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A DSP-BASED SOLUTION TO THE EARLY IDENTIFICATION OF HEARING IMPAIRMENT

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ABSTRACT

This paper describes the development of a low cost DSP solution for the early identification of hearing impairment. The desire is to develop a cost-effective, highly sensitive, and easily administered screening system for the evaluation of human hearing acuity.

The proposed system is called EARTEST. EARTEST is basically a DSP-based screening audiometer capable of performing pure tone air conduction testing.

INTRODUCTION

There is a clear need for the early identification of hearing impairment in infants and children. Studies have shown that reduced hearing acuity during infancy and early childhood interferes with the development of speech and language skills of the child, which if not immediately detected and if no appropriate intervention has been done, could cause adverse effects on the child's social, emotional, cognitive and academic development, as well as, on the person's vocational and economic potential [1] .

Although methods exist that allow universal screening of hearing-impaired infants [2], still it must be recognized that not all hearing impairments will be present and can be detected at birth. A significant number of them will develop hearing impairment during their early years. Such losses may be acquired as a result of medical conditions or of hereditary causes. Since new cases of hearing impairment can arise in early childhood, additional screening methods should be executed. As a practical matter, however, the cost of universal screening has been prohibitive, the biggest part of the problem being the huge expense that will be spent in operating a universal screening system. Another issue is the manageability of administering such testings at this large extent. For a universal screening procedure to be feasible, this should be fast, reliable and easily administered by trained individuals.

On these accounts, we proposed a system called EARTEST for the early detection of hearing impairment in children. The system is a DSP-based screening audiometer capable of performing pure tone air-conduction testing. Note that the system is intended only for screening children who exhibit difficulty of hearing. As such, the system could not provide accurate prognosis of the patient's hearing problems. However, results of the test provides sufficient information for the conducting specialist to recommend whether or not a patient needs to undergo a more thorough audiologic evaluation. An advantage of the system is that it interfaces to any IBM-compatible PC. A graphical user interface is provided that allows the user of the system to easily control the conduct of the audiologic examination. Moreover, a database system that handles records of patient audiograms is included in the system which allows important statistical data, e.g., mean level of hearing acuity pertaining to a certain locality or population, to be easily generated.

SYSTEM OVERVIEW

Pure tone audiometry is the standard measure of hearing acuity. A complete pure tone audiometry includes both air conduction and bone conduction testing. Air conduction testing evaluates the patient's sensitivity to pure tones via hearing from the auricle to the cochlea. Bone conduction testing, on the other hand, evaluates hearing acuity by direct stimulation of the cochlea through a bone oscillator placed on the patient's mastoid or forehead. Testing by both air conduction and bone conduction provides an indication of how much of a hearing loss is due to the transmission or conduction of sound and how much is due to inner ear or nerve damage [3].

Ideally, a screening audiometer should include both air conduction and bone conduction testings. However, cost constraints limit us to design the system for air conduction testing alone. Although air conduction testing by itself will not provide enough information to determine the patient's exact hearing condition, its test results will suffice for a specialist to note if a patient needs to be referred for a more thorough audiologic evaluation.

Air conduction testing involves the playing of pure tones at varying degrees of intensity levels on one of the patient's ear to determine his/her treshhold hearing level across selected frequencies in the audible sound spectrum. The generation of a pure tone is done digitally using a TMS320C10 digital signal processor. The algorithm used is the linear interpolation table-lookup method of sine wave generation.

Sometimes, it is necessary to introduce masking noise to the patient's non-test ear to prevent it from participating in the test of the other ear. This is necessary due to the occurrence of cross-over -- a condition in which sound introduced to the other ear may be perceived by the other ear since sound can travel from one side of the head to the other. Masking the patient's non-test ear is usually done when performing bone conduction testing. Nonetheless, this feature is included in the design of the EARTEST system. A pseudo-random bit sequence generator algorithm is assembled for the TMS320C10 processor to simulate the random noise source.

EARTEST has a software interface program, which runs on Windows 3.1 (see Figure 1), that controls the operation of the hardware. The hardware and software modules communicate through the PC's parallel port. Using this software, the person that conducts the examination will be able to change the frequency of the test tone, vary its intensity, and modify how the tone is played (i.e., continuous or interrupted play). It can also select whether masking is enabled on one ear and change where the test tone is played (i.e., right or left ear). It has a plotting function for displaying the patient audiograms on-screen, as well as, a database system that

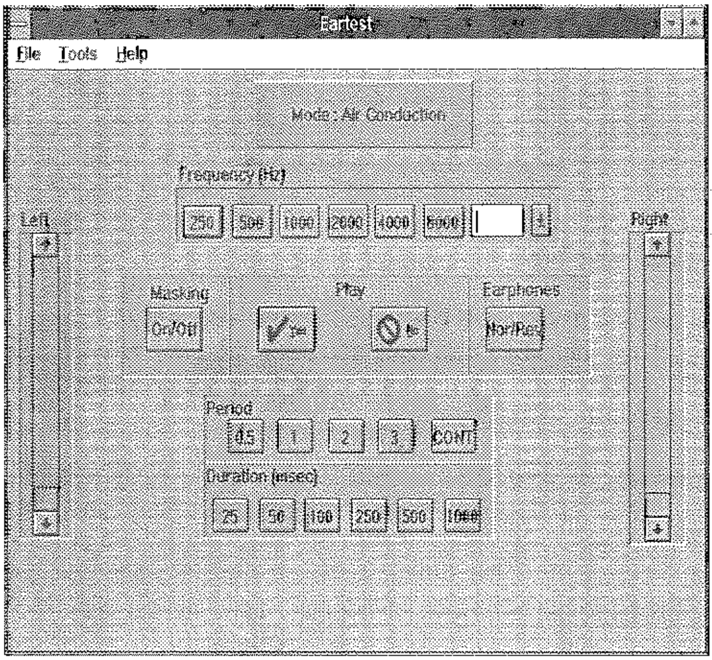

Figure1. EARTEST Graphical user interface

manages the collection and retrieval of patient audiogram records. A block diagram of the EARTEST system is shown in Figure 2:

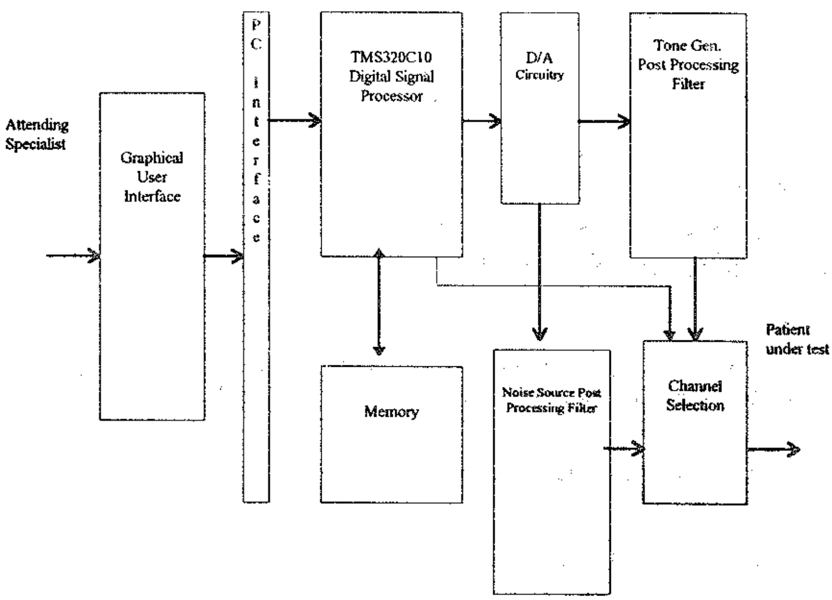

Figure 2. Block diagram of the EARTEST system

SINE WAVE GENERATION ALGORITHM

Pure tone used for testing is digitally generated using the TMS320C10 digital signal processor. The algorithm implemented to synthesize precise pure tones is the linear interpolation table-lookup method [4]. The implementation of the routine is based on a 256-point sine and slope tables. Each time this routine is called, the next sample point is evaluated and written to one of the selected digital-to-analog ports in the EARTEST board for conversion to the desired continuous waveform.

The values in the sine table are all scaled and represented in Q14 format. In Q14 format the decimal values, +1.0 and -1.0, are represented by the two's complement hexadecimal values 4000 and C000, respectively. All the other values are scaled and rounded to the nearest hexadecimal number to reduce signal distortion.

The linear interpolation method is an enhancement of the table-lookup method of sine wave generation. Just as in the table lookup algorithm, a sine wave is generated by successively accessing the sine table at a constant rate, wrapping around at the end of the table whenever 360 angle is exceeded. The table index is used as the angle parameter, denoted by ALPHA. ALPHA is regarded as having an integer and fractional part with the format:

Q	Q	Q	Q	Q	Q	Q	Q	.	Q	Q	Q	Q	Q	Q	Q	Q
15	14	13	12	11	10	9	8		7	6	5	4	3	2	1	0

DELTA denotes the step size for this routine and has the same format as ALPHA. Everytime this routine is called, the contents of DELTA is added to the contents of ALPHA. The integer pointer of ALPHA is the pointer to the sine table. Sample points falling between samples in the table are evaluated using the linear approximation formula given by:

$$\sin(360°(I + D)/N) \cong \sin(360° I/N) + D \times \{S[I+1] - S[I]\}$$
$$= S[I] + D \times \{S[I+1] - S[I]\}$$

where N is the sine table length,

I is an integer such that $0 \le I \le N-1$, and

D is a decimal number such that $0 \le D < 1.0$

The method of calculating the stepsize, DELTA, for a given sampling interval, t, and frequency can be obtained using the equation:

$$f = \frac{DELTA}{t \times N}[Hz]$$ where t is expressed in seconds.

At a sampling rate of 32768 Hz, the frequency resolution of the sine waveform generated is

$$\frac{1/512}{t \times 256} = \frac{32768}{131072} = 0.25 \text{ Hz}.$$

A flowchart of the table-lookup method of sine generation with linear interpolation is shown in Figure 3.

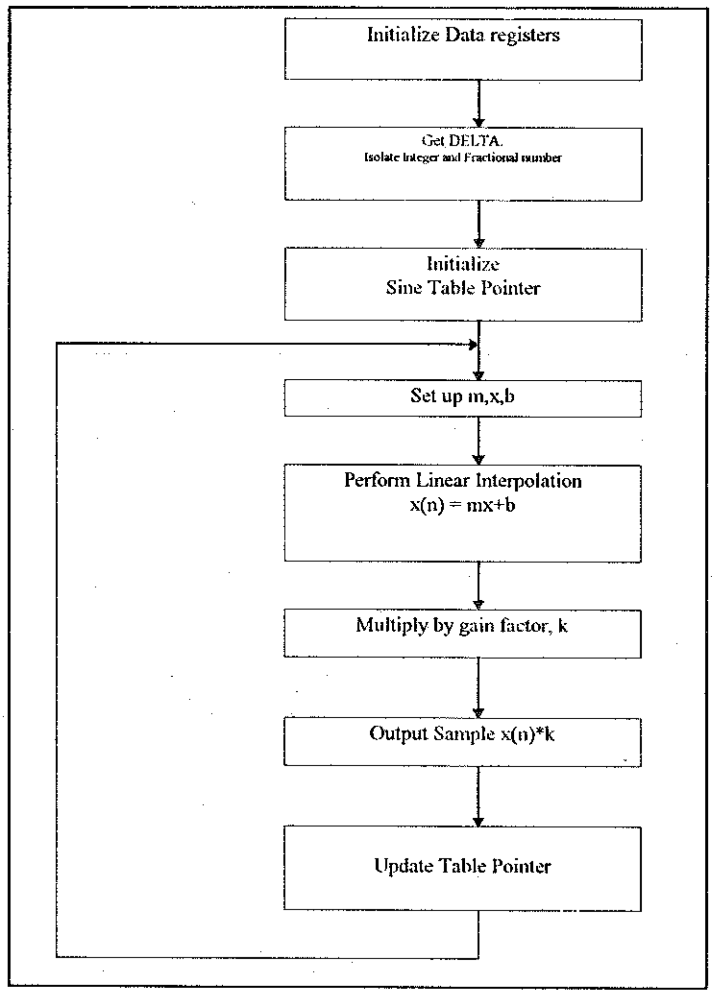

Figure 3. Flowchart of the table-lookup method of sinewave generation with linear interpolation.

NOISE GENERATION ALGORITHM

Masking noise is also digitally generated using the TMS320C10 processor. A pseudo-random bit sequence generator algorithm [5] is used to simulate the digital noise source which is then passed through a band limiter to obtain the desired analog noise waveform. The PRBS algorithm is described by the logic circuitry in Figure 4.

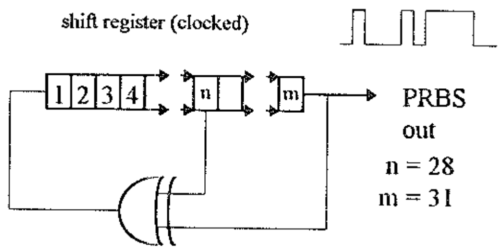

Figure 4. Pseudo-random bit sequence generator algorithm

The maximum length of the sequence that will be generated by a 31-bit register is $K = 2^{31} - 1$, i.e., the number of binary combinations of 31 bits minus the all zeros state. With the 31-bit register clocked at 500 Khz, the cycle time (time for the sequence to repeat itself) would be over 1 hour. The output spectrum generated by this filter consists of noise extending from the repeat frequency of the entire sequence, f_{clock}/K, up to the clock frequency and beyond. It is flat within 0.1dB up to 12% of the clock frequency, dropping rapidly beyond its -3dB point of $44\% f_{clock}$. Thus a low-pass filter with a high-frequency cut-off of 5%-10% of the clock frequency will convert the unfiltered shift register output to a bandlimited analog noise voltage.

DISCUSSION

The cost of performing a screening procedure has always been a very tasking and expensive endeavor because of the large number of testings that need to be executed. For a screening procedure to be feasible, it should be simple, low-cost, highly-sensitive and readily implementable. The EARTEST system we proposed for detecting hearing impairment seeks to satisfy these requirements.

The EARTEST system screens individuals who exhibit difficulty of hearing by testing for pure tone air conduction hearing. This procedure is the usual first step for identifying hearing impairments. It provides a profile of the patient's hearing acuity across the audible sound spectrum by eliciting feedback from the patients themselves. Hence, the data that are generated can be considered highly sensitive of the patient's hearing condition. Patient's response to this test are usually immediate. A complete audiogram can be performed in roughly three minutes which is ideal if you want the screening procedure to cover a large number of patients in a short time period.

The EARTEST system is easy to use and is readily implementable. Setting up the system takes only two steps -- 1) install the software interface program in the PC and 2) connect the accompanying hardware to the PC's parallel port. The layout of the software interface has been patterned after the front panel of a commercial audiometer [6] so that the audiologist that would be using the system could easily get familiarized with its operation. The GUI automatically performs system diagnostics so that if there are problems in the set-up, the user will be appropriately notified.

The EARTEST hardware component has been designed with cheap electronic IC's and a low-cost digital signal processor. This is done to lessen the cost of the system, without compromising the precision of the test tones generated by the system. It was designed to be as compact and as light as possible making it portable to bring to remote test sites.

The EARTEST system will be tested by a group of volunteer audiologists in one of the local schools in the country. The system shall be evaluated on the ease of its use, sensitivity of the system based on the number of misreferrals, and other points pertinent to the conduct of the screening procedure.

CONCLUSION

A low-cost DSP-based solution for detecting hearing impairment has been described. The system is called EARTEST and is primarily used in performing pure tone air conduction hearing tests. The system is presently being evaluated for its operability and feasibility as a screening procedure for detecting hearing impairment.

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