Development of an Intelligent Software Solution for AI -Enabled Stethoscope: Accurate CAD Diagnosis and Real-time Feedback System

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Abstract— *Although the classic stethoscope has long been a crucial diagnostic tool for cardiac conditions, it has an elementary level of accuracy in diagnosis capability. And mainly the diagnostic capability of traditional stethoscope relies on the listener's experience and expertise. Number of cardio patients are increasing day by day due to the low accuracy rate of the traditional stethoscope. And it has very limited capability to provide real time feed-back during auscultation. So, here we decided to develop software prototype for a tube-free intelligent stethoscope that not only diagnoses heart diseases but also provides real-time feedback and guidance during heart auscultation. This uses modern machine learning algorithms and real-time signal processing to diagnose heart problems accurately and quickly while providing real-time feedback to assist physicians during the heart auscultations. Here we specially focused on CAD (coronary artery disease). It captured audio signals from patient's heart using sensors and thereby the collected audio signals are preprocessed and converted into spectrograms using short-time Fourier transform (STFT) for frequency domain analysis. Then the trained convolutional neural network (CNN) model achieves a high accuracy rate in differentiating between normal and abnormal heart sounds, enabling accurate CAD diagnosis. And finally, we got an accuracy rate of 65 %. This research has significant implications for cardiology and healthcare, revolutionizing heart disease diagnosis by enabling faster, accurate, effective, and early diagnosis. The integration of real-time feedback and guidance during auscultation provides valuable insights for effective diagnosis and future enhancements in clinical settings.*

Keywords— **Tube-Free Intelligent Stethoscope, AI, software prototype, Coronary Artery Disease (CAD), Convolutional Neural Network (CNN), Cardiology, real-time heart sound analysis, feedback system, machine learning, deep learning, diagnosis, healthcare, heart auscultation, signal processing**

I. INTRODUCTION

"Ough!!! I have chest pain "is common in present all over the globe over the people with every walk of life. And they define it simply as gastritis by being physicians to themselves without any proper guidance of a doctor or any person assist in medical field. And if not, there is a probability that they will direct to the small medical centers near their houses, or may be a less probability that they will directed to the hospitals in the nearest city. Then after that doctor or the health worker in that specific place use traditional stethoscope to hear heart auscultation of the patient. As the outer environment is not such a mediatable & calm environment and instead it is with a surrounding of people talking, generators humming, boom of a moped on the main road , sounds of vehicles outside , sound of vehicle beepers in traffic and other unnecessary sounds of people ,the medical professional struggles to hear the heart auscultation through the general stethoscope ,so it lost their diagnosis accuracy of the heart diseases increasing the mortality rate .And the same time it fails to diagnose any heart disease by hearing abnormal lub-dub sound in the heart at its initial stage due to the limitations of the traditional stethoscope.(Gupta et al. 2022) Normal stethoscopes have a limited frequency range, typically around 20 HZ to 200 HZ. So, this range is incapable of capturing high -frequency sounds or subtle variations that could be indicative of certain cardiac conditions. And CAD is a fatal disease that is only can be diagnosed by general stethoscope when 40 % of it is developed in the heart .It means that the abnormal heart rhythm which could be heard by the traditional stethoscope is generating only, after developing the CAD in the heart up to 40%.(Bachtiger et al. 2022) So to diagnose it in the initial stage, our intelligent stethoscope will contribute a lot. And at the same time we got to know that the auscultatory findings with a normal stethoscope relies heavily on the listener's expertise and experience .And different healthcare professionals may have varying skills, abilities and experiences in identifying and distinguishing specific heart sounds or abnormalities, leading to subjective interpretations. So we wanted to make an equality among all the health care professionals meaning that not to depend diagnostic accuracy on the skills of the physicians.(Grzywalski et al. 2019; Bachtiger et al. 2022) And we acknowledged that traditional stethoscopes do not provide sufficient amplification or filtering capabilities causing difficulties to discern faint or abnormal heart sounds, particularly patients with obesity, chest deformities, or other factors will affect to the sound transmission through the general stethoscopes. And at the same time traditional stethoscopes haven't any ability to record or store auscultation findings for later review or comparison. These limitations could interrupt longitudinal monitoring, collaboration between doctors, and accurate documentation of patient records. And also normal stethoscopes do not possess any analytical capabilities to automatically detect or diagnose any cardiac conditions. And another main issue with traditional stethoscopes is that it has no integration with any digital health platform or telemedicine systems which is so much needed with current technologies. So, the tube-free AI-based intelligent stethoscope addresses these limitations by leveraging advanced machine learning algorithms and signal processing techniques. By converting heart sounds into digital data, it allows for automated analysis and pattern recognition, enabling the detection of subtle abnormalities that might be unnoticed with the general stethoscope.(Suzuki et al. 2022)

CAD (coronary artery disease), is a prevalent and significant health concern worldwide, including Sri Lanka. It is a long-term condition that refers to the narrowing or blockage of the coronary arteries, which supply blood and oxygen to the heart muscle, resulting in various symptoms. In Sri Lanka CAD has emerged as a leading cause of morbidity and mortality in recent years. According to the latest WHO data published in 2020 Coronary Heart Disease Deaths in Sri Lanka reached 26,304 or 22.66% of total deaths. So this much of people has died from this severe disease-causing burden on the healthcare system. So first, our idea was to reduce the mortality rate of population from the CAD disease and to make a healthy Sri Lanka with lowest rate of cardio-vascular diseases. So for this we initially thought to increase diagnosis accuracy at the initial stage of CAD. That is how the idea of tube-free intelligent stethoscope came here. This intelligent stethoscope incorporates a real- time feedback system, providing immediate guidance to the physicians during heart auscultation. So we expect through visual and auditory cues, it assists in the identification of specific heart sounds and abnormalities reducing the patient population with CAD causing reduction of the mortality rate. This interactive feedback system empowers healthcare professionals, especially those with limited experience in cardiology, to make informed decisions and improve the accuracy and efficiency of their diagnoses.

Finally, our aim of this research is to introduce this innovative tube-free AI-based intelligent stethoscope designed to revolutionize the field of cardiac diagnostics. By integrating artificial intelligence and real-time heart sound analysis, this intelligent stethoscope aims to overcome the limitations of traditional auscultation methods and provide enhanced diagnostic capabilities, immediate feedback, and personalized patient care.

II. LITERATURE REVIEW

A. *LungBRN: A Smart Digital Stethoscope for Detecting Respiratory Disease Using bi-ResNet.*

The team of scientists had invented a rudimentary classification of lung sounds using a digital stethoscope that utilized to provide a fast & accurate diagnosis for respiratory-related disorders such chronic obstructive pulmonary disease in situations when there is a significant shortage of experienced medical staff.(Aykanat et al. 2017) They had developed an improved bi-ResNet deep learning architecture, LungBRN, which uses STFT and wavelet feature extraction techniques to improve accuracy. They had used the official benchmark standards and the "train-and-test" dataset splitting procedure stated in the ICBHI 2017 challenge. Finally, they achieved a performance of 50.16%, which is the best result in terms of accuracy compared to all participating teams from ICBHI 2017.

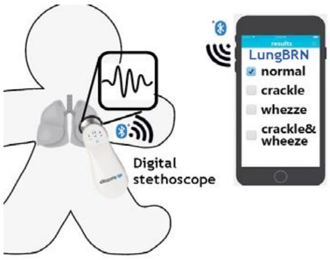

Figure 4. A line graph using colours

B. *Engineers from Johns Hopkins introduced a stethoscope with an AI upgrade for accurate pneumonia diagnosis*

A collaboration among engineers, doctors, and public health experts at Johns Hopkins University, in Baltimore completely rethink the stethoscope to develop it as an Intelligent stethoscope with AI upgrade specially to diagnose the severe lung disease "pneumonia "with the increasement of the pneumonia patients in the region. (Attia et al. 2022) They develop the intelligent stethoscope with the aid of Pulmonologists specially focused about child pneumonia which is the major reason of increasing the mortality rate of children population. This stethoscope is made with the techniques of prior diagnosis of pneumonia biased on the noise-cancellation algorithm that uses active and adaptive acoustics.(Correction to Lancet Digit Health 2022; 4: e37–45 (The Lancet Digital Health (2022) 4(1) (e37–e45), (S2589750021002284), (10.1016/S2589-7500(21)00228-4)). 2022) .The Upgrade of this device had started with its hardware, where the chest piece is packed with transducer arrays to achieve a uniform sensitivity over the entire active area. This design delivers a strong signal even when the chest piece isn't placed in precisely the right location, which gives a major assist to untrained users. And it is stated that they had experimented with a variety of transducers, including microelectromechanical systems (MEMS), which had allowed to pack many microphones into a small area, as well as nanofiber materials that match the acoustic properties of skin to limit signal loss. This intelligent stethoscope has an external microphone that records ambient sounds, and the system uses active and adaptive acoustics to remove those sounds, in real time, from the digitized audio signal transmitted to the user's ears. Pulmonologists are trained to ignore other body sounds, such as the heartbeat, when they listen to the lungs. As same as the way the smart scope detects those extraneous sounds and removes them, too. This algorithm trained on a database of recordings of about 1,500 patients from five African countries and two Asian countries and after testing with the AI-enabled app, they found that it could automatically distinguish healthy people from those with pneumonia with an accuracy of 87%, far surpassing other automatic diagnosis methods. And they worked on this algorithm, aiming to improve its performance with machine learning techniques. Health workers in rural clinics could use our smart stethoscope even if they don't have access to the Internet, the onboard technology does all the processing and provides an instant recommendation on diagnosis using a small built-in LED display. And the Johns Hopkins smart scope is designed to be significantly cheaper, with affordable electronic components and low-cost power and computing options, in hopes that it can be useful for lower source communities. They had created a noise-cancellation algorithm that uses active and adaptive acoustics. Instead of just setting up a filter and letting it run in a passive way, this system analyzes both lung sounds, and ambient sounds recorded by the external microphone, looking at their frequencies on the audio spectrum. Then after app adapts the degree and spectral span of noise cancellation as the algorithm tracks the two signals over time.As in a such a way they had develop this digital stethoscope specially based on the "noise cancellation system." Finally, their intention was to make at least one parent sees her child recover because of early diagnosis, due to this AI based stethoscope.

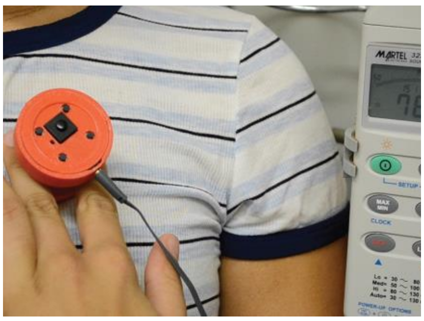

Figure 5. A line graph using colours

C. Development of a Finger-Ring-Shaped Hybrid Smart Stethoscope for Automatic S1 and S2 Heart Sound Identification

This is research that was developed by the group of scientists in Korea to improve the accuracy of auscultation, and to allow nonmedical staff to conduct cardiac auscultation anywhere and anytime, a hybrid-type personal smart stethoscope with an automatic heart sound analysis function. The device was designed with a folding finger-ring shape that can be worn on the finger and placed on the chest to measure photoplethysmogram (PPG) signals and acquire the heart sound simultaneously. The measured heart sounds are detected as phonocardiogram (PCG) signals, and the boundaries of the heart sound variation and the peaks of the PPG signal are detected in preprocessing by an advanced Shannon entropy envelope. According to the relationship between PCG and PPG signals, an automatic heart sound analysis algorithm based on calculating the time interval between the first and second heart sounds (S1, S2) and the peak of the PPG was developed and implemented via the manufactured prototype device. And they tested prototype device with 20 young adults, the experimental results showed that the proposed smart stethoscope could satisfactorily collect the heart sounds and PPG signals. This developed algorithm was as accurate in start-points of heart sound detection as professional physiological signal-acquisition systems. Experimental results from this device demonstrated that it was able to identify S1 and S2 heart sounds automatically with high accuracy.

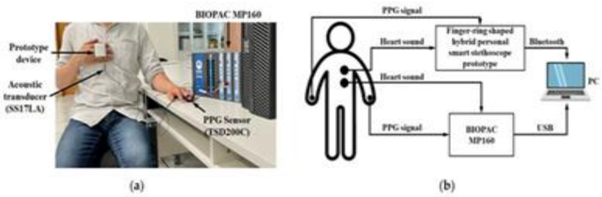

Figure 6. A line graph using colours

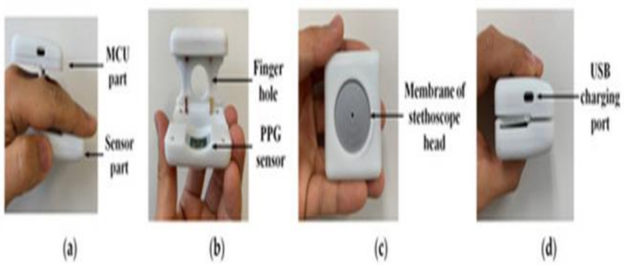

Figure 7. A line graph using colours

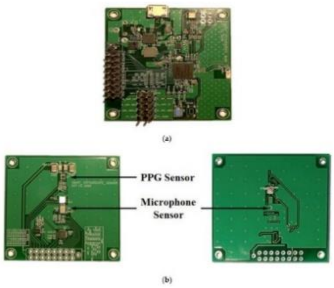

Figure 8. A line graph using colours

D. Real-Time Smart-Digital Stethoscope System for Heart Diseases Monitoring

Here the group of scientists from Malaysia, recognized that there is an unmet need for a portable system for the early detection of cardiac illnesses. And they proposed a prototype model of a smart digital-stethoscope system to monitor patient's heart sounds and diagnose any abnormality in a real-time manner.(Leng et al. 2015) This system consists of two subsystems that communicate wirelessly using Bluetooth low energy technology: A portable digital stethoscope subsystem, and a computer-based decision-making subsystem. The portable subsystem captures the heart sounds of the patient, filters and digitizes, and sends the captured heart sounds to a personal computer wirelessly to visualize the heart sounds and for further processing to decide if the heart sounds are normal or abnormal. In here the twenty-seven t-domain, f-domain, and Mel frequency cepstral coefficients (MFCC) features were used to train a public database to identify the best-performing algorithm for classifying abnormal and normal heart sound (HS). (Patel et al. 2022)The hyper parameter optimization, along with and without a feature reduction method, was tested to improve accuracy. And the used cost-adjusted optimized ensemble algorithm produced 97% and 88% accuracy of classifying abnormal and normal HS, respectively. Feature reduction, hyperparameter optimization, along with asymmetrical cost assignment in the training of algorithm were evaluated to obtain the best performance from this algorithm.So it is clear that scientist had tried hard to introduce and developed the concept of "smart Stethescope" but here we tried to present it with an additional real-time feedback system to make it more innovative .

III. METHODOLOGY

So here the objective of our research is to develop a tube-free intelligent stethoscope that not only diagnoses heart diseases (CAD) but also provides real-time feedback and guidance to the user during auscultation. Among the cardiac conditions in present, we mainly focused on CAD which is a deadly disease all over in Sri Lanka at the present. And surely it will be an innovative attempt to rescue one's life from cardiologic diseases and revolutionize the field of cardiac diagnostics. So by integrating artificial intelligence and real-time heart sound analysis, this intelligent stethoscope aims to overcome limitations of traditional auscultation methods and provide enhanced diagnostic capabilities, immediate feedback and personalized patient care. So the findings of this research will have implications for improving clinical practice, facilitating early detection, reducing misdiagnosis rates and finally improving patient outcomes(Sau and Ng 2023). This research design combines data collection, pre processing techniques, AI model development and real - time feedback implementation system.

I. Data collection

The audio data used in this study were collected from patients with known heart conditions and individuals without heart diseases. A total of 900 heart sound recordings were obtained from various healthcare facilities, research institutions and public websites. The inclusion criteria for the recordings included individuals of different areas, ages, genders, and diverse cardiac conditions.

II. Data preprocessing

Here we used so many preprocessing techniques as Resampling, noise removal using filters, signal normalization, signal segmentation, signal amplification, denoising, Artifact removal, Data augmentation and baseline correction, prior to the analysis of audio data. In here the artifacts and irrelevant sounds were eliminated to ensure the quality and the reliability of heart sound recordings. In this preprocessing stage the input data were subject to so many pre -processing techniques in order to clean and enhance the audio signals, filter out noise, Amplify the signals, enhance the quality of signals and to extract relevant features from the set of audio data.

III. Feature extraction

To extract the relevant features from the preprocessed audio signals, feature extraction is taking place. In here the Time-domain features as duration, intensity and rhythm were extracted. Here we used STFT (Short Time Fourier Transform) to convert the time-domain audio signals captured by stethoscope in to spectrograms which will provide a visual representation of frequency content of heart sound over time And also the frequency-domain features, such as spectral content and dominant frequencies were computed using STFT . Statistical features , including mean ,variance and entropy were also calculated to capture additional information from the heart sound signals.

IV. Spectrogram Generation

It is a visual representation of the frequency content over time. Spectrogram generation is one of the main techniques used in analyzing heart sounds. We wanted to develop it as a valuable insights into frequency components that present heart sound signals ,allowing detailed analysis and feature extraction .Here we used STFT which break down audio signals into smaller segments and applied Fourier Transform to each frame to obtain it's frequency contentment, which displayed a time – frequency representation of the preprocessed audio signal .And finally obtained a visual representation of the frequency content and changes in the heart sound over time ,and it was displayed on a small portable digital screen in the designing of this stethoscope to get a clear ,conscience idea about the heart rhythm rate over time . And we used SciPy and librosa in Python to compute the STFT and generate spectrograms from the audio data. And this spectrogram was used for further analysis, future extraction, and input to the CNN model for CAD identification and real -time feedback generation.

Then the spectrogram data were again preprocessed and organized with corresponding labels or annotations indicating the presence of heart abnormalities or classifications.

V. AI Model development using CNN

Here we used Convolutional Neural Network (CNN) architecture to develop the AI model. The CNN model was trained using the preprocessed heart sound data, with a training set comprising 80% of the data, a validation set of 10% and a test set of 10% . The model was optimized using the Adam optimizer with 0.001 learning rate. And also the loss function (categorical cross-entropy) is used, and the model was trained for 50 epochs . (And ReLU is used as the activation function here) In order to develop CNN model and to classify and diagnose abnormal heart sounds over normal heart sounds we used.

Then after training using CNN model it had the ability to predict new, unseen data to classify it as normal or abnormal data. And we tried to experiment with different configurations of convolutional and pooling layers to capture different levels of abstraction in the heart sound data. And finally added regularization techniques as batch normalization to prevent overfitting and improve generalization. Then the model was trained with a training set of data using batch-wise processing and backpropagation. Then this is the method that we used to classify abnormal cardiological audio patterns from normal ordinary patterns which cause the CAD conditions. So finally, we obtained an accuracy rate of 65%. Here in order to develop CNN model and to classify and diagnose abnormal heart sounds over normal heart sounds we used python libraries TensorFlow and pytorch.

```
import tensorflow as tf
from tensorflow. keras import layers
# Define the CNN model architecture
model = tf.keras.Sequential([
   layers.Conv2D(32,kernel_size=(3,3),
activation='relu',input_shape=(input_height, input_width,
input_channels)),
      layers.MaxPooling2D(pool_size=(2, 2)),
      layers.Conv2D(64,kernel_size=(3,3),
activation='relu'),
      layers.MaxPooling2D(pool_size=(2, 2)),
      layers.Flatten(),
      layers.Dense(128, activation='relu'),
      layers.Dense(num_classes, activation='softmax')
   ])
   # Compile the model
   model.compile(optimizer='adam',
loss='categorical_crossentropy', metrics=['accuracy'])
   # Train the model
   model.fit(x_train, y_train, batch_size=batch_size,
epochs=num_epochs, validation_data=(x_val, y_val))
   # Evaluate the model
   test_loss, test_accuracy = model.evaluate(x_test, y_test)
   # Make predictions
predictions = model.predict(x_test)
```

And still we had the real-time implementation & feedback system on the experimental stage. After the CNN model processes the spectrogram data and make the predictions, interpret the results based on the detected heart conditions or abnormalities and then we can define a set of rules to classify the predictions into different categories (e.g. - normal / abnormal / specific heart conditions) and also we can assign level of severity to each prediction based on the mode's output probabilities. And then we could customize the feedback system with visual cues, audio cues, textual feedback and with a Real-time guidance indicating the presence of abnormality or specific CAD condition.
(Patel et al. 2022)

IV. DISCUSSION AND FUTURE WORKS

Findings from this research depict the successful development of the software prototype for the tube-free-AI based intelligent stethoscope with real -time heart sound analysis and feedback system.
So mainly this system combines advanced signal processing techniques, STFT, machine learning algorithms and real -time feedback mechanisms to enhance the accuracy and the usability in cardiac auscultation.

Comparing with the traditional stethoscope this system has so many advantages as Accurate diagnosis of CAD ,prior Diagnosis of CAD at its initial stages ,No need of any expert physician to diagnose any cardiac condition ,enable to detect subtle abnormalities that may be missed by human listener, ability of obtaining visual feedback using the spectrogram, obtaining real time feedback with the cardiac condition of the heart and the ease of using this new device .And finally we can predict that this new design will enhances the accuracy, usability and standardization of the auscultation process.

However, it is important to acknowledge the limitations of our research. The performance of the intelligent stethoscope may be affected by variations in heart sound recordings, external noise interference and specific patient population. Further validation studies involving larger and more diverse patient cohorts are necessary to assess the system's accuracy and generalizability.(Neal et al. 2022)

And it is essential that, up to now we only developed the software prototype of this intelligent stethoscope, and we want to state that in future we aimed to develop the full hardware part of this stethoscope including the tube- free structure here. According to the opinion of so many physicians we got to know that tube in the traditional stethoscope is difficult when using due tangling, kinking and rigidity. So, we decided to make the hardware part, without the tube for our intelligent stethoscope in the future.

V. CONCLUSION

Finally, in this research we have developed a intelligent software part for a tube-free AI -based intelligent stethoscope with real-time heart sound analysis and feedback system, mainly aiming the CAD patient population to improve the accuracy and usability of cardiac auscultation. Through the integration of advanced signal processing techniques, machine learning algorithms and real- time feedback mechanisms our system has shown promising results in the early detection of CAD subsidizing the mortality rates of cardiac patients.

The implementation of AI algorithms has allowed the intelligent stethoscope to analyze heart sounds with higher level of precision, surpassing the capabilities of the traditional stethoscopes.

By leveraging a vast amount of training data, the system has demonstrated remarkable accuracy in identifying mainly the CAD including other various cardiac conditions. This breakthrough has the potential to to revolutionize cardiology practice by enabling early detection and prompt intervention, ultimately leading to improved patient outcomes. And the real -time feed back system embedded in our intelligent stethoscope has proven to be an invaluable tool during the auscultation.

In conclusion, the development of a tube-free AI-based intelligent stethoscope with real-time heart sound analysis and feedback system represents a significant advancement in cardiac auscultation in Sri Lanka. This technology has the potential to transform the field of cardiology by improving early detection, diagnosis, and management of heart diseases. By enhancing the diagnostic accuracy, usability, and standardization of the auscultation process, our intelligent stethoscope aims to empower healthcare professionals, improve patient outcomes, and reduce healthcare costs.

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