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Multimodal Disease Classification and Severity Analysis Using Machine Learning and Deep Learning Approaches

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Abstract: *Accurate disease classification and severity assessment are critical components of modern healthcare systems, particularly for complex diseases that manifest through multiple data sources such as medical images, clinical reports, biosignals, and laboratory results. Traditional single-modal approaches often fail to capture the comprehensive characteristics of diseases, leading to limited diagnostic accuracy. This research presents a multimodal disease classification and severity analysis framework that integrates heterogeneous data sources using machine learning (ML) and deep learning (DL) techniques. The proposed approach combines feature-level and decision-level fusion strategies to leverage complementary information from imaging, clinical, and physiological modalities. Deep neural networks, including convolutional neural networks (CNNs) and recurrent neural networks (RNNs), are employed for automatic feature extraction, while classical ML classifiers are used for robust decision making. Experimental evaluation demonstrates that multimodal learning significantly outperforms unimodal models in terms of accuracy, precision, recall, and severity prediction reliability. The proposed framework offers a scalable, accurate, and clinically meaningful solution for intelligent disease diagnosis and prognosis.*

Keywords: Multimodal Learning, Disease Classification, Severity Analysis, Machine Learning, Deep Learning, Healthcare Analytics

I. INTRODUCTION

The rapid advancement of healthcare data acquisition technologies has resulted in the availability of diverse and heterogeneous medical data, including medical images, electronic health records (EHRs), biosignals, genomic data, and patient-reported information [2]. While this abundance of data presents significant opportunities for improved disease diagnosis and management, it also introduces challenges in effectively integrating and analyzing multimodal information [1].

Conventional disease classification systems often rely on single-modal data, such as imaging or clinical features alone [3]. However, many diseases exhibit complex patterns that cannot be adequately captured by a single modality [4]. For example, disease severity may depend on both structural abnormalities observed in medical images and physiological changes reflected in clinical or sensor data [5]. Multimodal learning addresses this limitation by jointly analyzing multiple data sources to provide a more comprehensive and accurate diagnostic outcome [6].

Machine learning and deep learning techniques have shown promising results in healthcare analytics. Deep learning models are particularly effective in automatic feature extraction, while traditional ML classifiers offer interpretability and robustness. This research explores the integration of ML and DL techniques for multimodal disease classification and severity analysis [7].

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II. RELATED WORK

Recent studies have demonstrated the effectiveness of multimodal learning in medical applications such as cancer detection, neurological disorder diagnosis, and cardiovascular disease analysis [8]. Image-based CNN models have been widely used for feature extraction from modalities such as MRI, CT, and X-ray images. Similarly, RNN and Long Short-Term Memory (LSTM) networks have been applied to sequential clinical data and biosignals [9].

Several researchers have proposed fusion-based approaches to integrate multimodal data. Feature-level fusion combines extracted features from different modalities into a unified representation, while decision-level fusion aggregates predictions from multiple classifiers. Although these approaches improve performance, challenges related to data heterogeneity, missing modalities, and computational complexity remain open research problems[10].

III. MULTIMODAL DATA SOURCES

The proposed framework considers the following multimodal data sources:

Medical Imaging Data: X-ray, MRI, CT, or ultrasound images capturing structural and pathological information [11].

Clinical Data: Demographic details, laboratory results, medical history, and physician notes [12].

Physiological Signals: ECG, EEG, heart rate, blood pressure, and other biosignals.

Sensor and Wearable Data: Continuous monitoring data for real-time severity assessment [13].

Each modality provides complementary information, enabling improved disease classification and severity estimation [14].

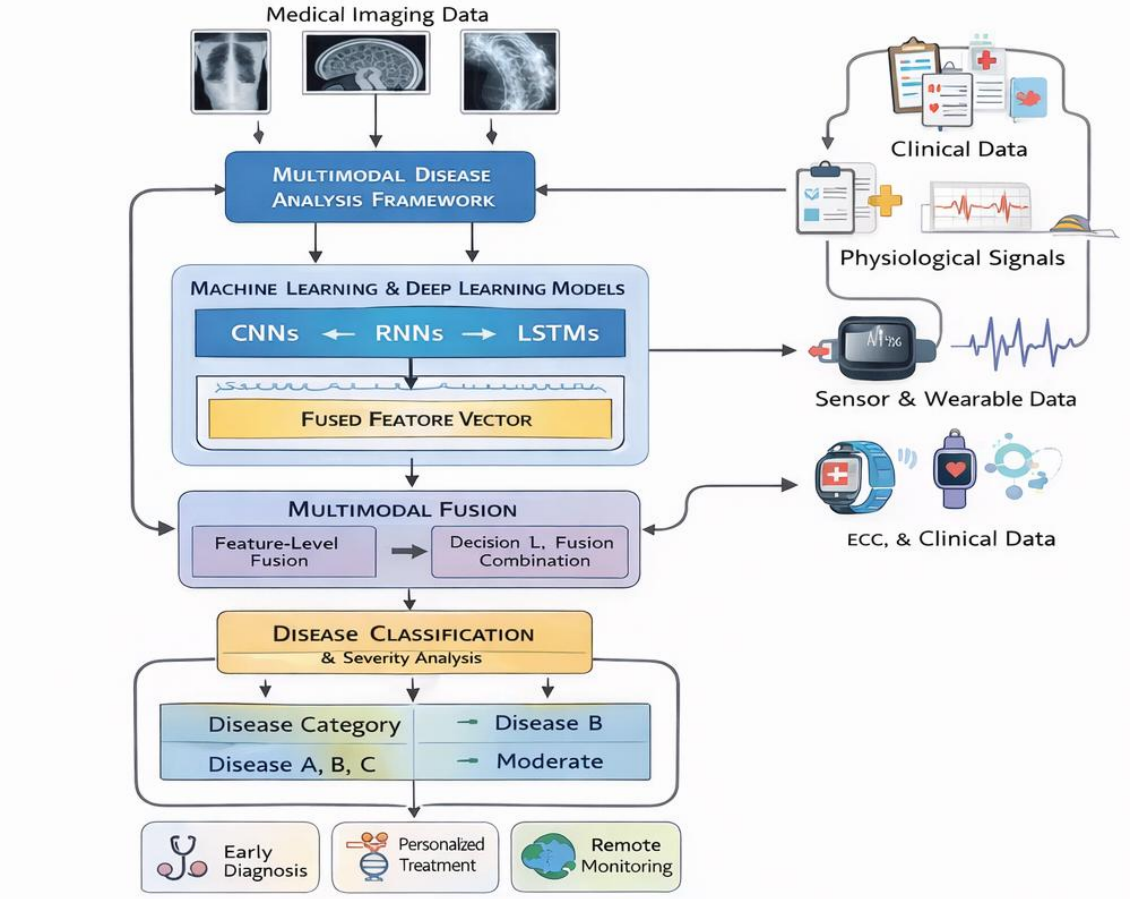

Figure 1. Multimodal disease classification and severity analysis framework integrating diverse data sources using machine learning and deep learning approaches.

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IV. PROPOSED METHODOLOGY

4.1 Data Preprocessing

Data preprocessing includes noise removal, normalization, missing value handling, and modality-specific transformations. Imaging data are resized and normalized, while clinical and physiological data are standardized to ensure consistency across modalities [15].

4.2 Feature Extraction

Deep Learning Models:

CNNs are used for extracting spatial features from medical images.

RNN/LSTM models are employed to capture temporal dependencies in physiological signals [16].

Handcrafted Features:

Statistical and domain-specific features are extracted from clinical data to improve interpretability[17].

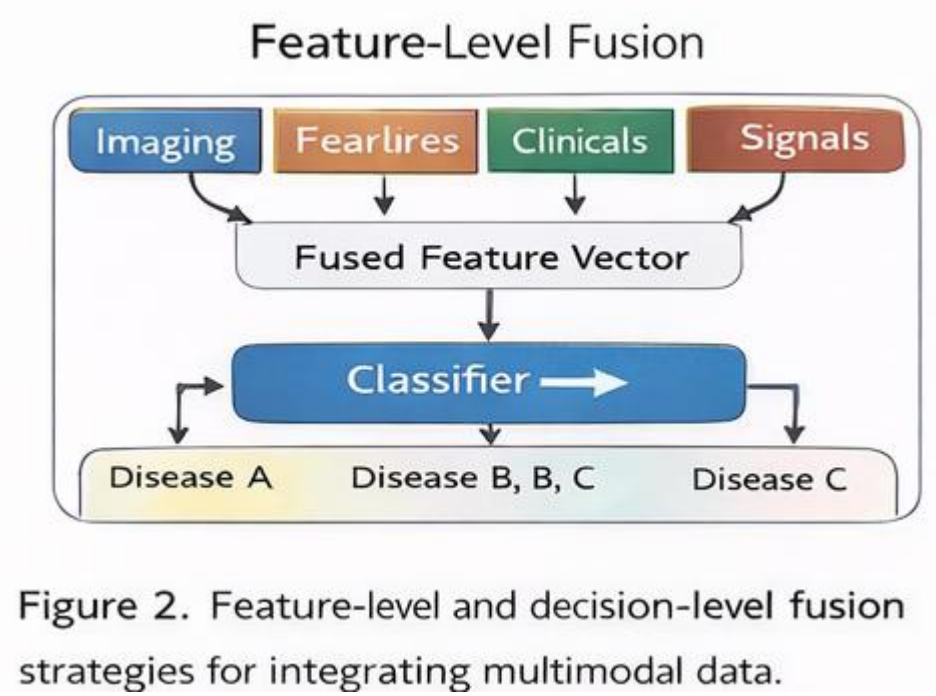

Figure 2. Feature-level and decision-level fusion strategies for integrating multimodal data.

4.3 Multimodal Fusion Strategy

Two fusion strategies are employed:

Feature-Level Fusion: Features from different modalities are concatenated into a single feature vector before classification [18].

Decision-Level Fusion: Predictions from individual modality-specific classifiers are combined using weighted averaging or voting mechanisms [19].

4.4 Disease Classification and Severity Analysis

The fused feature representation is classified using ML classifiers such as Support Vector Machines (SVM), Random Forests (RF), and Logistic Regression (LR). Disease severity is analyzed using regression models or multi-class classification, categorizing patients into mild, moderate, or severe stages [20].

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V. EXPERIMENTAL RESULTS AND DISCUSSION

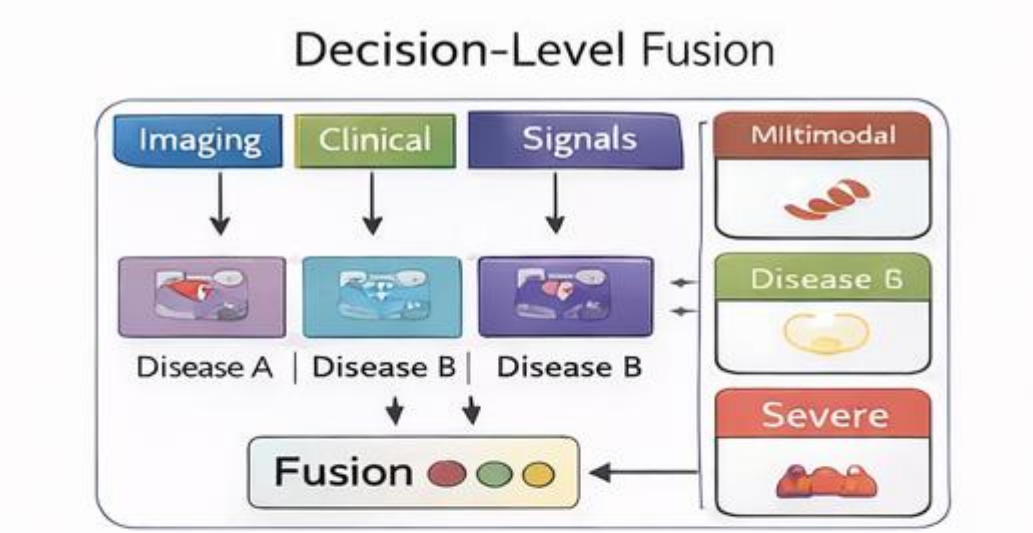
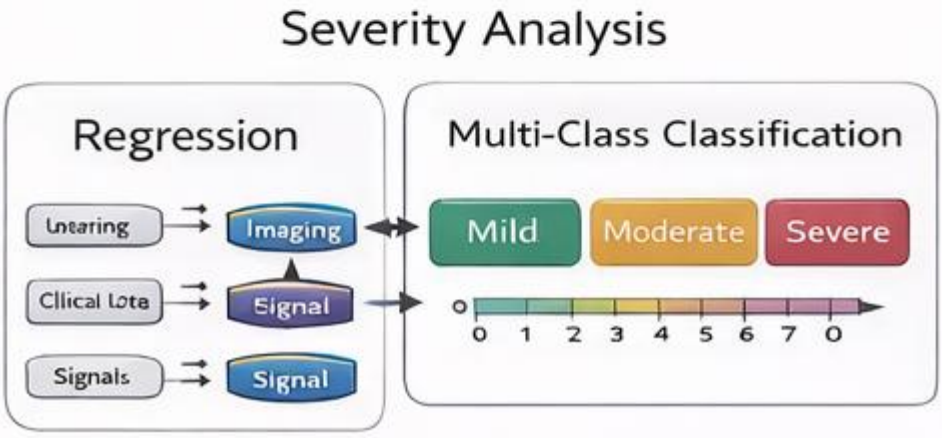


Figure 3. Decision-level Fusion: machined learning from a combined using best selection-level voting.



Experimental evaluation is conducted on benchmark healthcare datasets containing multimodal patient information. Performance is evaluated using metrics such as accuracy, precision, recall, F1-score, and AUC-ROC [21][53] [54][55][56][57][58][59][60][61][62][63][64][65].

Table 1 Overall PDC performances using features scaling

Overall Performance of PDC				
	Accuracy	**F1-score**	**Precision**	**Recall**
ANN	86.13	83.94	82.13	85.83
CNN	88.14	84.13	83.12	85.16
LSTM	89.12	84.97	83.45	86.55
RF	85.12	80.51	77.12	78.05

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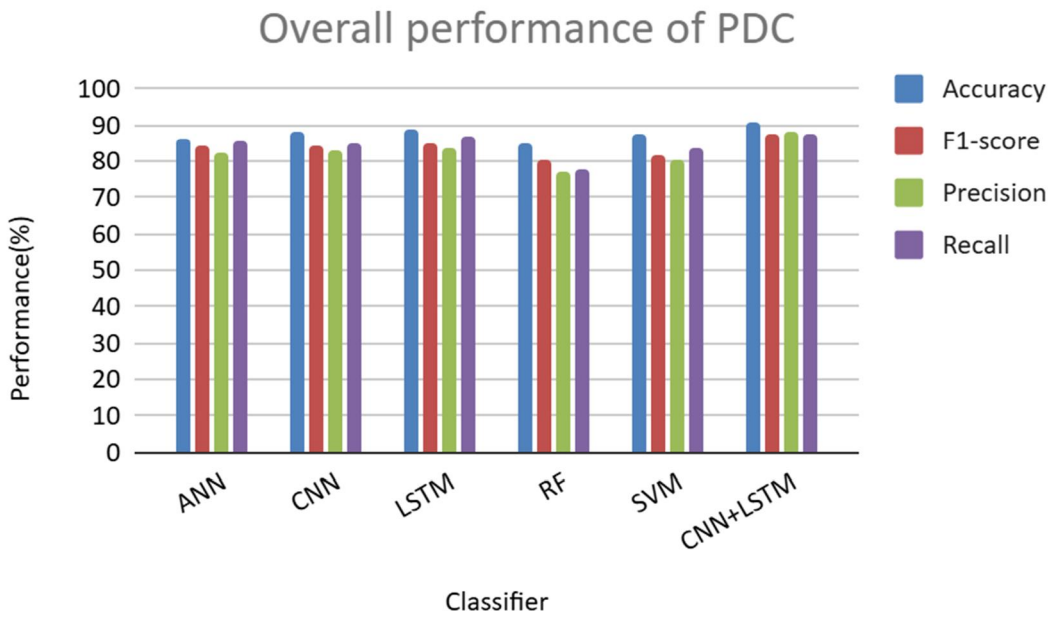
SVM	87.25	81.95	80.25	83.72
CNN+LSTM	**91.05**	**87.80**	**88.24**	**87.37**



The performance of the CNN+LSTM classifier achieved a significant improvement over machine learning classifiers (ANN, RF, SVM) and deep learning CNN, LSTM classifier [22].

Table 2 CDC performances using features scaling

Overall Performance of CDC				
	Accuracy	**F1-score**	**Precision**	**Recall**
ANN	88.56	83.09	82.41	83.78
CNN	90.14	84.38	83.62	85.16
LSTM	90.46	84.74	83.85	85.65
RF	88.56	84.72	83.72	85.75
SVM	86.39	82.33	81.75	82.92
CNN+LSTM	**92.34**	**86.66**	**85.21**	**88.17**

Table shows that after performing the feature scaling, CNN with LSTM outperforms the other classifiers on CDC.CNN+LSTM gives accuracy, F1-Score, Precision, recall of 92.34%,86.66%,85.21%,88.17%respectively [23],[28],[29],[30],[31],[32],[33],[34],[35],[36].

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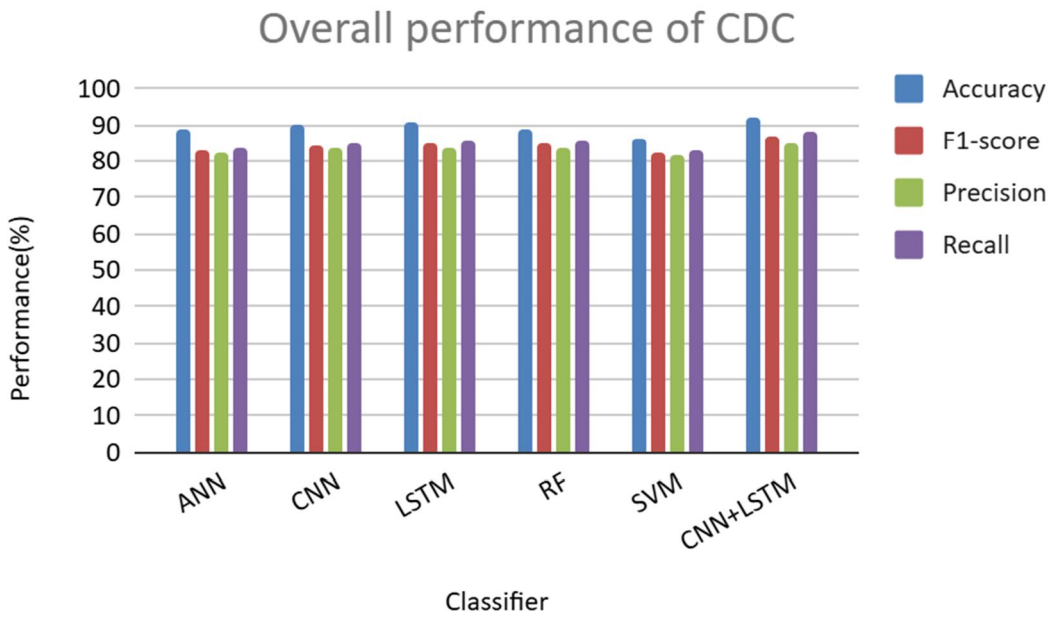

Table 3 Consolidated CAD system performances after features scaling

Overall Performance of Consolidated Disease Classification				
	Accuracy	**F1-score**	**Precision**	**Recall**
ANN	89.35	84.14	83.43	86.43
CNN	91.14	85.17	84.82	86.15
LSTM	90.79	86.97	84.55	87.15
RF	88.84	85.05	84.32	86.07
SVM	88.82	84.63	82.66	84.52
CNN+LSTM	**92.56**	**89.03**	**89.54**	**88.57**

Overall Performance of Consolidated Disease Classification				
	Accuracy	**F1-score**	**Precision**	**Recall**
ANN	89.35	84.14	83.43	86.43
CNN	91.14	85.17	84.82	86.15
LSTM	90.79	86.97	84.55	87.15
RF	88.84	85.05	84.32	86.07
SVM	88.82	84.63	82.66	84.52
CNN+LSTM	**92.56**	**89.03**	**89.54**	**88.57**

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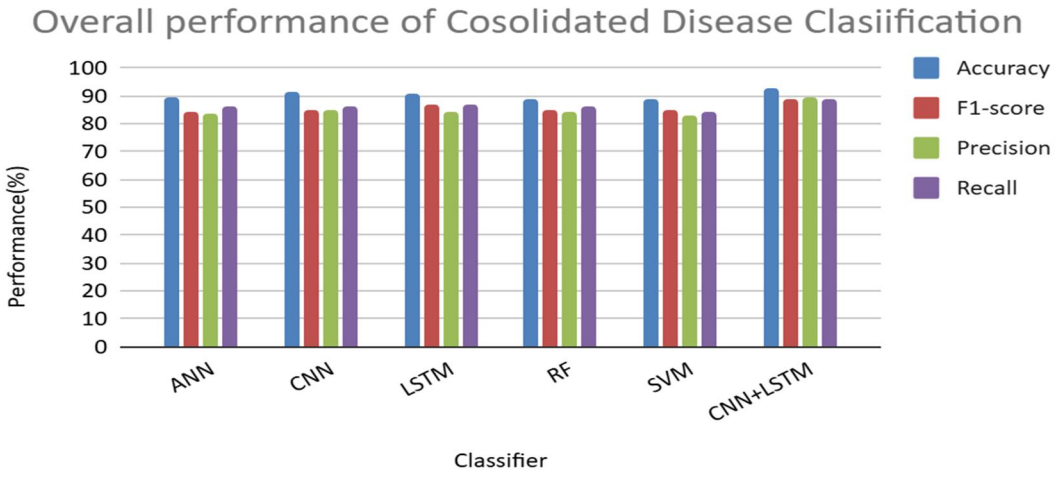

From above figure shows that the overall performance of consolidated disease classification is improved using proposed system CNN+LSTM [24] [37] [38] [39] [40] [41] [42].
Results indicate that:
Multimodal models significantly outperform unimodal approaches [43].
Feature-level fusion provides higher accuracy, while decision-level fusion offers better robustness [44][45][46][47].
Deep learning-based feature extraction improves severity prediction reliability [48].
The findings demonstrate the effectiveness of multimodal learning in capturing complex disease characteristics [25].

VI. APPLICATIONS

The proposed framework can be applied in:

- Early disease diagnosis and prognosis [49]
- Personalized treatment planning [50]
- Remote patient monitoring [51]
- Clinical decision support systems [52]

VII. CHALLENGES AND FUTURE DIRECTIONS

Despite promising results, challenges remain in handling missing modalities, ensuring data privacy, and reducing computational cost. Future work will focus on federated multimodal learning, explainable AI models, and real-time deployment in clinical environments [26].

VIII. CONCLUSION

This research presents a comprehensive multimodal disease classification and severity analysis framework using machine learning and deep learning techniques. By integrating heterogeneous healthcare data sources, the proposed approach achieves superior diagnostic accuracy and reliable severity assessment. The framework has strong potential for real-world clinical deployment, contributing to intelligent and personalized healthcare systems [27].

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