Inexpensive human audiometric system using Raspberry Pi and artificial intelligence

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ABSTRACT

The most common and widespread disease in Iraq is hearing impairment for children and newborns. Also, in cities, people are exposed to high levels of noise, loud sounds at work, like factories, and machinery noise. In this paper, a system was designed and implemented to measure the level of hearing in the human ear, in order to reduce the cost of these devices. This system uses Raspberry Pi 3 microcontrollers, which are considered cheap and have high capabilities in open-source programming. Their abundant availability will lead to the provision of these systems in homes, health centers, and hospitals. In this proposed algorithm, two sine waves are generated by the microcontroller with different frequencies. It is transmitted by the MP3 audio transmission cable through the analog-to-digital (ADC) port. These audio signals are generated at a frequency of (0.5 to 12 kHz), these frequencies are the ones that humans can hear, and they can be represented by pulse width modulator (PWM) technology (x=255 samples). Convolutional neural network (CNN) is trained on the dataset acquired through deep learning algorithms.

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1. INTRODUCTION

One of the most common diseases among young children is hearing loss. Hospitals in many developing countries lack modern medical devices due to their high cost. Early diagnosis of the hearing problem in children and newborns will lead to early treatment before the disease worsens [1]. Some researchers have spoken in previous studies that every year, more than 22 million workers are exposed to very loud sounds and noises in their daily work. This noise may lead to hearing loss in the short or long term. Noise-generated hearing loss is the most common cause of work-related hearing impairment, accounting for 72.5% of registered cases [2]–[6]. In this proposed study, devices are designed and implemented to measure the hearing level of the human inner ear. Through inexpensive microcontrollers, which are widely available and easy to use in homes. Without the need for specialists, it is lightweight, portable, and available to all. This saves cities and people time and effort instead of having the exclusive test in public hospitals. Newborns need an early diagnosis of their sense of hearing, which may lead to a solution to their speech and hearing problems and communication.

Diagnosing hearing impairment in time is a very important process for newborns, and avoiding serious problems such as difficulty speaking, mispronunciation, and a lack of understanding of speech. Called early detection of auditory brainstem response (ABR) and otoacoustic emissions (OAE). This project is to design a discount-cost and user-friendly device by proposed basic algorithms, such as a Raspberry Pi 3 microcontroller, a graphical user interface (GUI) using by MATLAB 2020 program. The audio wave is analyzed, and good results are given by using fast Fourier transform (FFT) to analyze the frequencies of the audio signal audible to humans. The results of this proposed system are compared with approved international standards using several methods and filters to improve the efficiency and quality of the results.

2. OVERALL PROCEDURE

OAEs measure the human hearing level in the cochlea. The most popular application is a comprehensive audiological examination of newborns and all age groups. Among its advantages is that it does not take long measuring periods, and does not require surgery [7], [8]. It does not require specialized clinical staff or a medical specialist. It is sending two sound with a frequency ranging from 500 to 8,000 Hz on ear, and the feedback signal is taken, filtered, and processed to find out the extent of the hearing strength of that patient [9]. It can be seen in Figure 1.

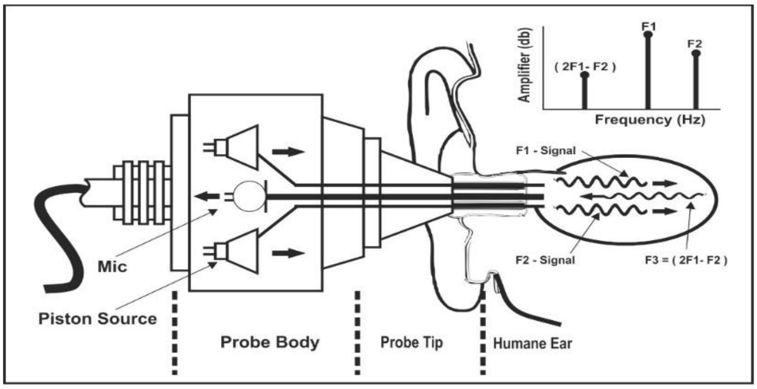

Figure 1. OAEs measure the human cochlea in ear

This study describes a generation of sound signals with human auditory frequencies, and sends them to the middle ear. First sine wave=F1, second sine wave=F2, and reserved data signal is F3. Look at (1) and (2) [10].

$$F3 = 2F1 - F2 \quad (1)$$

$$F1 = 1.2 \times F2 \quad (2)$$

When the cochlea is good. The probe contains two speakers and one microphone. The function of hearing aids is to send sound signals into the cochlea. The sounds generated from inside the cochlea are taken in by a microphone. The effect of these signals on the patient is received and saved in the database. Data acquisition, signal analysis using FFT, and specific spectra are detected with noise cancellation to improve signal-to-noise ratio (SNR). The following diagram represents the important basic components of the prototype block diagram, as shown in Figure 2.

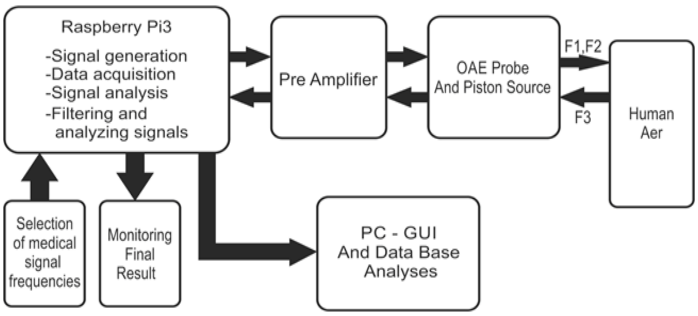

Figure 2. The block diagram of the system

Figure 2 represents block diagram for the design of this medical system prototype, and the most important element is Figure 2 represents the block diagram for the design of this medical system, and the most important element is the microcontroller. It performs many functions:
- Generate two audio signals in the form of sine waves.
- Send these signals to the patient's ear by amplifying the sound.
- Receiving and storing the signals emitted from the patient's ear.
- Analyze these signals after filtering them from noise.
- Sending results data to a computer and storing them in databases.

3. HARDWARE REQUIREMENTS

3.1. Raspberry Pi 3

The microcontroller is the basic component of this system. In a previous study in 2012, the (PIC16F877A) microcontroller was used [11]. which is considered an old and complex processor. It is limited capabilities were chosen, and required many components in their programming, and the programs used at that time were considered inefficient. In the year 2022, a hearing system was designed and implemented using Arduino and I2C-LCD, which is the latest [10]. In this study, Raspberry Pi 3 was used because of its high specifications, light weight, and low cost, see Figure 3. The various hardware features covered in Table 1. This table shows the general components of the proposed system of microcontroller Raspberry Pi 3.

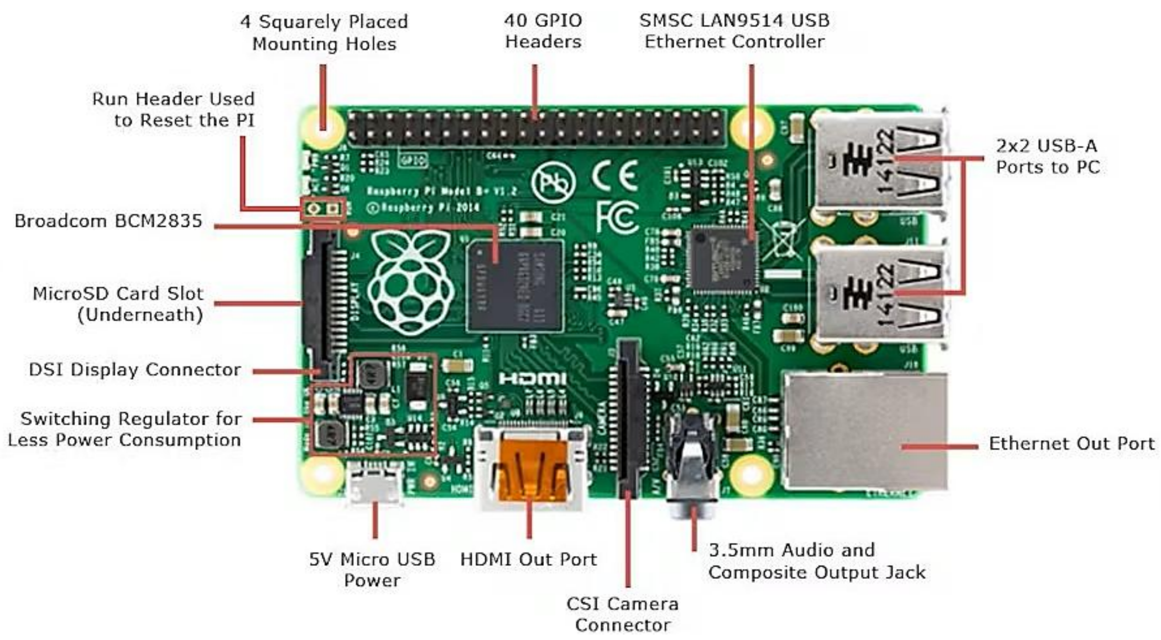

Figure 3. Schematic representation of Raspberry Pi 3

Table 1. Raspberry Pi 3 specifications [12], [13]

Components	Specifications
CPU	CPU: 1.2 GHz
Memory	Memory: 1 GB, internal RAM: 1 GB DDR2
Network board Shelled	Wireless-ethernet RJ45-bluetooth
Power source	(3.3–5) volt
Size	85.60×56.5 mm, not including protruding connectors
GPIO	PWM: GPIO (12, 13, 18, 19)
Ethernet	- Ethernet: 10/100 ethernet - 802.11n wireless LAN
USB voltage	- 5V/USB - Processor operating voltage: 3.3 V
Size (mm)	85.6×53.98×17
Weight	45 g
Programming language	C, C++, Java, Phyton

3.2. Matrix keypad-16 pines

The value of the audio frequencies generated by the microcontroller is controlled by this electronic circuit. Where a keyboard consisting of 16 keys is connected, connected to an eight-pin cable [14]. It can be seen in Figure 4 and Table 2. These switches are connected to the Raspberry microcontroller circuit via the following ports. This system can generate audible sound frequencies between 500 and 20,000 Hz through these keys, where the appropriate frequency is chosen according to each patient [15], [16].

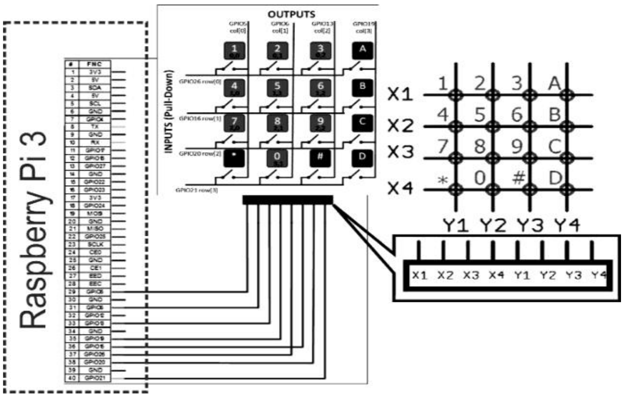

Figure 4. Keypad connection with Raspberry Pi 3

Table 2. Raspberry microcontroller ports

Inputs	Row	Outputs	Colom
GPIO26	0	GPIO8	0
GPIO16	1	GPIO6	1
GPIO20	2	GPIO13	2
GPIO21	3	GPIO19	3

3.3. Audio digital-to-analog converter board

This card is considered one of the most important boards compatible with the Raspberry Pi, as it contains 40 pins, which are connected to transmit audio signals via the microcontroller. It filters audio signals with very high accuracy and quality. It also processes outgoing signals, eliminates noise, and increases the SNR coefficient. This card contains more than separate audio ports for input and output. It has a microphone port. It is powered by the Raspberry Pi 3, [17]–[20], as presented in Figure 5. Figure 6 shows the main components of the proposed system and terminal devices. Raspberry Pi 3, audio digital-to-analog converter (DAC) board, matrix keypad-16 pins, and connection. DAC board features: compatible with all Raspberry Pi microcontrollers; stereo auxiliary (AUX IN) input channel; stereo auxiliary (headphone/AUX OUT) output channel; 24-bit 192 kHz digital audio; panel-mounted stereo phone (RCA) socket output; analogue (0–2 V RMS via P7) out; P1/GPIO 27-analogue output; P5/alternative power input; and P6/headphone output socket [21].

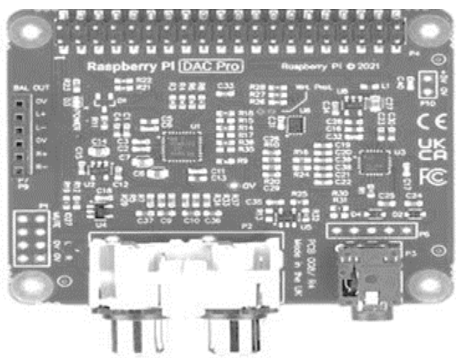

Figure 5. Audio DAC board

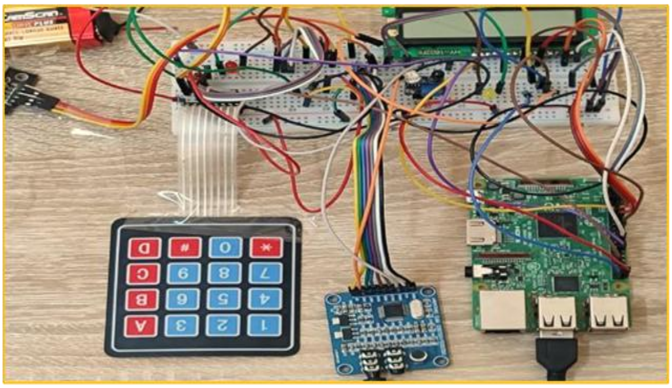

Figure 6. Main board system

4. SOFTWARE REQUIREMENTS

Support devices for building a sound-sense meter are microphones, sound card/analog-to-digital converter (ADC), and cables. In this study, a computer was used to program a microcontroller with the Linux operating system. This is considered one of the most important and famous systems because it is open source. The following diagram shows the proposed algorithm for programming this system, see Figure 7.

This diagram shows the algorithm used in programming this system. He begins to prepare the basic components of the microcontroller system, the amplifier card, and the input and output switch circuit. The audio frequency to be generated is chosen according to each patient. Two frequencies are generated with a sine wave to be sent to the patient and received via a loudspeaker. This signal is delayed by 250 milliseconds to be processed, filtered, and the final results displayed. When the program ends, press pin 20.

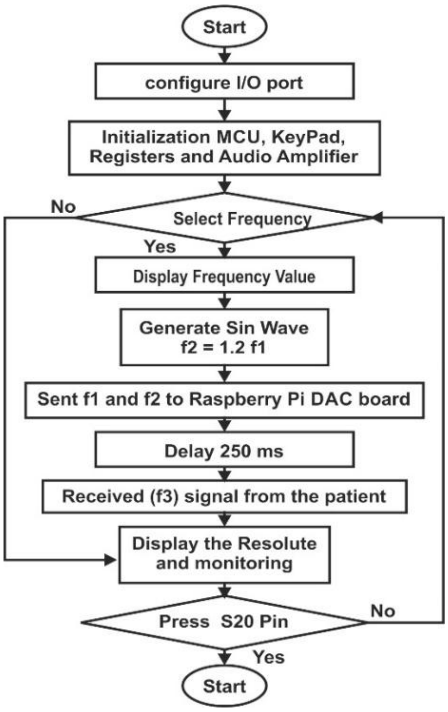

Figure 7. Software algorithm

5. CONVOLUTIONAL NEURAL NETWORK LAYER

A convolutional neural network (CNN) layer typically includes three operations: convolutional layers, activation layers, and max pooling layers [22]–[26]. Using the more general idea of parameter sharing. Instead of a full connection convolution operator in neural networks is as follows, see Figure 8.

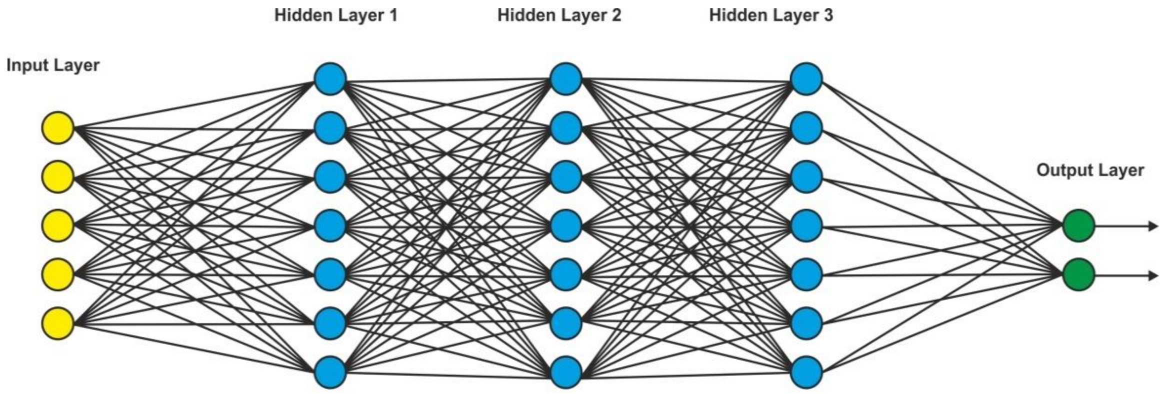

Figure 8. A basic CNN architecture

I is the input and K is called the kernels with the (3). The kernel K will be learned (replaces the weights W in a fully connected layer). Figure 9 shows the process of training a deep neural network, epoch 20, elapsed time 25 sec, iterations per epoch 3, and maximum iterations 60.

$$\theta(i,j) = (I * K)(i,j) \sum_k \sum_I I(i+k, j+I) K(k,I) \quad (3)$$

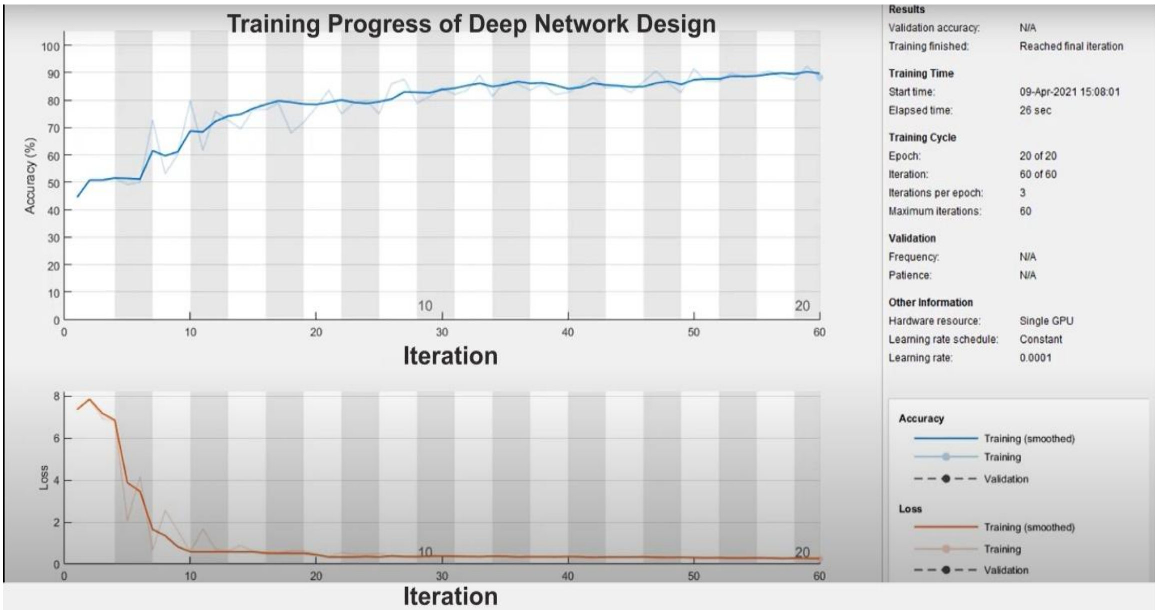

Figure 9. Training progress of deep network design

6. RESULTS AND DISCUSSION

The results in Figure 10 obtained through the graphical interface GUI in the MATLAB 2020 program indicate the wavelength spectrum of the frequencies of the audio signals generated by the system, which are: F1: 3.2 KHz, F2: 3.82 KHz, and the feeding signal F3 is 2.6 KHz. The proposed solution achieves an identification accuracy ranging from 93 to 98%, with false alarm rates between 1 and 2%. This 5% margin highlights the method's high efficiency in detecting harmful hosts.

When discussing these results, we find that the system operates with high efficiency and has many advantages, such as low price, light weight, small size, portability, and does not need a high power source, as it operates on 5 volts. The results we have reached are wonderful and reliable. This system can control the value of the generated frequencies within 0.5 to 20 kHz. Hearing test for all age groups. Figure 11 shows the shape of the signals generated by the system, the shape of the signal received from the patient's ear, and the difference between the intensity of these signals. Table 3 shows the analysis of the results when changing the filter sizes and kernel size with changing the layer level.

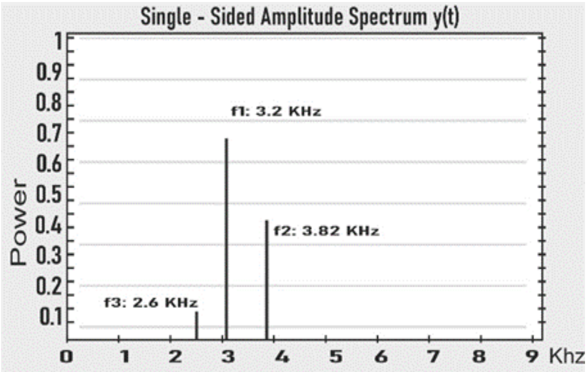

Figure 10. Spectrum analyst position in input/output signals

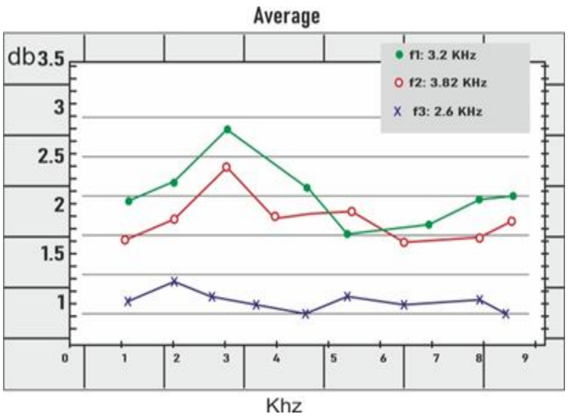

Figure 11. GUI by MATLAB 2020 (F1: 3.2 KHz, F2: 3.82 KHz, F3 is 2.6 KHz)

Table 3. The CNN results when changing the filter sizes and kernel size

	Layer	Kernel size	Size	Feature map	Stride	Activation
Input	Image	-	32×32	1	-	-
1	Convolution	5×5	28×28	6	1	tarih
2	Average pooling	2×2	14×14	6	2	tarih
3	Convolution	5×5	10×10	16	1	tarih
4	Average pooling	2×2	5×5	16	2	tarih
5	Convolution	5×5	1×1	120	1	tarih

7. CONCLUSION

This proposed study summarizes the design and implementation of an open-source system based on a low-cost Raspberry Pi 3 controller to measure human hearing levels for people with hearing loss. This system achieved its main objectives, the most important of which was to address the problem of hearing loss in Iraqi society and among many different age groups. The system achieved the best accurate results, which were discussed in the previous section, where the required audio frequency range (500 to 12 kHz) was generated using pulse width modulator (PWM) technology and signal analysis through the design and training of a CNN, proving the reliability between the problem and the technical solution. This system also has a large number of specifications (lightweight, low price, energy efficient, and easy to use). Future studies: in this study, excellent results were achieved and we suggest that future studies focus on developing the model, improving the accuracy of diagnosis and differentiation between different types of hearing loss, expanding the database used to train the CNN, designing and developing a user application for smartphones, and creating a simple web interface to make the system more user-friendly with the IoT.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
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Muataz Akram Hassan	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
Taha Hussein Marai Al-Hassan	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available on request from the corresponding author, [AHM]. The data, which contain information that could compromise the privacy of research participants, are not publicly available due to certain restrictions.

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