Smart Auscultation System for Heart and Lung Sound Transmission Over BLE

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Abstract

This work presents a smart acoustic diagnostic interface that captures and transmits cardiac and respiratory sounds with better clarity and mobility. The system uses a small condenser microphone to detect biological sounds. These sounds are amplified by a low-power operational amplifier and filtered through an optimized band-pass filter to eliminate background noise. A microcontroller with Bluetooth Low Energy (BLE) capability processes the digitized signal and wirelessly sends it to a receiver device like a smartphone or headset for real-time listening and analysis. A rechargeable lithium-ion battery powers the entire setup, ensuring it is lightweight and portable. Experimental evaluation indicates that the device maintains clear audio transmission, low latency, and stable connectivity, making it suitable for remote auscultation. This system allows healthcare professionals to monitor heart and lung activity without needing to be close to the patient, aiding telemedicine and digital health applications. The proposed design offers a cost-effective, compact, and energy-efficient alternative to traditional stethoscopes. It represents a practical advancement toward modernized and connected diagnostic healthcare.

Keywords: Smart Stethoscope, Acoustic Signal Processing, Bluetooth Low Energy, Telemedicine, Embedded Medical Device, Heart and Lung Sound Analysis.

1. INTRODUCTION

Auscultation is a fundamental diagnostic method used to evaluate heart and lung functions. Traditional acoustic stethoscopes depend heavily on the clinician's hearing ability and do not provide amplification, filtering, or digital storage, which limits diagnostic accuracy in modern clinical environments [1]. As healthcare increasingly adopts telemedicine and remote monitoring, there is a strong need for devices that can enhance auscultation quality while enabling wireless data transmission [2].

Recent advancements in biomedical instrumentation and embedded electronics have enabled the development of digital and smart stethoscopes capable of capturing low-intensity bioacoustic signals with improved clarity. Digital stethoscope platforms have demonstrated effective real-time remote auscultation using Bluetooth technologies, allowing clinicians to assess patients without physical presence [1], [3]. Studies evaluating tele-auscultation systems such as Stemoscope also confirm the feasibility and reliability of remote listening systems in real-world conditions [2].Wireless communication technologies such as Bluetooth Low Energy (BLE) have become central to modern auscultation devices due to their low power consumption, stable connectivity, and suitability for continuous medical monitoring [3], [4]. Embedded microcontroller systems further support digital filtering, amplification, and signal conditioning, enabling clinicians to detect subtle cardiac and pulmonary abnormalities with higher accuracy compared to traditional tools [8], [9].

Advanced research has also explored integrating smart diagnostic algorithms, wearable platforms, and multi-sensor architectures to improve cardiopulmonary assessment [4], [7]. AI-enhanced digital stethoscopes and automated auscultation systems demonstrate potential for future clinical applications, including anomaly detection and robotic sound acquisition [5], [7]. Additionally, advanced sound separation studies highlight the importance of noise reduction for obtaining clean, clinically useful signals, particularly in neonatal care [6].In this context, the present work proposes a smart acoustic diagnostic interface capable of capturing, processing, recording, and wirelessly transmitting heart and lung sounds. The system employs a high-sensitivity microphone, analog signal conditioning circuits, a microcontroller for digital processing, and BLE for wireless streaming. The inclusion of a recording feature allows the auscultation data to be stored for future comparison, follow-up evaluations, and medical education.

By combining embedded processing, wireless communication, and data storage, the proposed system provides a low-cost, portable, and user-friendly solution that aligns with the evolving needs of digital healthcare. This contributes to improved tele-auscultation, point-of-care diagnostics, and continuous cardiopulmonary monitoring [10].

2. Problem statement

Conventional acoustic stethoscopes let clinicians hear heart and lung sounds only in real time, depending entirely on the user's hearing ability. These traditional devices lack options for amplification, noise reduction, wireless transmission, or digital recording. This makes it hard to review past data, track patient progress, or conduct remote diagnoses.

As telemedicine and continuous monitoring become more common, the lack of recording capability becomes a significant drawback. Clinicians cannot store, analyze, or share auscultation sounds for future evaluation.

To tackle these issues, the proposed system presents a smart acoustic diagnostic interface. This interface allows for real-time listening, wireless transmission, and digital recording of heart and lung sounds. It improves diagnostic accuracy, supports remote healthcare applications, and enables storage of auscultation data for future clinical review and comparison.

3. Methodology

The approach taken to develop the smart acoustic diagnostic interface follows a clear process, starting with signal acquisition. This is followed by noise reduction, digital processing, wireless transmission, and receiving, with features for recording and analyzing the acoustic data.

The method for the proposed smart diagnostic interface uses a multi-stage process to acquire and process signals. This transforms raw physiological sounds into clean digital data that can be analyzed. The process starts with collecting heart and lung sounds using a high-sensitivity condenser microphone. This microphone is placed inside a sealed chest piece, which helps maintain strong acoustic coupling and limits background noise. It is chosen for its high gain, wide frequency response (20 Hz to 2000 Hz), and low internal noise. This setup allows accurate capture of heart sounds like S1, S2, and murmurs, as well as lung sounds such as wheezes, crackles, and airflow turbulence.

The captured acoustic signals are very weak and easily affected by the environment. Therefore, they go through an analog conditioning stage. This stage includes a low-noise pre-amplifier that boosts signal strength without causing distortion. It also uses a band-pass filter that keeps only the clinically relevant frequencies of the heart and lungs, along with a notch filter to remove 50/60 Hz power-line noise that often appears in indoor clinical settings.

Once conditioned, the waveform is digitized using the microcontroller's analog-to-digital converter. It samples at 8 to 16 kHz with a resolution of 12 to 16 bits to capture subtle diagnostic details. The digitized data then goes through digital signal processing, which includes refined filtering, spectral subtraction, and wavelet-based denoising. This helps reduce any leftover noise while preserving the natural characteristics of heart and lung patterns.

An automatic gain control (AGC) algorithm normalizes amplitude so both soft and loud sounds stay audible and useful for diagnosis. For systems that support automated interpretation, important acoustic features like frequency components, time-domain signatures, Mel-frequency coefficients, and heart-cycle markers are extracted to help identify abnormalities. The cleaned audio is then encoded into a format ready for transmission, either as raw PCM for the best sound quality or as a low-bitrate codec like SBC or LC3 when trying to optimize for BLE bandwidth. The processed frames are sent via Bluetooth Low Energy (BLE), ensuring low power use, stable connectivity up to 10 meters, encrypted data transfer, and low enough latency for real-time auscultation. At the receiving end, usually a mobile app, BLE packets are reassembled into a continuous audio stream. This stream is corrected for jitter or packet loss and played back instantly through smartphone speakers, wired earphones, or Bluetooth headsets. A major improvement over traditional stethoscopes is the ability to record the reconstructed audio in high-quality WAV or compressed formats. This feature enables clinicians to store, replay, compare, or share recordings for remote consultations or educational purposes. For additional diagnostic help, optional classification algorithms can examine live or recorded signals to detect murmurs, identify abnormal lung patterns like wheezes or crackles, and differentiate between normal and pathological recordings. Overall, this approach ensures reliable acquisition, noise-optimized processing, bandwidth-efficient wireless transmission, clear real-time playback, and optional AI-based interpretation, effectively addressing the limitations of conventional acoustic stethoscopes and supporting modern telemedicine workflows.

4. System architecture

The overall structure of the smart acoustic diagnostic interface is organized into four main layers: (1) signal acquisition, (2) processing and conditioning, (3) wireless transmission, and (4) reception, recording, and analysis. Each layer has a specific role in ensuring effective, low-noise, and real-time monitoring of heart and lung sounds.

The proposed smart acoustic diagnostic interface has a multi-layer architecture that combines sensing, conditioning, processing, and wireless transmission into a compact embedded platform. The system starts with an acoustic sensing module that uses a high-sensitivity condenser microphone in the chest piece. This microphone captures low-frequency heart sounds like S1, S2, and murmurs, as well as wide-band lung sounds like wheezes, crackles, and airflow patterns. It provides stable mechanical coupling to the chest while filtering out unwanted external vibrations.

The captured signal goes to the analog signal conditioning layer, which prepares it for digitization. It amplifies the weak microphone output with a low-noise pre-amplifier. Then, a band-pass filter keeps the important frequencies between 20 Hz and 2 kHz while removing motion artifacts and background noise. A notch filter also removes 50/60 Hz power-line interference, which is common in hospital environments.

Next, the conditioned signal enters the digital processing layer in the microcontroller, such as the ESP32. Here, the onboard ADC samples the waveform at 8 to 16 kHz with 12 to 16-bit resolution. Digital processing techniques, including band-pass filtering, spectral subtraction, wavelet denoising, and automatic gain control, improve clarity. Finally, the cleaned digital signal is formatted for wireless transmission using PCM or low-bitrate BLE codecs like SBC or LC3, while control logic oversees buffering, connection stability, and battery usage.

Wireless transmission occurs through Bluetooth Low Energy (BLE). It packetizes the audio into BLE frames, ensures secure encrypted transfer, has a range of up to 10 meters, and supports low-latency streaming that is suitable for real-time auscultation. On the receiving side, a dedicated mobile app reconstructs the audio from BLE packets. This allows playback through phone speakers, wired earphones, or Bluetooth headsets. It also lets users record the auscultation sounds as high-quality WAV files or compressed files for storage or cloud upload. The app can generate visualizations like waveforms, spectrograms, and heart cycle markers. For deeper analysis, an optional classification engine can use machine learning models, pattern recognition, or statistical detection to find abnormal heart or lung sounds, murmurs, crackles, or irregular rhythms. This engine can work locally on the mobile device or use cloud processing. Overall, the system captures clear sound, reduces noise effectively, encodes efficiently, transmits wirelessly in a reliable manner, and offers smart diagnostic support. It transforms a regular stethoscope into a smart, connected platform suitable for both real-time and long-term cardiopulmonary monitoring.

5. FLOW CHART

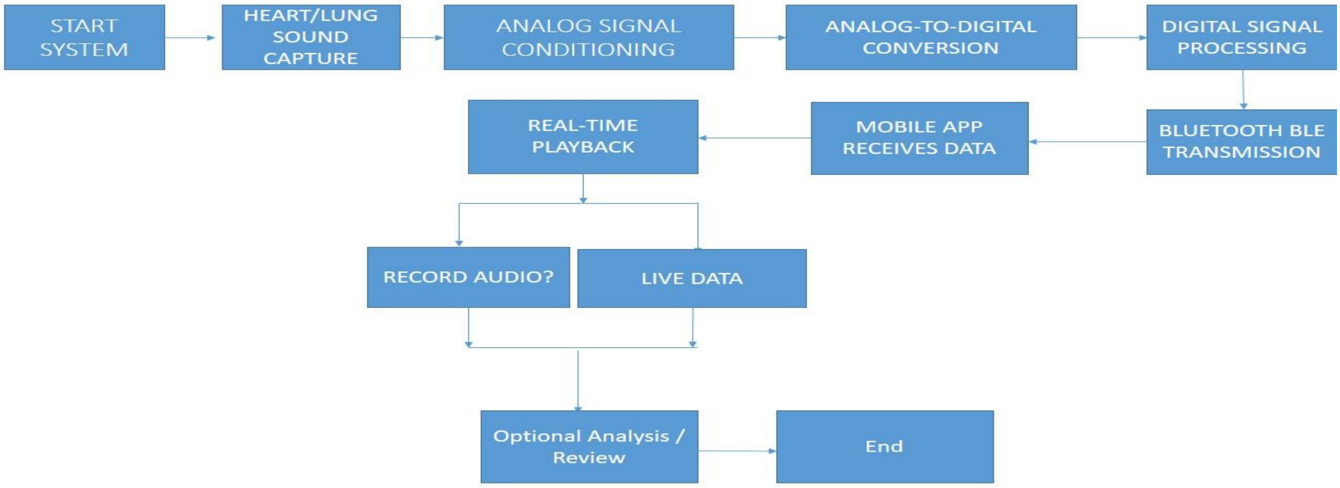

Fig. Flowchart of Working process

6. Conclusion

The smart acoustic diagnostic interface created in this study offers a practical way to update traditional auscultation. By using a sensitive microphone, analog conditioning circuits, digital signal processing, and Bluetooth Low Energy transmission, the system effectively captures, filters, and wirelessly delivers heart and lung sounds with greater clarity. The added recording feature provides important clinical benefits. It allows users to review, compare, and share stored audio for remote diagnosis or medical education.

Experimental observations show that the prototype keeps stable wireless connectivity and offers real-time playback, which is suitable for telemedicine applications. The system's portable, low-power design makes it convenient for point-of-care use, especially in rural or resource-limited areas where access to specialists is difficult. Overall, this device connects traditional acoustic stethoscopes with new digital healthcare technologies, providing an affordable and accessible solution for better cardiopulmonary assessment.
Future work may focus on incorporating new signal-classification techniques, enhancing noise reduction, or connecting the system to cloud-based diagnostic platforms for extended healthcare support.

7. Conflict of Interest

The authors state that there is no conflict of interest related to this research. The authors conducted all design, analysis, and system development independently. Some supporting information, including literature references and background data, came from publicly available online sources for academic use only. These outside materials did not affect the originality, integrity, or objectivity of the findings in this study.

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