Smart Stethoscope

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Abstract—**Worldwide, the major cause of death is Cardiac Dysfunction, which can be detected through heart sounds. Acoustic stethoscopes are one of the oldest methods of auscultation. An ordinary acoustics-based stethoscope is limited in providing high-quality sound in noisy environments. This paper addresses the problem of cost-effectively making a smart stethoscope using modern electronics and computing technologies for cardiac auscultation. Along with that, to have telemedicine involved with the utmost accuracy possible. The chest piece of stethoscope is used here to capture sound of the heart beats, MEMS microphone INMP441 is used to convert the sensed sound signals into electrical signals which is then sent to ESP32 (microcontroller) and stored in SD card due to the large amount of data available. The stored data is then sent to a server for implementing Machine Learning algorithm to classify the data as normal or abnormal. The output parameters i.e. BPM, waveform of the sound data, and audio data are sent to telegram bot which can be shared to a healthcare professional for review. This is an example of telemetry where doctor's physical intervention is not required to diagnose the condition of the subject's heart. The smart stethoscope is designed to record and transmit real-time heart sounds to healthcare professionals while considering cost-effectiveness and portability. In the future, a database can be added to store historical results for the analysis of the subject's heart condition, and also expand the classification model to include more heartbeat anomalies.**

Index Terms—**Cardiac auscultation, cost effective, ESP-32, Machine Learning Algorithm, MEMS microphone, Portability, Stethoscope, Telegram Bot, Telemedicine.**

I. INTRODUCTION

A smart stethoscope represents a significant advancement in the field of auscultation, the medical practice of listening to internal body sounds. These innovative devices integrate cutting-edge technology into the traditional acoustic stethoscope, transforming it into a powerful diagnostic tool. By incorporating digital sensors, advanced signal processing, and often, artificial intelligence, smart stethoscopes enhance the ability of healthcare professionals to capture, amplify, and analyse heart sounds with unprecedented accuracy.

In essence, smart stethoscopes empower healthcare providers with a more comprehensive and insightful understanding of patient conditions, ultimately leading to improved patient care and more informed clinical decision-making.

1.1. LITERATURE REVIEW

The advancement of digital stethoscopes has led to significant improvements in cardiac and pulmonary auscultation through the integration of modern electronics, signal processing, and artificial intelligence. Several studies have explored different approaches to enhance diagnostic accuracy, portability, and real-time monitoring using smart stethoscope technology.

These studies collectively demonstrate the evolution of stethoscope technology from traditional acoustic devices to AI-powered, portable, and real-time diagnostic tools. The advancements in signal processing, wireless transmission, and machine learning pave the way for more efficient and accessible healthcare solutions, enabling better cardiac disease detection in both clinical and remote settings.

1.2. OBJECTIVE

The objectives of the proposed system are:

- Accurate Heartbeat Measurement: The Smart Stethoscope provides precise heartbeat counts, minimizing the potential for errors inherent in manual counting.
- Automated Abnormality Detection: Utilizing sophisticated algorithms and machine learning models, the stethoscope can analyze heart sounds in real time to detect anomalies such as heart murmurs, arrhythmias, or other cardiac dysfunctions.
- Waveform Display and Analysis: Heart sounds are converted into digital signals, which are then visualized as waveforms on connected devices such as smartphones or tablets.

II. COMPONENTS

2.1. Stethoscope Chest Piece: The chest piece, often known as the head or diaphragm, is responsible for recording body noises. Usually, it has two sides: the diaphragm and the bell. The flat, circular diaphragm is ideal for high-frequency sounds, such as heart murmurs and respiration sounds, whereas the cup-shaped bell is ideal for low-frequency sounds, such as heart sounds.

The tubing facilitates the conveyance of sound between the chest piece and the earpieces. Superior tubing assures minimal sound loss, allowing for precise auscultation.

Figure 2.1 Stethoscope chest piece

2.2. INMP441 Microphone: The INMP441 is a high-performance, low power, digital output, omnidirectional MEMS microphone with a bottom port. The complete INMP441 solution consists of a MEMS sensor, signal conditioning, an analog-to-digital converter, anti-aliasing filters, power management, and an industry-standard 24-bit I²S interface. The I²S interface allows the INMP441 to connect directly to digital processors, such as DSPs and microcontrollers, without the need for an audio codec in the system.

The INMP441 has a high SNR and high sensitivity, making it an excellent choice for far field applications. The INMP441 has a flat wideband frequency response, resulting in natural sound with high intelligibility.

Figure 2.2 INMP441 MEMS microphone

2.3. ESP32 WROOM 32-bit Micro-Controller: ESP32 is a microcontroller board. ESP32 Wroom 32 has 36 pins and 18 on each side of the board as shown in the picture below. It has 34 GPIO pins and each pin has multiple functionalities which can be configured using specific registers. There are many types of GPIOs available like digital input, digital output, analog input, and analog output, capacitive touch, UART communication and USB cable.

Figure 2.3 ESP32 WROOM 32

2.4. SD Card Module: An SD card module serves as an external memory storage device for electronic systems. It facilitates the storage and retrieval of data through its interface, typically SPI. This enables applications like data logging, image/video storage, program storage, and audio playback. SD cards offer high storage capacities, fast data transfer rates, and non-volatility, making them a popular choice for their portability, cost-effectiveness, and ease of integration in various embedded systems and portable devices.

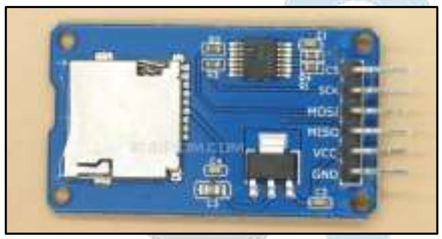

Figure 2.4 SD card module

2.5. SD Card: An SD card, when used within a device, functions as an external memory storage medium. It allows the device to store and retrieve data, such as images, videos, audio files, documents, and even software applications. This external storage capability expands the device's internal memory capacity, allowing users to store more data without limitations imposed by internal memory size.

Figure 2.5 SD card

III. PROPOSED SYSTEM

The proposed smart stethoscope is designed to acquire and analyze heartbeat sounds using a high-sensitivity INMP441 microphone mounted on a chest piece. The microphone captures the raw acoustic signals of the heart and transmits them to an ESP32 microcontroller, which digitizes the data for further processing. The digitized audio is then stored on a micro-SD card in a structured format to ensure easy retrieval and analysis.

Simultaneously, the ESP32 establishes a communication link with an MQTT server over a Wi-Fi network. The recorded heartbeat data, including audio files and signal parameters, is made accessible through HTTP links, allowing remote access and further processing. The stored data is then analyzed by a machine learning algorithm that extracts essential cardiovascular parameters such as Beats Per Minute (BPM), signal waveform characteristics, and an assessment of normality or abnormality in the heart rhythm.

Once the analysis is complete, the system compiles the results, including the BPM, waveform image, and an abnormality percentage, along with the original heartbeat audio. These insights are then transmitted via an MQTT broker and integrated with a Telegram bot. The Telegram bot serves as the user interface, allowing healthcare professionals or users to receive real-time feedback on their heart health. This enables remote monitoring, early detection of potential cardiac issues, and seamless interaction with the system for further analysis or medical intervention.

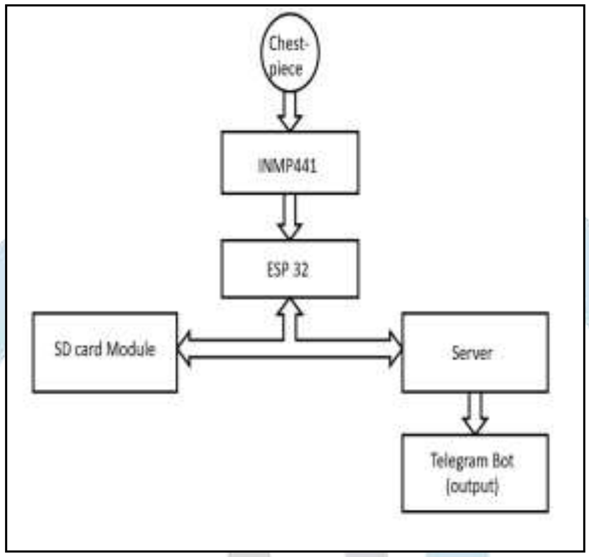

Figure 3.1 Block diagram of the proposed system

IV. IMPLEMENTATION

The connections are made as shown in the Figure 4.1. The system begins with an ESP32 device that records heartbeat audio using a microphone and makes the recorded .wav file available through an HTTP endpoint. A Python server continuously listens to a specific MQTT topic (sensor) using a secure TLS connection to an MQTT broker (e.g., HiveMQ). When a trigger message (e.g., "1") is received on this topic, the server initiates the workflow by downloading the .wav file from the ESP32's HTTP interface. The audio file is then processed using librosa to extract Mel Spectrogram features, which are input to a pre-trained TensorFlow/Keras model that classifies the heartbeat as either normal or abnormal. Simultaneously, the system filters the audio using a bandpass filter to isolate heartbeat frequencies and detects peaks in the signal to calculate the average time between beats, resulting in an estimated BPM. A visual plot of the heartbeat waveform with the classification label is generated for interpretation. Finally, the system sends both the processed .wav file and the waveform visualization .png to a Telegram bot for remote monitoring, while also publishing the results—including BPM and classification—to the MQTT topic for further processing or display on connected clients.

Figure 4.1 Circuit

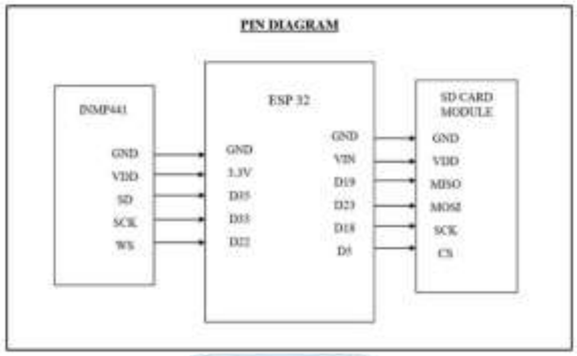

Figure 4.2 Pin diagram of the circuit

V. METHODOLOGY

The smart stethoscope is designed to efficiently capture, process, analyse, and transmit heartbeat sounds for remote monitoring and medical analysis. The heartbeat sound is initially captured by the chest piece, which is connected to an INMP441 microphone. This microphone converts the analog sound waves into an electrical signal. The audio signal is then fed into an ESP32 microcontroller, which is equipped with the I2S (Inter-IC Sound) communication protocol to facilitate the transmission of high-quality digital audio data. The ESP32 processes the incoming sound and stores it on an SD card in a specific file format, such as WAV or MP3, ensuring that a 10-second recording of the heartbeat is saved for analysis.

Simultaneously, the ESP32 establishes a connection with an MQTT server, enabling remote access to the recorded data. The heartbeat audio, along with metadata such as timestamps, is sent to the server for further processing. To facilitate easy access, the ESP32 generates an HTTP link pointing to the stored audio file, allowing device to retrieve and analyse the data. Once the audio data is stored, it is retrieved from the server and analysed using a machine learning algorithm. The algorithm extracts key cardiovascular parameters, including the Beats Per Minute (BPM) by counting heartbeats per minute, a normality check to detect abnormalities such as arrhythmias through pattern recognition, and a waveform image that visually represents the heartbeat's frequency and rhythm.

After the analysis is complete, the processed data, including the BPM, normality assessment, and waveform image, is transmitted to a Telegram bot. The bot allows users to interact with the results, access diagnostic insights, and download the processed heartbeat audio for further analysis or medical consultation. This integration of signal processing, network communication, and artificial intelligence enables the smart stethoscope to serve as a valuable tool for real-time cardiac health monitoring and telemedicine applications.

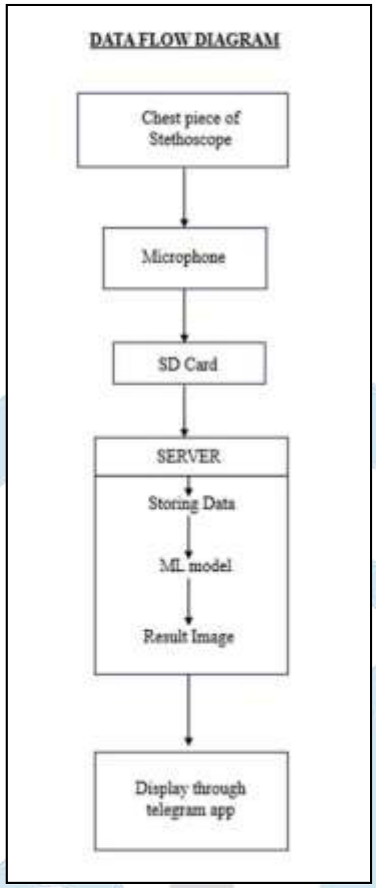

Figure 5.1 Data flow diagram

VI. RESULT AND CONCLUSION

The results after connecting the circuit and implementing the code is given below.

Here, the waveform of the heart beat sound is plotted from the data extracted, the recording of 10 sec of audio data and the bpm estimated from the data extracted is sent to the telegram bot via MQTT protocol and is shown below:

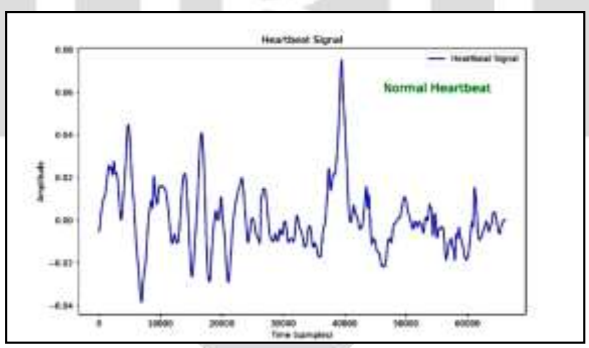

Figure 6.1 Waveform of heartbeat

Figure 6.2 Telegram message

The Smart Stethoscope represents a paradigm shift in cardiac diagnostics, combining traditional auscultation with state-of-the-art technology. This project not only aims to improve diagnostic accuracy but also to democratize access to quality healthcare by providing an affordable and portable diagnostic tool.

6.1 Advantages:

- Noise Reduction: They often incorporate noise-cancelling technology to filter out background distractions, improving sound clarity.
- Recording: Smart stethoscopes can record heart, allowing for later review, consultation with colleagues, or comparison with previous recordings to track changes over time.
- Data Analysis: Advanced model can analyse recorded sounds and provide insights, such as identifying potential heart murmurs or arrhythmias.
- Telemedicine: Recorded sounds can be shared with remote specialists for consultation, facilitating timely diagnosis and treatment, particularly in remote or underserved areas.
- Teaching and Learning: Smart stethoscopes can be valuable tools for medical students and trainees, allowing them to listen to and analyse a wide range of heart and lung sounds.

VII. FUTURE SCOPE

The possible advancements that can be made are:

- Add a database to store historical results for trend analysis.
- Implement additional filters to further remove noise from the audio signal.
- Expand the classification model to include more heartbeat anomalies.
- Seamless integration with electronic health records (EHRs) and other healthcare systems.
- Improved data security and privacy measures.
- Development of smaller, more portable and user-friendly devices.

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