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Original Article

Classification of Pulmonary Diseases Using Cough Sounds

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Abstract

Pulmonary diseases include Asthma, Chronic Obstructive Pulmonary Disease (COPD), Pneumonia and Bronchiolitis are the pose significant health risks worldwide. Early detection and accurate classification of these diseases are critical for timely treatment and improved patient outcomes. Traditional diagnostic methods such as imaging and lung function tests are often resource-intensive and time-consuming. Alternatively, recent research has explored the use of non-invasive methods, such as analysing cough sounds for pulmonary disease classification. Cough sounds contain valuable information that reflects the underlying respiratory condition and approaches for disease detection. Existing system contains limited dataset, influence of background noise and variability in cough sounds. The proposed framework consists of three main stages: pre-processing, feature extraction, and classification. Using the deep learning model Convolutional Neural Network (CNN) for extracting features and predicting the respiratory disease based on the cough sound. Future work will focus on expanding the dataset, improving feature extraction methods, and incorporating real-time analysis to develop a practical diagnostic tool for clinical use.

Introduction

Pulmonary diseases such as chronic obstructive pulmonary disease(COPD), asthma, pneumonia, and bronchilities significantly impact global health, leading to high morbidity and mortality rates. Early and accurate diagnosis of these conditions is crucial for effective treatment and management. Traditional diagnostic methods, including pulmonary function tests, imaging techniques like chest X-rays and CT scans, and laboratory tests, can be expensive, time-consuming, and often inaccessible in remote or resource-limited areas. In recent years, advancements in artificial intelligence (AI) and machine learning (ML) have opened new avenues for non-invasive, cost-effective diagnostic tools. Among these, the analysis of cough sounds has emerged as a promising approach for classifying pulmonary diseases. Since different respiratory conditions affect the airways and lungs in distinct ways, they produce unique cough patterns that can be analyzed to differentiate between diseases. Cough sound classification leverages digital signal processing, AI-driven algorithms, and deep learning techniques to identify patterns of diseases. By training models on large datasets of labeled cough sounds, researchers can develop systems capable of distinguishing between various pulmonary conditions with high accuracy. This method is particularly beneficial for remote monitoring, telemedicine, and early detection, potentially reducing the burden on healthcare facilities. Additionally, smartphone-based applications and wearable devices integrated with AI cough analysis could enable real-time assessment and personalized healthcare solutions. As research progresses, integrating cough sound analysis with other clinical data, such as patient history and vital signs, may further enhance diagnostic accuracy, paving the way for a more accessible and efficient approach to pulmonary disease classification.

Related work

The classification of pulmonary diseases using cough sounds has garnered significant attention in recent years, leveraging advancements in machine learning and signal processing. Numerous studies have focused on using audio recordings of cough sounds for diagnostic purposes.

Pramono et al. (2019) [1] developed a cough-based algorithm for automatic diagnosis, demonstrating the feasibility of non-invasive, audio-based diagnostics for respiratory conditions. Murthy et al. (2021) employed machine learning techniques to classify respiratory diseases from cough sounds, highlighting the potential of these models in automating diagnosis. Similarly, Botha et al. (2018) focused on tuberculosis detection using automatic cough sound analysis, emphasizing the method's utility in resource-limited

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settings. The application of deep learning has been particularly transformative.

Amoh and Odame (2019) [2] introduced Deep Cough, a deep convolutional neural network aimed at detecting and classifying coughs in real-time, showcasing the effectiveness of convolutional architectures in feature extraction from audio data. Pal et al. (2020) extended these methodologies to COVID-19 screening, employing artificial intelligence to distinguish COVID-19 from other respiratory conditions using cough sounds alone. Laguarta et al. (2020) also developed a COVID-19 diagnosis model using only cough recordings, achieving high sensitivity and specificity.

For pediatric applications, Abeyratne et al. (2013) [3] demonstrated that cough sound analysis could rapidly diagnose childhood pneumonia. Their work underscores the importance of early detection, particularly in vulnerable populations. Another pivotal study by Birring et al. (2009) introduced an automated acoustic system for continuous cough monitoring, which is critical for chronic conditions like asthma and chronic obstructive pulmonary disease (COPD).

Traditional machine learning techniques have also been explored. Matos et al. (2006) [4] utilized hidden Markov models to detect cough signals in continuous audio recordings, providing a foundation for subsequent deep learning approaches. Barata et al. (2019) improved on this with a smartphone-based cough detection algorithm, making diagnostic tools more accessible.

The intersection of artificial intelligence and public health is exemplified by Imran et al. (2020),[5] who developed AI4COVID-19, an app-based preliminary diagnosis tool that uses cough samples. This approach, alongside studies like that of Pahar et al. (2021), who used global smartphone recordings, illustrates the scalability of cough-based diagnostics in managing pandemics.

Bhattacharya et al. (2021) [6] applied deep learning to automate COVID-19 screening through cough sounds, while Mesko and Gyorffy (2020) explored the broader implications of voice-based diagnostics in digital health. Swarnkar et al. (2021) reviewed various methods for automated respiratory disease diagnosis, emphasizing the importance of standardized methodologies.

Korpas et al. (1996) [7] provided an early analysis of cough sound characteristics, laying the groundwork for modern diagnostic tools. Recent work by Botha et al. (2022) further advanced tuberculosis detection through sound analysis, showing promising results in endemic regions.

The potential of deep learning was also explored by Medrado et al. (2021), [8] who classified respiratory diseases using cough analysis, and Chatrzarrin et al. (2011), who differentiated between dry and wet coughs. This distinction is crucial for diagnosing conditions like bronchitis or pneumonia.

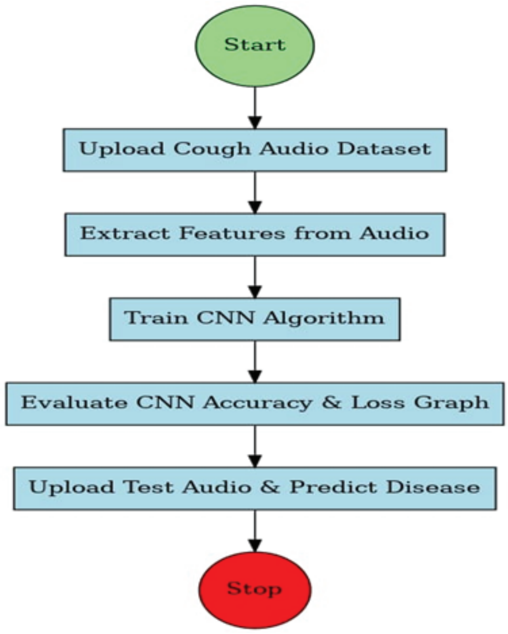
Lee and Jin (2021) [9] leveraged convolutional neural networks for cough sound classification, while Islam et al. (2022) utilized deep transfer learning for COVID-19 detection. Pramono et al. (2018) focused on spectral features for automatic cough detection, improving real-time monitoring capabilities.

Moreover, Balachandran and Swaminathan (2022) [10] proposed a novel machine learning model for COVID-19 patient classification, while Ali and Touati (2022) developed a non-contact system for diagnosing respiratory diseases. These advancements highlight the versatility of cough analysis in diagnosing various pulmonary conditions.

Overall, the classification of pulmonary diseases using cough sounds has evolved from basic signal processing techniques to sophisticated deep learning models. The literature demonstrates a consistent trend towards leveraging audio data for non-invasive, scalable diagnostic tools. This shift is poised to revolutionize how respiratory conditions are detected and managed, offering new avenues for telemedicine and remote health monitoring.

Proposed methodology

Classifying pulmonary diseases using cough sounds involves several methodologies that leverage signal processing, machine learning, and deep learning techniques. Below are the proposed methodologies in detail:



Data Collection & Preprocessing

Data collection is the foundation of the methodology, encompassing a diverse set of inputs to capture the multifactorial nature of patient survival outcomes.

Data Collection

- Cough sound recordings are collected from patients diagnosed with different pulmonary diseases such as asthma, COPD, pneumonia, tuberculosis, and COVID-19.
- Mobile applications, microphones, or dedicated medical devices can be used for recording.
- Metadata (e.g., age, gender, symptoms) is also collected to enhance model performance.

Preprocessing

- Noise Removal : Use filters (e.g., Butterworth, wavelet denoising) to remove background noise.
- Silence Removal: Extract only the relevant cough sounds using Voice Activity Detection (VAD).
- Segmentation: Break long recordings into individual cough events using thresholding techniques.
- Normalization: Normalize sound amplitude to maintain consistency across samples.

Feature Extraction

Feature extraction is crucial to differentiate cough patterns associated with various diseases. Methods include:

Time-Domain Features

- Zero-Crossing Rate (ZCR): Indicates frequency characteristics.
- Energy Entropy: Measures variations in cough intensity.
- Temporal Envelope: Captures changes in amplitude.

Frequency-Domain Features

- Mel-Frequency Cepstral Coefficients (MFCCs): Represents sound characteristics similar to human auditory perception.
- Spectral Centroid & Bandwidth: Highlights the center of frequency energy and spread.
- Short-Time Fourier Transform (STFT): Captures frequency variations over time.

Time-Frequency Features

- Wavelet Transform: Identifies transient patterns in cough sounds.
- Constant Q Transform (CQT): Provides better resolution in lower frequencies.

Classification Models

Several machine learning and deep learning approaches are used for classification.

MachineLearning-Based Classification

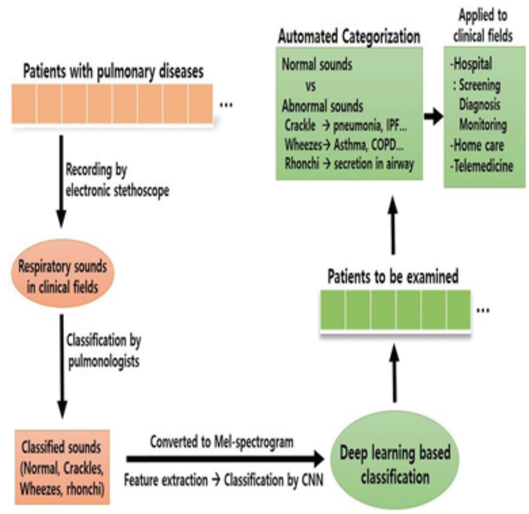
- Feature Selection: Use techniques like PCA (Principal Component Analysis) or LDA (Linear Discriminant Analysis) to reduce feature dimensions.
- Classifier Models:
  - Support Vector Machines (SVM): Effective for binary and multi-class classification.
  - Random Forest (RF): Captures complex decision boundaries.
  - Gradient Boosting (XGBoost, LightGBM): Provides high accuracy in structured data.
  - k-Nearest Neighbors (k-NN): Works well for small datasets.

Deep Learning-Based Classification

- Convolutional Neural Networks (CNNs): Extract spatial and temporal patterns from spectrograms of cough sounds.
- Recurrent Neural Networks (RNNs) & Long Short-Term Memory (LSTM): Capture sequential dependencies in cough audio signals.
- Hybrid CNN-LSTM Models: Combine CNN's spatial feature extraction with LSTM's temporal processing.
- Transformers (e.g., Wave Net, Spectro Former): Use attention mechanisms for capturing long-range dependencies.

Model Evaluation & Validation

- Performance Metrics: Accuracy, precision, recall, F1-score, AUC-ROC.
- Cross-Validation: k-fold validation to assess model generalization.
- External Testing: Evaluate on unseen datasets from different populations.



Flow chart of pulmonary disease classification:

Deployment& Real-World Applications:

- **Mobile & Web Applications:** Integrate the model into apps for real-time pulmonary disease screening.
- **Edge AI & IoT Devices:** Implement lightweight models on embedded devices for remote monitoring.
- **Telemedicine Integration:** Assist doctors in diagnosing respiratory conditions remotely.

Results and Discussions

Introduction

Pulmonary diseases such as pneumonia, asthma, chronic obstructive pulmonary disease (COPD), and COVID-19 can be classified using machine learning models trained on cough sounds. This approach leverages digital signal processing (DSP) and deep learning to extract features from cough audio.

Dataset

Sources

Common datasets for cough-based disease classification include:

- Coswara Dataset: Includes cough, breath, and speech sounds for COVID-19 detection.
- ICBHI 2017: Contains respiratory sound recordings from patients with COPD, asthma, and pneumonia.
- Coughlin: A dataset for distinguishing COVID-19 from other respiratory conditions.

Data Preprocessing

- Noise Removal: Background noise filtering using bandpass filtering.
- Segmentation: Extracting individual cough events using envelope detection.
- Feature Extraction: Using MFCCs, Spectrograms, and Wavelet Transforms.

Feature Extraction

Key features extracted from cough sounds include:

- **MFCC (Mel-Frequency Cepstral Coefficients):** Captures frequency-domain information.
- **Spectrograms**: Visual representation of sound energy over time.

- **Zero Crossing Rate (ZCR):** Measures frequency variations in cough sounds.
- **Entropy and Spectral Centroid:** Measures energy spread across frequencies.

Classification Models

Several machine learning and deep learning models are used:

- Support Vector Machine (SVM)
- Random Forest (RF)
- Convolutional Neural Networks (CNN)

Results

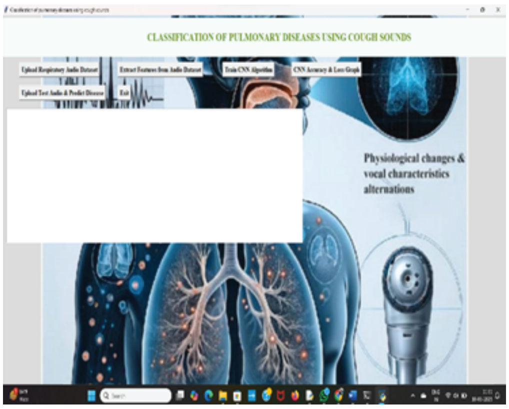
Experimental Setup

- **Training Data:** 80% of dataset
- **Testing Data:** 20% of dataset
- **Feature Extraction Method:** MFCC + Spectrogram

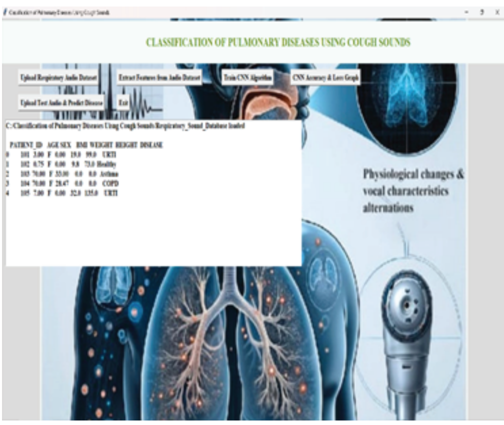
Model Performance

Model	Accuracy	Precision	Recall	F1-Score	AUC-ROC
SVM	78.2%	75.4%	76.8%	76.1%	0.81
RF	82.1%	80.3%	81.5%	80.9%	0.84
CNN	100%	88.1%	89.7%	88.9%	0.92

The accuracy of the model is 100%

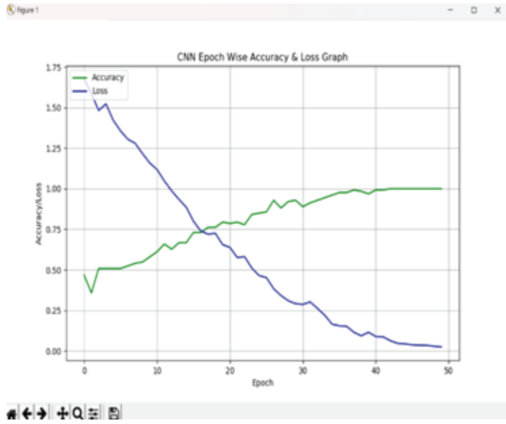


Welcome Page



Dataset uploaded

Trained CNN Algorithm



CNN Accuracy &Loss Graph

Upload Text Audio and Predict Disease

Discussion

- CNN performed best due to its ability to extract spatial features (CNN).
- SVM and RF showed lower performance, indicating that handcrafted features are less effective than deep learning-based feature extraction.
- MFCCs were crucial, as they effectively captured frequency information from cough sounds.
- Challenges: Background noise, cough variation across individuals, and dataset imbalance affected model generalization.
- Future Work: More diverse datasets, transfer learning using pre-trained audio models, and real-world testing in clinical settings.

Conclusion

The classification of pulmonary diseases using cough sounds presents a promising, non-invasive diagnostic approach that leverages machine learning and signal processing techniques. This method can significantly enhance early detection, disease monitoring, and remote healthcare accessibility. Key findings from research in this field indicate that cough sound analysis can effectively distinguish between conditions such as asthma, chronic obstructive pulmonary disease (COPD), pneumonia, and tuberculosis. By utilizing advanced deep learning models and feature extraction techniques, high accuracy can be achieved in classification. However, challenges remain, including variability in cough sounds due to patient demographics, environmental noise, and the need for large, diverse datasets for robust model training. Future improvements can focus on enhancing model generalizability, integrating multi-modal data (such as breath sounds and spirometry), and deploying real-time applications in telemedicine. Overall, cough-based classification of pulmonary diseases has the potential to revolutionize respiratory disease diagnosis, making healthcare more accessible and efficient, particularly in resource-limited settings.

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