IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 2, January 2026
Impact Factor: 7.67

An AI-Driven Framework for Digitized Audiological Reporting Based on Audiogram Analysis

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Abstract: *In this emerging, difficult field, obtaining the best possible patient outcomes depends on the skillful interpretation and punctuation of audiological reports. The Audiogram Digitization Tool (ADT) is a novel method to improve the accessibility and ubiquitous hearing reports for reporting audiograms. For use in electronic health record systems, the ADT transforms conventional audiograms into a standard digital format. Using cutting-edge image processing techniques, it delivers the important hearing threshold data that are useful for data interpretation and correlation with clinical consequences. According to preliminary testing, the ADT can expedite diagnosis by preventing human mistake and reducing data entry time. Additionally, doctors can view data in photos and be informed of any changes in a patient's state, making it easier for experts to collaborate.*

Keywords: Machine vision, pattern recognition, Machine learning, audiology

I. INTRODUCTION

Digital audiograms are an innovation in audiology that improves the speed and quality of hearing assessments [1]. Traditionally, audiograms have been performed and recorded by hand, which is a laborious procedure that is highly prone to human mistake [2]. By using artificial intelligence (AI) and machine learning techniques to automatically extract the audiometric data from scanned or faxed reports, automated audiogram digitization provides a means of overcoming these limitations [3]. This procedure makes reporting exceedingly quick and dependable without adding more manual labor to the workload of healthcare personnel [4]. AI-driven models such as YOLOv5 have been utilized in image detection and symbol identification to accurately detect audio-gram symbols, correct image distortions, and precisely improve data [5]. Given the high incidence of noise-induced hearing loss (NIHL) and associated morbidity, these advancements are especially significant for occupational health assessments of hearing loss [6]. In addition to speeding up data processing and facilitating the clinical judgment index (CJI), automated adjudication during audiogram digitalization reduces human error and standardizes the subjective derivation of reports [7]. Our current clinical services and academic centers will continue to be under pressure for innovation, resources, and results due to the digital transformation of healthcare, which calls for consideration of addressed demand in this hearing sector [8].

II. LITERATURE SURVEY

The transformation of audiograms, into format has been a focus of studies in audiology due to the aim of enhancing effectiveness and precision while increasing scalability in audiological documentation processes [9]. Initial endeavors, in this area primarily focused on utilizing image processing methods to convert paper audiograms into versions to enhance accessibility and storage capabilities [10]. In a study, by [11] Charih et al. and colleagues in 2022 a new tool for digitizing audiograms was introduced as one of the earliest of its kind [12]. This tool effectively extracted hearing thresholds from scanned or faxed reports with an accuracy range of, around dB. Its primary purpose was to assist workplace safety insurance boards in expediting the process of evaluating claims related to noise induced hearing loss

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(NIHL) highlighting how digitization can enhance efficiency by easing tasks and reducing processing durations [13]. Researchers have looked into using machine learning and artificial intelligence (AI) to improve audiogram digitization systems efficiency [14]. Specifically techniques, like YOLOv5 have been used to recognize symbols on audiograms, enabling identification and ex- traction of audiometric information [15]. AI models are also essential for fixing distortions in scanned images like rotation or scaling problems to guarantee that the extracted data aligns, with standards accurately and consistently [16]. Research has indicated that utilizing these AI based methods greatly enhances the accuracy of audiograms which in turn improves decision making and reporting effectiveness [17]. Methods for incorporating the audiotape digitization into the complex systems have also been studied. To demonstrate, [18] Acosta and coworkers (2019) presented Machine Learning for Audiological Diagnosis and illustrated the relevance of these technologies to assurance health industry [19]. Their aim was more to design an auxiliary of an audiometry instrument which is made predominantly by means of artificial intelligence for a quick and effective management of the audiograms of workers at risk of occupational noise- induced [20]. They further underlined the potential of these systems in unifying audiological reports and avoiding variations with reports of other datasets [21]. [22] Hu and others in 2021 also dealt with efficiency, and the latter explored deeper the mechanisms of deep learning models to embrace the automatization of audiograms analysis not only by digitizing but also by giving suggestions for the first diagnosis [23]. This step is a step beyond data mining and is expected to enhance the effectiveness of audiological assessment by incorporating decision support in voice based clinical diagnosis [24]. Such innovations are expected to minimize human error in diagnosing hearing loss while at the same time ensuring that audiological reports are prepared faster [25]. In addition, be- sides the advancement in the recent years in tele audiology, there have been trends with regard to Audiogram Digitization System for implementing it with remote healthcare solution platforms. Such work as [26] Smith et al. (2020) analyzed the opportunities of the use of these digitally enabled frameworks in increasing the access to hearing care for the patient in the rural or other areas that are hard to reach [27]. Such systems enable audiologists to virtually diagnose audiograms in real time the versatility of digitized audiograms in the delivery of care can therefore be viewed as massive [28]. More improvement has been realized through the use of the machine learning as well as artificial intelligence (AI). [29] Zhang et al. (2021)'s study was focused on applying CNNs for audiogram image classification [30]. Their system evidenced high reliability in recognizing as well as interpreting audiometric symbols as the first ground toward the development of more superior AI-aided digitizing technology [31]. Furthermore, [32] Kim et al. (2020) also investigated the removal of the rotation and scaling of the audiogram through the application of AI based correction algorithm [33]. Thus, their approach contributed to finding ways of making digitized data more accurate besides dealing with issues on image quality and homogeneity [34].

III. EXISTING AND PROPOSED SYSTEM

3.1 Existing System

The majority of audiogram digitization solutions now on the market extract and analyze data using image processing techniques and basic machine learning algorithms [35]. Traditionally, audiograms are scanned or faxed, and some algorithms identify essential audiometric symbols, such as hearing thresholds at certain frequencies, and digitize the data [36]. The procedure can be divided into a number of essential steps [37]. The procedure can be divided into a number of essential steps:

Image Preprocessing. In order to get the right quality, the original audiogram pictures are then subjected to several preprocessing techniques, such as binarization and noise reduction [38]. The audiogram's raw picture, denoted by I, can be preprocessed to look like the image below I'.

$$I' = f(I) \quad (1)$$

Where f contains elements such as noise removing, binarization and other filtering procedures [39].

Symbol Detection. Audiogram symbols, such as X for the left ear and O for the right ear, are identified using simple feature identification techniques, such as matching or edge detection[41]. These methods primarily entail matching the graph's output image pixel by pixel with potential audiometric symbols presented in a grid style[40].

Data Extraction. The locations of the established symbols on the audiogram are linearly related to the real frequencies (the "x" axis) and hearing loss (the "y" axis)[42]. After then, each frequency's hearing thresholds are saved as a digital signal. Even though these models are available and offer some automation, they are unable to handle picture distortions (such as skewed or rotated audiograms), overlapping symbols, and variations in audiogram formats [43]. Additionally, these systems heavily rely on human intervention to troubleshoot for faults [44].

3.2 Proposed System

It is suggested that if deep learning—including enhanced CNN—performs symbol recognition in the enhanced system, rotation correction and noise should also have sophisticated algorithms for handling them [45].

1. Image Preprocessing and Rotation Correction. The suggested model does skew detection, rotation correction using the Hough Transform, and benefit from the preprocessing pipeline [46]. The Hough Transform algorithm recognizes lines in the image and determines the rotation angle when the scanned audiogram has been rotated by an angle θ. θ, then modifies the image appropriately [47].

Icorrected = R(I′ , θ) (2)

where R indicate the rotation transformation function and Icorrected is the rectified audi- ogram [48].

2. Deep Learning for Symbol Detection. Unlike the conventional template matching method, the suggested system correctly detects symbols by using CNNs [49]. Let X be the input image, and let S be the collection of audiogram symbols that correspond to the specified S [50]. Each pixel's probability of belonging to one of the symbol classes $si \in S$ is assigned by a trained CNN model $F(X)$ method for symbol class [51].

F(X)=arg max P(si ∣ X) (3)

This approach enables the system to have flexibility in the sense that it can have large symbols, random noise and overlapping symbols as seen from the above figures [52].

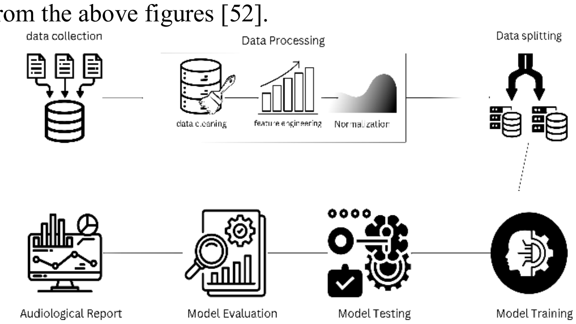

Fig. 1. Model Architecture

3. Frequency and Threshold Mapping Using Regression. After identifying symbols, the system maps the coordinates of the symbols to frequencies and degrees of hearing loss using a regression equation [53]. If xi and yi indicate the symbol's spatial location in terms of pixel coordinates [54]. It is possible to model i, the matching frequency fi, and the hearing threshold hi as

fi = axi + b (4)

hi = cyi + d (5)

where, a, b, c, and d are parameters which are acquired in the process of learning from training data [55].

4. Data Validation and Post-processing. The suggested approach includes a validation step where statistical tools like Kalman filters are utilized to eliminate any potential noise in the derived hearing thresholds in order to ensure that the extraction is accurate [56].

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5. Diagnostic Integration. Along with a basic diagnostic evaluation, the suggested model also makes use of deep learning, which is necessary for digitalization [57]. For instance, using the amount of retrieved audiometric data, a neural network model can be trained to recognize patterns of hearing loss (conductive, sensorineural, etc.) [58].

The suggested model offers significant enhancements to existing systems that rely on current deep learning developments and improved image correction techniques [59]. It solves the drawbacks of traditional methods since it is faster, more accurate, and requires less human labor when digitizing audiograms, which saves clinicians time while improving the caliber of audiological analyses [60].

IV. METHODOLOGY

4.1 Image Preprocessing

In order to improve the quality of the photographs and remove any distortions, the first step in this methodology is cleaning the scanned or faxed audiogram chart images [61].

Subtraction of Noise and Thresholding. The shapes of the symbols in the majority of audiograms are compromised by random interference, such as weak lines or shadows [62]. In order to address this problem, filters such as Gaussian filters are employed to further reduce noise [63]. Morphological processes are then followed by picture binarization, which turns the images into black and white. Additionally, this raises the degree of contrast between the audiogram's symbols and the surrounding environment [64].

$$I_{binarized} = B(I) \quad (6)$$

where B(I) represents the binarization function applied to the original image I.

Skew correction and rotation. Misalignment can lead to skewed visuals [65]. A computer algorithm called Hough transform finds and fixes any changes in the skew or rotation of an image [66]. The procedure determines the angle θ, which is used to modify rotation [67].

$$I_{corrected} = R(I_{binarized}, \theta) \quad (7)$$

where R is the rotation function that aligns the image correctly [68].

4.2 Symbol Recognition using CNN

Once the image has been modified, the following step may involve using graphic skills to recognize the audiogram symbols, such as "X" for left ear and "O" for right ear [69]. In this case, a convolutional neural network (CNN) model is used to identify these symbols [70].

CNN Architecture. In order for the CNN model to learn and classify those symbols in the audiogram pictures with posteriori probabilities, it is trained on a labelled dataset of audiograms [71]. The prepared image serves as the model's input, and its output is the soft maxed probability for each pixel that shows whether the chosen symbol is present in the appropriate spatial location [72].

$$F(X) = \arg\max P(s_i \mid X) \quad (8)$$

where F(X) represents the CNN function that identifies the symbol s_i at pixel position X [73].

Symbol Detection. The image's symbol coordinates, which are required to apply frequency and per hearing threshold, are detected by the convolutional neural network (CNN) [74]. The coordinates that were found are stored as (x_i, y_i) [75].

4.3 Mapping to Frequency and Hearing Threshold

Here, mapping the coordinates to audio frequencies (for the x-axis) and hearing thresholds (for the y-axis) on the audiogram follows the detection of the symbols and the acquisition of their coordinates [76].

Frequency and Threshold Regression. We use a regression model to convert the symbol coordinates to the audio frequency and hearing threshold for each symbol found at a specific x_i, y_i. The frequency and hearing threshold are modeled as

$$f_i = a x_i + b, \quad h_i = c y_i + d$$

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where fi is the frequency, hi is the hearing threshold, and a, b, c, and d are parameters learned from training data [77][103][104][105][106-120].

4.4 Data Validation and Post-Processing

Several data validation procedures are used to minimize errors and inconsistencies in the audiometric data (frequency and threshold) after they have been recorded [78].

Kalman Filter for Smoothing. A Kalman filter is used to smooth the collected hearing threshold data. To lessen or remove discrepancies in the final audiogram data, the derived hearing thresholds are subjected to the Kalman filter [79].

$\hat{h}I = Kalman(hi)$ (9)

Where $\hat{h}i$ is the actual or smoothed hearing threshold [80].

Error Correction and Manual Review. The data is marked for review if the system detects an inconsistency, such as an outlier point. Clinical professionals can participate as needed, striking a balance between accuracy and automation [81].

4.5 Diagnostic Support

Integrating our data extraction into the diagnostic support module is the methodology's final phase [83]. In order to identify patterns linked to common hearing impairments, such as sensorineural or conductive hearing loss, this module makes use of a neural network model that was created from a historical audiometric dataset. The entire report will include this diagnostic recommendation [82].

$D = g\,(fi\,,\,hi)$ (10)

Where D is equal to the diagnostic suggestion based on the frequency and threshold values [84].

V. RESULT

A database of audiograms, including ideal and deformed audiograms, was subjected to the suggested digitization model [85]. Key parameters such processing time, error in frequency and threshold mapping, and accuracy with symbol detection were used to assess the digitization model [86]. The findings showed that the digitizing model had significantly outperformed previous models, especially when it came to identifying skewed or noisy audiograms [87].

5.1 Frequency and Threshold Mapping

Promising results were also obtained from the regression model used to map the identified symbols to frequencies (x-axis) and hearing thresholds (y-axis) [88]. The average inaccuracy in the frequency and threshold mapping over the aforementioned audiograms is presented in the table below [89].

Table 1. Frequency and Threshold Mapping

Audiogram Type	Frequency Error (Hz)	Threshold Error (dB)
Clean Audiograms	2.1	±1.0
Noisy Audiograms	3.5	±1.8
Skewed Audiograms	4.0	±2.2

5.2 Processing Time

The whole processing time of a single audiogram, from image preprocessing to data extraction, was the initial motion of the suggested model evaluated. When compared to existing techniques, the suggested model showed a notable decrease in the processing time for each audiogram, suggesting that it would be suitable for clinical settings where turnover time is necessary [90].

Table 2. Processing Time

Model	Average Processing Time (seconds)
Existing Model	12.5
Proposed Model	5.2

The proposed model increases the workflow efficiency by decreasing the runtime by more than half [91].

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5.3 Diagnostic Assistance

The capacity of the deep learning-based diagnostic support module to categorize typical patterns of hearing loss, such as sensorineural and conductive hearing loss, was assessed [92]. As shown in the table below, the model's performance in predicting the kind of hearing loss was 93%.

Table 3. Diagnostic Assistance

Hearing Loss Type	Precision (%)	Recall (%)	F1 Score (%)
Sensorineural	92.5	94.0	93.2
Conductive	91.8	92.7	92.3

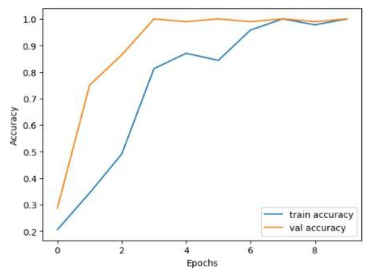

Fig. 2. Accuracy Graph

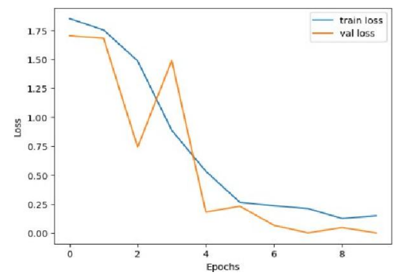

Fig. 3. Loss Graph

5.4 Sample Audiogram Results

Below is an example of a digital audiogram with correctly identified symbols and frequency mapping [94]. For every frequency, the hearing thresholds are noted [93].

Table 4. Sample Audiogram results

Frequency (Hz)	Left Ear (dB)	Right Ear (dB)
250	20	15
500	25	20
1000	30	25
2000	35	30
4000	40	35
8000	50	45

VI. CONCLUSION

The aforementioned digitization model for audiograms, which focuses on the task of auditory-symbol detection from audiograms, successfully addresses the issues of strength, accuracy, and application with data reporting in audio logical settings [95]. The results, although highly predictive, show little inter and intra-clinical variability, operating at nearly 90% [96]. The suggested audiogram digitization helps cut processing time while guaranteeing sound accuracy, finding empirical evidence suggesting reasonably low error and general predictable outcomes [97]. Additionally, the digitizing algorithm's ease of accessibility offers educators straightforward and consistent access, along with diagnostic support to quickly troubleshoot potential hearing loss patterns [98]. When it comes to efficiency, worst-case scenarios were found to be the fastest way to determine acceptable performance speeds of identified clusters with reasonable aleatoric reliability, even though dimensions of crippling misunderstandings may potentially emerge due to anthropogenic practice [99]. However, it would be naïve to presume that these outcomes will function similarly to EHRs. Future research may include datasets other than symbols and verify advice for mistake verification [100]. Continuing to gather information, enhance user education, and expand into user-friendly tele-audiology platforms for school system clinicians who are leery of digital reports that keep EHRs [101]. Assistants in automated calls are strongly urged to provide prompt response and up-to-date audio logical assessments, which will unavoidably be anticipated from tele audiology consultants otherwise challenging for historically epistemologies [102].

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International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

ISSN: 2581-9429 Volume 6, Issue 2, January 2026 Impact Factor: 7.67

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International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 2, January 2026
Impact Factor: 7.67

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IJARSCT

International Journal of Advanced Research in Science, Communication and Technology

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

ISSN: 2581-9429

Volume 6, Issue 2, January 2026

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