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AI-Based Multipurpose Disease Detection and Severity Prediction System for Asthma, Wheezing, and Tuberculosis

Safiya Sha[1], Ranjitha R[2], Darshan T M[3], Aruna B[4], Dr Prabhavathi K[5]
[1]Under Graduate Student, Department of Electronics and Communication Engineering, BGS Institute of Technology, Adichunchanagiri University, BG Nagara, Karnataka, India
[2]Under Graduate Student, Department. of Electronics and Communication Engineering, BGS Institute of Technology, Adichunchanagiri University, BG Nagara, Karnataka, India
[3]Under Garduate Student, Department of Electronics and Communication Engineering, BGS Institute of Technology, Adichunchanagiri University, BG Nagara, Karnataka, India
[4]Assistant Professor, Department of Electronics and Communication Engineering, BGS Institute of Technology, Adichunchanagiri University, BG Nagara, Karnataka, India
[5]Assosiate Professor, Department of Electronics and Communication Engineering, BGS Institute of Technology, Adichunchanagiri University, BG Nagara, Karnataka, India

ABSTRACT
In this paper, a prototype of artificial intelligence-based system that can be helpful in the diagnosis and forecasting of respiratory diseases such as asthma, wheezing, and tuberculosis is introduced. This system will be designed by utilizing the e-Nose sensor integrated into the smart face mask that will continuously monitor the patient without invasive measures. This system will have metal oxide semiconductor sensors to detect the presence volatile organic compounds in the breath of the patients, along with acoustic sensors to detect cough and wheezing.

In addition to that, temperature and humidity sensors will also be used to improve the accuracy of the system. The data gathered from the sensors will be processed through a microcontroller and transferred to the cloud-based platform via IoT technology. Finally, machine learning techniques will be used to process the data and classify the severity and types of diseases. Patients and their doctors can view this information through a web-based interface.This system offers an alternative solution as a portable and cost-effective continuous monitoring system respiratory diseases.

***Keywords*-Acoustic Analysis, Electronic Nose (e-Nose), IoT Healthcare, Machine Learning, Respiratory Disease Detection**

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I. INTRODUCTION

Disorders like asthma, wheezing, and tuberculosis are health issues that pose a major challenge to humans worldwide, potentially affecting millions of millions people and leading to substantial mortality and morbidity rates. The early identification and monitoring of this disorders are vital aspects of healthcare and therapy, but the existing techniques used for diagnosing and identifying them are currently complicated, costly, intrusive, and dependent on advanced healthcare facilities.

In recent years, many breakthroughs have been made in the areas of sensor technology, IoT, and AI. This innovation allows the creation of inexpensive, portable, and capable real-time monitoring smart health care equipment. Among these innovations, it would be best to consider e-nose systems which would enable the identification of various odor compounds using the collective work of gas sensors of different types. In the application of e-nose systems to analysis of human breath, one will be able to identify various VOCs that can serve as biomarkers for different lung diseases. The exhalation of asthma patients contain relatively high levels of nitric oxide as well as other VOCs due to inflammations of the airways. On the other hand, tuberculosis patients breathes out substances such as methyl nicotinate and short-chain hydrocarbons.

However, apart from VOCs, there are others acoustical signals that can serve as diagnostic instruments such as coughing and wheezing. These acoustical signals can be analyzed through signal processing techniques whereby some features such as frequency, amplitude, and duration can be identified.

The application of AI in design an integrated device for disease detection and prediction of its severity through the creation of an intelligent mask is explained in this paper. In this context, the mask is made up of a collection of gas sensors, acoustic sensors, and environmental sensors that are connected to the microcontroller to collect and preprocess data collected by sensors. Post-preprocessing, the information collected will then be uploaded to the cloud using IoT technology. Machine learning techniques can then be used to detect respiratory diseases and determine their severity levels. Moreover, a web interface has been created which will display patients information, predictions, and trends in real-time.

The use of AI in conjunction with IoT and machine learning in the proposed design will increase the efficiency of the detection and disease prediction process.

II. LITERATURE REVIEW

Recent developments in electronic sensors and artificial intelligence have brought great improvements in the development of non-invasive diagnosis approaches for respiratory illnesses. For example, there are e-Noses that can be used to diagnose various types of pulmonary diseases based on the detection of VOCs present in the breath. The paper by Zhang et al. [1] presents the application of the electronic nose in medical practice and provides a review of recent progress in the development of sensor array systems and pattern recognition methods. It demonstrates that accurate calibration and high sensitivity of sensors play a crucial role in the detection of diseases such as asthma and chronic pulmonary conditions.

Machine learning methods are increasingly applied in the improvement of classification accuracy based on sensor data analysis. Kumar and Patel [2] compared the performance of several algorithms such as SVM, Random Forest, and CNN. As pointed out by the authors, the integration of sensor data with machine learning methods has significantly enhanced classification accuracy and facilitated the automatic detection of abnormal respiratory patterns.

Acoustic analysis can also help in monitoring patients with breathing problems. Rodriguez et al. [3] investigated various approaches that could be applied to analyze acoustical signals associated with coughs and breaths. Based on the results provided in the study, it can be stated that some parameters, including frequency spectra and amplitudes, can be employed to identify specific diseases, such as pneumonia, bronchitis, and wheezing. In addition, wearable sensors that would enable monitoring of physiological processes in real time were developed by Thompson and Davis [4].

IoT technologies helped perform remote monitoring and transmit the data to healthcare specialists immediately. The problem of securing patient privacy was discussed by Anderson et al. [5]. According to the authors, appropriate measures need to be taken to ensure that personal data of patients is protected from disclosure. Wilson and Brown [6] also explored cloud computing of patients' health data.

Global health agencies have also stressed the importance of applying novel technology in managing respiratory diseases. WHO [7], for instance, emphasizes the importance of advanced technologies in diagnosing and preventing chronic respiratory diseases. Likewise, the FDA [8] guides on regulatory approaches for digital health technology based on the technology's validation and reliability to assure the safety and efficacy of their clinical usage.

Furthermore, scientific studies concerning e-nose technology have greatly helped improve modern technology. In their book, Gardner & Bartlett [9], for instance, describe the basic principle of e-nose technology as well as different technological uses. They argue that sensors could be employed to mimic human olfaction to detect respiratory diseases using chemical markers of exhaled breath.

In the same manner, scientific studies involving breath analysis techniques have also been very helpful in employing VOCs in disease diagnosis. As an illustration, Mazzone et al. [10] conducted a review on breath analysis in diagnosing respiratory diseases with exhaled breath analysis being used to detect the presence of respiratory diseases using chemical markers. Further, Phillips et al. [11] applied breath analysis in the identification of pulmonary tuberculosis using VOCs.

Studying certain respiratory illnesses helped to provide some useful information as well. For example, Ferrante and La Grutta [12] explored the problem of pediatric asthma and came to the conclusion that it is vital to diagnose such an illness and monitor the development process to avoid any negative consequences. This becomes one more argument to suggest that a diagnosis device should be developed because of these reasons as well.

Machine learning methods used to analyze the sound of cough were also helpful. For example, Larzelere et al. [13] found out that it was possible to distinguish various illnesses depending on the sound using machine learning. This technology could be used when creating a diagnosis device.

Hence, it is obvious that the application of the e-nose method, acoustic data, machine learning techniques, and IoT can contribute to the creation of advanced diagnosis tools that could help to monitor certain respiratory diseases effectively. Nevertheless, it needs to be stated that these devices are not developed appropriately. The reason for this is that there is a necessity to create a mask.

III. METHODOLOGY AND SYSTEMARCHITECTURE

3.1 System Architecture

The current research seeks to design a multi-purpose respiratory disease detection and prediction system that uses artificial intelligence. Specifically, the proposed model detects asthma, wheezing, and tuberculosis without conducting any diffiuclt process and keeps track of the development of mentioned diseases. For this purpose, the proposed system utilizes gas and acoustics analysis along with machine learning techniques and IoT technologies. In this regard, the proposed system is able to analyze the acquired information and predict some results, which will be provided through convenient web-based platform.

3.2 System Components

As dispayed in Fig. 1, the suggested system architecture consists of several components such as the smart mask with sensors, ESP32 as a microcontroller unit, IoT, cloud, and prediction module based on machine learning. First of all, the smart mask can be considered the key element, since it provides the means to acquire information about the user. It should be pointed out that the smart mask contains gas sensors and acoustic sensors.

Both data acquisition, processing, and sensing would be done using the ESP32 microcontroller. Thereafter, data will be sent to the cloud through IoT connectivity. Data will further analyzed using machine learning algorithms. Lastly, storage and data analysis will be done using data visualization on the web-based dashboard.

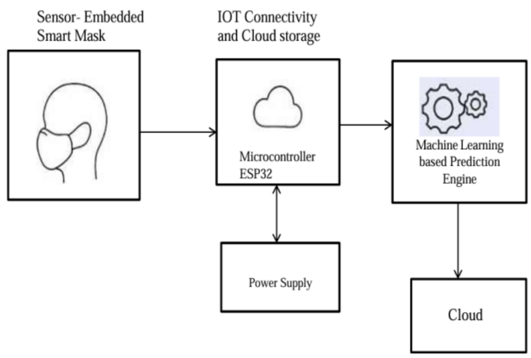

Fig 1: Block diagram of an AI-based multi-purpose disease detection and severity prediction system for asthma, wheezing, and tuberculosis

3.3 Selection of Sensors and Data Acquisition

The MQ series sensors are integrated into this project design as gas sensors for the detection of presence of VOCs within exhaled breaths. In particular, MQ-135 is utilized for the detection of

VOCs while MQ-137 is used for ammonia detection. Such sensors have been chosen since they are capable of detecting gases responsible for respiratory diseases.

Further, an acoustic sensor, which includes microphone, would be incorporated to capture sounds of coughing and wheezing. Additional sensors such as temperature and humidity sensors may also be taken into consideration during data acquisition processe.

3.4 Signal Processing and Data Preprocessing

Preprocessing of the data is performed to exclude any noise from the data collected from the sensors and make sure that the data is consistent. For example, one of the techniques that can be applied here includes high passe filtering, which can help remove noise from acoustic signals. In addition, threshold amplitude and envelope detections can be applied to identify if a person is coughing or wheezing.

Data coming from gas sensors is normalized, and the influence of temperature and humidity on its values is accounted for to minimize the impact of the environmental factors measurements. The purpose of the data preprocessing phase is to make sure that the data collected is appropriate for analysis.

3.5 Feature Extraction

The next step that needs to be accomplished in the data preprocessing process includes extraction of the needed information from data obtained through acoustic and gas sensor measurements. Gas sensors give an opportunity determine the level of VOCs, which indicates the state of respiratory system health. Acoustic measurements information is also analyzed.All features collected during the data preprocessing process are puttogether in a vector.

3.6 Developing Machine Learning Models

Machine learning models for classification and predicting the level of respiratory diseases will be developed. SVM algorithm and random forest will be applies to classify input data into several groups (asthma, wheezing, tuberculosis, normal).

A regression method is used to forecast the intensity of the problem, using features like concentration of VOCs and coughin frequency. The machine learning algorithm serves as an instrument for making a decision.

3.7 Machine Learning Model Training and Testing

To train machine learning models, the simulations of breath samples and VOC-acoustic parameters available in public datasets can be used. These datasets include extracted features, which are marked in labeled data examples.

The performance of the algorithm is checked by stats that provide accurate prediction results. Once the machine learning algorithm has been trained, it will be optimized and run.

3.8 Integrating IoT and Cloud Computing Solutions

The connection between the ESP32 microcontroller board and the cloud service is provided via uploading sensor data using protocols such as MQTT or REST API. Data from sensors, users, and predictive algorithms are stored in a cloud database (Firebase, MongoDB).

Data analysis and implementation of the machine learning models will happen in real-time mode with cloud computing technology. Besides, the historical data will be stored on the cloud for future monitoring and analysing purpose.

3.9 Deployment and Visualization

The interactive dashboard is developed for the user interface and health professional. The real-time sensor data, predicted disease, and the level of severity of that disease will be presented in dashboard. Visualization of historical data with alerting will also be shown in the dashboard.

This web-based application will involve remote monitoring and healthcare since physicians will have access to the data of their patients whenever and wherever.

3.10 System Workflow

Flowchart for the system workflow is illustrated in Fig. 2. First of all, the data will be collected with smart masks and sensors. Then, the collected data will be processed and analyzed with the help of machine learning models. Finally, the outcomes of data analysis will be transferred to the cloud and monitored with the web dashboard.

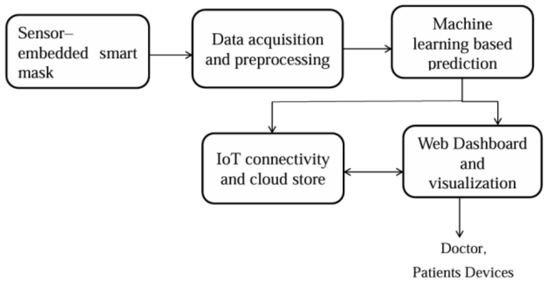

Fig. 2: Flowchart for AI-Based Multipurpose Disease Detection and Severity Prediction System for Asthma, Wheezing, and Tuberculosis

3.11 Suggestions Generation System

This system makes suggestions depending on the disease detected by the severity level. In situations where there are serious cases of the diseases, the system suggests that one visit to doctor as soon as possible. The suggestions generation system adds value to the system since the system becomes user-friendly.

3.12 Testing and Validation

This process involves function testing and validation as well as performance testing and validation. Real time testing is done in order to check the capability of the system to collect and transmit data. The machine learning system is tested using test data.

Once testing and validation are successfully carried out, the system is deployed as prototype system.

IV. RESULTS AND DISCUSSION

With respect to the above case, the development and testing of the mentioned multi-use artificial intelligence-based system that would be able to gather data, process information, and showrespratory diseases like asthma, wheezing, and tuberculosis was done based on this potential capability of the system.

4.1 Hardware Implementation

The hardware implementation design for the intelligent mask is presented where the MQ series of sensors have been correctly connected to the microcontroller.Proper insulation of the sensors has also been maintained.

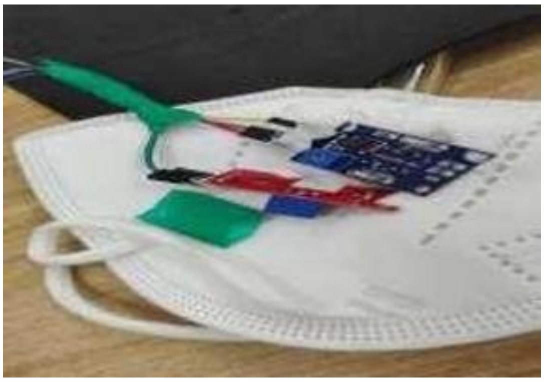

Fig4: Hardware Implementation of Sensor Embedded Intelligent Mask

4.2 Data Acquisition and System Performance

Data collection may be conducted through the sensors that have been installed to collect data regarding the gas concentration levels, environmental conditions, and acoustic data. Processing and transmission of the data will take between 5-15 seconds.

Using multiple sensors in data acquisition helps in enhancing the system performance because it becomes possible to detect both the chemical and acoustic signals of the respratory illnesses. Noise elimination will occur during data preprocessing in order to make the data ready for analysis using machine learning algorithms.

The real-time sensor outputs, including gas values, sound signals, temperature, and humidity, are visualized graphically as shown in Fig**.** 5.

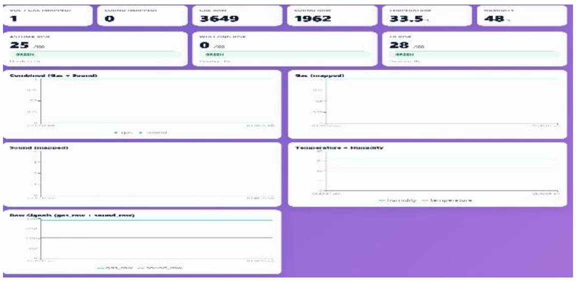

Fig. 5: Real-Time Sensor Data Visualization

4.3 Predictions and Analysis

Various machine learning algorithms applied to analyze the collected data can label the respiratory illnesses as asthma, wheezing, tuberculosis, or normal. Based on the analyzed data, the machine learning algorithms can predict the type and seriousness of the respiratory illness based on the VOC concentration, coughing frequency, and other factors.

Expected accuracy of the prediction of various respiratory diseases:

- Asthma – 83-87%
- Tuberculosis – 78-84%
- Wheezing – 87-91%

4.4 Software Interface and Visualization

In order to visualize obtained live data, prediction outcomes, and trends, the suggested software interface will be implemented using a web dashboard approach.

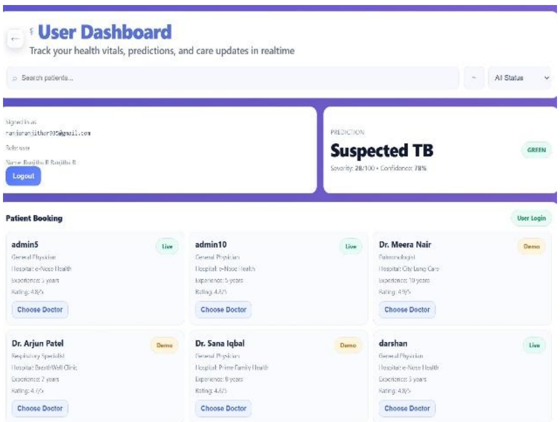

Fig. 5: Web Dashboard for Live Data and Prediction

4.5 Discussion

Therefore, the proposed technology successfully proved itself when implementing an e-Nose wearable sensor detect the occurrence of respiratory diseases through a non-invasive technique. The presented prototype was capable not only of data collection through sensors related to the respiratory system's work but of making predictions based on machine learning algorithms.

Based on the completed research, it can be said that the suggested technology provides a possibility to predict symptoms of respiratory illnesses 2-5 days prior to clinical techniques. Moreover, due to its always active working process, the battery usage does not exceed 8-12 hours per charge.

Nevertheless, one should mention that the above-discussed technology cannot be used for clinical diagnosis since its functioning depends not only on calibration processes but also on the accuracy of received data.

V. CONCLUSION

In the present paper, there was discussed the development and application of the multi-purpose disease detector for asthma, wheezing, and tuberculosis patients means of the AI-based technologies. In this regard, it is important to note that the proposed disease detector can be developed based on the integration of wearable electronics, which include an e-nose technology integrated a smart mask designed for the diagnosis of respiratory diseases.

By means of applying the Internet of Things and cloud computing along with advanced machine learning methods, it becomes possible ensure the uninterrupted flow of information based on sensor measurements concerning the presence of volatile organic compounds and signs of coughing or wheezing. Besides, there is the web interface proposed in order to help visualize the data collected during the process monitoring and analysis. There are multiple advantages that can be provided by the designed disease detector. They include portability, affordability, and real-time monitoring, as well as the opportunity to detect health problems in advance. but it is necessary to note that the proposed solution cannot be regarded as a diagnostic one because of its usage as a screening instrument remotely.

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