ARTHONOVA:
DEEP LEARNING APPROACHES TOWARDS KNEE OSTEOARTHRITIS

A research on Arthonova, a Knee Osteoarthritis (KOA) diagnostic detection system that leverages a well defined CNN model.

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Abstract

Knee osteoarthritis (KOA) affects millions worldwide, necessitating efficient diagnostic tools. This study introduced Arthonova, an innovative deep learning approach for automated KOA classification and severity assessment using X-ray images. We developed a 12-layer Convolutional Neural Network (CNN) model and trained it on the Osteoarthritis Initiative (OAI) dataset, incorporating the Kellgren-Lawrence (KL) grading system for multi-class classification.

Our model achieved an overall accuracy of 83% in distinguishing between five KOA severity levels: Healthy, Doubtful, Minimal, Moderate, and Severe. We integrated both imaging and non-imaging data to enhance diagnostic accuracy and efficiency. The CNN architecture demonstrated superior performance in feature extraction and classification, outperforming previous methodologies.

We also developed a user-friendly Streamlit web application, making KOA detection accessible to users without technical expertise. This AI-driven approach showed significant potential in improving early KOA diagnosis, assisting radiologists, and streamlining orthopedic assessments.

Our findings suggest that deep learning-based classification of KOA can be a valuable tool in medical imaging. Arthonova has the potential to revolutionize healthcare by providing more precise, efficient, and scalable solutions for KOA management. Future research should focus on incorporating additional imaging modalities and larger, more diverse datasets to enhance the model's generalizability and robustness.

Keywords: Knee Osteoarthritis, Deep Learning, Convolutional Neural Network, X-ray Classification, Kellgren-Lawrence Grading, Medical Diagnostics

Introduction

Context

Knee osteoarthritis (KOA) is a prevalent condition, affecting around 80% of individuals over 50, with an estimated 240 million adults worldwide experiencing symptoms. It primarily results from cartilage loss, leading to disability, pain, stiffness, and reduced mobility [1]. While arthroplasty is the last resort for treatment, it is expensive and not accessible to everyone. Early diagnosis through automated classification using deep learning (DL) can help manage KOA effectively.

Deep learning offers significant advantages over traditional Kellgren-Lawrence grading, enhancing diagnosis accuracy and reducing the need for invasive procedures [19]. Symptoms of KOA include pain, stiffness (especially after rest), swelling, and restricted movement. The condition can impact other joints like fingers, toes, pelvis, and spine. KOA can be classified into primary OA, which occurs naturally due to aging, and secondary OA, which develops from factors like obesity, high blood sugar, injuries, or prolonged kneeling [6].

Artificial intelligence (AI), particularly DL, has revolutionized medical imaging analysis, improving diagnosis speed and accuracy in orthopedic applications such as fracture detection, tumor diagnosis, and OA grading [14]. Unlike traditional machine learning, DL autonomously extracts features from data, reducing human error and workload while increasing objectivity. Despite its advantages, integrating medical imaging with non-imaging data enhances DL model performance for predicting OA severity, lesion staging, and assessing the need for knee replacement surgery [21].

Scientific Contribution

This study introduces a **12-layer Convolutional Neural Network (CNN)** designed specifically for the KOA classification and severity assessment of knee osteoarthritis (KOA) using medical images. By leveraging deep learning, the model provides an automated and efficient method for diagnosing KOA, reducing reliance on manual interpretation by orthopedic professionals. The incorporation of a cross-entropy loss function significantly improves classification accuracy compared to earlier models, ensuring reliable predictions. A key feature of the proposed model is the integration of the Kellgren-Lawrence (KL) grading scale, which enables a structured classification of KOA severity [16]. This enhancement makes the model highly useful in clinical applications, as it aligns with widely accepted diagnostic criteria.

The CNN model demonstrated a superior performance, achieving 83% accuracy for multiclass classification (grading severity levels). These results outperform many previous methodologies and highlight the model's robustness in medical imaging applications [17].

Another major contribution of this research is the integration of non-imaging data with imaging datasets, which improves the model's accuracy and reliability in predicting KOA severity and progression. The inclusion of patient-specific factors, such as medical history and risk factors, enhances the model's ability to provide more personalized and comprehensive assessments [7].

Additionally, the study underscores the role of deep learning in automating the interpretation of orthopedic radiographs, reducing the workload on medical professionals. By minimizing human error due to fatigue or inexperience, this approach ensures faster and more accurate diagnoses, ultimately leading to improved patient care and early intervention strategies [5].

These advancements highlight the significant potential of deep learning in the early detection and classification of osteoarthritis. The proposed methodology not only enhances diagnostic precision but also paves the way for integrating AI-driven solutions in orthopedic healthcare, benefiting both clinicians and patients [18].

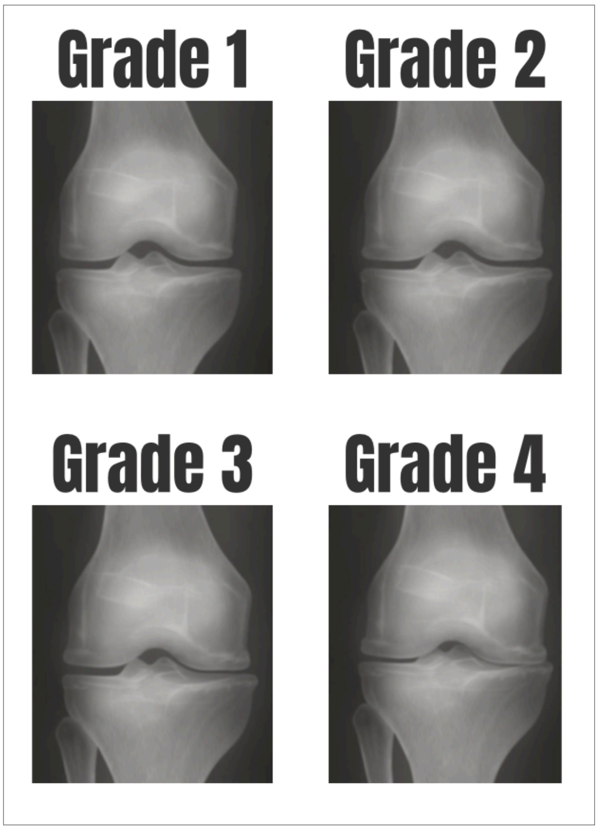


FIG 1: KL SEVERITY GRADING

Literature Review

Current Research

Knee Osteoarthritis (KOA) is a prevalent degenerative joint disease that primarily affects the elderly and is one of the leading causes of chronic pain and disability worldwide. The condition arises due to the gradual breakdown of cartilage, resulting in joint stiffness, inflammation, and reduced mobility. Traditionally, KOA diagnosis relies on clinical assessments, including physical examinations and imaging techniques such as X-rays and MRIs. However, these conventional methods often face limitations such as subjectivity, inter-observer variability, and difficulty in detecting early-stage KOA, which can lead to delayed intervention and progression of the disease [3]. As a result, researchers have turned to artificial intelligence (AI) and machine learning (ML) to enhance diagnostic precision, reduce inconsistencies, and enable early detection—potentially transforming KOA management.

The knee joint's complex anatomical structure makes KOA diagnosis particularly challenging. To address these difficulties, researchers have developed deep learning and computer vision-based models that can automatically analyze X-ray images and classify KOA severity with greater accuracy. Various AI-driven approaches have demonstrated significant improvements in KOA detection and classification. For instance, Bayramoglu et al. introduced a CNN-based model for KOA detection using X-ray scan data [14]. Their approach leveraged the Local Binary Pattern (LBP)method to extract key structural features from knee radiographs. Initially, their model achieved an Average Precision (AP) of 81.7% and an AUC of 48.7%. However, by expanding the region of interest (ROI) within the X-ray scans, the predictive accuracy improved significantly, with the model achieving an AP of 71.4% and an AUC of 88.9%. This study highlights how strategic feature extraction can enhance KOA classification.

In another study, Cheung et al. explored KOA severity assessment using the Kellgren-Lawrence (KL) grading scale, a widely accepted radiographic classification method [15]. They integrated AI-driven Convolutional Neural Networks (CNNs) to extract key radiological markers that influenced their model's findings, leading to an enhanced ability to identify subtle patterns in knee X-rays. Additionally, Tiulpin et al. developed a ResNet-based deep learning framework to estimate joint space width (JSW)—a crucial factor in KOA severity assessment [21]. Their model achieved an impressive 98.9% accuracy rate, demonstrating the effectiveness of advanced neural network architectures for precise KOA grading and diagnosis. These advancements underscore the transformative role of AI and deep learning in KOA detection and classification. By automating the assessment process, AI-driven models offer greater consistency, reliability, and efficiency in diagnosing KOA. Such innovations pave the way for real-time, automated KOA screening tools, enabling early intervention, personalized treatment plans, and improved patient outcomes.

Research Gap

Despite substantial progress in the application of machine learning techniques to the diagnosis of KOA, several gaps remain that our study addresses:

- It has been noted that earlier research mostly concentrated on applying traditional machine learning techniques, which necessitate laborious manual feature extraction and selection. Because of human error, this labor-intensive method may produce inconsistent results [10].

- There hasn't been much work done integrating non-imaging data to improve deep learning algorithms' capacity for KOA diagnosis. The potential of merging imaging datasets with clinical and demographic data to enhance the prediction of disease severity and progression has not been fully realized in previous efforts [11].

- A recognized shortcoming pertains to the utilization of sophisticated CNN architectures intended for the binary categorization and severity evaluation of KOA. Most existing studies utilize general-purpose deep learning models that may not be fully optimized for the specific nuances of medical image analysis in orthopedics [2].

- Although several studies have reported on the effectiveness of deep learning models, the accuracy rates often vary significantly. This indicates a need for more refined models that can consistently deliver high performance across diverse datasets [12].

- The potential of deep learning to reduce the cognitive load on healthcare professionals by automating the interpretation of medical images has not been fully realized. Previous implementations have not adequately addressed the reduction of human error brought on by fatigue and inexperience in clinical settings [15].

These gaps justify the contributions of our study, which has developed a specialized 12 layer CNN architecture for KOA and utilized a comprehensive approach integrating both imaging and non-imaging data to enhance diagnostic accuracy and efficiency.

Method

Research Methodology

Deep neural networks (DNNs) have greatly improved image classification in computational intelligence and computer vision, especially in medical diagnostics. Convolutional Neural Networks (CNNs) have been widely used for detecting and assessing osteoarthritis (KOA) through medical imaging techniques such as MRI and X-rays.

A typical machine learning pipeline for KOA classification involves data selection, preprocessing (removing null values, normalization), clustering to identify patterns, and feature engineering to optimize model performance. The final step, classification, is carried out using machine learning and deep learning models to categorize KOA severity.

This study employs a CNN architecture with multiple convolutional layers and a fully connected network. A multi-class classification approach based on the Kellgren-Lawrence (KL) grading system was used to assess KOA severity [16]. The model effectively utilizes deep CNN layers for feature extraction and classification, ensuring improved accuracy in distinguishing different KOA severity levels.

FIG. 2 GENERAL METHODOLOGY

Dataset used in KOA

The Osteoarthritis Initiative (OAI) dataset serves as a crucial resource for knee osteoarthritis (KOA) research, providing a diverse collection of imaging and medical data gathered over an extended period. This dataset includes radiographic images, clinical assessments, and patient-reported outcomes, making it highly valuable for analyzing KOA progression and severity. The Kellgren-Lawrence (KL) grading system, a widely accepted method for evaluating KOA severity, was used to perform multi-class classification in this study [17].

To improve classification accuracy, advanced machine learning (ML) and deep learning (DL) techniques were applied to analyze the dataset efficiently. This enables an automated approach to identifying KOA severity levels, which can assist medical professionals in early detection, monitoring disease progression, and personalizing treatment strategies. By leveraging this dataset, the study aims to enhance KOA detection, optimize patient care, and improve clinical decision-making.

Additionally, this research incorporates the Digital Knee X-ray dataset from Kaggle, which consists of 3,300 imagesdivided into two separate datasets. Each dataset is further structured into four directories, corresponding to different severity levels of KOA based on KL grading [21].

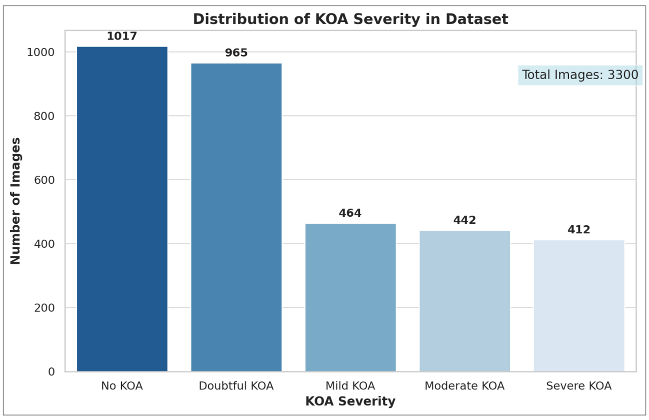


FIG. 3 OAI DATASET IMAGES

The dataset provides comprehensive representation of KOA severity, allowing for a well-structured multi-class classification approach. By utilizing deep convolutional neural networks (CNNs), the study aims to automate KOA severity assessment.

Model Architecture

Detailed 12 Layer CNN

This Convolutional Neural Network (CNN) model is specifically designed for Knee Osteoarthritis (KOA) classification using X-ray images, leveraging a structured architecture to extract relevant features progressively and enhance classification accuracy.

The model begins with the first convolutional layer, which consists of 32 filters with a 3×3 kernel and ReLU activation. This layer is responsible for extracting low-level features such as edges and textures, providing the foundational patterns necessary for deeper analysis. To ensure that the spatial dimensions are maintained, padding='same' is applied. This is followed by a MaxPooling layer (2×2), which helps in reducing dimensionalitywhile preserving the most important features, ensuring computational efficiency without loss of crucial information.

Next, the second convolutional layer utilizes 64 filters with the same 3×3 kernel and ReLU activation. At this stage, the network begins to identify more complex patterns, such as shapes and structures within the knee joint. Another MaxPooling (2×2) operation is applied to further reduce the feature map size, focusing on the most prominent details [21].

The third convolutional layer increases the filter count to 128, maintaining the 3×3 kernel and ReLU activation. This deeper layer is essential for detecting higher-level patterns, such as joint space narrowing and cartilage loss, which are critical indicators of KOA severity. Again, MaxPooling (2×2) is used to downsample the feature maps, ensuring the model retains only the most informative aspects of the X-ray images.

After feature extraction, the model includes a fully connected layer with 256 filters, a 3×3 kernel, ReLU activation, and MaxPooling. This layer refines the previously extracted features, making them more abstract and suitable for classification. To prevent overfitting, a Dropout layer (0.5) is introduced, ensuring the model generalizes well to new data.

Following this, a Flatten layer converts the 2D feature maps into a 1D vector, allowing the information to be processed by dense layers. The dense layer consists of 512 neurons with ReLU activation, playing a crucial role in high-level feature learning by fully connecting all neurons for optimal representation. Another Dropout layer (0.5) is applied to enhance model robustness and mitigate overfitting.

Finally, the output layer contains 5 neurons with a Softmax activation function, responsible for predicting KOA severity levels (0-4). The Softmax function assigns probabilities to each class, enabling the model to determine the most likely classification outcome.

The model is compiled using the Adam optimizer with a learning rate of 0.0001, ensuring efficient weight updates for faster convergence. It employs categorical crossentropy loss, making it well-suited for multi-class classification tasks. This structured architecture enables the CNN to progressively extract features from raw X-ray images and accurately classify KOA severity, contributing to reliable automated diagnosis and clinical decision support.

By integrating deep learning techniques into KOA detection, this model holds potential for improving early diagnosis, assisting radiologists, and streamlining orthopedic assessments in real-world healthcare applications.

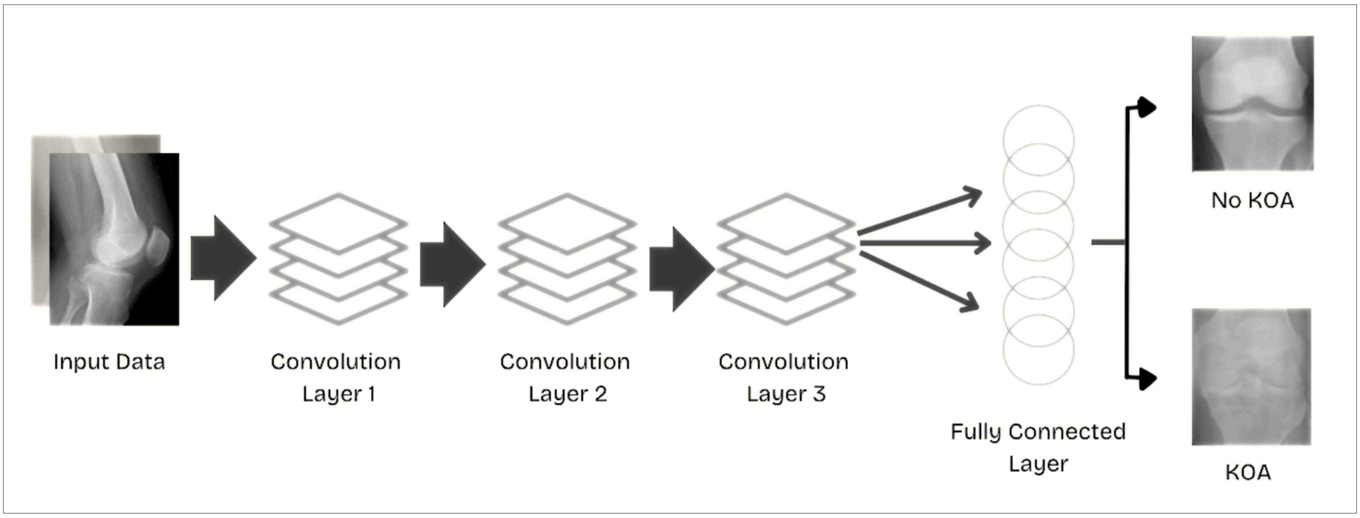


FIG. 4 CNN 12-LAYERED MODEL ARCHITECTURE

Experiment Analysis

A preliminary processing is the first step in the data preprocessing for knee osteoarthritis classification and severity detection using the OAI dataset. This includes important activities including data cleansing, standardisation, and filling in the data gaps.

Model training

This model is a deep CNN designed specifically for image categorization applications. Convolutional layers are used to extract features from visuals, layers with maximum pooling are used to reduce dimensions, fully linked layers are used for additional data processing, and an outcome layer is created for binary classification and early severity detection through multiclassification. The model is constructed to receive input data, process it, and provide a classification and degree of severity detection with the aid of the assigned layers.

Experiment Results

The proposed CNN architecture was employed in this study to use the OAI dataset for classification and severity detection. Compared to previous papers, this one has improved performance accuracy. The deep learning approach was employed in this article to diagnose KOA which made use of accuracy. An enhanced CNN architecture that is more effective is used in KOA for classification and further, the severity detection is proposed in this paper. This made use of the Google Collab notebook and Keras. Using the Cross entropy loss and accuracy in this case demonstrated a decrease in loss and a gain in accuracy.

Classification Report: The classification report provides an in-depth analysis of the model's performance with respect to each classes. It is a complete compilation of many classification metrics, including precision, recall, F1-score, and support for each class. The performance of KOA classification is shown in Table 1.

Based on KL, the knee was classified into three classes: class 0 represents a healthy knee, class 1 represents a doubtful stage, class 2 represents a mild stage, class 3 shows moderate and class 4 represents severe stage for which there is currently no treatment other than arthroplasty.

The model works best in the "healthy" class, followed by the a "moderate and "extreme" classes, with the "Severe" class showing a considerable decline in accuracy and F1-Score due to lesser support (fewer cases). In the future, we will use regularisation approaches to balance the complexity of models and prevent over-fitting.

Figure 5 shows the confusion matrix for KOA classification where Fig. 6 depicts the model loss. Fig. 11 showcases the ROC curve for the deep CNN model This graph shows a confusion matrix for a multi-class classification issue with five classes (0, 1, 2, 3 and 4). It summarises the model's performance by comparing real labels (rows) to predicted labels (columns).

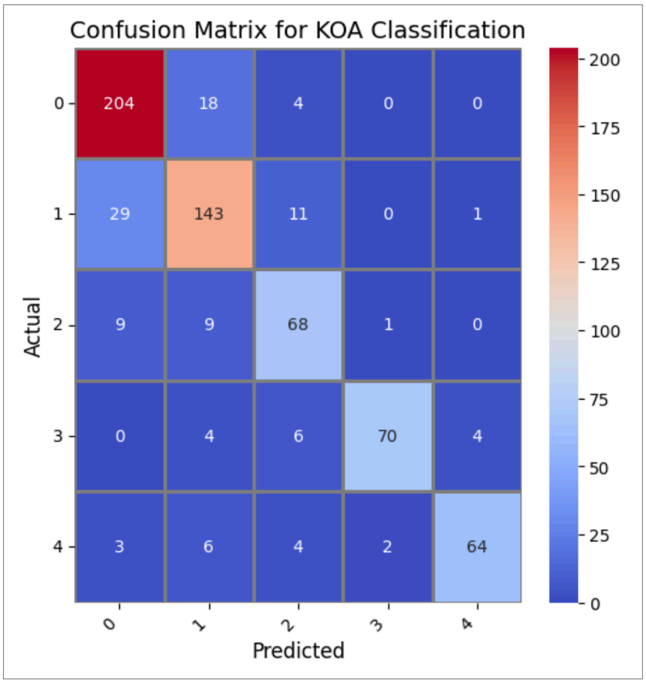
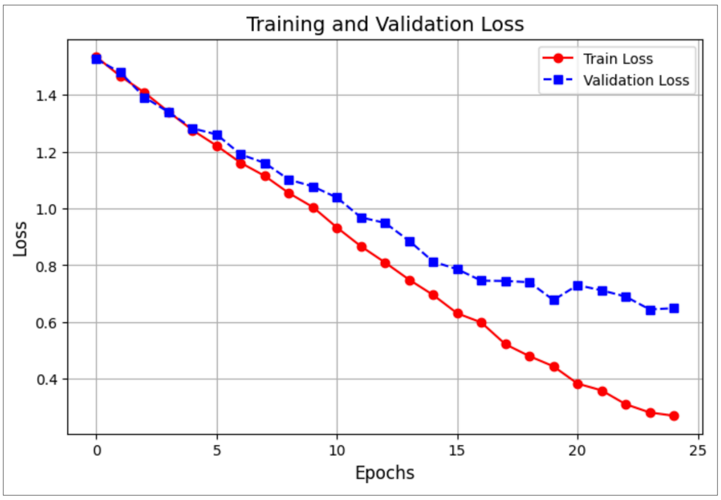


FIG. 5 CONFUSION MATRIX FOR KOA CLASSIFICATION

Grade	Category	Precision	Recall	F1-Score	Support
0	Healthy	0.83	0.90	0.87	226
1	Doubtful	0.79	0.78	0.79	184
2	Minimal	0.73	0.78	0.76	87
3	Moderate	0.96	0.83	0.89	84
4	Severe	0.93	0.81	0.86	79
	Accuracy			0.83	660
	Macro Avg	0.85	0.82	0.83	660
	Weighted Avg	0.84	0.83	0.83	660

TABLE 1 REPORT FOR KOA CLASSIFICATION



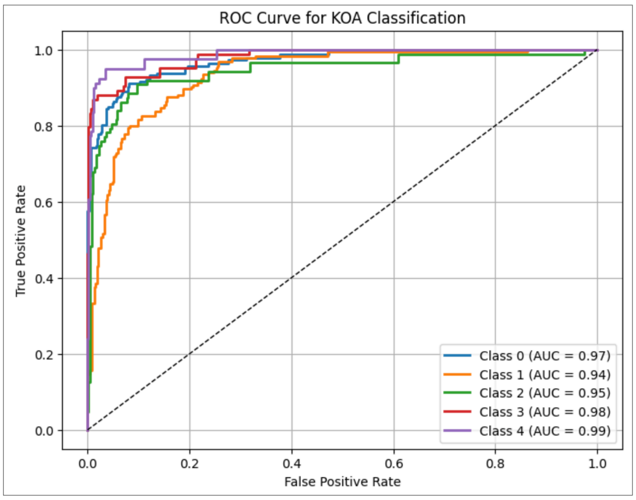


FIG. 6 TRAINING AND VALIDATION LOSS

FIG. 7 ROC CURVE FOR THE CLASSIFICATION MODEL

The training and validation loss graph demonstrates that the model's loss decreases steadily over the epochs, indicating effective learning. The training loss (red line) continuously declines, while the validation loss (blue line) also reduces but stabilizes after a certain point. The slight gap between training and validation loss suggests minimal overfitting, showing that the model generalizes well. The ROC curve graph further confirms the model's strong performance, with AUC values ranging from 0.94 to 0.99 across all KOA severity classes. Higher AUC values indicate that the model effectively distinguishes between different KOA severity levels, with Class 4 (severe KOA) achieving the highest AUC of 0.99. Overall, the model demonstrates strong classification capability with good generalization and high discriminative power across all classes.

User Interface

Integration with Streamlit

The Arthonova Streamlit Web App was designed with an intuitive and visually appealing UI, making knee osteoarthritis (KOA) detection seamless and accessible. The web-based application allowed users to upload an X-ray image, which was then processed using a deep learning model trained specifically for KOA severity classification. The model categorized the condition into one of five distinct severity levels: Healthy, Doubtful, Mild, Moderate, or Severe. Upon classification, the app provided detailed diagnostic findings, outlining key indicators observed in the uploaded X-ray. Additionally, it displayed common symptoms associated with each severity level, helping users correlate their potential experiences with the detected condition. enhance the usability of the platform, the app also generated relevant medical suggestions, including general care recommendations and possible next steps for managing or addressing the condition.

The UI design focused on delivering a user-friendly and professional experience, ensuring accessibility for individuals without technical expertise. The structured navigation bar provided seamless transitions between different sections of the app, allowing users to explore functionalities such as image upload, model predictions metrics, and visual data representations. The model performance page showcased critical evaluation metrics, including accuracy, precision, recall, and the confusion matrix, presented through clear visualizations for better comprehension.

Overall, the integration of AI-driven KOA detection with an interactive UI made Arthonova a powerful tool for users seeking quick and reliable insights into their knee health, empowering them to take informed steps toward treatment and management.

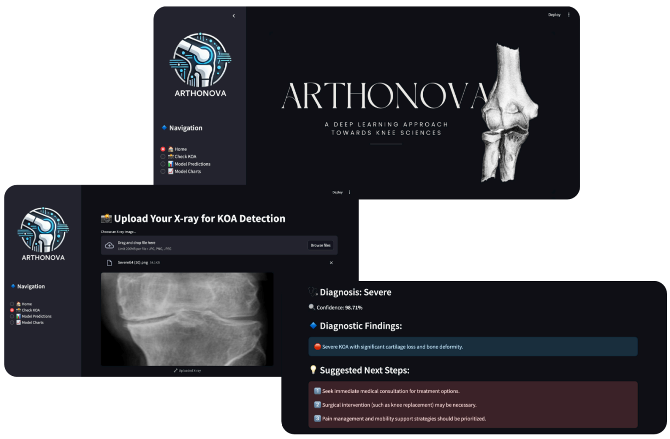


FIG. 8 USER INTERFACE FOR MODEL PREDICTIONS

Conclusion

Knee osteoarthritis is a progressive joint disorder that significantly impacts mobility and overall quality of life. As one of the most prevalent musculoskeletal conditions, it presents a major healthcare challenge, often requiring early diagnosis and timely intervention to prevent severe deterioration. The ability to accurately classify different stages of knee osteoarthritis using deep learning techniques holds immense potential in improving clinical decision-making and patient management. Automated image processing and deep learning-based classification can assist radiologists and medical professionals by providing consistent and efficient assessments, ultimately leading to better treatment strategies and improved patient outcomes.

In this study, we exclusively focused on multi-class classification, distinguishing between five different severity levels of knee osteoarthritis: Healthy, Doubtful, Minimal, Moderate, and Severe. Unlike binary classification, which only differentiates between the presence and absence of the disease, multi-class classification provides a more detailed assessment, which is crucial for tracking disease progression and personalizing treatment plans. The model was trained on X-ray images and evaluated using multiple performance metrics, including accuracy, precision, recall, and F1-score, to ensure a comprehensive evaluation of its classification ability.

Our model demonstrated strong performance in classifying knee osteoarthritis (KOA) severity, achieving an overall accuracy of 83%. Among individual categories, the Healthy class had a precision of 0.83, recall of 0.90, and F1-score of 0.87, reflecting high accuracy in identifying non-affected cases. The Doubtful class showed precision of 0.79, recall of 0.78, and F1-score of 0.79, while the Minimal class had the lowest precision at 0.73, with recall of 0.78 and F1-score of 0.76, indicating some misclassification. The Moderate class achieved the highest precision (0.96) but a slightly lower recall (0.83), leading to an F1-score of 0.89. The Severe class exhibited precision of 0.93, recall of 0.81, and F1-score of 0.86, effectively identifying advanced cases.

Macro average scores across severity levels were 0.85 (precision), 0.82 (recall), and 0.83 (F1-score), with weighted averages closely matching, confirming balanced and reliable performance. High recall across categories highlights the model's effectiveness in capturing true effectiveness in capturing true positive cases, which is critical for early diagnosis and intervention.

Our findings suggest that deep learning-based classification of knee osteoarthritis has substantial clinical potential. By leveraging convolutional neural networks (CNNs), we have demonstrated that automated multi-class classification can be a valuable tool in medical imaging.

Future Scope

Future research should aim to improve the classification accuracy further by incorporating additional imaging modalities such as MRI scans, which provide more detailed soft tissue information. Additionally, integrating multi-modal learning and larger, more diverse datasets could enhance the model's generalizability and robustness.

Overall, this study highlights the potential of AI-driven approaches in improving knee osteoarthritis detection and classification. The ability to accurately differentiate between severity levels can aid in early intervention, personalized treatment planning, and improved patient outcomes. As advancements in deep learning and medical imaging continue to evolve, AI-powered diagnostic tools have the potential to revolutionize healthcare by providing more precise, efficient, and scalable solutions for disease management.

Abbreviations

- **KOA** – Knee Osteoarthritis
- **CNN** – Convolutional Neural Network
- **OAI** – Osteoarthritis Initiatives
- **KL** – Kellgren and Lawrence
- **NJS** – Narrow Joint Spacing
- **DL** – Deep Learning
- **ML** – Machine Learning
- **AI** – Artificial Intelligence
- **TKR** – Total Knee Replacement
- **AP** – Average Precision
- **AUC** – Area Under the Curve
- **JSW** – Joint Space Width
- **JSM** – Joint Space Mapping
- **MRI** – Magnetic Resonance Imaging
- **ReLU** – Rectified Linear Unit
- **CV** – Computer Vision

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