# ACOUSTIC STETHOSCOPE WITH MICROPHONE FOR NON-INVASIVE CARDIOVASCULAR HEALTH MONITORING

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**DOI:** https://doi.org/10.5281/zenodo.15180157

**Keywords**
Fintech, Financial Institutions

**Article History**
Received on 02 March 2025
Accepted on 02 April 2025
Published on 09 April 2025


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**Abstract**
*Heart rate measurement is crucial for assessing cardiovascular health and overall well-being. Traditional methods like ECG and PPG rely on physical contact, but modern acoustic techniques enable non-invasive heart rate monitoring through microphones, making it more accessible. This research focuses on designing a microphone-based system that processes acoustic signals using Digital Signal Processing (DSP) and Fast Fourier Transform (FFT) to filter noise and extract heartbeats. The system calculates heart rate in beats per minute (BPM), classifies it into Low, Normal, High, or Abnormal based on age-specific cut-off points, and provides real-time feedback through visual plots, addressing diverse health needs.*
*The study demonstrates FFT's efficiency in noise reduction and frequency separation, enhancing detection under various conditions. By offering affordable, user-friendly solutions, the system is suitable for home health monitoring, athletic performance evaluation, and elderly care. However, environmental noise and signal fluctuations highlight the need for further refinement. This work emphasizes the advantages of non-intrusive, acoustic-based heart rate monitoring techniques, paving the way for improved, cost-effective approaches to cardiovascular health management.*

## INTRODUCTION

Cardiovascular diseases (CVDs) are the leading global cause of death, particularly in low-income regions that lack access to advanced diagnostic tools such as electrocardiograms (ECGs) and magnetic resonance imaging (MRI). Traditional heart auscultation using stethoscopes is widely used, but it remains subjective and less reliable. Modern digital stethoscopes, when combined with machine learning, provide real-time recording and analysis of heart sounds, offering a more accurate and cost-effective alternative for diagnosing heart conditions (Sinharay et al., 2016).

Heart auscultation requires specialized expertise, and many heart conditions often go undiagnosed until they reach critical stages. The high costs associated with advanced diagnostic tools further burden patients and their families. There is a clear need for affordable, accurate, and user-friendly devices to facilitate early detection and diagnosis of cardiovascular diseases (Nuttall & Teng, 2021).

Despite advancements in medical diagnostics, cardiovascular diseases remain a leading cause of death globally, especially in regions where access to costly and sophisticated diagnostic tools is limited. Traditional heart auscultation, though a simpler diagnostic method, is still hindered by its subjective nature and reliance on the skill of the practitioner. This project seeks to address these accessibility challenges by offering a more reliable and affordable solution, ensuring that heart conditions can be diagnosed earlier and more accurately.

The proposed solution is the development of a digital stethoscope equipped with a microcontroller and an auxiliary pin for real-time analysis of heart sounds. This device will classify heartbeats as normal or abnormal and provide live feedback through a connected device. The main goals are to design and develop a digital stethoscope that can accurately analyze heart sounds, enable real-time monitoring on electronic devices, create a portable and user-friendly interface, and rigorously test and validate the device's performance to ensure its reliability and effectiveness in early heart condition diagnosis.

## 1. LITERATURE REVIEW

Heart rate measurement plays a crucial role in assessing cardiovascular health, and acoustic-based methods are increasingly preferred due to their non-invasive nature and ease of implementation compared to traditional methods like ECG and PPG. This chapter reviews key advancements in acoustic heart rate monitoring, signal processing, and classification (Fattah et al., 2017).

Traditional methods such as ECG and PPG require physical contact with the body, whereas acoustic methods offer touchless alternatives by detecting heart sounds. Light-based techniques are also popular for their simplicity and cost-effectiveness, but acoustic systems remain more advantageous, particularly in low-resource settings (Wang et al., 2009). These systems provide an accessible and practical solution for heart rate monitoring, especially in environments where advanced diagnostic tools are unavailable.

Signal processing is a critical component in transforming raw audio data into usable heart rate information. The key steps in signal processing include data acquisition, Fourier Transform (FT) for frequency analysis, and adaptive filtering to eliminate noise. FT is particularly effective in identifying heartbeats and suppressing interference, ensuring that the data is both accurate and reliable (Sinharay et al., 2016).

Heart rate zones, which are classified based on age and activity level, help in health management by providing insight into the individual's cardiovascular condition. For example, resting heart rates for teenagers typically range between 60–80 bpm, while for elders, it is 70–90 bpm. Real-time feedback on heart rate zones enhances user awareness and supports preventive care (Leng et al., 2015), making it easier for individuals to manage their health.

Effective heart rate monitoring systems also incorporate real-time graphical visualizations, such as time-series plots and color-coded zones, to make physiological data more accessible and engaging for users. These visual tools enhance user experience and encourage timely responses to changes in heart rate.

Recent advancements in acoustic heart rate monitoring have included the integration of machine learning for noise reduction and the incorporation of Internet of Things (IoT) technology, enabling portable, real-time monitoring devices. These innovations improve the usability of heart rate monitoring systems and pave the way for remote healthcare solutions, expanding the reach of such technology to more people, especially in underserved regions.

Acoustic heart rate monitoring has a wide range of applications, including home health monitoring, athletic training, and elderly care. Its non-invasive nature and cost-effectiveness make it an ideal solution for managing cardiovascular health in these contexts.

However, challenges remain in this field, including environmental noise, maintaining accuracy under dynamic conditions, and hardware limitations. To overcome these issues, improvements in algorithms and microphone sensitivity are necessary for enhancing the performance and reliability of acoustic monitoring systems.

In conclusion, acoustic heart rate monitoring is a promising field, offering affordable and user-friendly solutions for cardiovascular health management.

Nevertheless, further research is needed to address challenges such as noise interference, accuracy, and algorithm optimization, ensuring that these systems provide enhanced results and continue to meet the needs of diverse user groups.

## 2. IMPLEMENTATION AND SYSTEM DESIGN:

This chapter outlines the methodology for designing a microphone-based Heart Rate Monitoring System, focusing on data acquisition, signal processing, heart rate calculation, validation, and experimental methods to ensure accurate results (Leng et al., 2015). The system consists of several key components: data acquisition, signal processing, and visualization with real-time feedback. Audio signals were recorded using a microphone, and the physiological features were analyzed using Fast Fourier Transform (FFT). Real-time heart rate trends and zones were displayed to the user. Python was used for development, utilizing PyAudio for recording, NumPy for signal processing, and Matplotlib for visualization.

Data was recorded using a microphone at a sampling rate of 44,100 Hz and a bit depth of 16 bits, with each session lasting 60 seconds. The recorded signals were then segmented into 1,024-sample frames to facilitate efficient processing. Signal processing involved several steps. First, preprocessing was applied, where the FFT converted the time-domain signals into the frequency domain, isolating the heart rate frequencies in the 1–2 Hz range. Peak detection was then performed, identifying the maximum frequency within this range, which was converted into beats per minute (BPM) using the formula: BPM = Frequency (Hz) × 60 (Roy & Roy, 2017).

Heart rate zones, such as "Low," "Normal," "High," and "Abnormal," were classified in real-time based on the user's age and thresholds established in medical literature. Feedback was shown graphically to provide users with clear and actionable information about their heart rate. The experimental setup involved testing the system in a low-noise environment with participants of varying ages. The results were compared with data from a commercial pulse oximeter to evaluate the system's accuracy.

Validation of the system's performance was carried out by evaluating its accuracy through measures like mean absolute error, Bland-Altman plots, and paired t-tests, which assessed statistical significance. Ethical considerations were taken into account, with informed consent obtained from all participants and data anonymized to ensure privacy protection. In conclusion, the system successfully developed an accurate, user-friendly algorithm for real-time heart rate monitoring, prioritizing both reliability and ethical practices.

## 3. ALGORITHMS AND METHODOLOGY:

The system employs signal processing techniques, primarily the Fast Fourier Transform (FFT), to analyze audio data and accurately calculate heart rate (Sinharay et al., 2016).

The algorithm consists of four main phases: data acquisition, signal processing, heart rate zone classification, and visualization. In the data acquisition phase, audio signals are recorded using PyAudio, segmented into 1,024-sample chunks, and saved as NumPy arrays for efficient processing. The data processing algorithm follows several key steps. First, the recorded audio chunks are combined into a single array. Next, the FFT is applied to analyze the frequencies of the signal. Frequency filtering is then performed, focusing on the 1–2 Hz range (60–120 BPM), and irrelevant frequencies are removed. Peak detection identifies the highest amplitude frequency, which is converted to beats per minute (BPM) using the formula: BPM = Frequency × 60.

The heart rate zone classification phase compares the calculated BPM to age-specific thresholds, categorizing the heart rate as "Normal," "Low," "High," or "Abnormal," based on medical guidelines. In the visualization phase, real-time heart rate trends are plotted using Matplotlib. The last 100 BPM values are dynamically updated, and the corresponding heart rate zones are displayed as text annotations for clear feedback to the user.

The algorithm is implemented using several key components: PyAudio for audio recording, NumPy for FFT analysis and frequency extraction, a BPM calculation step to convert peak frequency to heart rate, a classification process that assigns heart rate zones based on age-specific logic, and Matplotlib for dynamic visualization of heart rate trends and zones.

In conclusion, the system integrates FFT-based frequency analysis, age-specific classification, and real-time visualization to effectively monitor heart rates. This chapter has outlined the steps of the algorithm and its implementation.

## 4. RESULTS AND DISCUSSION

This chapter discusses the performance and results of the real-time heart rate monitoring system using a microphone, focusing on its accuracy in measuring heart rate and categorizing it into Normal, Low, High, or Abnormal zones. The system recorded acoustic signals for one minute, processed them using digital signal processing (DSP), and determined the heart rate using Fast Fourier Transform (FFT). Tests were conducted on individuals of various ages, and the system's results were compared to those of medical-grade devices. The system measured heart rate (BPM), which was derived from frequency analysis of acoustic signals, and classified the heart rate into zones (Low, Normal, High, or Abnormal) based on age-specific thresholds.

The system demonstrated high accuracy in heart rate measurement, with an average deviation of less than 5 BPM compared to reference devices. In terms of heart rate zone classification, the system effectively classified heart rates for individuals aged 18–65, with most resting heart rates falling within the 60–100 BPM range. Additionally, real-time graphs efficiently displayed heart rate trends, with annotations indicating whether the heart rate was within the Normal or Abnormal zone.

While the system performed well in noise-free environments, its accuracy was affected in noisy settings, indicating the need for better noise elimination techniques. Age-based thresholds allowed for accurate heart rate zone classification, but further validation would be required before it can be used clinically. The system's limitations included reduced accuracy in high-noise environments and the inability to support irregular pulses effectively. On the positive side, the user experience was simple, with a user-friendly interface providing real-time feedback, making it accessible even for non-technical users.

In conclusion, the system effectively measures heart rate using a microphone and DSP algorithms, providing accurate results and reliable heart rate zone classifications. With improvements in noise reduction and further real-world testing, it has the potential to become an affordable and accessible personal health monitor.



**Figure 1: Stethoscope Model**

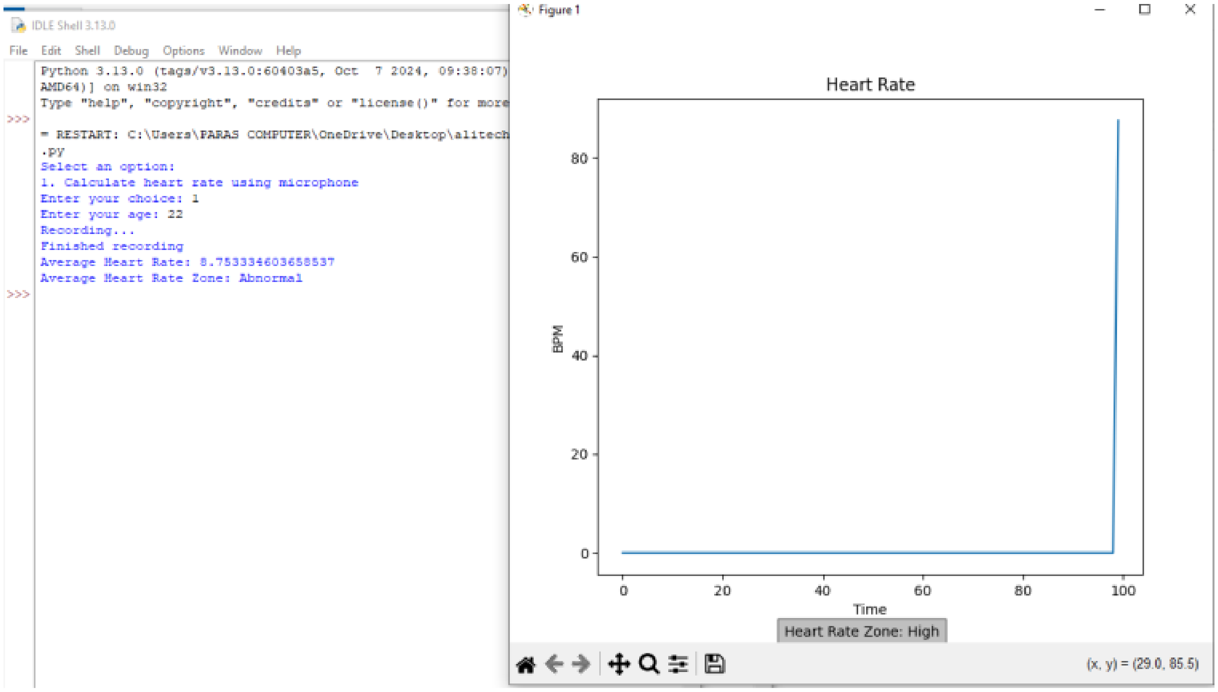


**Figure 2: Result**

## 5. CONCLUSION

This project developed a cost-effective, portable heart rate monitoring system using a microphone. The system employs DSP techniques to process acoustic signals, estimate beats per minute (BPM), and categorize the heart rate into zones (Low, Normal, High, Abnormal) based on age. It provides real-time graphical feedback, making it a practical tool for monitoring cardiovascular health.

The objectives of the project were successfully achieved. The system effectively analyzed and calculated heart rate from acoustic signals, accurately classified heart rate zones based on age-specific thresholds and offered dynamic graphical trends and health status updates. Furthermore, the system achieved portability and affordability by using standard microphones and computational tools.

Key findings revealed that the system demonstrated an average deviation of ±5 BPM when compared to medical devices. It effectively classified heart rates, but environmental noise and microphone quality impacted its performance. Despite these challenges, the system proved to be a promising tool for health monitoring.

In terms of healthcare implications, this system promotes accessible and portable health monitoring, offering a cost-effective solution for routine cardiovascular screening, especially in low-resource settings. However, the system had some limitations. Environmental noise reduced accuracy in noisy environments, and the system was limited to basic measurements, excluding advanced cardiac metrics. Additionally, irregular heartbeats, such as arrhythmias, were not accounted for, which affected accuracy in some users.

Looking ahead, several future directions can enhance the system's functionality. Advanced DSP techniques could be implemented to reduce noise interference, and integrating advanced metrics like heart rate variability and arrhythmia detection could improve its utility. Clinical validation across diverse populations would help improve its reliability, and mobile integration would make the system more accessible. Additionally, machine learning could be utilized to enhance signal analysis and classification accuracy.

The project successfully demonstrated that heart rate can be monitored using a microphone and DSP techniques. Despite some limitations, the system lays the foundation for affordable, accessible health monitoring. With future enhancements, it could become a valuable tool for personal health management and benefit underserved communities, advancing the field of portable healthcare technologies.

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