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Next-Generation AI-Enhanced Spirometer for Home-Care and Remote Health Management

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Abstract
This paper introduces a smart spirometer that uses AI to enhance respiratory monitoring, patient safety, and caregiver response. The system combines a portable airflow-measurement device with real-time artificial intelligence algorithms that can detect abnormal breathing patterns. This includes sudden drops in airflow, irregular breathing cycles, and early signs of distress. When it identifies these issues, the device sends a wireless alert to a connected mobile application, which quickly notifies the caregiver. This allows for prompt action for patients who cannot express their symptoms clearly. Unlike traditional spirometers that are meant only for diagnostic testing, this model is designed for at-risk groups, such as the deaf, mute, elderly, and non-responsive individuals. By integrating AI analysis, IoT connectivity, and alert systems, this solution provides a cost-effective option for home care, telehealth, and ongoing remote respiratory monitoring.

Keywords: Smart Spirometer, Artificial Intelligence, Respiratory Monitoring, IoT Healthcare, Abnormal Breathing Detection, Caregiver Alert System, Assistive Medical Device, Remote Health Monitoring

1. INTRODUCTION

Respiratory monitoring is an essential component of clinical assessment, particularly for patients with chronic respiratory disorders, elderly individuals, and those requiring continuous observation. Conventional spirometers, while widely used in hospitals, are often bulky, non-portable, and unsuitable for home-care settings where continuous monitoring is needed [1]. The growing demand for compact, user-friendly, and intelligent respiratory devices has encouraged the development of portable monitoring systems that can function reliably outside clinical environments.Recent advances in artificial intelli-gence (AI) have significantly improved the ability to detect abnormal breathing patterns and early signs of respiratory distress [2][5][10]. These AI-driven approaches enhance diagnostic accuracy by analyz-ing airflow signals, identifying deviations from normal breathing, and providing early warnings that traditional manual observation might miss. Integrating these technologies into a portable spirometer creates new possibilities for preventive healthcare and patient safety.The rise of IoT-enabled medical devices further supports real-time monitoring and remote data access. Modern IoT healthcare architec-tures enable wireless data transmission, allow caregivers or clinicians to receive alerts instantly, and make remote consultation more accessible [3][6][9]. Such connectivity is especially valuable for pa-tients who cannot communicate symptoms effectively, such as deaf, mute, or neurologically impaired individuals. Assistive

technologies also play a crucial role in supporting users with communication challenges, ensuring greater independence and safety [7].From a design perspective, building a reliable smart spirometer requires proper sensor integration, airflow measurement accuracy, and efficient signal processing to produce clinically useful data. Digital spirometry systems must incorporate robust filter-ing, amplification, and processing methods to remove noise and extract meaningful respiratory parame-ters [4]. Embedded microcontroller platforms enable low-power, portable, and real-time execution of these algorithms, making them suitable for continuous use in home-care environments [8].
Given these technological advancements, this research focuses on developing a smart, AI-driven spi-rometer equipped with real-time abnormal-breathing detection and automated alert features. By inte-grating AI analytics, IoT connectivity, and assistive notifications, the proposed system provides a pro-active respiratory monitoring tool designed for home-care, remote health supervision, and continuous patient support.

2. Objective

To design and develop a portable smart spirometer that can accurately capture airflow and breathing patterns in real time.
To implement AI-based algorithms that identify abnormal respiratory events and early signs of breathing distress.
To integrate wireless communication for smooth transmission of respiratory data to a mobile app for monitoring and analysis.
To create an automated alert system that instantly notifies caregivers when it detects abnormal or emergency breathing conditions.

3. Proposed Method

The AI-assisted smart spirometer continuously monitors airflow, detects abnormal breathing patterns, and immediately alerts a caretaker when there are signs of distress. The system works through a clear process that includes sensing, signal processing, wireless communication, and real-time AI analysis.
The process starts with the airflow measurement unit, where a differential pressure sensor or hot-wire sensor changes the patient's inhalation and exhalation into electrical signals. These initial signals usually have low amplitude and include background noise. To make them clinically reliable, the signals go through analog signal conditioning, which includes amplification, noise filtering, and baseline stabilization. This process produces a dependable respiratory waveform. The conditioned signal is then digitized using an embedded microcontroller platform, which carries out important digital signal processing like smoothing, artifact removal, and cycle segmentation. This ensures that the airflow waveform accurately reflects the patient's breathing pattern.
The processed data goes to the AI module, where machine learning models analyze real-time respiratory features such as airflow rate, peak expiratory flow, inhalation-exhalation ratio, and waveform irregularities. The model compares incoming patterns with known signs of abnormal breathing, including airway obstruction, shallow breathing, irregular rhythm, and sudden drops in airflow. If the algorithm finds any deviations beyond a set clinical threshold, the system generates a risk event right away.
This information is encoded and sent wirelessly using IoT-based BLE communication to a mobile app. The app reconstructs the incoming data, shows live respiratory curves, and logs historical readings. In critical situations like prolonged apnea or rapidly declining airflow, the app activates an automated alarm

to the caretaker's linked device. The alert can include vibration, sound notifications, or message prompts, ensuring a quick response even when the patient cannot communicate their condition.

This method combines precise airflow sensing, smart AI-based event detection, low-power wireless communication, and a real-time caregiver alert system. This integrated design improves patient safety and extends respiratory monitoring to home care, elderly care, and telehealth settings where continuous clinical supervision is not available.

4. Methodology

The methodology of the proposed AI-assisted smart spirometer includes a sequence of sensing, processing, transmission, and alert mechanisms aimed at continuous respiratory monitoring. The process starts with airflow acquisition. A differential pressure sensor or hot-wire airflow sensor measures the user's inhalation and exhalation patterns. As airflow moves through the sensing chamber, the sensor turns pressure or thermal changes into electrical signals. These raw signals often contain low amplitude and noise from movement, temperature shifts, or background disturbances. Therefore, they undergo analog signal conditioning first. This stage involves low-noise amplification, baseline correction, and band-pass filtering to focus on the clinically relevant respiratory frequency range. The conditioned waveform is then digitized using the microcontroller's ADC, allowing for further processing in the digital domain.

In the digital signal processing (DSP) stage, the microcontroller uses smoothing algorithms, moving-average filters, and artifact removal to improve the airflow waveform. It performs cycle segmentation to distinguish between inhalation and exhalation phases. The system extracts features such as peak flow, tidal volume trends, breathing rate, and airflow irregularities. These features are then sent to the AI analysis module, where machine learning-based classification models assess respiratory behavior in real time. The model compares the extracted features with patterns of abnormal breathing events, like reduced airflow, irregular rhythm, obstructed breathing, shallow respiration, or sudden drops that suggest respiratory distress. If the AI engine detects patterns outside normal limits, it generates an abnormality flag.

The processed data and event status are encoded and transmitted wirelessly using Bluetooth Low Energy (BLE) to a connected mobile application. BLE provides low power use, secure data transfer, and reliable communication in a typical home-care setting. The mobile application reconstructs the incoming data, shows the live respiratory waveform, and stores the readings for future analysis. If an abnormal detection occurs, the app sends an instant alarm notification to the assigned caretaker through audible alerts, vibrations, or message prompts. This ensures timely intervention, especially for deaf, mute, elderly, or non-communicative patients who cannot express respiratory distress.

Overall, the methodology combines precise airflow sensing, effective signal conditioning, smart AI-based detection, low-power wireless connectivity, and caregiver alert functions. This setup guarantees precise monitoring, early abnormality detection, and improved patient safety beyond what traditional spirometers offer.

5. System architecture

The system architecture of the AI-assisted smart spirometer is a multi-layer framework. It combines sensing hardware, signal processing units, wireless communication modules, and software for real-time respiratory monitoring and caregiver alerts. Each layer has a specific function. Together, they allow for continuous, accurate, and automated assessment of a patient's breathing.

The architecture starts with the sensing layer. This layer contains a differential pressure sensor or hot-wire airflow sensor located within the spirometer's airflow chamber. When the user inhales and exhales, the airflow moves through a calibrated pathway. The sensor picks up changes in pressure or temperature from the air movement. These changes turn into electrical signals that show the user's breathing pattern. To ensure reliability, the sensing chamber is built with controlled airflow resistance, minimal leakage, and proper shielding to reduce interference from the environment.

The electrical output from the sensor goes into the analog signal conditioning layer. This layer prepares the raw signal for digital processing. It includes low-noise amplification to strengthen the weak airflow signal, baseline stabilization to remove drift, and band-pass filtering to isolate important respiratory frequencies while filtering out motion artifacts and ambient noise. This ensures the waveform entering the digital domain is clean, consistent, and suitable for automated analysis.

Next, the conditioned signal goes into the digital processing and microcontroller layer. Here, it is converted into digital form using the microcontroller's built-in analog-to-digital converter (ADC). The microcontroller performs key digital signal processing tasks such as smoothing, noise reduction, breathing-cycle segmentation, and feature extraction. It identifies important respiratory parameters like airflow rate, inhalation and exhalation timing, peak expiratory flow, and unusual breathing patterns. These features are sent to the AI engine.

The AI analysis layer assesses the patient's respiratory status in real time. Machine learning algorithms compare incoming respiratory features with known patterns of abnormal breathing, like shallow breathing, airway obstruction, irregular cycles, or sudden drops in airflow. If the system detects deviations beyond clinically acceptable limits, it creates an abnormality flag and sends it to the communication unit.

The refined data and abnormality status are sent to the wireless communication layer. This layer uses Bluetooth Low Energy (BLE) for low-power, secure, and stable data transmission. BLE packets containing respiratory waveforms, extracted features, and alert signals are sent to a paired mobile device with minimal delay. This ensures real-time monitoring and ongoing connectivity in home-care settings.

On the receiving side, the mobile application layer reconstructs the BLE data. It shows the real-time respiratory waveform, logs historical measurements, and visualizes trends for detailed analysis. Most importantly, when an abnormal breathing pattern is detected, the mobile app immediately sends an alert to the caretaker using sound, vibration, and message notifications. This alert system enables a quick response for vulnerable patients, such as the deaf, mute, elderly, or those unable to communicate their breathing difficulties.

Finally, the data storage and cloud integration layer supports long-term monitoring. It saves recordings locally or uploads them to a secure cloud platform for telehealth consultations, medical reviews, or further AI training. This layer allows healthcare professionals remote access and provides continuity in patient monitoring.

Overall, the system architecture promotes smooth interaction between sensing, processing, wireless connectivity, and intelligent analysis. It creates a strong and reliable platform for continuous respiratory monitoring and early detection of respiratory distress.

6. Flow chart

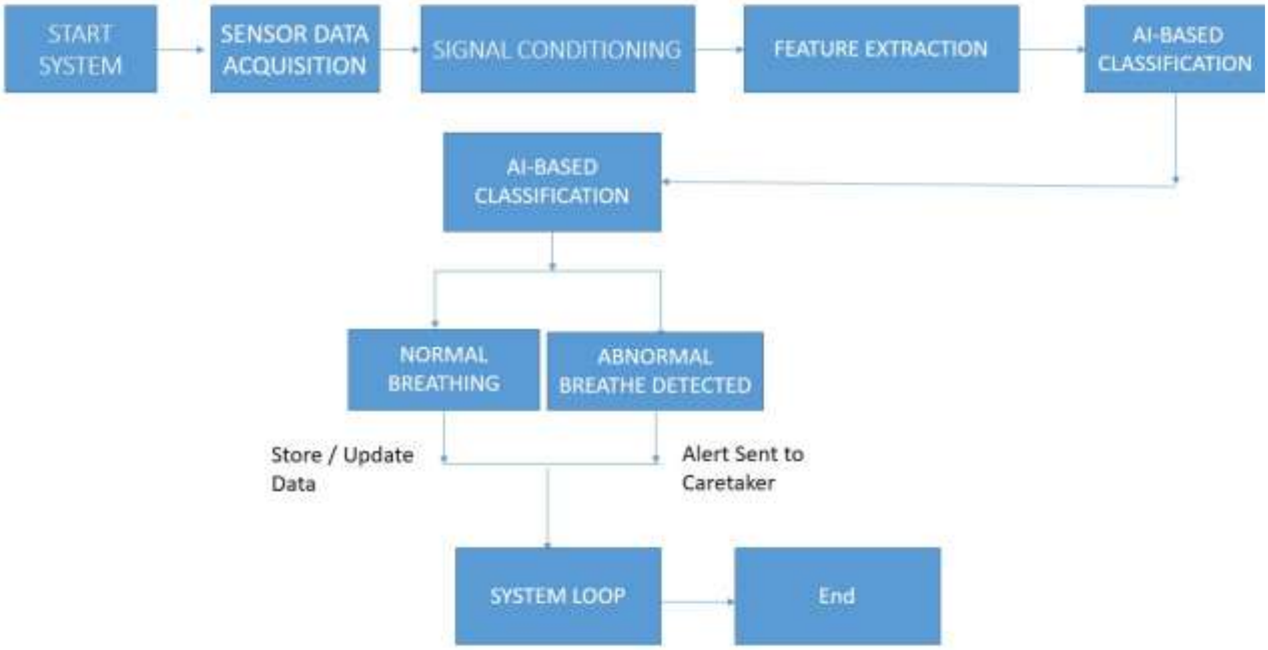

Fig.Flowchart of Working process

7. Conclusion

The proposed AI-assisted smart spirometer offers a practical solution for continuous monitoring of respiratory health, early detection of issues, and timely help from caregivers. By combining accurate airflow sensing, strong signal conditioning, smart machine learning analysis, and low-power wireless communication, the system addresses the weaknesses of traditional spirometers that need clinical supervision and lack real-time alerts. The automatic alarm for caregivers significantly improves patient safety, especially for at-risk groups such as the deaf, mute, elderly, and non-verbal individuals who cannot communicate respiratory problems. The mobile app adds value by allowing live monitoring, data visualization, and long-term storage for clinical review and telehealth support. Overall, this work shows a cost-effective and accessible respiratory monitoring platform that is suitable for home care, rehabilitation, and remote health use. Future updates may include cloud-based data analysis, predictive models, and integration with electronic health systems to improve respiratory disease management further.

8. Conflict of Interest

The authors state that there are no conflicts of interest related to this research. The authors completed all design, development, analysis, and interpretations independently. While some background information and literature references came from publicly available online sources for academic purposes, these materials did not affect the originality, integrity, or objectivity of the results and conclusions reported in this study.

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