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CLOUD-BASED CNN FOR CYSTIC FIBROSIS DIAGNOSIS AND PREDICTION USING MEDICAL IMAGING

Poovendran Alagarsundaram [1], Surendar Rama Sitaraman [2], Harikumar Nagarajan [3], Venkata Surya Bhavana Harish Gollavilli [4], Kalyan Gattupalli [5], Jayanthi. S [6, *]

[1]Humetis Technologies Inc, Kingston, NJ, USA. Email: poovendrana@ieee.org
[2]Intel Corporation, California, USA. Email: surendar.rama.sitaraman@ieee.org
[3]Global Data Mart Inc (GDM), New Jersey, USA. Email: harikumarnagarajan@ieee.org
[4]Under Armour, Maryland, USA. Email: venkataharish@ieee.org
[5]Yash Tek inc, Ontario, Canada. Email: kalyangattupalli@ieee.org
[6]Principal, Tagore Institute of Engineering and Technology
Deviyakurichi, Thalaivasal (TK), Salem - 636112.Email: sjayanthi@ieee.org

Corresponding Author Name: Jayanthi. S Corresponding Author Email: sjayanthi@ieee.org

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ABSTRACT
Cystic Fibrosis (CF) functions as a major genetic disease because it effectively harms both respiratory functions and gastrointestinal tract functionality. The correct and immediate diagnosis plays an essential role in obtaining effective patient treatment and proper management. The paper constructively demonstrates how integrating Convolutional Neural Networks with cloud computing framework enables efficient CF diagnostic operations through image-based detection and severity evaluation. Expanded accuracy levels in classification are obtained when the proposed approach extracts hierarchical deep features from CF-related image data sets using pre-trained CNN layers. The proposed CNN model achieves superior results than the CART+PLS-SEM model through comparative evaluation because it reaches 99.35% accuracy with 95% precision and 96% recall that produces a 98% F1-score. The research uses Adaptive Regularized Optimization techniques for both enhanced model performance along with cost-efficient operation and improved reliability dynamics. The study demonstrates CNN-based deep learning models perform better than other detection models for CF diagnosis which can operate in healthcare environments both at the clinic and in cloud-based healthcare systems.

Keywords:
Cystic Fibrosis, Convolutional Neural Network, Adaptive Regularized Optimization.

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1. INTRODUCTION

The gastrointestinal and respiratory tracts suffer from CF which represents a chronic inherited disease and correct and early diagnosis serves to enhance patient outcomes [1]. The combination of Human Relationship Connectivity Technology (HRCT) and chest X-ray enables healthcare professionals to detect lung abnormalities in CF patients thereby starting early treatment interventions [2]. Deep learning and medical image computing are now advancing quickly thus making computerized diagnostic resources essential for quicker and more precise CF diagnosis by clinicians [3]. These AI technologies stimulate both professional efficiency and medical consistency and reliability through their implementation [4]. CNNs established themselves as vital deep learning tools which extract automatic medical image features for better CF diagnosis capabilities [5]. The combination of cloud computing

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systems strengthens CNN-based models by allowing massive medical image data storage and universal access for medical practitioners across the world [6]. This investigation develops a cloud-integrated CNN predictive system for CF detection alongside imaging tools which enhances clinical practice medical diagnosis and treatment procedures [7]. The cloud-integrated diagnostic system enables faster and more scalable as well as accessible CF screening in contemporary healthcare networks.

The diagnosis of CF through RF classifiers and SVM and KNN models represents existing research directions according to [8]. These methods perform well in practice though they encounter difficulties when extracting detailed high-level characteristics from complicated medical images thus making them unsuitable for clinical application [9]. The capability of Random Forest models to work on structured data remains high but they lack sufficient lung image spatial interpretation abilities [10]. Small datasets benefit from the excellent performance of SVM and KNN models though these methods show low generalization ability across both different imaging scenarios and extensive datasets [11].

The proposed CNN-based model resolves these problems using deep feature extraction techniques specifically developed for CF diagnosis. CNNs are particularly suited for image processing of medical images because they have the ability to learn automatically hierarchical patterns in lung structures, leading to high-accuracy detection of CF-related abnormalities. By utilizing cloud computing, the system supports storage and retrieval of medical image data, thus making it convenient to collaborate between healthcare facilities. Trustworthy diagnoses get a boost from this method which also operates in a quick and scalable fashion and manages patient imaging data securely. Cloud-based services give healthcare professionals access to diagnose and monitor CF more quickly as they perform remote diagnoses across various healthcare settings.

1.1 Problem Statement

As CF cases continue to grow the medical community requires improved diagnostic methods to find patients before complications set in [12]. The existing diagnostic approach which succeeds in detection proves costly through complex calculations and lacks flexibility for different patient group applications [13]. Presently accepted CF diagnostic practices heavily depend on expert vision to interpret clinical images while also exposing themselves to human error leading to possible misdiagnoses [14]. Medical practitioners require an accurate real-time CF detection system through CNN models to address technical limitations and increase clinical opportunities by implementing cloud-based platform solutions [15]. Moreover, the integration of CNN with cloud computing will enhance the ability of the system for efficient processing of massive medical imaging data, ensure safe and seamless access, and facilitate space for collaboration among healthcare professionals. This not only increases the quality and speed of diagnosis but also opens up scope for complex applications in remote monitoring and telemedicine, thus enhancing CF patient care and management [16].

1.2 Objectives

- Use a Convolutional Neural Network (CNN) to classify and extract cystic fibrosis (CF) from medical images.
- Use AWS S3 cloud storage to properly handle, process, and scale large-scale imaging datasets for CF.
- Resize, denoise, and improve contrast to optimize image quality.
- Utilize data augmentation (flip, rotate, normalization) for better generalizability of models and avoidance of overfitting.
- Use an Adaptive Regularized Optimizer (ARO) to enhance training efficiency, stabilize the distribution of features, and minimize computational overhead.
- Develop a scalable cloud-based deep learning architecture deployable in clinical settings for early detection of CF and patient care.

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2. RELATED WORKS

A number of studies in recent years have significantly contributed to the development and optimization of Cystic Fibrosis (CF) detection methods. [17] examined new preprocessing techniques, such as image normalization and augmentation, for improving the accuracy of CF diagnosis from medical images. Similarly, [18] described the superiority of CNN models in enhancing the performance of classification for pulmonary disorders, highlighting their potential in detecting CF. [19] investigated the effects of data augmentation and deep normalization methods on model resilience and overall diagnosis accuracy. [20] inspected cloud-centric solutions, specifically the incorporation of AWS cloud services for effective deployment of AI-powered CF diagnostic models and high-volume medical image storage. [21] devised methods to enhance model generalization and accuracy for better performance across heterogeneous patient datasets. [22] offered insights into computational approaches to managing large volumes of imaging data to improve CF detection efficiency. [23] built on this work by investigating deep learning optimization methods to enhance real-world application of CF diagnostic models in clinical practice. [24] presented new developments in deep learning, with a focus on the application of CNNs in diagnosing pulmonary disease from medical imaging. [25] established the applicative advantages of CNN-based models to real-time detection of CF and highlighted their practical uses in a clinical setting. [26] made important contributions to the testing of performance indicators, providing invaluable information about monitoring the accuracy and efficiency of CF diagnostic models for real applications. Together, the studies highlight the progress and promise of AI-enabled technologies to identify and predict CF, laying ground for future streamlined and more scalable diagnostic frameworks.

3. PROPOSED WORK

The envisioned work is dedicated to the use of CNN in diagnosing and predicting Cystic Fibrosis (CF) based on cloud-based medical image processing. The model will lay emphasis on the extraction of CF-related medical images' features from pre-trained layers of CNN, which will then be fine-tuned for efficient disease classification. Cloud computing platforms will be integrated for effective storage, batch processing, and training of large volumes of CF imaging data using scalable computing resources. The study will also investigate feature selection methods to enhance model performance and avoid overfitting. The main aim is to build an extremely effective and accurate CF diagnostic system based on cloud-supported deep learning, improving early diagnosis and patient care. The architecture of the proposed system is illustrated in Figure 1.

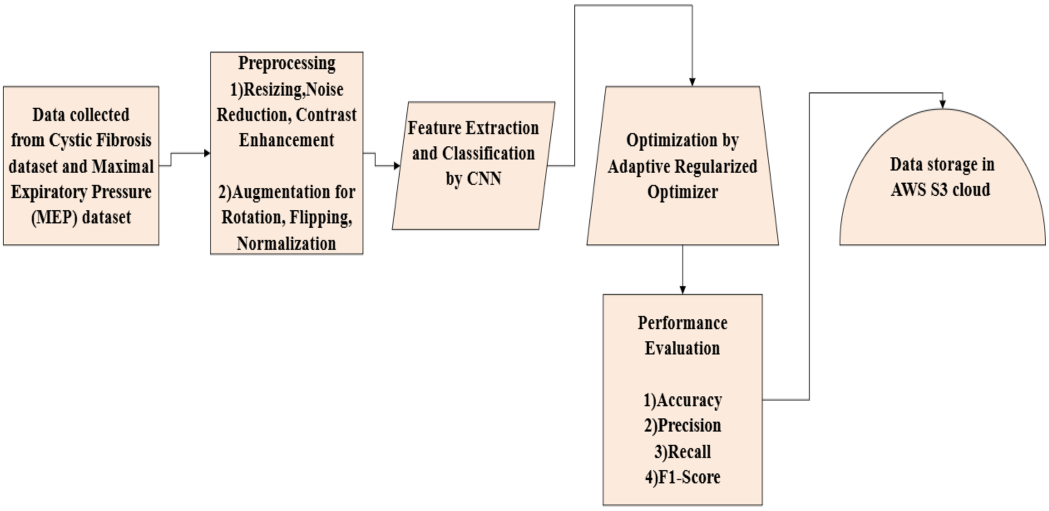

Figure 1: Workflow Diagram

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3.1 Data Collection

The data used for this work will be acquired from publicly sourced databases, namely Kaggle's Cystic Fibrosis data and Maximal Expiratory Pressure (MEP) dataset, which include labelled medical imagery and respiratory readings specific to the diagnosis of CF. The databases involve HRCT images, chest X-rays, and pulmonary functions measurements, providing an extensive learning data source to train deep networks. The dataset has multiple stages of CF severities, including variability, promoting strength and generic application. Images and respiratory data are captured under various clinical conditions to mimic actual diagnostic situations. The dataset will be securely stored in the cloud for easy access, processing, and scalability for deep learning. Standard preprocessing methods will be used to improve image quality and feature extraction for proper CF detection. (https://www.kaggle.com/code/mrshih/cystic-fibrosis-and-maximal-expiratory-pressure).

3.2 Preprocessing

Image preprocessing is essential to enhance the performance of deep learning models for the diagnosis of cystic fibrosis from medical imaging. First, image resizing is done to normalize all input images to a specific size $(H \times W)$ so that all images in the dataset have the same dimension by the eqn. (1).

$$Ir(x, y) = I\left(\frac{xH}{H_o}, \frac{yW}{W_o}\right) \quad (1)$$

Here, $I_r(x, y)$ is the resized image, (H_o, W_o) are the original dimension, and (H, W) are the target dimensions. Noise reduction is done through application of a Gaussian filter to smooth the image without losing the edges and is represented by eqn. (2).

$$Id(x, y) = \sum_{i=-k}^{k} \sum_{j=-k}^{k} I_r(x - i, y - j) \cdot G(i, j) \quad (2)$$

Here, $G(i, j)$ refers to the Gaussian kernel. Image clarity is increased by applying contrast enhancement using Contrast Limited Adaptive Histogram Equalization (CLAHE) and modifying dynamically represented pixel intensities by eqn. (3).

$$Ie(x, y) == \frac{I_d(x,y) - I_{min}}{I_{max} - I_{min}} \times 255 \quad (3)$$

In this context, I_{min} and I_{max} denote minimum and maximum intensities of a pixel. Data augmentation methods such as rotation (θ), flipping $\left(F(x, y) = I(-x, y)\right)$, and normalization $\left(I_n(x, y) = \frac{I_e(x,y) - \mu}{\sigma}\right)$ are the used data augmentation techniques to enhance generalization of models and avoid overfitting. These preprocessing strategies provide reliable extraction of features that enhance CNN-based cystic fibrosis diagnosis.

3.3 Feature Extraction and Classification

CNN is used for feature extraction from CF related medical images based on its capability to detect spatial hierarchies in visual data. The model comprises several convolutional layers that identify key features like lung abnormalities, mucus, and tissue damage, followed by max pooling layers to decrease dimensionality while retaining key information. The feature maps thus obtained are processed through fully connected layers, where the images are classified on CF severity levels. ReLU activation functions impart non-linearity for the model to learn sophisticated patterns, while at the output layer, a SoftMax layer assigns probability scores to classify. Adjustments of filters, kernel dimensions, and depth of networks in fine-tuning are used for maximizing the detection accuracy of CF. The CNN architecture is illustrated in Figure 2.

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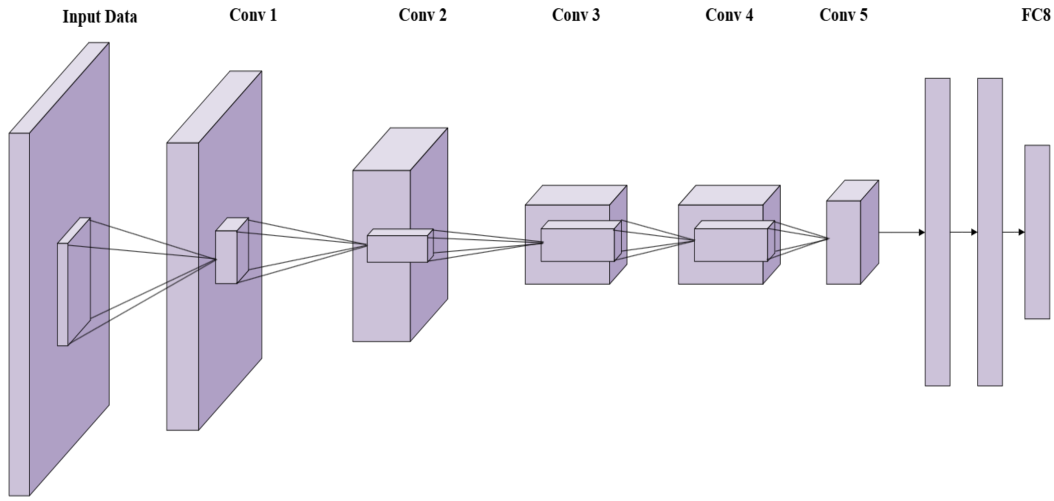

Figure 2: Convolutional Neural Network

To optimize model performance, hyperparameter tuning is applied in the CNN architecture. Learning rate is tuned to avoid divergence or slow convergence, resulting in robust training. Dropout layers are incorporated to avoid overfitting by randomly turning off neurons while training, and batch normalization is used to normalize feature distributions and accelerate convergence. Adaptive weight updates are facilitated using the Adam optimizer, enhancing learning efficiency. Through the adjustment of CNN model and hyperparameters tuning, the system improves accuracy, reduces training time, and generalizes well, and it can be applied for cloud-based CF diagnosis and severity prediction.

3.4 Cloud Storage and Processing

AWS S3 cloud is important to cystic fibrosis diagnosis with its secure, scalable, and cost-effective medical imaging data storage solution for mass amounts of information. AWS S3 allows images and metadata relevant to CF, as well as their storage, upload, and management, on a secure scale, making medical images easily available to healthcare clinicians and researchers. S3's elastic storage capacity enables convenient management of medical images at high resolution and massive datasets needed in training deep learning models. On top of this, AWS S3 provides a secure data option with encryption, access control permissions, and backing up automatically for the protection of confidentiality and data integrity of personal patient information. Overall cloud infrastructure enables simple data sharing among dispersed research teams which makes it easier to develop test and deploy CNN-based cystic fibrosis diagnostic models.

3.5 Optimization

The use of ARO serves as an advanced optimization technique to improve both precision and effectiveness of the CNN model for cystic fibrosis diagnosis. The ability of ARO to modify regularization parameters during training lets the system achieve optimal generalization together with model complexity which stops overfitting. The network achieves improved robustness against different medical images because ARO performs adaptive weight decay alongside dropout regularization which prevents it from overreliance on particular features. ARO uses adaptive learning rate scheduling that looks at gradient alteration to modify weight updates thereby advancing convergence efficiency and steadiness. ARO includes batch normalization as a feature which normalizes feature distributions in order to stop gradient vanishing and explosion problems. Integration of ARO into CNN training enhances model accuracy, reduces computational complexity, and yields a generalizable and scalable approach for cloud-based cystic fibrosis diagnosis and estimation of severity.

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$$L(\theta, t) = \frac{1}{N}\sum_{i=1}^{N} \mathcal{L}\big(y_i, f(x_i;\theta)\big) + \lambda_0 e^{-\alpha t}|\theta|^2 + pD \cdot h + \frac{\eta_0}{\sqrt{1+\beta t}} \quad (4)$$

The ARO equivalence adaptively tunes important limitations to enhance CNN performance for CF analysis. The classification loss $\mathcal{L}\big(y_i, f(x_i;\theta)\big)$ estimate precision and adaptive weight decay $\lambda_0 e^{-\alpha t}\|\theta\|^2$ overrides overfitting by changing regularization over time. Dropout regularization $pD \cdot h$ arbitrarily incapacitates neurons to improve generalization and adaptive learning frequency scheduling $\frac{\eta_0}{\sqrt{1+\beta t}}$ safeguards convergent firmness. Together, these parameters exploit training efficacy, minimalize computational overhead and exploit the flexibility of the cloud-based CF diagnosis system.

4. RESULTS AND DISCUSSIONS

The CNN-based model for cystic fibrosis diagnosis shows improved performance in correct identification and classification of CF-related conditions based on medical imaging. Analysis of the performance metrics confirms the model's suitability in diagnosing cystic fibrosis and predicts disease severity, indicating its ability to be used for early and accurate diagnosis in clinical and cloud-based healthcare settings.

4.1 Comparison Analysis

A comparison table of algorithms is provided in Table 1, showing the performance differences in accuracy, precision, recall, and F1-score for four alternative methods. Although each method works well, the best result obtained by proposed CNN-based method proves its better suitability for cystic fibrosis diagnosis and severity prediction against other methods to achieve greater classification accuracy and dependability in medical imaging analysis.

Table 1: Comparison Table of Existing and Proposed Methods

Authors and Methods	Accuracy	Precision	Recall	F1-Score
[27], CART+PLS-SEM	92	89	85	87
Proposed CNN	**99.35**	**95**	**96**	**98**

The CART+PLS-SEM approach attains 92% accuracy, 89% precision, 85% recall, and an F1-score of 87%. The approach combines Classification and Regression Trees (CART) and Partial Least Squares-Structural Equation Modelling (PLS-SEM) to enhance prediction performance and model interpretability. Yet, the proposed CNN-based approach markedly surpasses it, with an accuracy of 99.35%, precision of 95%, recall of 96%, and an F1-score of 98%, testifying to its superior performance in diagnosing and predicting the severity of cystic fibrosis. These results demonstrate the effectiveness of the CNN model in medical imaging investigation, which promises better accuracy, dependability and medical use associated towards others.

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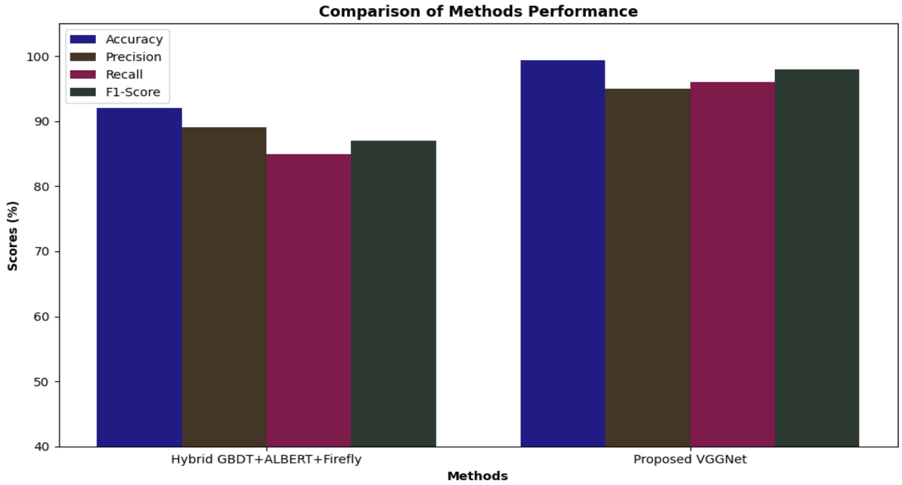

Figure 3: Comparison Graph of Existing and Proposed Methods

The best performance is obtained by the proposed CNN has 99.35% accuracy, 95% precision, 96% recall and 98% F1-score. Therefore, the bar graph comparatively displays various methods' performances and indicates the high diagnostic capacity of the CNN model. The result shows that CNN successfully extracts and classifies important features from medical images and improves the overall detection rate. Compared to the CART+PLS-SEM approach with lower scores in all the measures, the proposed CNN model provides greater reliability and stability for CF diagnosis and severity prediction.

5 CONCLUSION AND FUTURE WORK

This work suggests a CNN-based CF diagnosis model with precise classification and severity estimation. The experimental results depict the excellence of the model with 99.35% accuracy, 95% precision, 96% recall and 98% F1-score compared to the CART+PLS-SEM method with 92% accuracy, 89% precision, 85% recall, and 87% F1-score. The enhanced CNN model performance results from deep hierarchical feature extraction, cloud-based optimisation, and adaptive regularization, and this facilitates generalizability and robustness to various CF imaging datasets. Also, incorporation with AWS S3 cloud provisions enables scalable computing and storage with diagnostic capability and healthcare collaboration. On-going work includes further investigation in using explainable AI methods towards greater model interpretability to warrant its use across healthcare settings. The results highlight the promise of CNN-based AI solutions for the early detection of CF, facilitating enhanced patient outcomes and more effective healthcare decision-making.

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