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# X-Ray Insight: Deep Learning-Enhanced Detection and Grading of Knee Osteoarthritis

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**_Abstract_**

*Osteoarthritis (OA) is the most prevalent form of arthritis affecting the knee. It is a degenerative joint disease characterized by the gradual deterioration of cartilage, typically impacting individuals aged 50 and above, although it can also occur in younger people. The condition progresses slowly, with symptoms intensifying over time, leading to significant pain and discomfort. Early diagnosis and intervention can significantly alleviate pain and enhance the quality of life for patients. Recent advancements in medical imaging, particularly X-ray technology, have shown considerable promise in supporting the diagnosis of knee OA (KOA). This paper introduces an automated deep learning-based ordinal classification system designed for the detection and classification of KOA. The proposed system introduces an innovative approach utilizing deep learning for the automated detection and ordinal classification of KOA based on X-ray images. It aims to achieve high accuracy, offering critical insights to medical professionals for making informed decisions regarding patient care and treatment strategies. By leveraging the power of deep learning, this approach aims to achieve high accuracy in diagnosis, thereby providing critical insights for medical practitioners. These insights can inform better decision-making in patient care and treatment planning, ultimately leading to improved outcomes for those suffering from KOA.*

**Keywords:** Deep learning, osteoarthritis, classification, severity, radiographic changes, accuracy

## INTRODUCTION

Knee osteoarthritis (KOA) is a widespread and painful joint issue that impacts many people around the world. It mainly damages the cartilage in the knee, causing pain, difficulty in movement, and making life less enjoyable for many. Because people are getting older and changing how they live, KOA is becoming more common. Identifying strategies for early diagnosis and improved management of the condition is essential.

This paper proposes a new way to deal with the challenges of finding and classifying KOA by using X-ray images and something called deep learning. This deep learning method is like teaching computers to understand these images. The researchers carefully chose a set of images and used some really good computer techniques (they call them CNN architectures) to improve how accurately KOA can be spotted.

This research aims to enhance the accuracy of KOA diagnosis. If successful, this could help doctors make better decisions for their patients. By using advanced techniques to analyze the X-ray

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images, this study could change how KOA is managed. This could enable doctors to provide earlier interventions and develop personalized treatment plans for each patient. Simply put, KOA is a significant issue that leads to knee pain and mobility challenges. This study wants to use special computer programs to look at X-ray pictures of knees. These programs are really smart and can learn from the pictures to help doctors find KOA better. The researchers believe that if they can do this well, it will help doctors make better choices for patients. By using these smart programs to study the pictures, the study could change how one takes care of KOA. This might mean that doctors can find problems earlier and create special treatments for each person.

## LITERATURE SURVEY

Initially, Xen Chen et al. developed a computer-based approach using entropy-based features from surface electromyogram data to distinguish individuals with KOA from healthy controls during walking in 2019 [1]. Here, fuzzy entropy exhibited high accuracy (92%) in identifying KOA patients. Further, Abdelbasset Brahim et al., developed a decision support tool for early KOA detection using knee X-ray images and machine learning in 2019 [2]. The system showed strong performance with high accuracy, sensitivity, and specificity, making it effective for early intervention. Moreover in 2019, Pingjun Chen et al. proposed fully automated KOA severity grading using deep neural networks with an ordinal loss function [3]. The authors achieved high performance in both knee joint detection and OA grading, enhancing automation in KOA diagnosis.

Further in 2020, Soon Bin Kwon & Hyuk Soo Han developed an automated classification model for KOA severity using radiographic imaging and gait analysis data [4]. In this study, combining gait and radiographic features with deep learning achieved high accuracy, outperforming radiographic-only approaches. Next in 2020, Deepak Saini et al. proposed a novel method for automatically assessing KOA severity using X-ray images [5]. By employing convolutional neural networks (CNNs), the approach achieved improved results on public datasets, surpassing existing methods. Moreover, Huy Hoang Nguyen & Simo Saarakkala introduced a semi-supervised learning approach for KOA severity grading from radiographs in 2020 [6]. Here, the Semi mix-up algorithm outperformed fully supervised methods with fewer labeled datasets, offering potential for widespread use. Further in 2020, Aleksei Tiulpin & Simo Saarakkala, developed a deep learning method for automatic grading of KOA features from radiographs [7]. In this paper, an ensemble of residual networks achieved high performance in OA detection, providing a reliable tool for radiographic assessment by authors.

Next in 2021, D. Rezaul Karim & Jiao addressed challenges in KOA diagnosis using deep learning by proposing the deepkneeexplainer method [8]. Here authors preprocess images, extract features, and provide human-interpretable explanations for predictions, achieving 91% classification accuracy.

Next, Aobo Wang & Deyil proposed a novel mobile, wearable gait monitoring method analyzing plantar pressure signals to identify KOA individuals in 2022 [9]. In this study, support vector machine achieved high accuracy (up to 93.15%) by analyzing pressure distribution and landing patterns. Further, Tayyaba Tariq & Zobia Suhail automated KOA detection and classification using deep learning on X-ray images, achieving 98% overall accuracy in 2023 [10]. Transfer learning and ensemble neural networks outperformed existing methods, enabling accurate and efficient KOA diagnosis.

## METHODOLOGY

### Dataset

The paper utilized the Osteoarthritis Initiative dataset, which includes 5578 X-ray images. These images were assessed based on the Kellgren-Lawrence (KL) grading scheme, which categorizes the severity of osteoarthritis. Within this dataset, there were varying numbers of images for each Grade: 2286 images were in Grade 0, 1046 in Grade 1, 1516 in Grade 2, 757 in Grade 3, and 173 in Grade 4.

Every image in the dataset is sized at 224 × 224 pixels. However, the distribution of images across the different grades is not balanced, meaning some grades have significantly more images than others.

 

To address this imbalance, the data was divided into separate sets for training, testing, and validation while taking into account the differing numbers of available samples for each severity grade. This step helps ensure that the models created using this data are trained, tested, and validated effectively across the range of severity grades despite the uneven distribution of images as seen in Table 1.

**Table 1.** Dataset.

| Set | Grade 0 | Grade 1 | Grade 2 | Grade 3 | Grade 4 | Total |
|---|---|---|---|---|---|---|
| Train | 2286 | 1046 | 1516 | 757 | 173 | 5578 |
| Validation | 328 | 153 | 212 | 106 | 27 | 826 |
| Test | 639 | 296 | 447 | 223 | 51 | 1656 |

**Kellgren and Lawrence Grades**

This study uses KL grades as the reference for classifying KOA X-ray images. The KL grading system remains the standard method for initially assessing the severity of knee OA in X-rays. It includes five grades: "Grade 0" for normal, "Grade 1" for doubtful, "Grade 2" for minimal, "Grade 3" for moderate, and "Grade 4" for severe. Figure 1 illustrates the KL grading system.

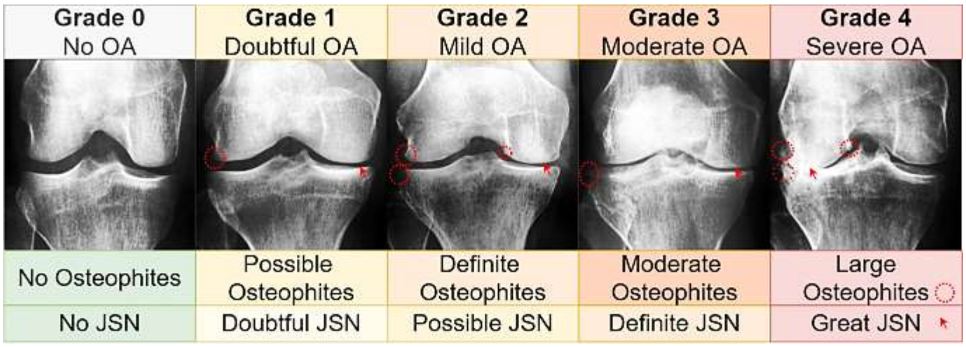


**Figure 1.** Kellgren and Lawrence's grading (KL) grading scheme.

**Algorithm**

*A Convolutional Neural Network (CNN) is a specialized type of artificial neural network designed for processing and analyzing visual data, such as images and videos.* Based on how the human visual system works, CNNs are particularly good at tasks such as identifying images, detecting objects, and classifying visuals. Their architecture consists of multiple layers, including convolutional layers that extract features by applying filters to input data, pooling layers that down sample and retain essential information, and fully connected layers that perform higher-level reasoning based on the features learned. CNNs are particularly effective because they can automatically learn intricate hierarchies of features from raw data as seen in Figure 1. Their ability to learn and understand features in layers makes them valuable in many areas, such as computer vision, medical imaging, and self-driving cars. The adaptability and proficiency of CNNs in understanding and interpreting visual information have significantly contributed to their widespread application and effectiveness in diverse real-world scenarios.

## RESULT AND DISCUSSION

The images display the performance metrics of model-trained on dataset. The graph consists of two main plots: accuracy and loss, which are crucial indicators of the model's performance during training as seen in Figure 2.

**Accuracy Plot**

The accuracy plot shows the progression of the model's accuracy over multiple epochs. It illustrates how well the model predicts the correct labels. An increasing trend shows that the model is getting better at making predictions as time goes on as seen in Figure 3.

 

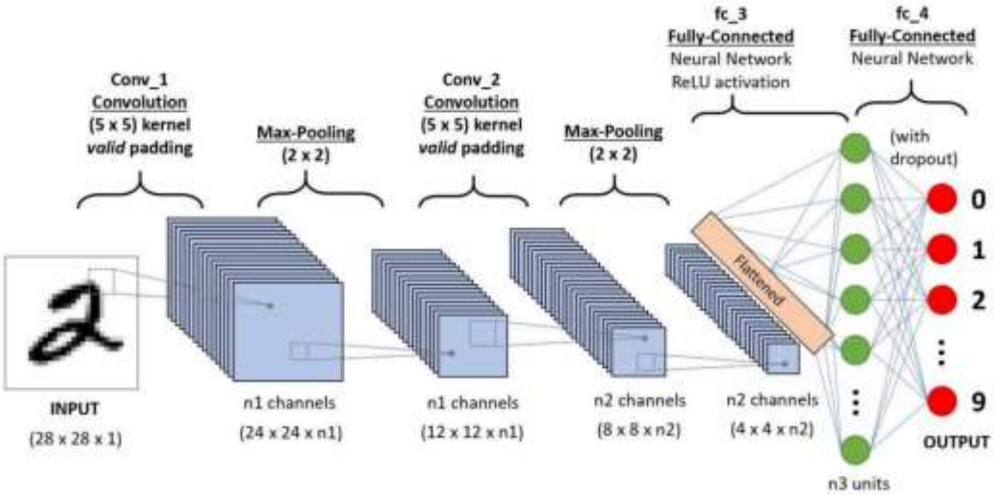


**Figure 2.** CNN sequence.

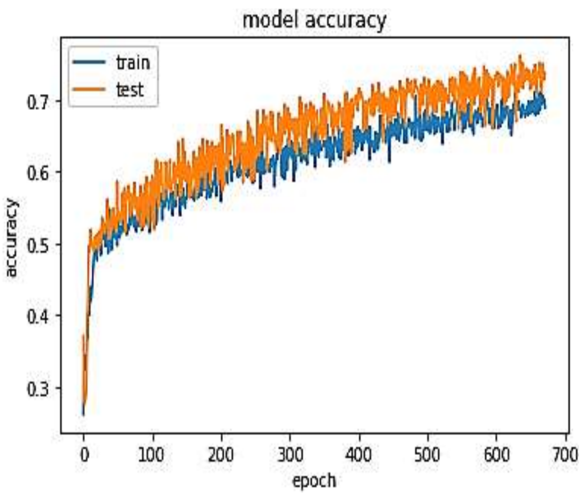


**Figure 3.** Accuracy plot.

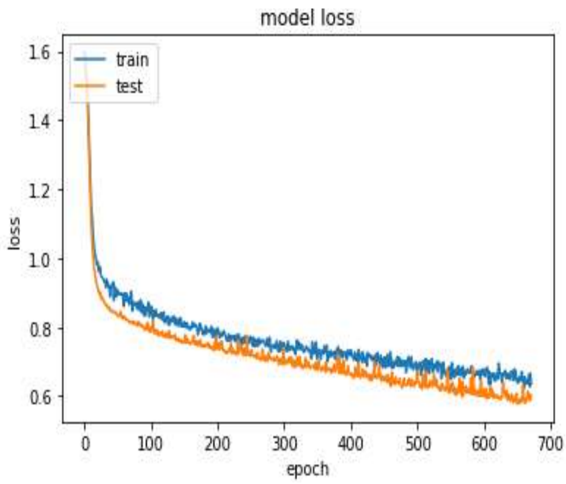


**Figure 4.** Loss plot.

### Loss Plot

The loss plot represents the model's loss (error) over the training epochs. It measures how well the model's predictions align with the actual labels. A decreasing loss indicates that the model is minimizing its errors and getting closer to optimal performance as seen in Figure 4.

### ROC

In the study of KOA, a receiver operating characteristic (ROC) analysis is employed to assess the performance of diagnostic CNN model in distinguishing between different levels of OA severity. The ROC analysis provides valuable insights into the sensitivity and specificity of these tests across various thresholds as seen in Figure 5.

Existing methods for KOA detection vary widely, utilizing techniques like entropy-based features, machine learning with X-rays, and deep neural networks. They offer strong performance, with high accuracy and advanced features like semi-supervised learning and ensemble networks. However, limitations include data imbalance, additional data requirements (e.g., gait analysis), and computational complexity. The proposed deep learning-based ordinal classification system aims to enhance KOA detection by providing high accuracy and detailed ordinal classification of disease severity using X-ray images. While it enhances automation and efficiency, it can encounter challenges such as data imbalance and high computational requirements. Overall, the proposed system builds on existing methods' strengths, addressing some of their limitations while striving to improve diagnostic precision and patient care as seen in Table 2.

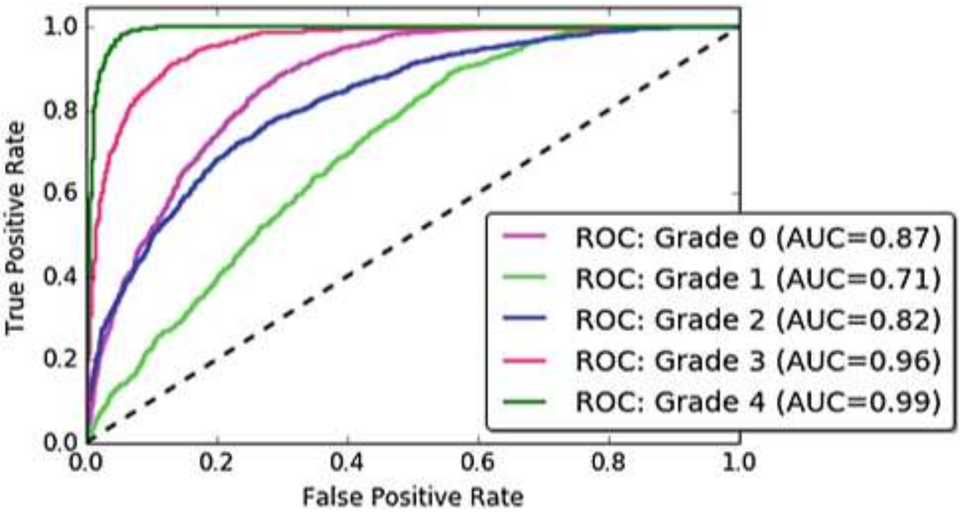


**Figure 5.** ROC analysis.

**Table 2.** The data summaries below present the ROC results for the CNN model used in the study.

| Performance | | | | |
|---|---|---|---|---|
| *Grades* | *Precision* | *Recall* | *F1* | *AUC* |
| 0 | 0.64 | 0.77 | 0.74 | 0.87 |
| 1 | 0.68 | 0.68 | 0.65 | 0.71 |
| 2 | 0.50 | 0.57 | 0.57 | 0.82 |
| 3 | 0.73 | 0.73 | 0.73 | 0.96 |
| 4 | 0.75 | 0.66 | 0.66 | 0.99 |
| Mean | 0.79 | 0.68 | 0.67 | 0.87 |

## CONCLUSION

This study introduces a Knee Osteoarthritis Detection and Classification system using X-ray imaging, promising significant advancements in diagnosing and managing this common degenerative joint condition. By leveraging deep learning and computer vision methodologies, the system aims to revolutionize the identification and categorization of osteoarthritis, enhancing patient care and treatment planning. The integration of advanced technologies allows for accurate and efficient analysis of X-ray images, providing healthcare professionals with precise diagnostic tools. This automated approach ensures timely and accurate detection of KOA, enabling earlier interventions and improved patient outcomes. Additionally, the system's capability to perform ordinal classification offers a detailed understanding of disease progression, facilitating the development of personalized treatment strategies. Overall, the proposed system represents a significant leap forward in osteoarthritis diagnostics, with the potential to transform patient care and optimize treatment outcomes.

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