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Software intelligent system for effective solutions for hearing impaired subjects

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ABSTRACT

Purpose: The anatomy and physiology of the ear is complex in nature, which makes it a challenge for audiologists to prescribe solutions for varied hearing-impaired subjects. There is a need to increase the satisfaction level of hearing-aid users by adopting better strategies that involve modern technological advancements.

Aim: To design and develop a decision support Software Intelligent System (SIS) that performs audiological investigations to assess the degree of hearing loss and to suggest appropriate hearing-aid gain values.

Methods: SIS is developed based on the study conducted in the Government General Hospital, Chennai, India, between 2013 and 2015. In the study period, audiological investigations were performed on 368 subjects, using the clinical audiometer (Inventis-Piano, Italy) and the SIS. Gain suggestions were recommended for hearing-aid users (Siemens Intuis life & Intuis-SP) using standard prescriptive procedures, alterations made by the audiologists, and by the SIS. It was developed with artificial neural network-based gain predictions.

Results: Of the tested subjects, 256 were identified as hearing-impaired. The calculated sensitivity, specificity and accuracy of the computerised audiometer incorporated in the SIS are 93%, 85% and 90% respectively. Furthermore, 86% of the hearing-impaired subjects were satisfied during their first hearing-aid trial with the gain recommendations from SIS.

Conclusion: The findings suggest that the proposed SIS could be used to perform audiological screening tests and to recommend appropriate hearing-aid gain values to the hearing-impaired subjects. This could eventually be helpful for audiologists in the areas where routine mass audiological screening and fast hearing-aid solution is required.

1. Introduction

The hearing impairment percentage is continuously increasing in the modern world, mainly because of noise, age, and environmental factors. The identification of hearing impairment is often difficult in many cases. It affects the social, psychological, vocational, and educational skills of an individual [1]. Rehabilitation of hearing impairment is necessary at the earliest. The level of hearing loss is measured by performing audiological investigations (e.g. pure tone and speech audiometry tests) using conventional audiometers [2–6]. Presently, computer-based audiometers are

Abbreviations: AC, air conduction; AGC, automatic gain control; ANN, artificial neural network; ANSI, American National Standards Institute; ASHA, American Speech-Language Hearing Association; BTE, behind the ear; DSL I/O, desired sensation level input/output; HL, hearing level; ISHA, Indian Speech Hearing Association; MDE, mean differential error; NAL- NL1, National Acoustics Laboratory - Non-linear 1; NAL- NL2, National Acoustics Laboratory - Non-linear 2; PB, phonetically balanced; PTA, pure tone average; RMS, root mean square; RSS, required signal strength; SDS, speech discrimination score; SDT, speech discrimination threshold; SIS, software intelligent system; SPL, sound pressure level; SRT, speech reception threshold.

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developed and are capable of performing mass screening to identify hearing loss, as they have many advantages like storage, retrieval of audiogram data, etc. [7,8]. Constraints of the developed computer-based audiometers are that either they do not analyse the test results or do not exactly replicate conventional audiometric procedures [9–11]. The ipad-based play audiometer proposed by Yeung et al. is intended for children, based on picture identifying tasks [12]. The audiometer proposed by Convery et al. uses only specific test frequencies for audiological investigations; the tones are stored and played back, and not generated [13]. The significance of the computer in the development of expert systems to gain an expert's review of electronic health records, forecasting the possibility of epidemic disease and evaluation of gastro-intestinal symptoms, has been emphasised [14–16].

Here, a computerised audiometer is developed in order to provide better usage and solutions; it is incorporated into an expert system. Based on the results of the audiological investigations, if the audiologist infers that the subject will gain better speech perception with the use of hearing-aids, he/she needs to undergo hearing-aid trials. The objective of the hearing-aid is to process the perceived speech, so as to hear optimal sounds with speech clarity in different environmental conditions. The hearing-aid is able to help hearing-impaired subjects as it is a safe and non-invasive procedure. The prescriptive procedures are a set of protocols developed by different research groups in order to suggest the gain values for different frequency bands of the hearing-aid. In the current scenario, more time is spent by the audiologists in selecting an appropriate prescriptive procedure to provide better gain values and for subsequent modifications of it, to provide better satisfaction to the hearing-impaired subjects. The satisfaction level among hearing-aid users across the globe is low. The speech perception of the hearing-impaired subjects with a higher degree of hearing loss is poor; hence, the hearing-aid is to be fine-tuned to increase the satisfaction level among them [17,18]. To fix suitable gain values and for fine tuning, the hearing-aid is to be connected to a specialised piece of hardware called a hearing-aid programmer. It is incorporated with the algorithms of different existing prescriptive procedures. Audiologists need to select the best prescriptive procedure to provide satisfactory solutions to the subject. Frequently, the audiologist finds it difficult to select a particular prescriptive procedure. Even after selecting a particular procedure, arriving at the changes in the gain values is required. The electro-acoustical characteristics of the hearing-aid and the gain suggestions prescribed to the patients with different levels of hearing were analysed in detail to develop the proposed system [19–22]. Keidser et al. discussed the variation in the preferred gain for experienced users [23]. Dillon et al. and Keidser et al. explained the procedures involved in the development of NAL-NL1 and NAL-NL2 prescriptive procedures [24–26]. Keidser et al. explained the empirical measurements made in the development of NAL-NL2 procedures [27]. The effectiveness of the developed prescriptive procedures is validated by a comparison with other procedures [28–30]. Ching et al. made an effective comparative analysis of the gain suggestions using NAL prescriptive procedures with DSL procedures [31,32]. Although different prescriptive procedures are used in practice, the procedures based on the enhancement of speech intelligibility developed by the National Acoustics Laboratory (NAL) such as NAL-NL1 and NAL-NL2 were considered as benchmarks in the proposed system, because of their success rate in giving satisfactory solutions to hearing-impaired subjects. Existing conventional and computer-based audiometers are connected to the hearing-aid programmer, and they require an expert audiologist to adjust the gain values. In the proposed SIS, the results of the audiometer are transferred to the gain suggestion program to recommend hearing-aid gain values. Hence, the aim of this study was to develop an intelligent decision support software system: (i) to assess the degree of hearing loss, and (ii) to predict and suggest appropriate hearing-aid gain values for hearing-impaired subjects.

2. Materials and methods

2.1. Study population

Periodic screening camps for audiological investigations were conducted between February 2013 and February 2015 at the Madras Medical College and Hospital, Chennai, India. The study protocol was approved by the Institutional ethical committee (certificate no.: 27072010). A total of 368 subjects (126 females and 242 males) participated in the camp. The subjects were given a voluntary written consent form and asked to fill in a questionnaire that contained information about the demographic details and basic hearing-related problems. Audiometric tests (viz. pure tone audiometric test and speech audiometric test) were performed, in order to measure the degree of hearing loss and integrity of the auditory system. All the subjects underwent audiological investigations using a 'Piano clinical conventional audiometer' (by Inventis in Italy), and also with the developed computerised audiometer inbuilt in the SIS. Hearing loss classification was performed based on the guidelines formulated by the American Speech-Language Hearing Association (ASHA) [33] here. Based on the test results of the conventional audiometer (The Pure Tone Average (PTA) value: an average of the measured minimum threshold of hearing levels at the frequencies 500 Hz, 1000 Hz and 2000 Hz [2,4]), the study subjects were classified into a normal hearing group (PTA<25 dB) and hearing-impaired group, as detailed in Table 1.

2.2. Development of the proposed SIS

The framework of the hearing-aid suggestion system with the conventional work flow and with the proposed SIS is outlined in Fig. 1. The framework consists of two stages: (i) conduction of audiometric tests in order to detect the degree of hearing loss; and (ii) suggestion of appropriate gain values for the hearing-aid. In the existing setup for hearing-aid gain suggestion, the measurement of the speech discrimination score (SDS), which is the ratio of the percentage of correctly identified words to the total words presented, was the vital factor in the assessment of the speech intelligibility of the impaired subjects. In this procedure, the impaired subjects are advised to use hearing-aids; the hearing-aid trials are performed by fixing the hearing-aid (with the gain values suggested by any one of the existing standard prescriptive procedures selected by the audiologist). The audiologist iteratively adjusts the gain values by conducting the speech audiometric test until the impaired subject obtains a satisfactory result. Then, the final gain values are programmed into the hearing-aid and fitted to the impaired subjects. In the proposed setup for the hearing-aid gain suggestions, unlike the conventional procedure, the system calculates the required gain values automatically with the aid of the artificial intelligence technique. The developed SIS reduces the efforts of the audiologist and the procedural timings significantly.

Digital, programmable, and behind-the-ear (BTE) instruments (Intuis-Life and Intuis-SP-DIR, Siemens, USA) with amplification control in four channels and built-in automatic gain control (AGC) circuit were used. The hearing-aids were programmed with the help of the hearing-aid programmer model Hi-pro. The Fonix FP-35 hearing-aid analyser was used to measure the gain values of the hearing-aids with the testing standard ANSI S3.22 −2003 of the American National Standards Institute (ANSI) [33]. The HA-2 coupler that mimics the real ear was used in the gain measurements to connect the hearing-aid to the analyser. The real ear coupler difference was also considered.