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DESIGN AND IMPLEMENTATION OF LOW-COST MEDICAL AUDITORY SYSTEM OF DISTORTION OTOACOUSTIC USING MICROCONTROLLER

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Abstract

New-borns hearing screening and diagnosis are very important for the early discover of any problem that might affect their hearing and consequently their communication. Babies may hear or respond to some sounds, but this is not enough indication that they can hear all the sounds properly. The early diagnosis of hearing efficiency and the functionality of the internal cochlea using Otoacoustic Emission is necessary. In this research, a new device of Distortion Otoacoustic system was designed and developed to be used as prototype instrument for technical college student training. The low-cost microcontroller developed device is efficient and sensitive as it is capable of generating and capturing signals from the external ear canal, as well as analysing signals and determining the efficiency of the inner ear. The proposed algorithm for the microcontroller based on generating two sinusoidal waves with different frequencies that transferred by MP3 shield cable. Analog to Digital Convertor (ADC) will be responsible of the control operation for all the system parts. The input signals are generated by Pulse Width Modulator technology (PWM), and the number of samples are n =28 or n = 256, with frequencies range value 0.5-8 kHz which is the human auditory range that a person can hear.

Keywords: Distortion otoacoustic, Hearing screening, Low cost; Medical auditory system, Microcontroller.

1.Introduction

Hospitals in many under-developing countries are lacking in equipment and funds. Some devices and equipment are given less priority such as the new-borns hearing screening due to a large number of patient and limited resources. An efficient low-cost device will make them available in every hospital, medical centres, or even cheap enough to be available for families at home [1]. This will save the government and people money, effort and time instead of doing the test at certain hospitals only. The early diagnosis of the hearing problem will lead to early treatment that may save the children haring and communication [2].

Hearing loss is one of the most common diseases among new-borns. Detection in time is very important operation, to prevent the nervous system and avoid serious problems like difficulty speaking, language and cognitive development. The common and recommended procedures for early detection are based on acoustic emissions (OAE) and / or an auditory brainstem response (ABR).

This work aims to design a low-cost system using embedded system, low-cost open sources programs such as microcontroller unit and design graphic users' interface and present or save the signals in personal computer [3]. The signal then will be processed using FFT to analyse the different signal frequencies.

2. Materials and Methods

The system saves the signals in the data base. The signals will be analysed and detect the specified spectrums with noise cancelation to enhance the SNR (Signal to Noise Ratio). This will give fast results with high accuracy and low cost [4].

This study consists of three main scenarios:

- Storing of signals in the database and the analysis step will be later. The advantages of the design are; allowing for collecting data from a large number of samples; it is mobile and flexible that can be used in remote areas where computers are not available [5].
- Real time results present on the LCD screen. This can be done by analysing the data by (FFT) inside the (MCU) and writing algorithms to filter and give the results directly on the LCD screen or can be printed.
- Data collection only for post analysis. In this method, the Microcontroller will be used as data acquisition (Data Acquisition). In this case, it is only transferring the data via USB port in the (MCU) to the personal computer, or the mobile phone, and designing a graphic user interface (GUI) to Store, analyse, detect, process noise, and plot graphs [6].

3. How it works

The system generates different sound wave frequencies (sine waves) that can be tuned based on international standards by the Microcontroller. The signal will be sent into the human ear to stimulate the cochlea. The signals generated inside the ear will be captured by the sound sensor and transferred to the (MCU) to be analysed, filtered and processed [7]. LCD screen, a personal computer screen or the mobile phone can be used via the user interfaces to display the results that help to instantaneously diagnose any abnormal conditions in the ear. This can give the result for all age groups at a very low cost [8].

4. Medical Examination of the Cochlea

There are two methods for examining the human ear using acoustic devices; Transient Evoked Otoacoustic Emissions (TEOAE) and Distortion Product Otoacoustic Emissions (DPOAE) method, which are explained as following:

- TEOAE: Sound signals are generated at different frequencies, and pulses according to international standards, to stimulate the cochlea which will generate a sound signal which can be received by sound waves sensor [4, 9].
- DPOAE, is a more common method. DPOAE is a medical amplifier device that works to enlarge, filter and convert the input signals into audio signals that the human ear can hear. It contains a button to enlarge from 20 dB to 40 dB as needed. This amplifier works on two 9-volt batteries as shown in Fig. 1.

This method was applied in this study by generating two audio signals (sine wave) at different changeable frequencies ranging between 0.5-8 kHz. These two signals go to the amplifier to be converted into sound waves and then go to the ear to stimulate the cochlea. The difference between these two signals is [10].

$F1 = 1.2 \times F2$.

When cochlear is stimulated, it generates audio signals that can be captured and analysed into a spectrum of waves. The received signals are combination of many signals, including the original signals transmitted F1, F2 and the signal to be captured Fd that generated by cochlear stimulation. The rest of the signals are considered as noise.

In this paper, Arduino Uno controller microcontroller was chosen to be programmed due to many reasons:

- Low cost.
- Contains a USB port to transfer data to a computer, a mobile phone or tablets with high flexibility through the serial port.
- Contains 6 ADC ports with high conversion accuracy (20-bit).
- The ability to convert digital signals into analog signal using Pulse Width Modulation PWM technology
- Low power source of 5v
- Small size and lightweight [11, 12].

5. The System Building Process and Components

The system can be divided into hardware and software.

5.1. Hardware specifications

Figure 1 shows the block diagram of the physical parts (hardware) of this system [12]. The microcontroller chip used is ATmega328. Microcontroller chip is connected to the sound card which is compatible with the microcontroller that amplifies the signals and converts them into analog audio signals that can be recognized by the human ear. The MIC port is the microphone and is used to capture the audio signals generated inside the cochlea [13]. The picture below shows the contents of the device that radiates inside the ear. It consists of two Speicher's (Piston Source) and one microphone (see Fig. 2)

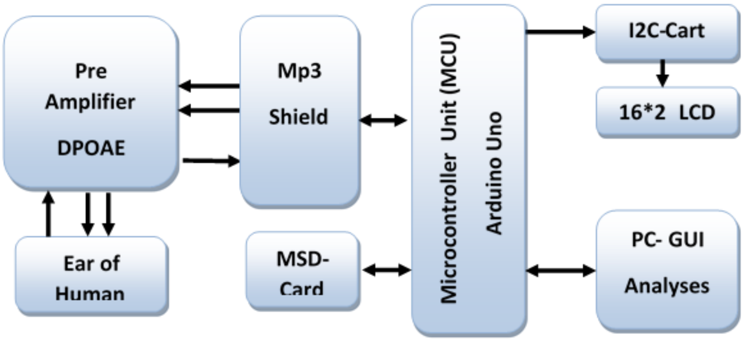

Fig. 1. Block diagram of the physical parts of this system.

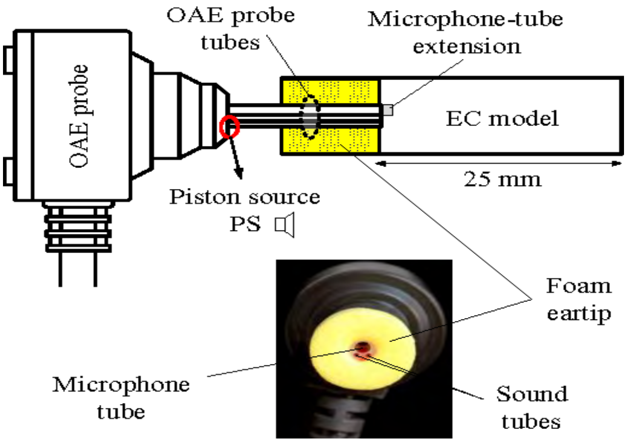

Fig. 2. Microphone and piston sensor from preamplifier DPOAE.

To convert the generated sine wave to audible signals using MP3 Shield with Arduino card as shown in Fig. 3. which is equipped with data and voltages by Arduino. The SPK stereo port is used as an output for the sinusoidal waves and the MIC port is mono input port from feedback data [14].

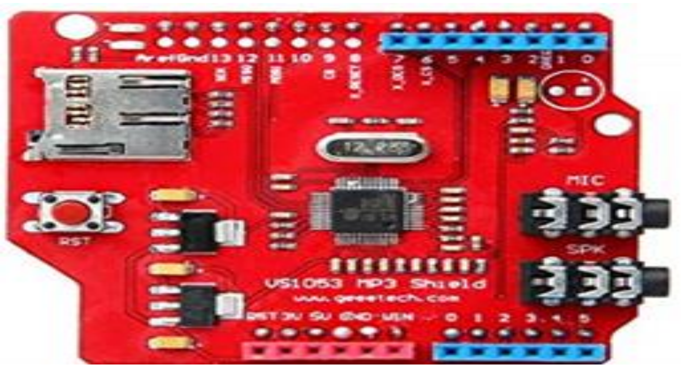

Fig. 3. Amplifier sound card - shield with Arduino (VS1053- MP3).

The proposed algorithm for the microcontroller generates two sinusoidal waves with different frequencies transferred by MP3 shield cable controlled via the ADC port. This port is connected to a variable resistance to calibrate the device to generate the desired frequency [7, 9] as shown in Fig. 4 [15].

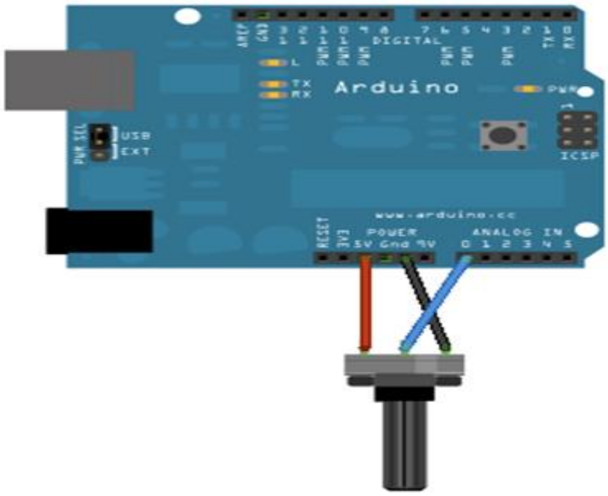

Fig. 4. Arduino Uno and pot resistance connection.

These signals are generated by Pulse Width Modulator technology. The number of samples *n* =28 or *n* = 256, with frequencies between 0.5-8 kHz which is the human auditory range that a person can hear [12].

The difference between these two signals is (F1 = 1.2 × F2). Table 1 shows the practical signals that were used in this research.

Table 1. Frequency range of **sine waves generation.**

F2=kHz	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8
F1=kHz	0.6	1.2	1.8	2.4	3	3.6	4.2	4.8	5.5	6	6.6	7.2	7.8	8.4	9	9.6

The feedback data from the cochlea is received using the microphone. These signals go to MCU and saved in matrices form according to their frequencies. Due to the small MCU memory, an external memory board MSD type is connected to expand the storage memory to store the received data. The data then will be analysis and the signals are converted to have the spectra of frequencies values of F1= 65 kHz, F2=55 kHz and Fd=15 kHz. Subprogram is needed to remove the unwanted noise that represented the band pass filter of the signal [16].

Signal power characteristics

The processed data can be displayed in three methods:

First method: It display the output on the LCD screen attached to the MCU through (I2c) card that change and converts the screen connection from a parallel link to a chain link as shown in Fig. 5 [10].

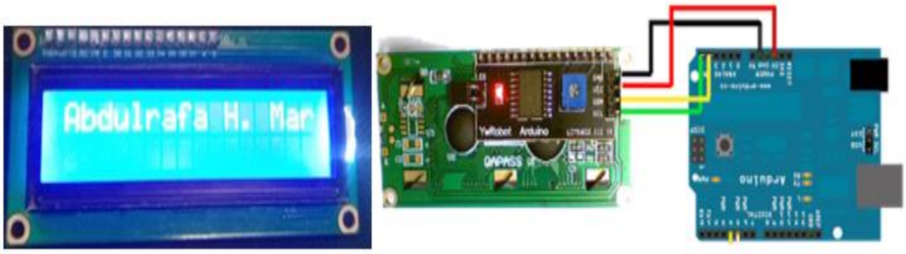

Fig. 5. The prototype of the device after assembling AVR-microcontroller and liquid display.

This reduces the numbers of wires between the LCD screen and MCU to four wires only as shown in Table 2. Table 3 shows the address (labels/naming) of the I2C card.

Table 2. I2C Board pines.

SDA	SCL	VCC	GND
Data	Clock	5V-Dc	0 V

Table 1. Knowledge address in I2C.

Inputs			I2c SLAVE ADDRESS
A2	A1	A0	
L	L	L	0×20
L	L	H	0×21
L	H	L	0×22
L	H	H	0×23
H	L	L	0×24
H	L	H	0×25
H	H	L	0×26
H	H	H	0×27

H=Open Jumper L=Close Jumper

After generating the frequencies F1 and F2 using the (PWM) technique, the analogue port (A3) send data from the amplifier to be saved in the internal memory of the (MCU) in matrix. These data will be processed and analysed using (FFT). The results of the hearing level will be judged by as percentage based on the received signal frequency and intensity values [17].

This method does not require a computer system or a tablet, inexpensive, hardly has any weight is mobile, and it can generate and receive signals self with Give the result immediately after performing the necessary analyses and filtering it. However, the main drawbacks of this method are the limited number of taken samples and unable to double the accuracy and increase (Sampling Ratio).

The second method: This method is similar to the first method except for replacing the (I2C) card and the display screen (LCD) with the external memory card type (Micro DS).

The data can be saved in an external memory in the form of matrices in order to be analysed later by a computer or a portable tablet. This method does not require include the signal analysis programs inside the microprocessor. It can take larger numbers of testing samples of more than one patient, and it is able to increase the accuracy of the signal more than the previous method. On the other hand, a computer and a program (GUI) are needed for the hearing level result to be finalised [12, 17].

The third method: It is similar as the previous methods, where the microcontroller generates audio signals (F1, F2), sends them to the patient's ear and receive the audio signals (Fd). The user interface program inside the computer will analyse process the signals and generate a graph that shows the detail results and saves them inside the computer. In this case there is no need to consume the internal memory of the processor or use an external memory [8].

5.2. Software algorithm

Figure 6 illustrates the MCU programming flowchart for the first method which needs to configure the Cyril port in order to deal with the (I2C card and the LCD screen). The microcontroller analyses the signals by (FFT) using C++ programming language. To remove unwanted noise, this chart gives the percentage of diagnosis and review of results directly on the LCD screen. The flowchart in Fig. 6 shows the LCD and MCU programming method [17, 18].

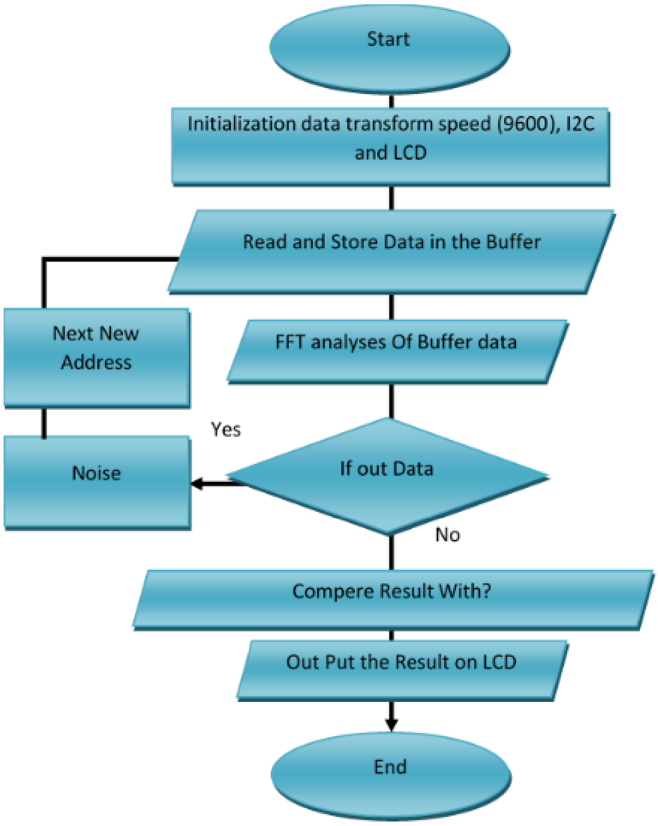

Fig. 6. Flow chart algorithm for MCU and I2c-LCD.

6. Results and Discussion

Figure 7 shows the Matlab2019a analysis outcome of the system when data is taken from the SD-Card. The signals are converted to spectra and the first frequency is 3.9 kHz and the second frequency is 3.3 kHz. The total result frequency is Fd=2.69 kHz) on the x axis, and the y axis represents the signal intensity measured in units dB.

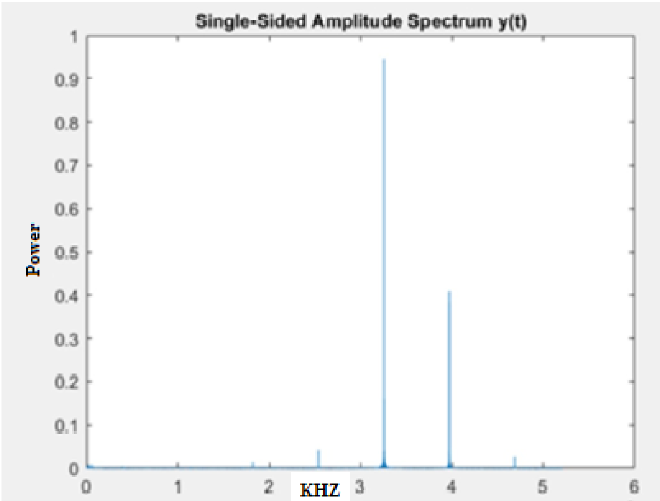

Fig.7. M-File using data from SD-Card (F1=3.9 kHz, F2=3.3 kHz, Fd=2.69 kHz)

Figure 8 explains how the GUI operated using Matlab2019a software. The required frequency can be chosen by clicking on the buttons to assign to the value of the first frequency F1 to the microcontroller. Then the second wave will be generated based on the formula of F1 = 1.2F2. these two signals will be sent first to the amplifier, then to the ear. The signals generated by the cochlea are captured, analysed and their spectrum displayed.

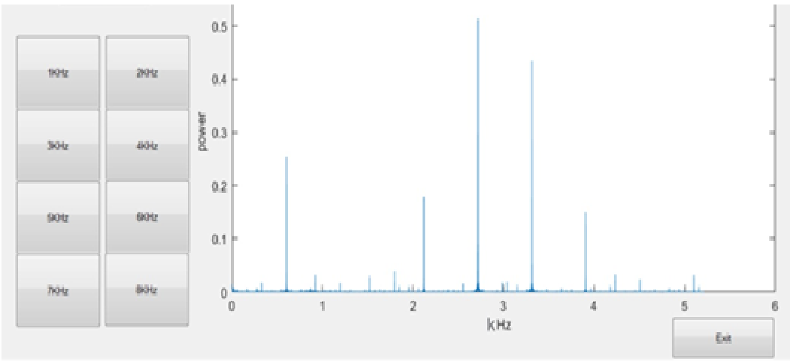

Fig. 8. GUI by Matlab2019a (F1=3.25 kHz, F2=2.7 kHz, Fd=2.2 kHz).

Figure 9 is a chart presents the level of analysis in the of the results of the frequencies start from 1 kHz to 6 kHz. This figure shows that the transmitted waves (F1, F2) are higher than the received signal Fd. The maximum Fd signal intensity

(0.3 dB) was found at (2 kHz). In sick cases, the results are different from the forms of these signals depending on the severity of the patient's response, and these devices remain an aid to the doctor.

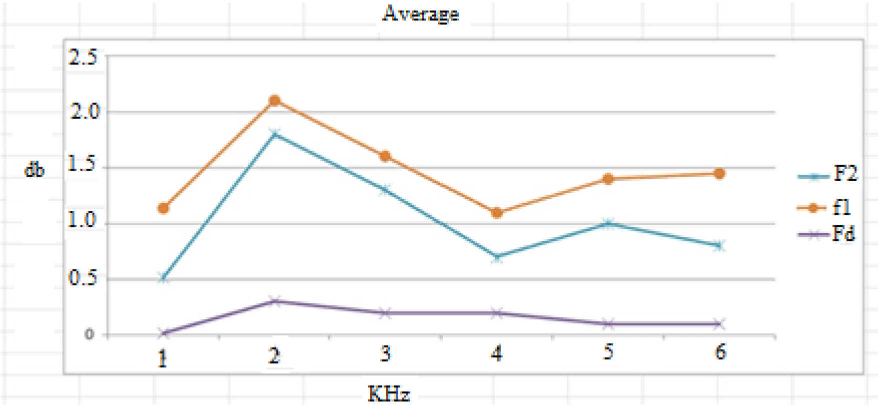

Fig. 9. Results analyses of data F1, F2 and Fd.

The horizontal axis in Fig. 9 explains the amount of change in frequency 1-6 kHz. The vertical axis also represents the amount of change in the intensity of the signal (dB). As discussed previously, F1 and F2 are sine wave generated by the system, while Fd represents the final result.

7. Conclusions and Future Work

In this paper, a new device of Distortion Otoacoustic system was designed, in order to meet the requirements of the medical device market in terms of providing an inexpensive device that works on a public microcontroller (Arduino).The results shows a good capability of low-cost microcontroller to operate as a good device that used to diagnose ear problems for children.

In future work, more sophisticated types of microcontrollers can be used, as well as the ability to program them by artificial intelligence algorithms in order to be more efficient and accurate.

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