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Chronic Kidney Disease Detection using Deep Learning: A Systematic Review

[1]Gulam Jilani, [2]Ms. Ruchi Dronawat, [3]Dr. Mohit Singh Tomor, [4]Rupali Chaure

Department of Computer Science and Engineering (Data Science), Sagar Institute of Research and Technology, Bhopal[1]

Department of Computer Science and Engineering, Sagar Institute of Research and Technology, Bhopal[2,4]

Associate Professor & HOD, Department of Computer Science and Engineering, Sagar Institute of Research and Technology, Bhopal[3]

ABSTRACT

Chronic Kidney Disease (CKD) is a serious and rapidly increasing health disorder that affects kidney function and may lead to kidney failure if not detected at an early stage. Accurate and timely diagnosis of CKD is important for reducing mortality rates and improving patient care. In recent years, deep learning techniques have emerged as powerful tools in medical diagnosis due to their capability to automatically learn complex patterns from healthcare data. This systematic review provides a comprehensive study of deep learning methods applied for CKD detection and prediction. Various approaches including Convolutional Neural Networks (CNN), Deep Neural Networks (DNN), Recurrent Neural Networks (RNN), Long Short-Term Memory (LSTM), and hybrid deep learning models are analyzed based on datasets, preprocessing techniques, performance metrics, and classification accuracy. The review also examines the advantages and limitations of these models in clinical applications. Most studies reported high accuracy, sensitivity, and specificity, demonstrating the effectiveness of deep learning in CKD diagnosis. However, issues such as limited datasets, data imbalance, overfitting, and lack of interpretability continue to affect model performance. This review highlights current research trends, challenges, and future directions for improving CKD detection systems using deep learning. Overall, the study concludes that deep learning-based approaches have significant potential to support healthcare professionals in early and reliable diagnosis of CKD.

Keywords: Chronic Kidney Disease (CKD), Deep Learning, Systematic Review, Medical Diagnosis, Convolutional Neural Network (CNN)

1. INTRODUCTION

Chronic Kidney Disease (CKD) is a long-term medical condition in which the kidneys gradually lose their ability to filter waste products and excess fluids from the blood. CKD has become a major global health concern due to its increasing prevalence, high treatment cost, and severe complications such as kidney failure, cardiovascular diseases, and hypertension. According to global health reports, millions of people suffer from CKD every year, and many cases remain undiagnosed during the early stages because symptoms often appear slowly. Early

detection and timely treatment are therefore essential to reduce mortality rates and improve patient quality of life.

Traditional methods for CKD diagnosis mainly depend on laboratory tests, medical imaging, and physician expertise. Although these methods are widely used, they may sometimes lead to delayed diagnosis, human error, and difficulty in handling large-scale healthcare data. In recent years, Artificial Intelligence (AI) and Machine Learning (ML) techniques have been increasingly applied in the healthcare sector to improve disease diagnosis and prediction accuracy. Among these techniques, Deep Learning (DL) has gained significant attention because of its capability to automatically extract important features from complex medical datasets without requiring extensive manual feature engineering [1, 2].

Deep learning models such as Convolutional Neural Networks (CNN), Recurrent Neural Networks (RNN), Deep Neural Networks (DNN), Autoencoders, and Long Short-Term Memory (LSTM) networks have shown promising results in CKD detection and classification. These models are capable of analyzing electronic health records, medical images, and clinical parameters with high precision and efficiency. Several studies have reported that deep learning-based systems achieve better accuracy, sensitivity, and specificity compared to traditional machine learning approaches. Furthermore, advancements in cloud computing, big data analytics, and medical imaging technologies have accelerated the adoption of deep learning in kidney disease diagnosis [3].

Despite these advantages, several challenges still exist in developing effective CKD detection systems. Limited availability of high-quality medical datasets, class imbalance problems, overfitting issues, lack of model interpretability, and privacy concerns are some major limitations affecting the practical implementation of deep learning models in healthcare environments. Additionally, many proposed models are evaluated only on small or region-specific datasets, which reduces their generalization capability in real-world clinical applications [4, 5].

This systematic review aims to provide a comprehensive overview of deep learning techniques used for Chronic Kidney Disease detection and prediction. The review analyzes different deep learning architectures, datasets, preprocessing methods, evaluation metrics, and research outcomes reported in recent studies. It also highlights current challenges, research gaps, and future directions for improving CKD diagnosis using advanced deep learning approaches. The findings of this review may assist researchers, healthcare professionals, and practitioners in understanding the potential of deep learning for reliable and early CKD detection [6, 7].

2. LITERATURE REVIEW

Ms. Neela K et al. [1], in this study, the authors focused on improving the prediction accuracy of chronic kidney disease progression using Convolutional Neural Network (CNN) architectures integrated with machine learning techniques. The proposed methodology utilized clinical datasets containing patient health parameters such as blood pressure, albumin level, sugar level, hemoglobin, and serum creatinine. Data preprocessing techniques including

normalization, missing value handling, and feature extraction were applied to enhance model performance. The CNN model automatically extracted deep features from the dataset and improved classification capability compared to conventional machine learning approaches. Experimental results demonstrated that the proposed CNN-based framework achieved higher accuracy, precision, and sensitivity in identifying CKD stages. The study concluded that deep learning techniques are highly effective for automated CKD progression analysis and can support healthcare professionals in early diagnosis and treatment planning.

K. M et al. [2], investigated the effectiveness of different machine learning algorithms for early CKD diagnosis using healthcare datasets. Several classification techniques including Decision Tree, Random Forest, Support Vector Machine (SVM), and Logistic Regression were implemented and compared based on accuracy and prediction efficiency. Data preprocessing methods such as feature scaling, outlier removal, and missing value imputation were used to improve the quality of input data. Among the tested algorithms, Random Forest produced superior performance due to its capability to handle nonlinear relationships and large feature spaces effectively. The study emphasized that early CKD detection using machine learning can significantly reduce disease severity and improve patient survival rates. The researchers also highlighted the importance of integrating intelligent diagnostic systems into modern healthcare environments.

A. Pathak et al. [3], the research concentrated on evaluating different machine learning methodologies for accurate CKD prediction. The authors used multiple supervised learning algorithms including Naïve Bayes, Decision Tree, Random Forest, and K-Nearest Neighbor (KNN) to classify kidney disease conditions. Feature selection and preprocessing techniques were incorporated to remove redundant attributes and improve computational efficiency. The study showed that ensemble-based algorithms achieved higher prediction performance compared to traditional classifiers. Experimental outcomes demonstrated improved classification accuracy and reduced false prediction rates. The authors concluded that machine learning methodologies provide efficient support systems for nephrologists and healthcare practitioners in early disease identification and patient monitoring.

R. Rani et al. [4], in this research, the authors applied the Extreme Gradient Boosting (XGBoost) algorithm for improving CKD diagnosis performance. The study focused on feature importance analysis and classification optimization using healthcare datasets. Advanced preprocessing methods including data balancing, normalization, and missing value replacement were performed before model training. XGBoost demonstrated excellent predictive capability because of its ensemble boosting mechanism and ability to minimize overfitting. The model achieved high accuracy, recall, and F1-score in CKD classification tasks. The researchers concluded that XGBoost provides reliable diagnostic insights and can be effectively integrated into clinical decision support systems for accurate kidney disease detection.

N. Sonone et al. [5], the study explored the use of machine learning algorithms for predicting CKD at early stages and monitoring disease progression. The researchers applied multiple algorithms such as Random Forest, SVM, Decision Tree, and Gradient Boosting on clinical datasets containing patient laboratory reports and health indicators. Feature engineering and preprocessing methods were implemented to improve model robustness and prediction efficiency. Comparative analysis revealed that ensemble learning approaches produced better accuracy and stability than individual classifiers. The study emphasized that intelligent prediction systems can assist doctors in providing timely treatment and reducing CKD-related complications. The authors also suggested that future work should focus on hybrid deep learning models for further improvement.

T. G. Jang et al. [6], this study introduced an innovative approach for detecting CKD stages using physiological signals collected during sleep monitoring. Ensemble learning techniques were employed to analyze biomedical data and classify different stages of kidney disease. The framework combined multiple classifiers to improve robustness and minimize prediction errors. Signal preprocessing, feature extraction, and statistical analysis were performed before model training. Experimental results demonstrated that ensemble learning approaches significantly enhanced CKD stage detection accuracy and sensitivity. The study highlighted the potential of wearable healthcare technologies and intelligent monitoring systems in continuous kidney disease assessment and patient care.

Anurag et al. [7], the authors developed a robust machine learning framework for predicting CKD using patient clinical data. Several classification models including Random Forest, SVM, KNN, and Decision Tree were implemented and evaluated using different performance metrics. Data preprocessing techniques such as feature normalization and missing data handling improved model stability and prediction quality. Among the applied methods, Random Forest achieved superior accuracy due to its ensemble structure and better generalization capability. The study concluded that robust machine learning techniques can provide efficient and accurate prediction systems for kidney disease diagnosis in healthcare applications.

N. K. Pareek et al. [8], in this research, the authors proposed a CNN-based deep learning model for early-stage CKD prediction. The model automatically extracted hidden features from patient datasets without requiring extensive manual feature engineering. Data preprocessing techniques including scaling and normalization were applied to improve training performance. The CNN model achieved better classification accuracy and lower prediction error compared to traditional machine learning algorithms. The study demonstrated that deep learning approaches can effectively support early diagnosis and clinical decision-making for CKD patients. The authors emphasized that CNN models are highly suitable for large-scale medical data analysis.

S. S. Vellela et al. [9], the research focused on optimizing CKD prediction performance using advanced machine learning techniques. Multiple classifiers were implemented and compared to identify the most suitable prediction model. Feature optimization and preprocessing methods

improved computational efficiency and classification performance. Experimental analysis showed that optimized machine learning algorithms produced high prediction accuracy and reduced diagnostic complexity. The authors concluded that intelligent optimization strategies enhance CKD diagnosis reliability and can support efficient healthcare management systems.

K. Shankar et al. [10], the study emphasized the importance of feature selection in improving CKD classification performance using deep learning techniques. The authors applied optimal feature selection methods to identify the most relevant medical attributes from healthcare datasets. A deep learning classifier was then trained using the selected features to enhance prediction accuracy and reduce computational complexity. Experimental results indicated that optimal feature selection significantly improved classification efficiency and minimized redundant information. The research concluded that combining feature optimization with deep learning classifiers provides a highly accurate and efficient framework for CKD diagnosis and healthcare analytics.

Problem Formulation:

Chronic Kidney Disease (CKD) is one of the most critical health problems worldwide, affecting millions of people and leading to severe complications such as kidney failure, cardiovascular diseases, and increased mortality rates. Early diagnosis of CKD is essential for effective treatment and prevention of disease progression. However, traditional diagnostic approaches mainly depend on laboratory testing, medical expertise, and manual analysis, which may result in delayed detection and inaccurate diagnosis, especially in the early stages of the disease. The increasing volume of healthcare data also makes manual analysis difficult and time-consuming for medical professionals.

Existing machine learning and deep learning models for CKD detection face several limitations, including insufficient dataset quality, missing clinical values, class imbalance, overfitting, and poor generalization capability. Many traditional machine learning algorithms require manual feature extraction and selection, which reduces efficiency and prediction performance. In addition, some existing models fail to capture complex nonlinear relationships present in medical datasets, leading to reduced classification accuracy and higher false prediction rates.

Another major challenge is the lack of interpretability and reliability in automated CKD prediction systems. Several studies are trained on small or region-specific datasets, which limits their practical implementation in real-world healthcare environments. Furthermore, inconsistent preprocessing methods and inadequate optimization techniques negatively affect the robustness of disease prediction models. These limitations create the need for more advanced and intelligent approaches capable of handling large-scale medical data efficiently.

Deep learning techniques have shown promising performance in healthcare applications because of their ability to automatically learn hidden patterns and extract meaningful features from complex datasets. However, selecting suitable architectures, improving model accuracy, reducing computational complexity, and ensuring reliable prediction remain important research

challenges. Therefore, there is a need to develop an efficient deep learning-based CKD detection system that can provide accurate, fast, and reliable diagnosis with improved performance metrics such as accuracy, precision, recall, and F1-score.

3. CHRONIC KIDNEY DISEASE

Chronic Kidney Disease (CKD) is a long-term medical condition in which the kidneys gradually lose their ability to filter waste materials, excess water, and toxins from the blood. Healthy kidneys help maintain the body's fluid balance, regulate blood pressure, produce hormones, and remove harmful substances through urine. When kidney function decreases over time, waste products accumulate in the body, leading to serious health complications such as hypertension, anemia, cardiovascular diseases, and kidney failure. CKD generally develops slowly and may not show clear symptoms during the early stages, making early diagnosis very important for effective treatment and disease management.

The major causes of CKD include diabetes, high blood pressure, obesity, genetic disorders, kidney infections, and prolonged use of certain medications. Common symptoms include swelling in legs and feet, fatigue, nausea, loss of appetite, difficulty in urination, muscle cramps, and shortness of breath. CKD is usually classified into five stages based on the Glomerular Filtration Rate (GFR), where Stage 1 represents mild kidney damage and Stage 5 indicates complete kidney failure requiring dialysis or kidney transplantation.

Modern healthcare systems increasingly use Artificial Intelligence (AI), Machine Learning (ML), and Deep Learning (DL) techniques for early CKD detection. Deep learning models such as CNN, RNN, and LSTM can analyze clinical data, laboratory reports, and medical images to identify kidney disease with high accuracy. These intelligent systems assist doctors in making faster and more reliable decisions, reducing diagnostic errors and improving patient care.

4. DEEP LEARNING

Deep Learning is a subset of Artificial Intelligence (AI) and Machine Learning (ML) that enables computers to learn complex patterns and relationships from large amounts of data using artificial neural networks. It is inspired by the structure and functioning of the human brain, where interconnected neurons process and transfer information. Deep learning models consist of multiple hidden layers that automatically extract important features from raw data without requiring manual feature engineering. Because of this capability, deep learning has become highly effective in applications such as image recognition, speech processing, natural language processing, healthcare diagnosis, and disease prediction.

In healthcare systems, deep learning plays an important role in analyzing medical images, electronic health records, laboratory reports, and clinical datasets. Models such as Convolutional Neural Networks (CNN), Recurrent Neural Networks (RNN), Deep Neural Networks (DNN), and Long Short-Term Memory (LSTM) networks are widely used for disease detection and prediction. These models can identify hidden patterns in complex medical data and provide highly accurate diagnostic results. In Chronic Kidney Disease (CKD)

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detection, deep learning algorithms help doctors identify disease stages at an early stage, reduce human errors, and improve treatment planning.

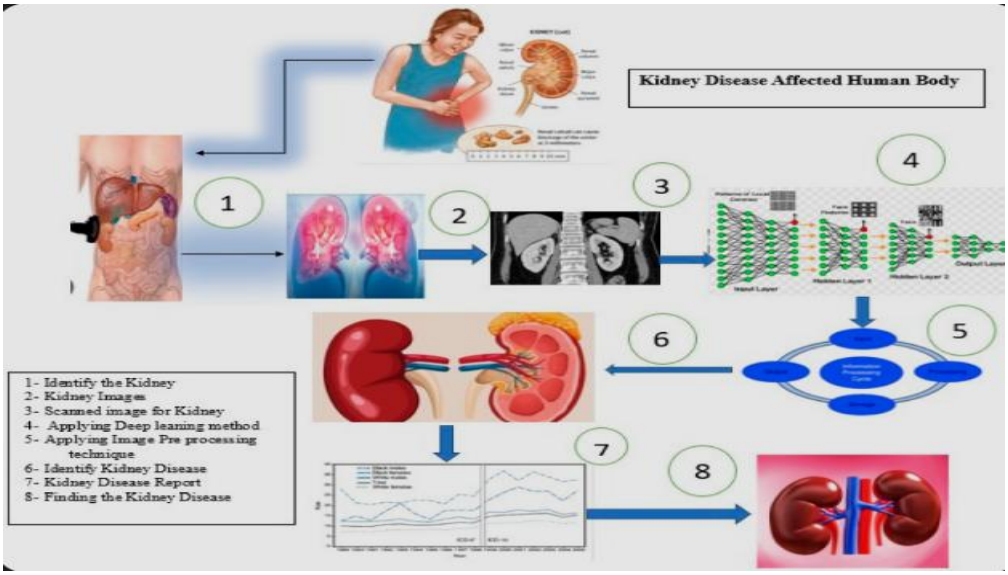

Fig.1: Deep Learning

Deep learning models operate through a training process in which input data is passed through multiple neural network layers. Each layer performs mathematical operations and learns specific features from the data. During training, the model adjusts its internal parameters using optimization algorithms such as Gradient Descent and Adam Optimizer to minimize prediction error. After successful training, the model can accurately classify or predict unseen data. Due to their high learning capability, deep learning methods often outperform traditional machine learning algorithms in complex healthcare applications.

5. CONCLUSION

Chronic Kidney Disease (CKD) is a serious and life-threatening medical condition that requires early and accurate diagnosis to reduce complications and improve patient survival rates. This systematic review analyzed various deep learning and machine learning techniques used for CKD detection and prediction. Different models such as Convolutional Neural Networks (CNN), Deep Neural Networks (DNN), Recurrent Neural Networks (RNN), Long Short-Term Memory (LSTM), ensemble learning methods, and hybrid approaches were studied based on their methodologies, datasets, preprocessing techniques, and performance metrics.

From the reviewed studies, it was observed that deep learning models provide superior prediction accuracy, sensitivity, and specificity compared to traditional machine learning methods. Deep learning approaches are highly effective in automatically extracting hidden features from complex healthcare datasets and reducing manual feature engineering efforts. Several studies reported accuracy values above 95%, demonstrating the capability of deep learning techniques in improving CKD diagnosis and disease progression prediction. In addition, feature selection, data preprocessing, and ensemble learning methods were found to significantly enhance model performance and reliability.

However, despite these advancements, several challenges still remain in practical CKD prediction systems. Issues such as limited dataset availability, missing clinical values, class imbalance, overfitting, high computational complexity, and lack of interpretability affect the robustness and real-world implementation of deep learning models. Moreover, many studies are evaluated on small datasets, which limits their generalization capability across different populations and healthcare environments.

This review concludes that deep learning has significant potential to transform Chronic Kidney Disease diagnosis by enabling early, accurate, and automated prediction systems. Future research should focus on developing lightweight and explainable deep learning models, integrating multimodal healthcare data, improving dataset diversity, and applying advanced optimization techniques to enhance prediction performance and clinical applicability. The integration of artificial intelligence with healthcare systems can support medical professionals in efficient decision-making and contribute to better patient care and disease management.

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