Implementation of a Portable Multi-channel Psychoacoustic System

Jianjun Li∗a) Non-member

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This letter presents a full-function design and implementation of a multi-channel audiometer with programmable devices. Audiologists perform a battery of tests to measure the psychoacoustic and auditory capabilities of a patient. However, there is an increasing need for developing a multi-channel psychoacoustic testing system to evaluate the spatial hearing abilities of hearing impaired subjects, and also to measure the perceptual benefits of directional hearing aids. The design combines programmable devices and software to obtain higher-quality and complete signals required for audiometric tests. Electro-acoustic measurements and perceptual evaluations of the proposed design show that the proposed system provides comparable performance as a commercial audiometer, with increased programmability, portability, and multi-channel testing capabilities.

Keywords: Audiometer, Distortion, USB, FPGA, Psychoacoustic

1. Introduction

As we know hearing is one of our five important senses (touch, smell, taste, sight and hearing). A reduction in hearing ability is called hearing loss or hearing impairment. Approximately 10% of the general population, 20% of those over 65 years of age and 40% of those over 75 years of age have significant hearing problem (1). Hearing loss must be accurately assessed prior to choosing a hearing aid; otherwise the wrong prescription may be selected. Current available audiometers are typically bulky and inflexible in that newer audiometric tests cannot be readily implemented. Another drawback is that they are limited in testing the auditory function using only two channels. This limitation does not allow for evaluating the spatial hearing capabilities of hearing impaired listeners i.e. the listener’s ability to respond to and process sounds coming from different directions simultaneously cannot be measured using the audiometer (2). Therefore, the objective of this letter is to develop a programmable, portable, easy-to-use, yet powerful and versatile hardware/software platform for multi-channel psychoacoustic testing.

The letter is organized as follows: section 2 discusses the system design. Section 3 addresses the electro-acoustic and perceptual validation of the proposed system and section 4 presents conclusions and summary.

2. System Design

2.1 Architecture

A combined PC + Universal Serial Bus (USB) + Field Programmable Gate Array (FPGA) model has been adapted for the proposed design. FPGA-based controllers offer advantages such as high speed, complex functionality, and low power consumption (3)-(5). This design philosophy allows the system to be programmable, portable, flexible, and powerful. The block diagram of the proposed multi-channel psychoacoustic test system is shown in Fig. 1. This system can be divided into four parts: a stand-alone Windows application combined with the USB driver; USB2.0 controller for communicating between host PC and FPGA; Programmable FPGA for pure tone and noise generator and distributing audio data into eight channels output; Digital-Analog-Converter, filters, attenuator and amplifier for outputting sounds.

2.2 Software Design

Software design is the main part of the system, which includes 3 parts: 1). Graphical User Interface (GUI) to transfer the audio data and user commands from the user application to the USB controller; 2). USB firmware to provide the user to access the USB controller; 3). Verilog code to control the system.

3. Experimental Results

The validation of the proposed system is undertaken to demonstrate the proof of concept and its performance. In particular, the electro acoustic performance of the system in terms of its frequency response and distortion is investigated.

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a) Correspondence to: Jianjun Li. E-mail: Jianjun.li@hdu.edu.cn

∗ Computer Engineering Faculty of Hangzhou Dianzi University Hangzhou, China

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In addition, perceptual measurement is performed with normal hearing listeners.

3.1 The Total Harmonic Distortion (THD) In order to measure the distortion and frequency response of the system, we define the Total Harmonic Distortion (THD) by the following formula:

\[
\%THD = \frac{\sqrt{H_2^2 + H_3^2 + \ldots + H_n^2}}{H_1} \tag{1}
\]

Where the terms \(H_1, \ldots, H_n\) are the power levels of the harmonic components and the term \(H_1\) is the power level of the fundamental. In general, the value of \(n\) is set equal to 3, as the power level of higher harmonics becomes insignificant.

3.2 Headphone Measurement In the proposed system, the PC houses the graphical user interface which provides the audio data for the headphone channels. The outputs of the proposed system are connected to a pair of earphones, which act as transducers that convert the electrical output of the system into acoustic signals. The earphones are typically placed in the listeners ears to measure their hearing sensitivity.

3.3 Multi-channel Measurement Multi-channel performance measurement is another important part of our system evaluation. In this section, multi-channel pure tone tests, pink noise tests and multi-channel speech tests and free-field acoustic measurement are conducted in a sound-treated chamber, where a microphone was positioned at the center of six surround speakers. The output of the microphone is connected to a microphone preamplifier and then on to an USB-based data acquisition system. Spectrum analyzer software residing on the laptop was used to acquire the microphone audio data and conduct the analysis.

3.4 Perceptual Test The hearing test described above was performed on ten young normal hearing subjects (25 ~ 35 years old). The subjects were tested for their hearing sensitivity for audiometric frequencies between 250 Hz to 8000 Hz. The perceptual measurement always started with 0 dB HL. If the subject cannot hear the pure tone, the dB HL was lowered to 20 dB HL, then to 10 dB HL, and to 0 dB HL. If the subject cannot hear the pure tone, the dB HL is increased by 2 dB and the process is repeated. The dB HL beyond which the subject cannot reliably hear the signal was noted on the subjects audiogram. Similar procedure was followed for other test frequencies, and for measurements using the audiometer. One of the results is showed in Fig. 2, which means that the values of sound loudness from both the audiometer and our system are within ±5 dB across the entire audiometric frequency range.

\[
t = \frac{\bar{x} - \mu_0}{s / \sqrt{n}} \tag{2}
\]

Paired sample t test between the audiograms from our system and the audiometer can be calculated by equation 2, \(\mu_0\) is mean, and \(s\) is the sample standard deviation and \(n\) is the sample size. The paired sample value revealed no significant differences across the subjects (\(t = 1.434; p = 0.185\) for subject 1, \(t = 2.135; p = 0.061\) for subject 2, \(t = 1.064; p = 0.315\) for subject 3 respectively).

4. Conclusion In this letter, a portable audiometer system designed using programmable devices was presented, which offers an audiologist more options for comprehensive evaluation of auditory function. To this extent, a multi-channel psychoacoustic testing system was successfully designed and evaluated in this paper. Software-based design brings flexibility with the system while programmable devices based design improves its accuracy and performance as shown in Table 1. The system was tested by simulations and evaluated by both objective and subjective experiments, demonstrating good stability and performance. The system modules are reusable and reconfigurable, which can be cooperated new algorithms and technology.

References