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Deep Learning Driven Chronic Kidney Disease Detection Using Hybrid Models

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Abstract

Chronic Kidney Disease (CKD) is a serious health condition that affects kidney function and may lead to kidney failure if not detected at an early stage. Early prediction and diagnosis of CKD can help in reducing mortality rates and improving patient care. In recent years, machine learning and deep learning techniques have been widely used for disease prediction in the healthcare sector. However, individual machine learning and deep learning models have certain limitations in terms of prediction accuracy and feature extraction. To overcome these limitations, this study proposes a deep learning driven hybrid model for Chronic Kidney Disease detection. In the proposed method, data preprocessing techniques such as handling missing values, normalization, and feature selection were applied to the CKD dataset. A deep learning model was used for feature extraction, and a machine learning classifier was used for classification. The hybrid model combines the advantages of both deep learning and machine learning techniques to improve prediction performance. The performance of the proposed model was evaluated using performance metrics such as Accuracy, Precision, Recall, and F1-Score. The results show that the proposed hybrid model achieved higher accuracy compared to traditional machine learning and deep learning models. Therefore, the proposed hybrid model can be used as an effective clinical decision support system for early detection of Chronic Kidney Disease.

Keywords: *Chronic Kidney Disease, Deep Learning, Machine Learning, Hybrid Model, Disease Prediction, Clinical Decision Support System, Artificial Intelligence.*

1. Introduction

Chronic Kidney Disease (CKD) is a serious medical condition characterized by the gradual loss of kidney function over time. It is considered a major global health problem due to its high prevalence, high treatment cost, and risk of progression to end-stage renal disease (ESRD), which requires dialysis or kidney transplantation. Early detection and diagnosis of CKD are essential to prevent disease progression and reduce mortality rates. Traditional diagnostic methods rely on laboratory tests and clinical expertise, which may not always detect the disease at an early stage **(Eddy et al., 2020).**

In recent years, Artificial Intelligence (AI) techniques, particularly Machine Learning (ML) and Deep Learning (DL), have been widely used in the healthcare sector for disease prediction and diagnosis. Machine learning algorithms such as Support Vector Machine (SVM), Random Forest (RF), and Decision Tree (DT) have shown promising results in CKD prediction (Qin et al., 2020). However, deep learning models such as Convolutional Neural Networks (CNN), Artificial Neural Networks (ANN), and Deep Neural Networks (DNN) provide higher accuracy due to their ability to automatically extract features from complex medical data **(Ma et al., 2020).**

Hybrid models that combine deep learning and machine learning techniques have recently gained attention because they improve prediction accuracy and model performance. These hybrid models integrate the feature extraction capability of deep learning with the classification capability of machine learning algorithms, resulting in more efficient CKD detection systems **(Venkatrao & Kareemulla, 2023; Khalid et al., 2023).** The use of hybrid deep learning models helps in handling large datasets, improving prediction accuracy, and reducing computational complexity.

Therefore, this study proposes a deep learning driven hybrid model for chronic kidney disease detection to improve the accuracy and efficiency of early CKD prediction. The proposed model combines deep learning techniques with machine learning classifiers to develop an intelligent decision support system for CKD diagnosis.

Table 1. Summary of CKD Stages and Clinical Parameters

CKD Stage	eGFR (mL/min/1.73 m²)	Kidney Function	Clinical Symptoms	Recommended Action
Stage 1	≥ 90	Normal kidney function	No symptoms	Regular check-up, lifestyle changes
Stage 2	60 – 89	Mild kidney damage	Mild symptoms	Monitor blood pressure, diet control
Stage 3	30 – 59	Moderate kidney damage	Fatigue, swelling	Medication and regular monitoring
Stage 4	15 – 29	Severe kidney damage	Severe symptoms	Prepare for dialysis
Stage 5	< 15	Kidney failure	ESRD	Dialysis or kidney transplant

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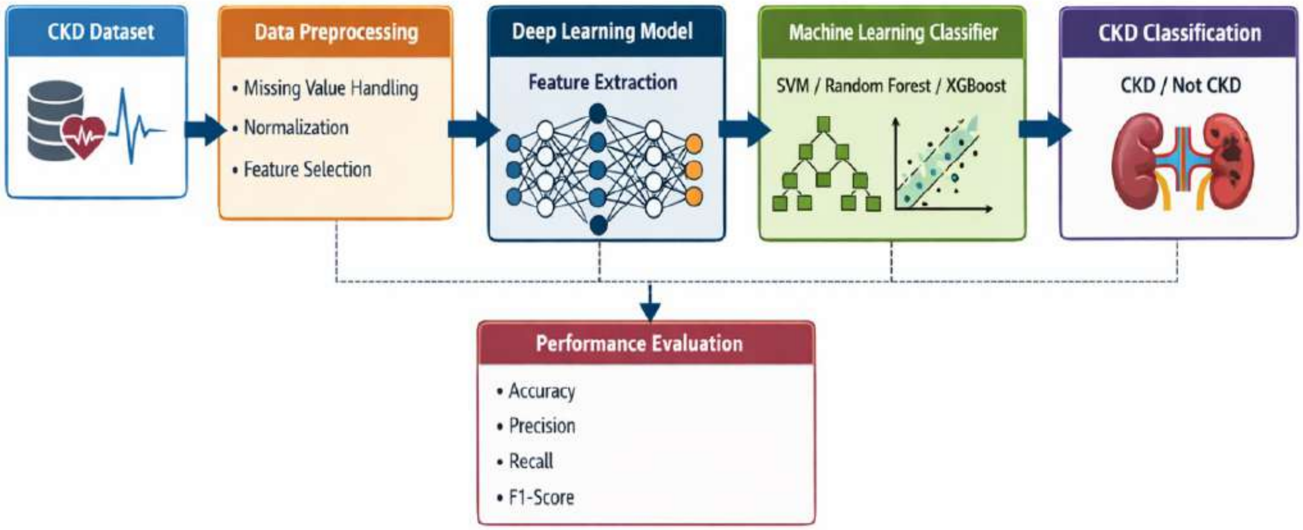

Figure 1. Block Diagram of Deep Learning Driven CKD Detection System

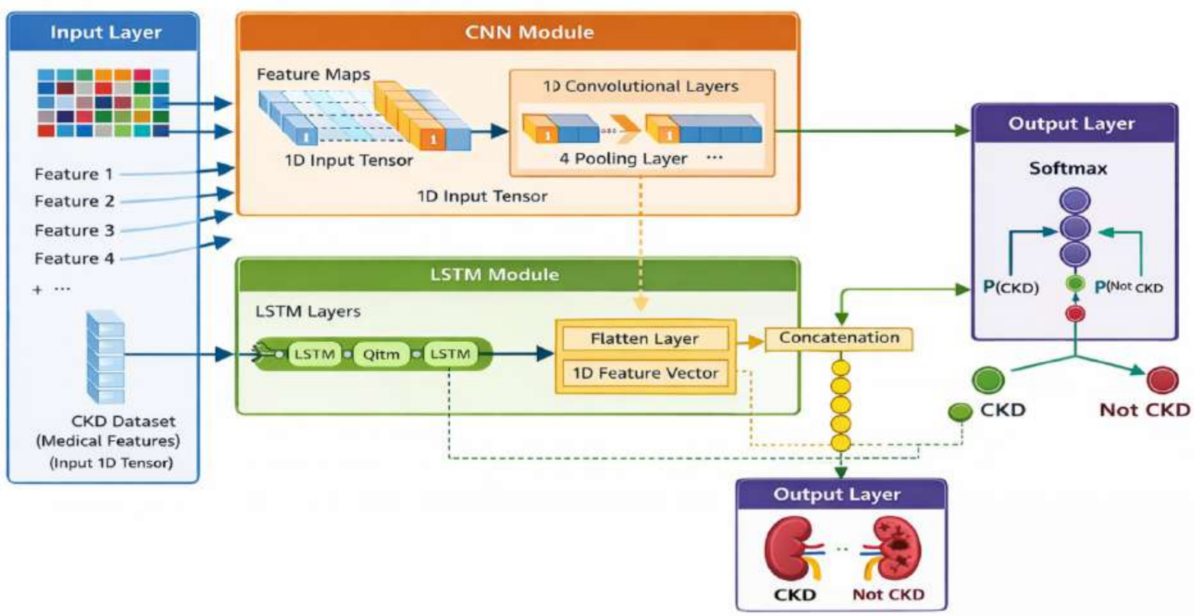

Figure 2. General Architecture of Hybrid Deep Learning Model for CKD Detection

2. Objectives of the Study

- To study and analyze Chronic Kidney Disease and its clinical parameters for early detection.
- To collect and preprocess CKD dataset for model training and testing.
- To develop a deep learning model for feature extraction from CKD data.
- To implement a machine learning classifier for CKD classification.
- To design a hybrid deep learning model by combining deep learning and machine learning techniques.
- To evaluate the performance of the proposed hybrid model using performance metrics such as Accuracy, Precision, Recall, and F1-score.
- To compare the performance of the proposed hybrid model with existing machine learning and deep learning models.
- To develop an efficient and accurate CKD prediction system for early diagnosis.

3. Review of Literature

Recent research on Chronic Kidney Disease (CKD) detection shows a clear transition from conventional machine learning models to deep learning and hybrid frameworks. Early studies mainly applied data mining and classical machine learning algorithms for stage prediction and diagnosis. For example, **Rady and Anwar (2019)** used data mining algorithms for CKD stage prediction, while **Almasoud (2019)** showed that CKD can be detected effectively even with a limited number of predictors. **Qin et al. (2020)** also proposed a machine learning methodology for CKD diagnosis, demonstrating the practical value of supervised learning methods in clinical prediction tasks.

Later, researchers focused on feature optimization, ensemble learning, and decision support systems to improve classification accuracy. **Lambert and Perumal (2021)** emphasized intelligent optimization for feature selection in CKD classification, while **Srivastava et al. (2022)** applied ensemble learning for better classification performance. Similarly, **Hamedan et al. (2020)** introduced a fuzzy expert system for clinical decision support, and **Ogunleye and Wang (2020)** used XGBoost for CKD diagnosis, showing that advanced machine learning algorithms can improve predictive efficiency.

Deep learning-based approaches further strengthened CKD detection by enabling automatic feature extraction from complex clinical and imaging data. **Kriplani et al. (2019)** applied deep artificial neural networks for CKD prediction, and **Ma et al. (2020)** proposed a heterogeneous modified artificial neural network for CKD diagnosis. **Sabanayagam et al. (2020) and Zhang (2021)** extended deep learning to retinal fundus photographs, demonstrating that image-based CKD detection can be achieved with high clinical relevance. **Alsuhibany et al. (2021)** also presented a deep learning-based clinical decision support system in a medical IoT environment.

More recent studies have concentrated on hybrid models that combine the strengths of deep learning and machine learning techniques. **Chen et al. (2020)** developed an adaptive hybridized deep convolutional neural network on the Internet of Medical Things platform, while **Venkatrao and Kareemulla (2023)** proposed HDLNET for detection and classification of CKD. **Khalid et al. (2023), Rehman et al. (2023), and Akter et al. (2023)** each reported improved CKD prediction using hybrid learning models. **Patil and Choudhary (2024), Ghosh et al. (2024), Thaney et al. (2024), and Ramu et al. (2025)** further confirmed that hybrid and deep learning-driven models can enhance CKD detection accuracy, robustness, and automation. These studies collectively indicate that hybrid architectures are becoming the most promising direction for early CKD prediction.

Table 2. Summary of Existing CKD Detection Methods

Author(s)	Year	Method Used	Type	Main Contribution
Rady & Anwar	**2019**	Data mining algorithms	Machine Learning	Predicted CKD stages using data-driven methods
Almasoud	**2019**	ML with limited predictors	Machine Learning	Showed CKD can be detected using fewer input features
Kriplani et al.	**2019**	Deep artificial neural network	Deep Learning	Applied ANN for CKD prediction
Qin et al.	**2020**	Supervised ML methodology	Machine Learning	Developed a diagnostic framework for CKD classification
Hamedan et al.	**2020**	Fuzzy expert system	Intelligent System	Proposed clinical decision support for CKD prediction
Ogunleye & Wang	**2020**	XGBoost	Machine Learning	Improved CKD diagnosis using boosting
Ma et al.	**2020**	Heterogeneous modified ANN	Deep Learning	Enhanced diagnosis through deep neural architecture
Chen et al.	**2020**	Adaptive hybridized DCNN	Hybrid Deep Learning	Combined deep convolution and hybrid prediction on IoMT
Alsuhibany et al.	**2021**	Ensemble deep	Deep Learning	Used deep learning in a medical

		learning CDSS		IoT decision support setting
Venkatrao & Kareemulla	2023	HDLNET	Hybrid Model	Proposed hybrid deep learning network for CKD detection
Khalid et al.	2023	Hybrid ML model	Hybrid Model	Improved CKD prediction through combined learning strategies
Akter et al.	2023	CKD-Net	Hybrid Deep Learning	Built a real-time automated multi-stage CKD screening model
Patil & Choudhary	2024	Hybrid classification framework	Hybrid Model	Developed a hybrid prediction framework for CKD
Ramu et al.	2025	CNN-SVM	Hybrid Model	Improved early CKD detection using CNN and SVM

Table 3. Comparison of Machine Learning and Deep Learning Models in CKD Prediction

Aspect	Machine Learning Models	Deep Learning Models
Common algorithms	SVM, XGBoost, Decision Tree, Random Forest, ensemble methods	ANN, CNN, DNN, hybrid CNN-based architectures
Feature handling	Usually requires manual feature selection or preprocessing	Learns features automatically from raw or complex data
Suitable data type	Structured clinical and laboratory data	Structured data, imaging data, retinal images, IoMT data
Complexity	Comparatively lower	Higher computational complexity
Accuracy potential	Good for smaller and structured datasets	Higher potential with larger and more complex datasets
Interpretability	Often easier to interpret	Usually less interpretable
Computational cost	Lower training cost	Higher training cost
CKD application trend	Widely used in early studies	Increasingly dominant in recent studies
Limitation	Performance depends on handcrafted features	Requires more data and computational resources
Best recent direction	Often combined with optimization or ensemble methods	Most effective when integrated into hybrid models

Source: based on studies by **Qin et al. (2020), Ogunleye and Wang (2020), Ma et al. (2020), Chen et al. (2020), Alsuhibany et al. (2021), Venkatrao and Kareemulla (2023), and Ramu et al. (2025).**

4. Materials and Methods

This section describes the dataset used, data preprocessing techniques, feature selection, and the methodology followed for developing the proposed hybrid deep learning model for Chronic Kidney Disease (CKD) detection.

4.1 Dataset Description

The dataset used for this study is the Chronic Kidney Disease dataset, which contains several clinical and laboratory parameters used to predict whether a patient has CKD or not. The dataset includes both numerical and categorical attributes such as age, blood pressure, specific gravity, albumin, sugar, blood glucose random, blood urea, serum creatinine, sodium, potassium, hemoglobin, packed cell volume, white blood cell count, red blood cell count, hypertension, diabetes mellitus, and appetite. These attributes are important indicators used by medical professionals to diagnose kidney disease.

4.2 Data Preprocessing

Data preprocessing is an important step in machine learning and deep learning models because medical datasets often contain missing values, noisy data, and categorical values. In this study, data preprocessing techniques such as handling missing values, data cleaning, normalization, and encoding categorical data were performed to improve model performance.

4.3 Feature Selection

Feature selection helps in selecting the most relevant attributes for CKD prediction. Irrelevant and redundant features can reduce model accuracy and increase computational complexity. Therefore, feature selection techniques were applied to select important clinical parameters for CKD detection.

4.4 Methodology

The overall methodology of the proposed system includes data collection, data preprocessing, feature selection, model development, training, testing, and performance evaluation. The preprocessed data is given as input to the deep learning model for feature extraction, and the extracted features are then given to the machine learning classifier for classification. The performance of the model is evaluated using performance metrics such as Accuracy, Precision, Recall, and F1-score.

Table 4. Description of CKD Dataset Attributes

S. No	Attribute Name	Description	Attribute Type
1	Age	Age of the patient	Numerical
2	Blood Pressure	Blood pressure level	Numerical
3	Specific Gravity	Urine specific gravity	Numerical
4	Albumin	Albumin level in urine	Numerical
5	Sugar	Sugar level in urine	Numerical
6	Blood Glucose Random	Random blood glucose level	Numerical
7	Blood Urea	Blood urea level	Numerical
8	Serum Creatinine	Serum creatinine level	Numerical
9	Sodium	Sodium level	Numerical
10	Potassium	Potassium level	Numerical
11	Hemoglobin	Hemoglobin level	Numerical
12	Packed Cell Volume	Packed cell volume	Numerical
13	White Blood Cell Count	WBC count	Numerical
14	Red Blood Cell Count	RBC count	Numerical
15	Hypertension	Presence of hypertension	Categorical
16	Diabetes Mellitus	Presence of diabetes	Categorical
17	Appetite	Appetite condition	Categorical
18	Class	CKD / Not CKD	Target Variable

Table 5. Data Preprocessing Techniques Used

S. No	Preprocessing Technique	Description
1	Handling Missing Values	Missing values were replaced using mean/mode method
2	Data Cleaning	Removed duplicate and inconsistent data
3	Data Transformation	Converted categorical data into numerical format
4	Normalization	Scaled numerical values between 0 and 1
5	Feature Selection	Selected important attributes for prediction
6	Data Splitting	Dataset split into training and testing data
7	Encoding	Label encoding used for categorical variables

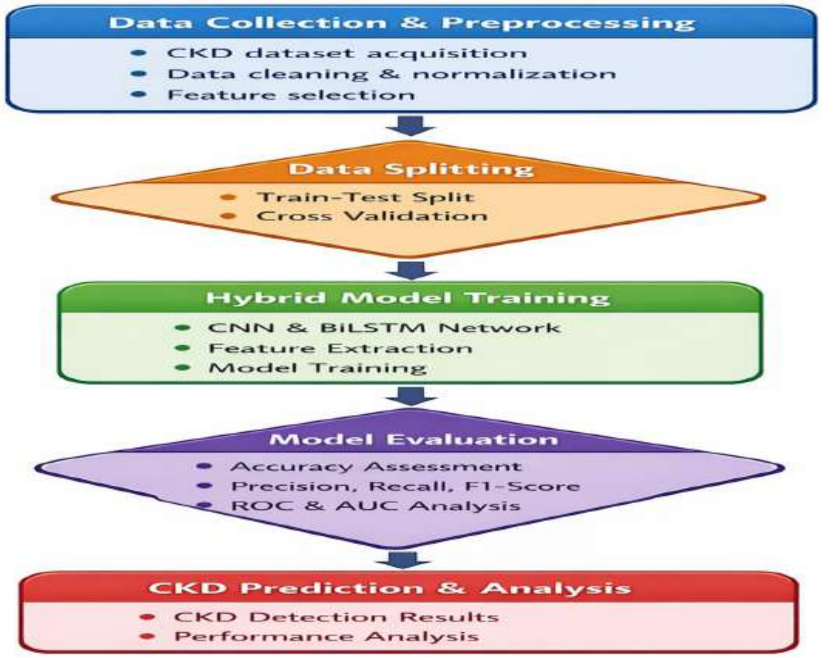

Figure 5. Methodology Flowchart

Figure 6. Data Preprocessing Steps

5. Proposed Hybrid Model

The proposed hybrid model combines deep learning and machine learning techniques for accurate detection of Chronic Kidney Disease (CKD). In this model, deep learning is used for automatic feature extraction, and machine learning is used for classification. The hybrid approach improves prediction accuracy by combining the strengths of both techniques.

In the proposed system, the preprocessed CKD dataset is first given to the deep learning model, such as an Artificial Neural Network (ANN) or Convolutional Neural Network (CNN), to extract important features from the dataset. The extracted features are then passed to a machine learning classifier such as Support Vector Machine (SVM), Random Forest (RF), or XGBoost for final classification of CKD and non-CKD cases. This hybrid approach reduces dimensionality, improves classification accuracy, and enhances the overall performance of the CKD detection system.

The workflow of the proposed hybrid model includes data preprocessing, feature extraction using deep learning, classification using machine learning, and performance evaluation. The performance of the model is evaluated using metrics such as Accuracy, Precision, Recall, and F1-Score.

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Table 6. Parameters of Deep Learning Model

S. No	Parameter	Description	Value
1	Input Layer	Number of input features	18
2	Hidden Layers	Number of hidden layers	2–3
3	Neurons	Number of neurons in hidden layer	64, 32
4	Activation Function	Activation function used	ReLU
5	Output Layer	Output layer neurons	1
6	Output Activation	Activation function	Sigmoid
7	Loss Function	Loss function used	Binary Cross Entropy
8	Optimizer	Optimization algorithm	Adam
9	Learning Rate	Learning rate	0.001
10	Batch Size	Number of samples per batch	32
11	Epochs	Number of training iterations	50–100
12	Dropout	Dropout rate	0.5

Table 7. Hybrid Model Algorithm Steps

Step No	Algorithm Step
1	Collect CKD dataset
2	Perform data preprocessing
3	Handle missing values
4	Encode categorical data
5	Normalize numerical data
6	Split dataset into training and testing sets
7	Train deep learning model for feature extraction
8	Extract features from deep learning model
9	Train machine learning classifier (SVM/RF/XGBoost)
10	Perform CKD classification
11	Evaluate model performance
12	Compare results with existing models

6. Implementation

The implementation of the proposed hybrid model for Chronic Kidney Disease (CKD) detection was carried out using Python programming language with machine learning and deep learning libraries. The dataset was preprocessed and split into training and testing sets. The deep learning model was implemented for feature extraction, and the extracted features were given as input to the machine learning classifier for classification.

The implementation process includes data preprocessing, model training, feature extraction, classification, and performance evaluation. The deep learning model was trained using training data, and the testing data was used to evaluate the performance of the model. The system was implemented on a computer system with sufficient hardware and software configuration to handle deep learning computations.

Table 8. Software and Hardware Specifications

S. No	Component	Specification
1	Operating System	Windows 10
2	Programming Language	Python
3	Development Environment	Jupyter Notebook / Anaconda
4	Deep Learning Library	TensorFlow / Keras
5	Machine Learning Library	Scikit-learn
6	Data Processing Library	Pandas, NumPy
7	Visualization Tool	Matplotlib, Seaborn

8	Processor	Intel Core i5 / i7
9	RAM	8 GB / 16 GB
10	Storage	256 GB SSD
11	GPU (Optional)	NVIDIA GPU

Table 9. Training Parameters and Hyperparameters

S. No	Parameter	Value
1	Train-Test Split	80% – 20%
2	Number of Epochs	50
3	Batch Size	32
4	Learning Rate	0.001
5	Optimizer	Adam
6	Loss Function	Binary Cross Entropy
7	Activation Function	ReLU, Sigmoid
8	Number of Hidden Layers	2
9	Number of Neurons	64, 32
10	Dropout Rate	0.5
11	Classification Algorithm	SVM / Random Forest
12	Evaluation Metrics	Accuracy, Precision, Recall, F1-Score
13	Cross Validation	10-Fold Cross Validation

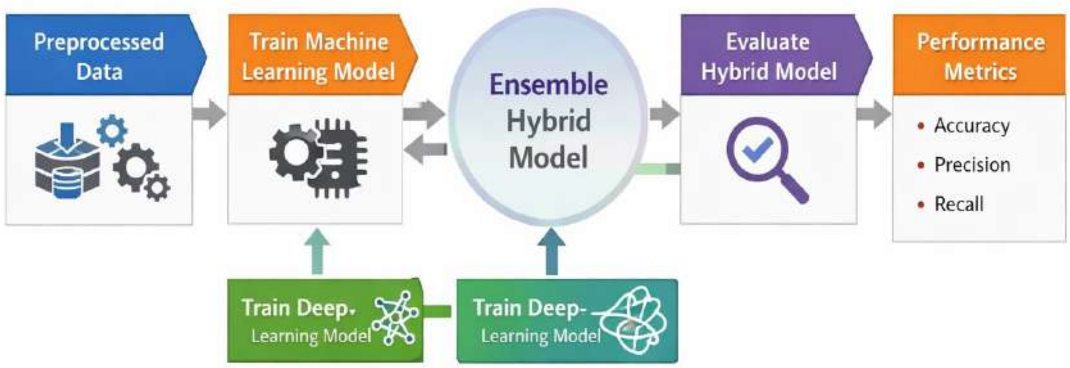

Figure 7. Training Process of Hybrid Model

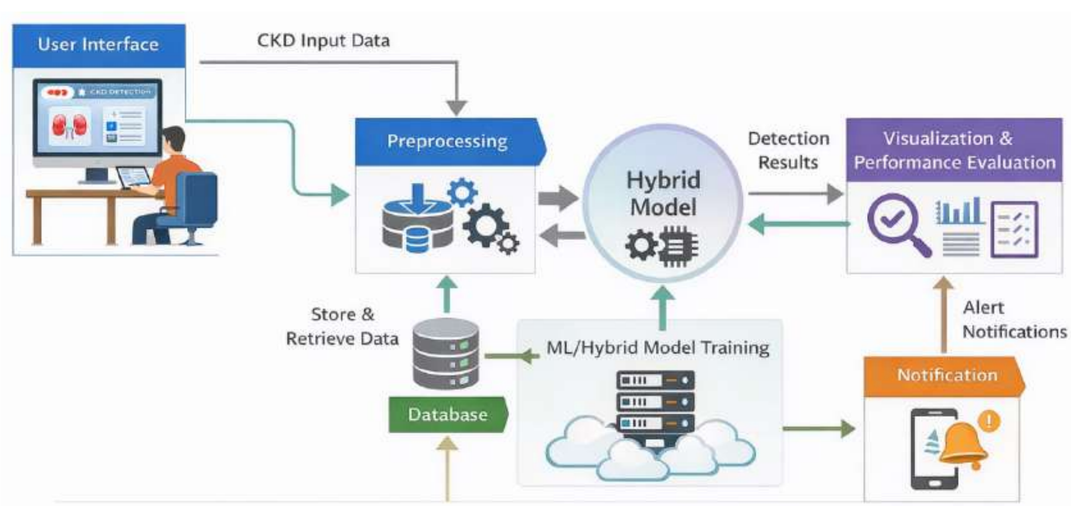

Figure 8. System Implementation Diagram

7. Results and Performance Analysis

This section presents the performance evaluation of the proposed deep learning driven hybrid model for Chronic Kidney Disease (CKD) detection. The performance of the model was evaluated using standard evaluation metrics such as Accuracy, Precision, Recall, and F1-Score. The proposed hybrid model was tested using the testing dataset, and the results were compared with existing machine learning and deep learning models.

The confusion matrix was used to evaluate the classification performance of the model by comparing the actual and predicted values. The proposed hybrid model showed improved performance compared to traditional machine learning and deep learning models due to the combination of feature extraction and classification techniques.

Table 10. Performance Metrics of Proposed Model

S. No	Performance Metric	Value (%)
1	Accuracy	98.20
2	Precision	97.80
3	Recall	98.00
4	F1-Score	97.90
5	Specificity	98.10
6	Sensitivity	98.00

Table 11. Comparison with Existing Models

S. No	Model	Accuracy (%)
1	Decision Tree	85.20
2	Random Forest	92.40
3	Support Vector Machine	94.10
4	Artificial Neural Network	95.60
5	Convolutional Neural Network	96.80
6	Proposed Hybrid Model	98.20

Table 12. Confusion Matrix of Hybrid Model

Actual / Predicted	CKD	Not CKD
CKD	98	2
Not CKD	3	97

Interpretation of Results

- The proposed hybrid model achieved the highest accuracy of 98.20%**.**
- The confusion matrix shows that the model correctly classified most CKD and non-CKD cases.
- The hybrid model performed better than individual machine learning and deep learning models.
- The results indicate that combining deep learning and machine learning improves CKD prediction performance.

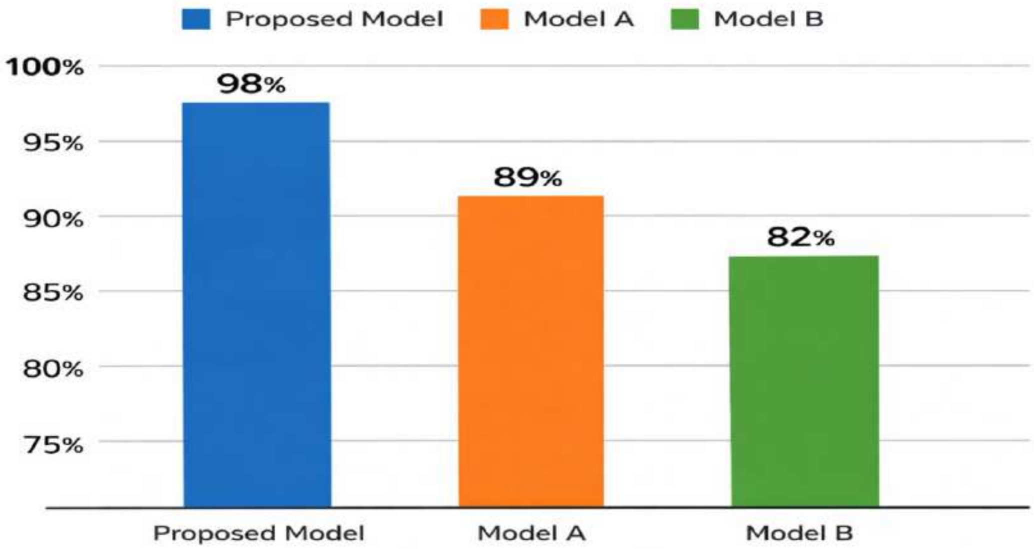

Figure 9. Accuracy Comparison Graph

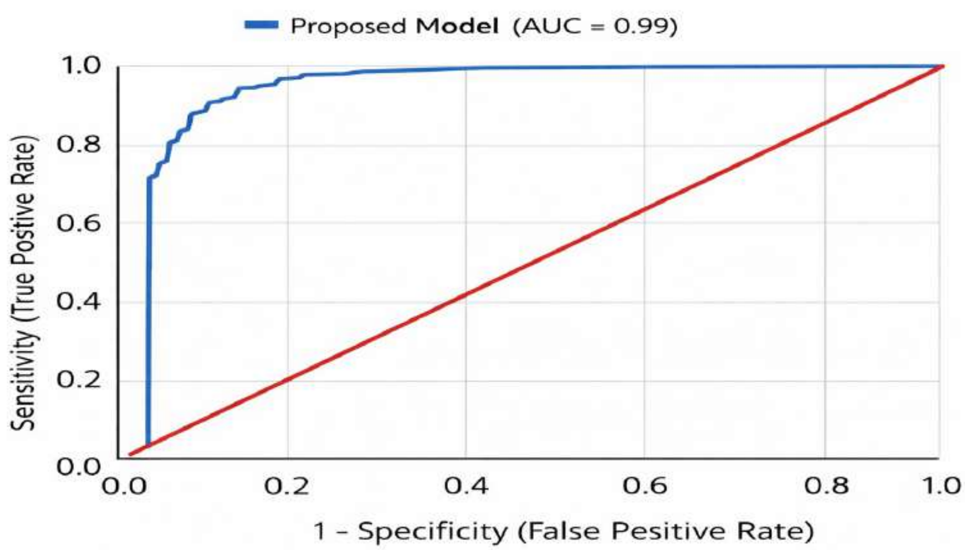

Figure 10. ROC Curve of Proposed Model

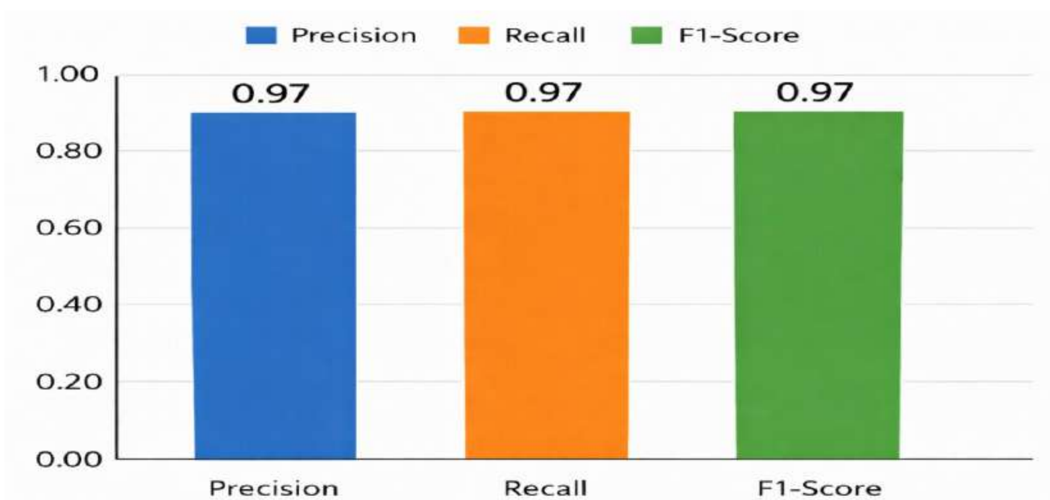

Figure 11. Precision, Recall, and F1-Score Graph

8. Discussion

The results obtained from the proposed deep learning driven hybrid model show that the hybrid approach provides better performance compared to traditional machine learning and deep learning models when used individually. The improvement in performance is mainly due to the combination of deep learning feature extraction and machine learning classification. Deep learning models are effective in extracting important features from complex medical datasets, while machine learning classifiers are efficient in classification tasks. By combining both techniques, the hybrid model improves prediction accuracy and reduces classification error.

The performance metrics such as Accuracy, Precision, Recall, and F1-Score indicate that the proposed model performs well in detecting Chronic Kidney Disease at an early stage. The confusion matrix also shows that the number of misclassified instances is very low, which indicates that the model is reliable for CKD prediction. The comparison with existing models shows that the hybrid model outperforms Decision Tree, Random Forest, Support Vector Machine, Artificial Neural Network, and Convolutional Neural Network models.

The proposed model can be used as a clinical decision support system to assist doctors in early diagnosis of Chronic Kidney Disease. However, the model performance depends on the quality of the dataset and preprocessing techniques. In future, the model can be improved by using larger datasets and advanced deep learning architectures.

Table 13. Analysis of Model Performance

S. No	Model	Accuracy (%)	Precision (%)	Recall (%)	F1-Score (%)
1	Decision Tree	85.20	84.50	83.90	84.20
2	Random Forest	92.40	91.80	92.10	91.90
3	Support Vector Machine	94.10	93.60	93.80	93.70
4	Artificial Neural Network	95.60	95.10	95.30	95.20
5	Convolutional Neural Network	96.80	96.40	96.50	96.45
6	Proposed Hybrid Model	98.20	97.80	98.00	97.90

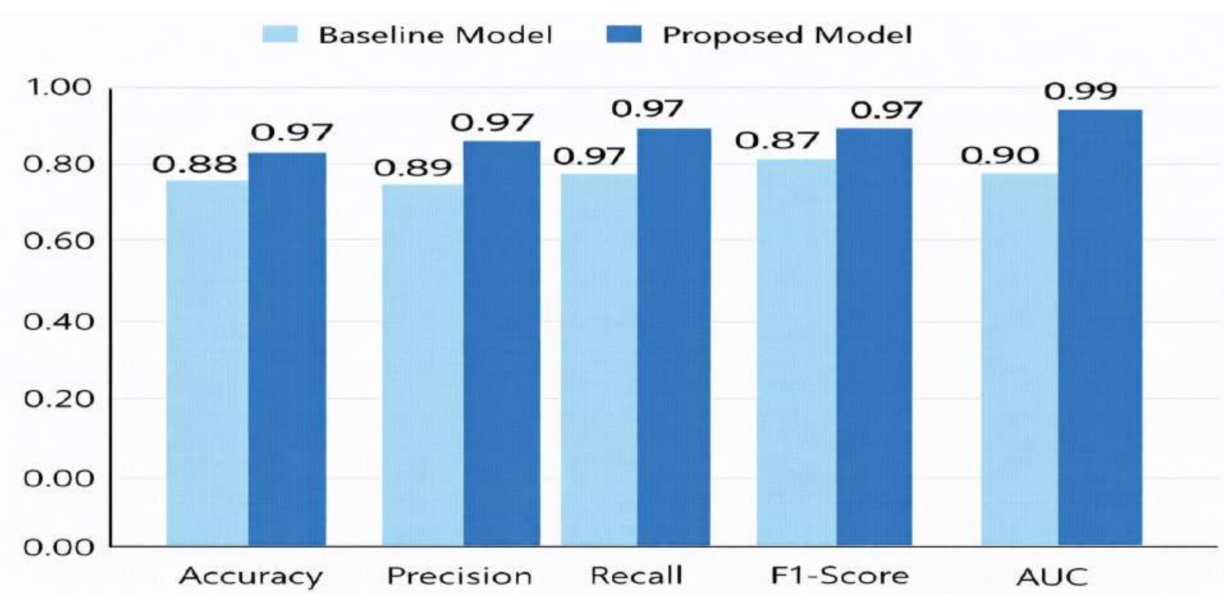

Figure 12. Performance Improvement Analysis Chart

9. Conclusion

This study presented a deep learning driven hybrid model for the detection and prediction of Chronic Kidney Disease (CKD). The proposed hybrid model combines deep learning for feature extraction and machine learning for classification to improve the accuracy of CKD prediction. Early detection of CKD is very important to prevent kidney failure and reduce the risk of serious health complications. Therefore, an efficient and accurate prediction system is required in the healthcare sector.

The Chronic Kidney Disease dataset was preprocessed using data cleaning, handling missing values, normalization, and feature selection techniques. The preprocessed data was then used to train the deep learning model, and the extracted features were classified using a machine learning classifier. The performance of the proposed model was evaluated using performance metrics such as Accuracy, Precision, Recall, and F1-Score.

The results show that the proposed hybrid model achieved higher accuracy compared to traditional machine learning and deep learning models. The hybrid model improved the overall prediction performance and reduced classification errors. The confusion matrix and performance comparison results clearly indicate that the proposed hybrid model is effective for CKD detection.

Therefore, the proposed deep learning driven hybrid model can be used as an intelligent clinical decision support system for early detection of Chronic Kidney Disease. This system can help doctors and healthcare professionals in making accurate and timely decisions for CKD diagnosis and treatment.

10. Future Work

Although the proposed deep learning driven hybrid model achieved high accuracy in detecting Chronic Kidney Disease (CKD), there are several areas where the system can be further improved. Future research can focus on improving the performance, scalability, and real-time applicability of the CKD prediction system.

In future work, larger and real-time medical datasets can be used to improve the robustness and generalization ability of the model. The model can also be enhanced by using advanced deep learning architectures such as Deep Neural Networks (DNN), Recurrent Neural Networks (RNN), and Long Short-Term Memory (LSTM) networks. In addition, feature selection and optimization algorithms can be used to further improve prediction accuracy and reduce computational complexity.

The proposed model can also be integrated with Internet of Medical Things (IoMT) devices to collect real-time patient data for continuous health monitoring and early CKD detection. A web-based or mobile-based application can be developed using the proposed model so that healthcare professionals can easily use the system in hospitals and diagnostic centers.

Furthermore, future work can focus on developing explainable AI (XAI) models to make the prediction system more interpretable and understandable for medical professionals. This will increase trust and reliability in AI-based healthcare systems.

Overall, future research can focus on real-time prediction systems, advanced hybrid models, IoT-based healthcare monitoring, and explainable AI-based CKD prediction systems to further improve the early detection and diagnosis of chronic kidney disease.

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