ABSTRACT

The precious gifts of nature to mankind are our eyes and ears, which are used for the purpose of perceiving and transmitting most of the worldly matters to the human brain. In the present scenario, with the increasingly polluted environment, especially noise pollution, ears are susceptible to a decrease in the hearing level. To overcome the hearing difficulties, wearing a hearing aid is preferred normally, because it is a noninvasive and safe procedure. However, hearing aid users are not fully satisfied at times as a result of the uniform increase in the hearing level without considering the other actual technical parameters of the hearing aid and the feedback from the users. The satisfaction level of the hearing aid users will be increased further by adopting better strategies and techniques.

In the present state of advancement of technology, if the gradation of deafness is measured accurately, and the hearing aid is programmed accordingly, the probability of improving the satisfaction level of the hearing aid users will be high. The present research work focuses on these two issues and attempts to provide solutions in this respect. To provide satisfactory solutions to the hearing impaired subjects, it is highly essential, to arrive at the degree of hearing loss at the earliest before much deterioration happens. Presently, audiological investigations are performed only in specialty hospitals with the use of a specialized instrument, i.e. an audiometer. But it is difficult for all of them to undergo this process due to many reasons. Hence, an easily accessible computer based audiometer is required to solve this problem. Though some useful researches were done in the field of designing computerized audiometers, they were either not exact replicate of the conventional audiometer or not having storage capacity and not capable of analyzing the test results. The present work considered all these factors and
designed, developed and validated a computerized audiometer, which could
perform the audiological investigations using a computer. The validation of
the developed computerized audiometer was done by performing audiological
tests on 256 subjects (176 males, 80 females), and also, with the standard
conventional audiometer at the Madras Medical college, Chennai. The
validation processes were made with the analysis of the test results and
calculated values of accuracy, sensitivity, and other statistical parameters. The
sensitivity of the developed audiometer is 93%, and its specificity is 86%.
The proposed system has a high positive predictive value of 92.4%,
a negative predictive value of 85.7% and an accuracy of 90.2%. The
important parameter of the pure tone audiometric test used to assess the
hearing loss is the Pure Tone Average (PTA) value, which is an average of
the minimum threshold of hearing measured at 500 Hz, 1000 Hz, and
2000 Hz. The Pearson’s correlation coefficient obtained between the
calculated PTA values of the tested subjects with the use of the conventional
and the developed computerized audiometer is ($R^2 = 0.884, p < 0.001$); it
proves an almost linear relation between them. Because of its high sensitivity,
correlation and simplicity, it can be used for mass screening to identify the
level of hearing easily and effectively.

After identifying the hearing loss level exactly before much
deterioration happens, it is highly essential to identify the most appropriate
hearing aid and program it with suitable gain values for the different
frequency bands. Hearing aid is programmed by connecting it with hearing
aid programmer. Based on the test results, the gain suggestions for hearing
aids are recommended with the use of any one of the existing prescriptive
procedures. Prescriptive procedures are set of protocols developed to predict
the gain values of the hearing aid. Various prescriptive procedures have been
developed so far for calculating the Real Ear Insertion Gain (REIG) values for
different frequency bands of a digital hearing aid. But the problem for the
audiologists lies in selecting an appropriate procedure and to modify the gain values, if the subject is not satisfied. In this work, before developing independent solutions, the success of the gain suggestions of various linear and nonlinear prescriptive procedures was analyzed, in order to select a better procedure for a specific type of impairment. The important prescriptive procedures used in the current study for suggesting the gain values include NAL-R, NAL-RP, POGO II, DSL I/O, FIG6, IHAFF, NAL-NL1 and NAL-NL2. These procedures are based either on the aspect of loudness equalization or to improve speech intelligibility. The success rate of the prescriptive procedures is based on the satisfaction level of the hearing impaired subjects, and it was concluded with the calculated value of the Speech Discrimination Score (SDS). SDS is the vital parameter calculated using a speech audiometric test, and is the ratio of correctly identified words with that of total words presented to them, and it directly indicates the speech intelligibility.

Based on the results, especially, the SDS value and feedback received from the 159 hearing impaired subjects, it has been found that the hearing aid gain values suggestions made by the procedures based on speech intelligibility produced better satisfaction. The subjects who visited the hospital found it difficult to understand the test words in English, and in turn, a lower SDS value was obtained when compared to the SDS value arrived at while using the test words in their mother tongue. Tamil is the mother tongue for most of the subjects who partook in the present study. Hence, Tamil words as recommended by the Indian Speech Hearing Association (ISHA) were used for the speech audiometric test instead of the conventional English test words. The comparative frequency spectrum analysis of the each of the test words in Tamil was performed to ascertain them as equivalent to the English test words used by the international standards. In the case of the subjects not satisfied with the gain values suggested by any of the existing prescriptive procedures...
procedures and for the subjects who required a better satisfaction level, the gain values were carefully adjusted by the expert audiologists based on the feedback obtained from the subjects through a questionnaire.

The core objective of the work is to design and develop an adaptive expert system, which could be effectively used to perform audiometric tests to identify the exact level of hearing impairment, and to recommend suitable gain suggestions for the frequency bands of a digital hearing aid on a single platform for providing the most satisfactory performance. The evaluation of the proposed expert system was done over the period of two years involving 368 subjects. Among the tested subjects, for 256 who were identified as having hearing loss, appropriate hearing aid were fitted and successful gain suggestions were made to them either by the existing procedure or by the audiologists, by analyzing their hearing loss level in different frequencies or by the expert system designed and developed in the present work. The suggested successful gain values were stored in the database.

The database of the successful gain recommendations appended by the audiologists sequentially was explored in the present work for better deployment of the digital hearing aids. Initially, the expert system used the database of the successful gain suggestions made by the NAL prescriptive procedures, and later on, the gain alterations made by the audiologists considering the feedback obtained through a questionnaire were also included. The database which gave better results by way of enhanced satisfaction among the hearing aid users was used by the expert system. Initially, the gain values were predicted by the expert system using the correlation algorithm. The gain values were suggested for the new subject based on the data of the most correlated subject in the database. In the subsequent period, the expert system used the neural network algorithm for the prediction of gain values. The neural network incorporated in the expert system was trained with the input parameters; minimum threshold of hearing
at a particular frequency, SDS value obtained without the use of hearing aid, and successful gain suggestions of the 159 subjects as the target data. The PTA value played a critical role in the enhancement of speech intelligibility. The performance of the developed expert system was analyzed and validated by comparing the gain suggestions and SDS value obtained with the use of NAL setting, audiologist alteration and the expert system. The percentage of subjects obtaining a maximum level of satisfaction was high for those having a lower PTA value. The successful gain suggestions made using the correlation algorithm were compared with the gain predictions of the various neural network algorithms. The feed forward back propagation algorithm which produced less mean differential error value and training time is used in the expert system. With the gain suggestions predicted by the expert system, 240 hearing impaired subjects out of 256 subjects, the satisfaction level was enhanced.

The strategy, standards, and algorithm discussed were used in the design and development of the expert system, to predict appropriate gain values in order to satisfy the hearing impaired subjects. The developed expert system could be adopted for any of the languages, provided the test words for the speech audiometric test are to be chosen according to the international standards. The procedure designed and developed in the present work would be able to benefit people of different languages and varieties of dialects.