 dB. If the patient does not hear it, the tone is increased by 5dB. In this way, by several presentations of the test tone, the minimum hearing threshold is stored by accepting the 'Yes and Save' option.

Step-5: The same testing procedure is to be followed for the other testing frequencies and the minimum threshold of hearing for the respective octave frequencies have to be found out, and stored in the database for future reference and analysis. Finally, the 1 KHz tone is again presented and the threshold of hearing is found out, and compared with the result obtained earlier, such that the reliability of the pure tone test is verified. The procedure for the bone conduction test is similar to that done for the air conduction test, except that the presenting of the tone is through the bone vibrator instead of the headphone [22-26]. In the pure tone test with masking, the nontest ear is presented with a narrow band noise signal with the test frequency as the center frequency, so as to prevent the non test ear from participating in the test, for the subjects identified for this test [27-29]. The pure tone signal along with the masking noise signal is shown in Figure-2. The pure tone signal is represented in red color and the masking signal in blue color. In the case of the speech audiometric test, the standard test words stored in the database as word file as an example, the word "crash" shown in Figure 3 are fed to the subject through the head phones, and the patient is asked to repeat the same. Based on the number of words correctly identified, with the number of words totally presented, the percentage score, known as Speech Discrimination Score (SDS) will be calculated. The calculated SDS value has to reflect an almost similar interpretation done by the pure tone audiometric test [22, 30]. All the test results are stored in the data base, and analyzed for useful interpretation, and also for future reference.

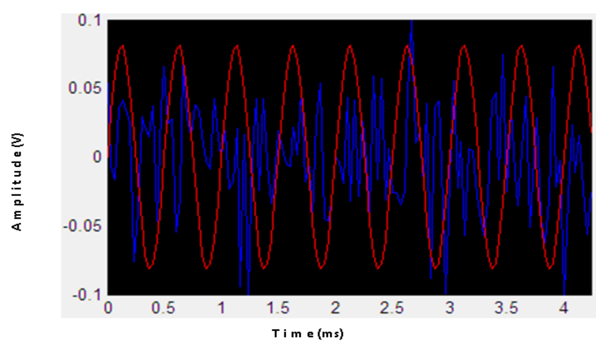

Figure-2. Result of air conduction test signal along with the masking signal.

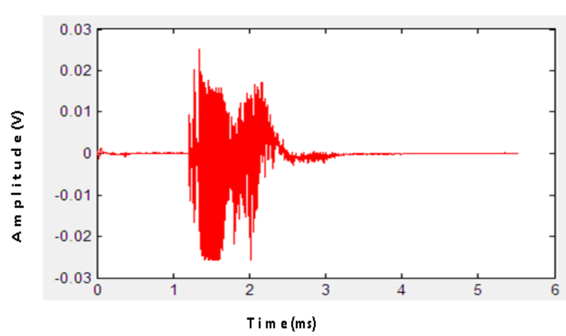

Figure-3. Result of a wave file of the word "CRASH".

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2.2. System calibration

The proposed auditory test system should be calibrated, before it is used for performing audiometric tests. Initially, a calibration test signal with a frequency of 1 kHz at 0 dB from a standard signal source is generated. Using the potentiometer inbuilt, the calibrator is programmed, so that the voltage value is stored. At first, the amplifier output is connected to a voltmeter, and an artificial ear and acoustic analyzer are coupled to the TDH-39 model headphones of the computer based audiometer. With the help of the analyzer, the acoustic pressure level measurements were done. The "Integrating-averaging Sound level meter" Type 2240 manufactured by M/s Bruel and Kjaer was used for the calibration purpose. The gain controller is adjusted, such that the acoustic pressure level at the head phone has to match audiometric zero. Now, the computer based audiometer plays back the tones generated in the system at the level of 0 dB, which will match the other test frequencies. The value that differs from the audiometric zero will be shown in the sound level meter of acoustic pressure, attached to the artificial ear. The deviations from the audiometric zero for all frequencies, apart from 1 kHz are compensated, and during the calibration process the same will be recorded in the computer. It will be used for automatic leveling of the computer based audiometer being used [31].

2.3. Testing sequence

The computer based audiometer was tested with 256 subjects; of these, 176 were male and 80 were female, in the age group of 19 to 74 years, in a period of 2 years and 10 months in multi speciality hospitals. The test results taken from subjects with both the conventional audiometer model 2001 Digital Clinical Diagnostic Audiometer from Arphi Electronics pvt Ltd., and with the computerized audiometer, are compared for validation under ideal testing conditions. The necessary condition for this comparison is that the tests done using both modalities of audiometer are to be conducted on the same day to get common testing circumstances in all aspects. The testing room should be not necessarily sound proof room and a room with the maximum noise level of 30 dBSPL may be considered for evaluation. The choice of type of audiometer between the conventional and computerized for testing the subject was randomly selected. Initially, the audiological investigations were conducted with the use of the computer based audiometer for few subjects, and later on they were tested with the conventional audiometer [2, 22]. Similarly, few subjects were tested alternatively so as to cross check the reliability of the test results.

3. RESULTS

The results of the conventional audiometer and the proposed computer based system have to be compared, for the reliability of the proposed system. A female subject was tested for her left ear using the conventional audiometer. Average of measured hearing threshold for the frequencies 500Hz, 1000Hz and 2000Hz called as the pure tone average (PTA) was 53.33, and it was clinically interpreted as a moderately severe conduction loss in the left ear. The same subject was tested with the computerized audiometer, and the results were compared with those of the conventional audiometer, as shown in Figure-4. The results of the computerized audiometer are marked in thick green color, whereas the conventional audiometer readings are marked in thin blue color. The pure tone average arrived at using the computerized audiometer is 51.66, which reflects the same interpretation done with the conventional audiometer results. The tests were carried out with both types of audiometers for a male patient, who had mild hearing loss, and the comparison of the audiograms was done [32], as shown in Figure-5. The pure tone average was 35 in the case of the computerized audiometer as against 36.66 with the conventional audiometer. The interpretations of the computerized audiometer and the conventional audiometer were almost the same, except for a tolerable variation in the value of the pure tone average. The subjects were also tested with the speech audiometric test, using the computerized audiometer. The SDS score of 78 for the subject with a moderately severe loss, and 92 for the subject with mild hearing loss had been arrived at. It was validated and also cross checked with the results of the pure tone audiometer test conducted with the computer based audiometer. The test results of the pure tone and speech audiometric tests have to reflect an almost similar interpretation. Otherwise, both these tests should be conducted once again, to suggest a better solution to the subject.

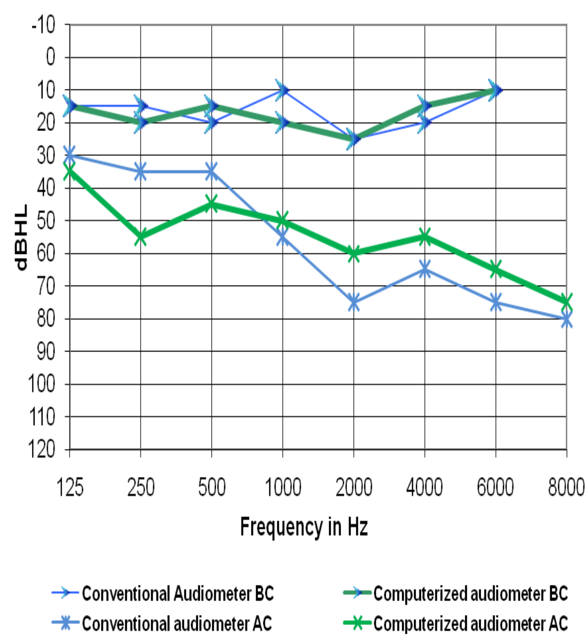

Figure-4. Comparison of the audiograms of a patient with conduction loss.

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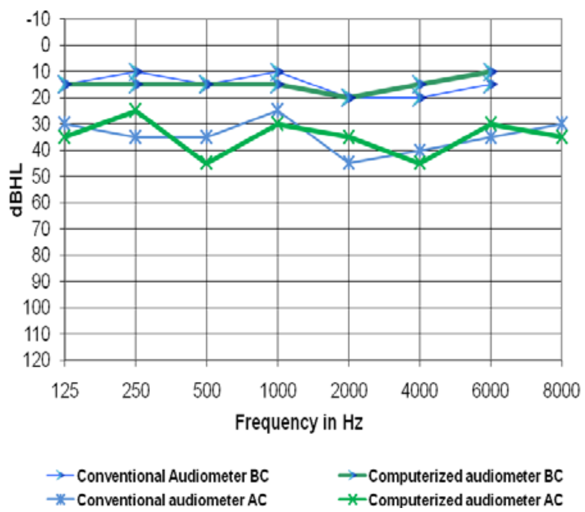

Figure-5. Comparison of the audiograms of a patient with mild hearing loss.

4. DISCUSSIONS

All the 256 subjects were tested with both modalities, and the test results obtained in both modalities were cross checked for validation. Of the tested subjects, 84 were found to be normal (59 male and 25 female) and 172 were found to have hearing loss (117 male and 55 female). The subjects' classification of the age ranges and hearing level is shown in table 1.As the age increases the percentage of the normal patients reduces drastically. Similarly, the percentage of abnormal cases is less compared to the normal cases in lower age ranges.

Table-1. Subjects' classification of the age and hearing condition.

Age range (Years)	Normal (n)	Abnormal (n)	Total (n)
20 - 29	36	13	49
30 - 39	24	6	30
40 - 49	19	49	68
50 - 59	5	36	41
60 - 69	0	40	40
70 - 85	0	28	28
	84	**172**	**256**

n indicates the number of subjects in each sub-group

The classification of subjects based on the hearing loss condition, and the comparison of the test results taken with both modalities, are given in Table-2. The average age of the normal subjects is 33.17, and the standard deviation (SD) value was 9.74. For abnormal subjects the average age was 54.63, and the SD value was 14.20. The test results reveal that the majority of the abnormal subjects were aged, and the loss was due to prolonged noise exposure. The Pure Tone Average (PTA) calculated using the test results, taken with the conventional audiometer and computerized audiometer, was used to classify the subject as normal and abnormal. The average PTA value for the normal subject was 16.50 and the SD value was 5.46, whereas for the abnormal subjects the average PTA was 52.69, and the SD value was 17.88, when they were tested with the conventional audiometer. In the case of the computer based audiometer the values for normal subjects are 17.96 and 6.59 and for abnormal subjects 54.95 and 19.18 respectively. In this aspect also the proposed system was validated with the comparative values of the conventional audiometer. The sensitivity and specificity of the proposed system were calculated as 93.8% and 82.2% respectively. The positive predict value, i.e., the capability of the system to identify the diseased condition correctly, was 92.2%. The negative predictive value, i.e., the capability of the proposed system to identify the normal condition correctly, was 85.7%. The accuracy of the proposed audiometer was calculated, and found to be 90.2%.

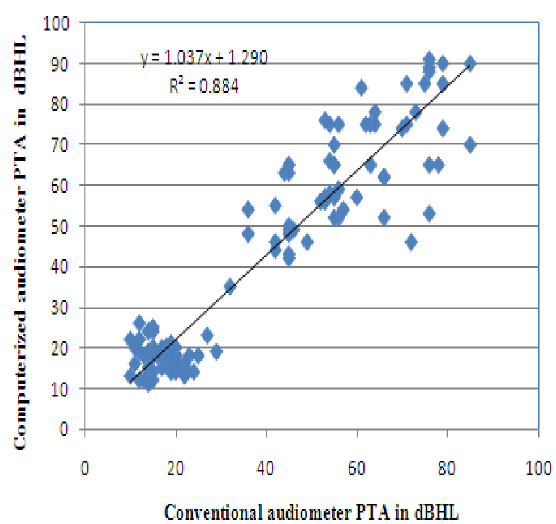

Figure-6. Scatter plot showing the comparison of PTA value obtained with computer based audiometer and conventional audiometer.

The computerized audiometer has more sensitivity, so that it can be used to find the hearing loss at the earliest. The results of the computer based audiometer were also validated by plotting a scatter plot, using the PTA values taken with both modalities, as shown in Figure-6. The figure clearly shows the linearity of the test results with those of the conventional audiometer. The Pearson's correlation coefficient was calculated for analyzing the performance of the computerized audiometer. The correlation coefficient calculated was 0.884; it indicated that the proposed system results were almost similar to those obtained using the conventional audiometer

5. CONCLUSIONS

The designed computer based audiometer has the potential to be widely accepted for the early detection of the hearing loss of an individual, before much deterioration occurs in the hearing level because of its simplicity and accuracy. The proposed system was validated with subjects of different sex, age groups, type of hearing loss and subjects living in different conditions. The proposed system has more sensitivity (93.8), a reasonable value of specificity (82.2), and high accuracy of 90.2%. The correlation of the test results, taken with the system and with the standard audiometer was also done and which revealed that an almost linear relation between them. The Pearson's correlation coefficient calculated was high and hence, this system can be efficiently used to predict the hearing loss of an individual with ease, and at the earliest. It can be used as the testing system in the area or institute where noise is the important factor affecting the hearing level. Audiologists find this as a very much useful tool for the early identification of hearing loss, and also it has the other potential advantages in terms of the storage and retrieval of significant clinical data, in a real time database management. The database available in the MS Access is extremely useful in analyzing and improving the formula to calculate the Real Ear Insertion Gain (REIG), required for different bands of frequencies in the digital hearing aid.

Table-2. Analysis of the tested subjects and the t-test results.

Considered factor	**Male** (n = 176)			**Female** (n = 80)		
	Normal (n = 59)	**Abnormal** (n = 117)	**p value**	**Normal** (n = 25)	**Abnormal** (n = 55)	**p value**
Age (Years)	27.3 ± 6.2	46.2 ± 14.4	< 0.000	27.2 ± 6.0	44.8 ± 14.7	< 0.000
Conventional audiometer result (PTA in dBHL)	16.8 ± 6.1	53.3 ± 18.3	< 0.000	15.8 ± 3.4	51.3 ± 17.1	< 0.000
Computerized audiometer result (PTA in dBHL)	17.9 ± 7.5	55.1 ± 19.4	< 0.000	18.2 ± 3.9	54.7 ± 19.0	< 0.000

n indicates the number of subjects in each sub-group

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