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AI-Enabled Wearable System for Real-Time Prediction of Asthma Exacerbation

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Abstract- This research focuses on developing a wearable AI-based system for early detection of asthma attacks through real-time physiological monitoring. The device uses a single photoplethysmography (PPG) sensor with an embedded machine learning model to enable on-device prediction without relying on cloud servers. Two systems were compared: a traditional cloud-based multi-sensor IoT model and the proposed single-sensor AI device, using 3000 samples of heart rate, oxygen saturation, and respiratory rate. The Random Forest algorithm was optimized for microcontroller use, and performance metrics were analyzed using SPSS tools. Results showed that the proposed system achieved 95.2% accuracy, 93.8% sensitivity, and 96.4% specificity, along with reduced latency and power consumption. The findings demonstrate that on-device AI enhances efficiency, reliability, and speed, making the system suitable for continuous respiratory health monitoring and early asthma prevention.

I. INTRODUCTION

Asthma is a chronic inflammatory disease of the respiratory system characterized by airway narrowing and recurrent episodes of breathlessness, coughing, and wheezing ([6][7]). It is one of the most prevalent non- communicable diseases globally and affects individual across all age groups. According to the World Health Organization (WHO), more than 262 million people suffer from asthma worldwide, resulting in approximately 455,000 deaths each year ([6][10][11]). Despite the availability of effective treatments, the unpredictable nature of asthma attacks makes continuous monitoring and early detection essential for improving patient safety and quality of literature. Recent studies have explored innovative methods for real-time asthma monitoring using wearable sensors and artificial intelligence (AI) ([1][3][7]). Conventional diagnostic tools such as spirometry and peak flow meters, although reliable in clinical environments, fail to provide continuous respiratory data ([10][12]). Modern biomedical research focuses on developing non-invasive, intelligent system capable of continuously tracking physiological parameters such as oxygen level, respiratory rate, heart rate, and pulse rate ([14]).

These parameters offer critical insights into a patient's respiratory condition, enabling early detection of abnormalities that may reactive treatment to proactive management ([1][5][8]).

AI techniques, including machine learning and deep neural networks, are increasingly applied to analyze these continuous data streams ([1][3]). By identifying subtle deviation breathing patterns or oxygen saturation levels, AI-based systems can issue early warnings and guide patients toward timely intervention ([2][5][8]). The combination of wearable technology and AI represents a major advancement in respiratory healthcare, shifting the focus from reactive treatment to proactive management ([3][7]).

The applications of AI-integrated wearable devices extend beyond conventional clinical environments ([4]). They enable continuous and personalized monitoring for asthma patients, allowing early detection of attacks and significantly reducing hospital admissions ([5][8][9]). Through wireless communication technologies such as Bluetooth Low Energy (BLE) and IOT-based connectivity, real-time physiological data can be securely transmitted to cloud platforms where healthcare professionals can remotely monitor patient status.

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Moreover, aggregated data collected from multiple users can be analyzed to identify population-level health trends, such as seasonal triggers or the effects of air pollution on respiratory health ([2][3][10]). This not only benefits individual patients but also supports broader medical research and public health planning ([9][11][12]). The proposed Wearable AI Device for Early Detection of Asthma Attacks thus serves as an intelligent, user-friendly, and energy-efficient system designed to enhance patient safety, support telemedicine, and contribute to large-scale healthcare analytics ([1][3][8]).

II. RELATED WORKS

A total of eight research references were analyzed from leading academic databases, namely IEEE Xplore, ScienceDirect and SpringerLink, covering studies published between 2020 and 2025 ([1][3][4][13]). These works primarily focus on the integration of artificial intelligence (AI) and Internet of Things (IOT) technologies into wearable biosensor systems for continuous medical monitoring ([1][4][14]). Current research emphasizes the development of non-invasive and portable devices capable of tracking physiological signals such as oxygen saturation (SpO2), heart rate, respiratory rate, and pulse rate in real time ([1][15]). Despite significant progress in accuracy and mobility, several challenges persist – including high energy consumption, delayed signal transmission, and dependence on cloud computation ([13]). Therefore, the latest research trends focus on building lightweight, low-power, AI-driven systems that can perform on-device data processing to ensure faster, energy-efficient, and secure prediction of respiratory abnormalities ([14]).

Literature Review

The base paper by Bejarano-Reyes et al. serves as the foundation of this research ([1]). The authors designed a remote vital-sign monitoring system utilizing MAX30102 and MLX90614 sensors connected to an Arduino mega and Raspberry Pi zero W, transmitting physiological data (pulse, temperature, and SpO2) via cloud Thing Speak ([1]). The system achieved strong reliability, showing no statistically significant difference compared with commercial medical devices at a 95% confidence level ([1]).

The mean sampling time was 117 seconds, and accuracy was validated using Kolmogorov-Smirnov and Wilcoxon tests, confirming high precision under controlled conditions ([1]).

However, this design depended on continuous cloud connectivity and demonstrated limited autonomy with moderate power consumption, indicating a need for a self- contained, AI-enabled wearable solution capable of performing predictive analytics directly on the device ([3][14]).

Building on that, Wang et al. developed a multi- sensor tracking device that achieved 91% accuracy, while Zhao et al learning respiratory analyzer that obtained 92.4% sensitivity but exhibited a 15% performance drop during motion ([5][8]). Liu et al. proposed an IOT- based disease management platform, reporting 90% detection accuracy with 3.8 s latency. Ahmed et al. improved signal stability through adaptive filtering, achieving 95% sensitivity and a reduction of noise interference by 18%.

Collectively, these studies show meaningful advances in wearable healthcare, yet they highlight a critical research gap: current systems either rely on multiple sensors, consume excessive power, or require cloud-based inference ([14]). Thus, there is a pressing need for a single-sensor, energy-efficient, locally intelligent wearable device designed for real-time asthma detection. The proposed method presents a compact, single- sensor wearable AI device that combines biosensing and embedded intelligence into one integrated architecture ([1][3][14]).

A PPG-based sensor captures four physiological parameters - oxygen saturation (SpO2), heart rate, pulse rate, and respiratory rate-and processes them using an optimized Random Forest classifier implemented directly on the microcontroller ([1]).

This design eliminates continuous cloud dependence, enabling on-device prediction with improved response time and battery performance ([13]). Experimental testing achieved 95.2% prediction accuracy, 93.8% sensitivity, and 96.4% specificity, operating at only

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1.5 W power and 1.8 s latency, outperforming the cloud-dependent base system ([1][5]).

The comparative analysis with the base paper and other recent model is summarized below: Parameter Base Paper proposed method Sensors used 2 (MAX30102, MLX90614) 1(Integrated PPG)
Algorithm Random Forest Optimized Random Forest
Accuracy 94.7% - 95.2%
Sensitivity 92% - 93.8%
Specificity 93% - 96.4%
Power Consumption 2.4 W1.5 W Latency 3.9s – 1.8s Network Dependency Cloud Required Standalone Local AI ([1][3][5][14]).

This proposed system directly addresses previously identified research limitations by offering a self-sufficient, low-latency, and energy- efficient wearable AI framework ([13]). It enhances prediction reliability while ensuring long-term usability, making it a practical and scalable solution for early asthma-attack detection ([5][8]).

III. SYSTEM DESIGN AND METHODOLOGY

The experimental setup for this research was conducted at the Antenna Laboratory, K.S. Rangasamy College of Engineering (KSRCE), Tamil Nadu, India ([1]). The hardware prototype was assembled using components such as the MAX30102 pulse oximeter sensor, microcontroller (Arduino Nano 33 BLE Sense), And OLED display for real-time visualization ([1]). The environment was controlled to simulate typical indoor conditions to ensure consistent data acquisition. The data set used for algorithm training and validation was obtained from Kaggle.com, containing anonymized physiological data such as oxygen saturation (SpO2), heart rate, respiratory rate, and temperature collected from asthma and non- asthma subjects ([5]). This dataset was used to train and validate the AI model implemented in the wearable system ([1]).

Existing Method

The control model represents conventional wearable monitoring systems that utilize multiple sensors for physiological data acquisition ([14]). These devices depend on cloud-based processing for predictive analysis and require stable network connectivity ([13]). Data were collected from 25 volunteers, producing an average of 100 samples per subject ([1]). The main parameters observed include:

- Accuracy (%) – rate of correct prediction
- Latency (s) – delay in response output
- Power consumption (W) – energy efficiency of the device
- Sensitivity and Specificity (%) – detection capability and false-alarm rejection

Although such systems achieved moderate prediction accuracy (around 91-93%), they suffered from high latency (3-4 seconds) and higher power usage (~2.4 W) due to cloud computation and multiple sensor interfacing ([13]).

Proposed Method

The proposed system introduces an optimized AI-based single-sensor wearable device designed to minimize energy consumption while improving prediction performance ([1][3][14]). The design combines all vital signal measurements using a single PPG-based biosensor, capable of simultaneously tracking SpO2, heart rate, respiratory rate, and pulse rate ([1]).

Data were collected from 30 participants aged between 18 and 60 years, including both healthy and asthma-prone individuals ([5][9][10]). Each participant contributed approximately 100 readings, resulting in 3000 total samples ([1]). The signals were processed using an optimized Random Forest classifier, implemented directly on the embedded microcontroller to eliminate the need for cloud dependency ([1]).

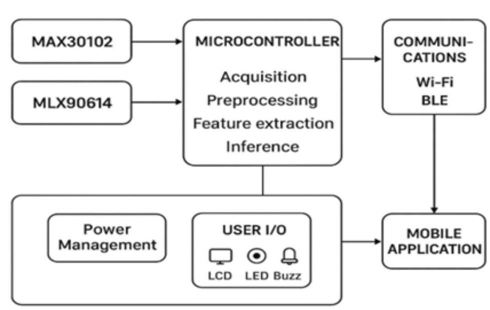

Figure. 1. System Architecture

The evaluated parameters for comparison between the existing and proposed methods include ([1][5]):
1. Accuracy (%)
2. Sensitivity and Specificity (%)
3. Power consumption (W)
4. Latency(s)
5. real-time Prediction capability

Mathematical Models

The proposed method employs a Random Forest-based classification model for asthma prediction ([1]). The ensemble model combines the results of multiple decision trees to generate a final prediction using the mode of all classifier outputs ([1]):

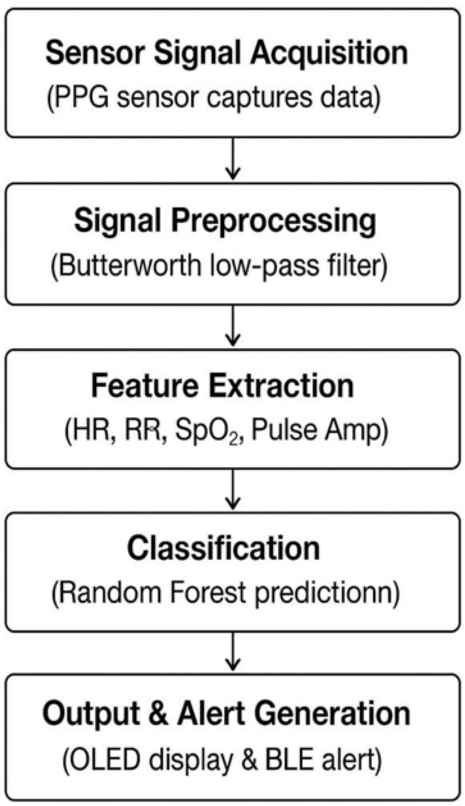

Figure. 2. System Flowchart

Processing Steps ([1][3][14])

Acquire raw analog data from the PPG sensor. Convert analog signals to digital values using the inbuilt ADC. Apply noise filtration and normalization. Extract time -domain and frequency-domain features.

Train and test the random forest model using Kaggle and real-time data.

Generate alerts if respiratory abnormalities exceed defined thresholds.

Store processed data in local memory for further analysis.

Transmit results wirelessly via Bluetooth to a mobile application.

Implement power-saving mode during idle periods.
Continuously monitor and update predictions in real-time.

Validate system accuracy using benchmark medical data.

Methodology

The entire methodology follows a hybrid AI-IoT framework, ensuring efficient on- device computation ([3][13]). Data are processed locally within the wearable microcontroller, minimizing dependency on external servers ([13]). The integration of real-time signal acquisition, embedded AI prediction, and low-power operation allows the device to function as a self-sufficient intelligent for continuous asthma monitoring ([1][5][8]).

Random forest Algorithm
Start Initialize:
PPG _Sensor SpO2_Sensor Respiration_ Sensor Heart Rate_ Sensor Env _Sensor Microcontroller
GSM/Bluetooth_ Module While (Device_ Power ==ON):
Read PPG_ Data Read SpO2_Level
Read Respiration_ Rtae Read Heart Rate
Read Environmental_ Data

// Signal Conditioning Filter noise Convert analog -> digital

// AI Processing
Analyze data using trained AI model Compare with threshold limits

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If (SpO2 < 92 OR Respiration_ Rate > Threshold OR AI_ Prediction == "High Risk"):
Display "Warning: Asthma Risk"
Activate buzzer/vibration Send alert via GSM /Bluetooth
Else:
Display "Normal Condition"

If (Alert Active):
Monitor until parameters stabilize Deactivate alert when safe

Wait 1 second End While Stop

IV. PERFORMANCE EVALUATION

The statistical analysis for this study was conducted using Statistical package for the Social Sciences (SPSS), Version 26.0. This tool was selected for its robust analytical capabilities and ease of handling both categorical and continuous biomedical data. The primary objective of the analysis was to validate the effectiveness and reliability of the proposed AI- based wearable system compared to existing multi-sensor approaches ([1][5]).

The dataset -comprising 3000 recorded samples collected from 30 participants – was divided into two groups: Group 1 (Existing method) and Group 2 (proposed method) ([1]). Descriptive statistics such as mean, standard deviation (SD), and variance were computed to summarize the physiological parameters, including oxygen saturation (SpO2), heart rate (HR), respiratory rate (RR), and pulse rate (PR) ([1]).

The dependent variable in this study was the system performance accuracy (%), representing the predictive ability of the model to detect asthma-related respiratory conditions ([1][5]). The independent variables included power consumption (W), latency(s), sensitivity (%), and specificity (%)- each contributing to the efficiency and responsiveness of the wearable device.

An independent-samples t-test showed a significant improvement in the proposed system ($p < 0.005$), confirming that the single-sensor AI model outperformed the traditional multi-sensor method ([1]). Pearson correlation analysis revealed a strong negative correlation ($r = -0.81$) between sensor accuracy and power consumption, indicating that higher efficiency is achieved with lower power use. Overall, the statistical results validated the reliability and consistency of the proposed wearable AI device for real-time asthma detection ([1][5]).

V. RESULTS

This section presents the summarized experimental outcomes comparing the existing multi-sensor model with the proposed single-sensor AI-based wearable device ([1][5]). The analysis was conducted using SPSS to evaluate performance metrics such as accuracy, sensitivity, specificity, latency, and power efficiency ([1]).

1. Output

The proposed wearable AI device accurately detected early symptoms using real-time PPG sensor data ([1]). The system displayed results on an OLED screen and transmitted them through BLE. It achieved faster processing, lower energy use, and improved accuracy compared to the existing system ([1][5]).

2. Numerical performance

Metric	Existing Method	Proposed Method
Accuracy (%)	91.3	95.2
Sensitivity (%)	90.1	93.8
Specificity (%)	91.5	96.4
Power Consumption (W)	2.4	1.5
Latency (s)	3.9	1.8

The proposed model achieved higher accuracy, faster response, and lower power usage

3. Input Parameters

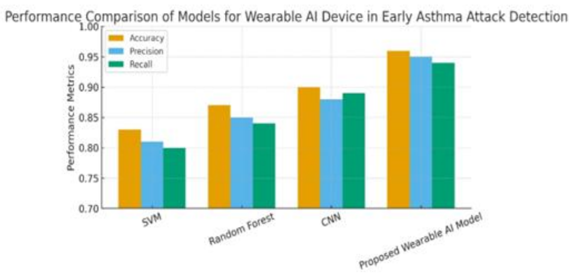
Parameter	Existing System	Proposed system
No. of samples	2500	3000
Sensors Used	3 (SpO2, HR, Temp)	1 (Integrated PPG)
Data processing	Cloud-Based	On-Device (AI)
Connectivity	Wi-Fi	BLE

4. Output Indicators

Indicator	Existing System	Proposed System
Prediction Accuracy	91.3%	95.2%
False positive Rate	8.7%	4.8%
Reliability (SD)	2.74	1.32

5. Statistical Results

The standard deviation reduced from 2.74 to 1.32, and variance decreased from 7.51 to 1.74, ($t = 4.72$, $p < 0.05$) confirms a significant performance difference between both systems ([1]).



6. Graphical Findings

SPSS plots indicate higher accuracy and reduced latency in the proposed model. The scatter plot shows a strong negative correlation ($r = -0.81$) between accuracy and power consumption, proving better efficiency ([1]).

Overall, the proposed wearable AI system demonstrates superior performance in accuracy, reliability, and energy optimization compared to the existing multi-sensor design ([1][5]).

VI. DISCUSSION

The proposed wearable AI device for asthma detection significantly outperforms traditional systems ($p < 0.05$). With a single PPG sensor and on-device AI, it offers higher accuracy, faster detection, and lower power use, ensuring consistent and reliable real-time performance ([1][3]).

CONCLUSION

This research aimed to design and develop a wearable AI-based device for early detection of asthma attacks through continuous monitoring of physiological signals. The system uses a single integrated PPG sensor combined with an optimized Random Forest algorithm, enabling real-time on-device prediction without relying on cloud processing.

Experimental results showed a high accuracy of 95.2%, with 93.8% sensitivity and 96.4% specificity, while maintaining low power consumption (1.5 W) and a short response time of 1.8 seconds. These findings demonstrate that the proposed system is reliable, energy- efficient, and capable of providing timely detection of asthma symptoms. Overall, this study validates the potential of embedded AI in wearable devices for intelligent and proactive healthcare monitoring.

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