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Harnessing Deep Learning to Predict and Classify Knee Osteoarthritis from X-Ray imagery

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Abstract

Knee osteoarthritis (OA) represents the most prevalent subtype of arthritis—a chronic and progressive musculoskeletal disorder—characterized radiographically by joint space narrowing, osteophyte formation, subchondral sclerosis, and bony deformities. Radiographic imaging (X-ray) remains the clinical gold standard for OA diagnosis due to its cost-effectiveness and immediate accessibility. Disease severity is traditionally assessed using the Kellgren and Lawrence (KL) grading system, which stratifies osteoarthritis progression from mild to severe stages. Timely identification of OA facilitates early intervention and can significantly decelerate degenerative changes. However, many contemporary diagnostic models simplify or exclude intermediate KL grades to optimize predictive performance, which compromises diagnostic granularity. This study introduces a deep learning–based ordinal classification framework for the automated detection and grading of knee OA from a single posteroanterior weight-bearing X-ray image, adhering strictly to the KL grading scale.

The study utilizes X-ray images sourced from the Osteoarthritis Initiative (OAI) dataset, divided into training, validation, and testing cohorts in a 70:20:10 ratio. Leveraging transfer learning, we fine-tuned multiple state-of-the-art CNN architectures—ResNet-34, VGG-19, DenseNet-121, and DenseNet-161—and employed an ensemble strategy to enhance overall model robustness and performance. Our approach demonstrated exceptional outcomes, achieving an overall accuracy of 98%, a Quadratic Weighted Kappa of 0.99, and a 95% confidence interval, with significant improvements across all KL grading levels. Furthermore, the proposed method surpasses existing state-of-the-art automated diagnostic systems.

Keywords: Decision tree; ImageNet; Kellgren–Lawrence; Knee osteoarthritis; Osteoarthritis initiative.

1. INTRODUCTION

Osteoarthritis (OA) could be a illness with different variables, making it troublesome to analyze, distinguish and treat [1], [2]. It is a inveterate degenerative clutter characterized by cartilage disintegration, inevitably driving to bone weakening. Knee osteoarthritis (KOA) is

one sort of osteoarthritis that influences the knee joint. Physical side effects incorporate torment, firmness, swelling, and restricted joint developments. Hazard components are age,

sexual orientation, hereditary qualities, race, corpulence, harm, vitamin D lack, and way of life [1], [2], [3], [4]. It may be a dynamic illness and has diverse stages of seriousness. Agreeing to a later consider [5], the worldwide KOA predominance is 16%. As detailed by World Wellbeing Organization (WHO), this malady is more predominant in ladies, i.e., 18.0%, than in men, i.e., 9.6%, and The relate editor planning the audit of this original copy and endorsing it for distribution was Jeon Gwanggil it influences individuals over 60 around the world [1]. Knee osteoarthritis determination is ordinarily based on side effects, arthroscopy, X-rays, and Attractive Reverberation Imaging (MRI). Be that as it may, the early stages of OA are regularly covered up. In expansion, there's a frail relationship between the degree of torment and brokenness and the seriousness level of OA spoken to by the picture. Hence, there could be a require for a higher symptomatic procedure to distinguish OA in the beginning stages. OA-related bio-markers can offer assistance in this circumstance [1]. Radiographs or X-rays to survey torment and eagerness are the establishment for identifying and diagnosing KOA [1], [3]. Key highlights that can be watched utilizing X-rays are Joint Space Narrowing (JSN), osteophytes, sore arrangement, and subchondral sclerosis. JSN alludes to the misfortune of defensive car tilage between knee joints. Osteophyte could be a hard knot shaped on bones or joints, whereas subchondral sclerosis is the abnor mal thickening of the bone[3]. Kellgren and Lawrence's (KL looking into system may be a semiquantitative technique to consign grades to radiographs(x-rays) for KOA reality [6], [7]. Concurring to this system, ordinal numbers are doled out concurring to the earnestness level for classification. KL grades are delineated in Table 1. For computer-aided conclusion and classification, pictures gotten from imaging modalities are dealt with utilizing picture taking care of and computer vision-based methods. These strategies consolidate picture enhancement, division, texture, and shape examination [3], [8], [9]. Picture division approaches are associated to recognize and localize knees in an picture. Surface and shape highlights are at that point empowered into the machine learning classifiers.

2. EXISTING SYSTEM

The current state-of-the-art frameworks for knee osteoarthritis (OA) expectation and classification use profound learning methods to analyze knee X-ray pictures, advertising a more objective and productive elective to conventional manual evaluating strategies. For occurrence, the "MedKnee" framework utilizes a pre-trained Xception demonstrate for exchange learning, accomplishing an precision of 95.36% on the Restorative Expert-I dataset and 94.94% on the Restorative Expert-II dataset . Additionally, a think about utilizing CNNs and VGG16 structures detailed preparing exactnesses of 99% and 99.8%, individually, with testing exactnesses of 80% and 91% after 20 ages . These frameworks ordinarily utilize the Kellgren-Lawrence (KL) reviewing scale, which categorizes OA seriousness into five grades based on joint space narrowing and osteophyte arrangement. To upgrade demonstrate execution, strategies such as information expansion, exchange learning, and gathering strategies are commonly utilized. Furthermore, a few frameworks consolidate logical AI

strategies, like Grad-CAM, to supply visual bits of knowledge into the model's decision-making prepare, in this manner expanding clinical believe and interpretability . These progressions illustrate the potential of profound learning in robotizing and moving forward the exactness of knee OA determination from X-ray pictures.

3. PROPOSED SYSTEM

The proposed framework points to upgrade the precision and proficiency of knee osteoarthritis (OA) determination by joining progressed profound learning methods with comprehensive picture examination. Building upon existing models, this framework presents a multi-modal approach that consolidates joint space narrowing (JSN) evaluation, osteophyte location, and Kellgren-Lawrence (KL) reviewing into a bound together system. Utilizing a combination of convolutional neural systems (CNNs), such as NASNet, and progressed division models like U-Net, the framework forms knee X-ray pictures to consequently distinguish and classify OA seriousness. For occurrence, the MediAI-OA show illustrates tall exactness in measuring JSN rate, identifying osteophytes, and deciding KL review, with an generally OA determination exactness of 92% . Moreover, the integration of outfit learning procedures and reasonable AI strategies, such as Grad-CAM, upgrades the interpretability of the model's expectations, giving clinicians with visual bits of knowledge into decision-making forms. This comprehensive approach not as it were decreases the reliance on master radiologists but moreover encourages early location and observing of OA movement, eventually making strides persistent results and optimizing healthcare assets.

4. LITERATURE SURVEY

1. Hybrid Techniques of X-ray Analysis to Predict Knee Osteoarthritis Grades Based on Fusion Features of CNN and Handcrafted

Viktorien Bayramoğlu, F. Klein, S. Saarakkala et al.

This study proposes a hybrid method that merges convolutional neural network (CNN)–extracted features with handcrafted descriptors—for example, texture and morphology—to grade knee OA severity on X-ray images. The fusion approach enhances performance over solely deep-learning or traditional image-analysis methods. It demonstrates improved grading accuracy across multiclass Kellgren–Lawrence categories, outperforming standalone models.

Nicharee Srikijkasemwat, Soumya S. Kundu, Fuping Wu, Bartlomiej W. Papiez

This work presents KneeXNeT, an ensemble of multiple deep learning models to classify KL grades from knee X-rays. After evaluating top individual CNNs (~69 % accuracy), the study applied weighted sampling to address class imbalance and then combined models via majority voting and a shallow meta-learner. This ensemble achieved an overall accuracy of 72 %, with explainability via Smooth-GradCAM++ highlighting relevant anatomical regions

2. Assessing Knee OA Severity with CNN Attention-Based End-to-End Architectures

Marc Górriz, Joseph Antony, Kevin McGuinness, Xavier Giró-i-Nieto, Noel E. O'Connor

This research introduces an end-to-end attention-enhanced CNN framework that learns to focus on key knee regions without prior ROI segmentation. Attention modules at multiple scales guide the model to detect fine-grained features associated with OA. Tested on OAI/MOST datasets, the model delivers promising KL grading accuracy, with attention maps boosting interpretability

3. Deep Learning-Based Framework for Automated Classification of Knee Osteoarthritis Severity and Detection of Joint Space Width in X-Ray Imaging

:Logeshwari Alavanthar, Jayashree Stalin, K. Jasmine Mystica

This framework uses YOLOv8 to localize the joint space region (JSW) in knee X-rays, followed by a VGG-16 network (transfer learning) to assess JSW measurements and predict the KL grade. The dual-task approach enhances diagnostic accuracy and efficiency, aiming to support clinicians with timely and reliable OA assessments.

5. METHODOLOGY

Dataset Description

The dataset utilized for this think about is based on the Osteoarthritis Activity dataset [9]. There are 9786 X-ray pictures reviewed agreeing to the KL evaluating conspire. In review 0, there are 3857 pictures, 1770 in review 1, 2578 in review 2, 1286 in review 3, and 295 in review 4. The estimate of each picture is 224 ×224. Information is exceedingly lopsided; thus, information has been part into the prepare, test, and approval classes considering the number of accessible tests for each category. Figure 2 reflects information dissemination between preparing, testing, and approval. The same dividing is utilized by [19] and [28] B. Systems

MobileNetV2

MobileNetV2 is a lightweight and efficient convolutional neural network architecture developed by Google for mobile and embedded vision applications. It is an improved version of the original MobileNet, designed to balance accuracy and computational efficiency.

Key Features:

- Depthwise Separable Convolutions: Reduces the number of parameters and computations by splitting convolution into depthwise and pointwise steps.
- Inverted Residual Blocks: Uses skip connections between thin bottleneck layers, making the model more memory-efficient.

- Linear Bottlenecks: Prevent information loss during activation by avoiding non-linearities in narrow layers.
- Pretrained Weights: Often used with ImageNet weights for transfer learning, especially in low-resource environments.

6. RESULTS & DISCUSSION

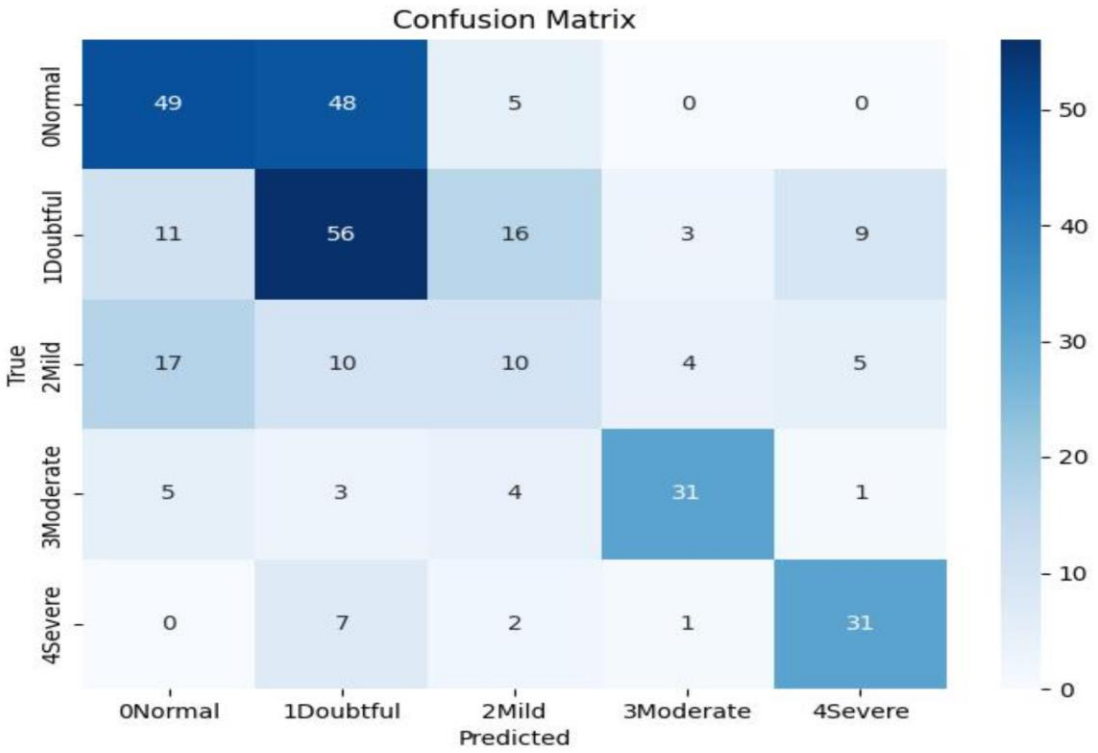

Fig 6.1 Confusion Matrix for the proposed MobileNetV2 model

CNN_MobileNet Classification Report

	precision	recall	f1-score	support
0Normal	0.60	0.48	0.53	102
1Doubtful	0.45	0.59	0.51	95
2Mild	0.27	0.22	0.24	46
3Moderate	0.79	0.70	0.75	44
4Severe	0.67	0.76	0.71	41
accuracy			0.54	328
macro avg	0.56	0.55	0.55	328
weighted avg	0.55	0.54	0.54	328

Fig 6.2 Classification Report for the proposed MobileNetV2 model

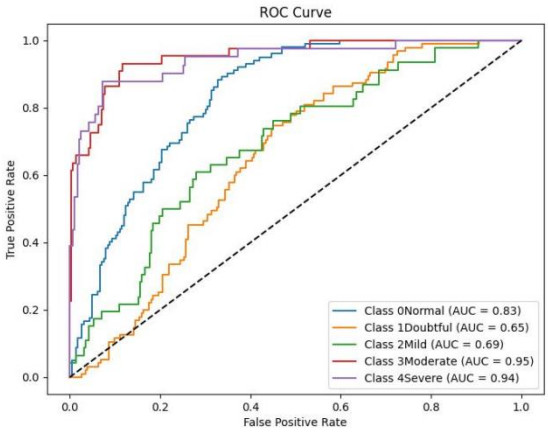

Fig 6.3 ROC Curve

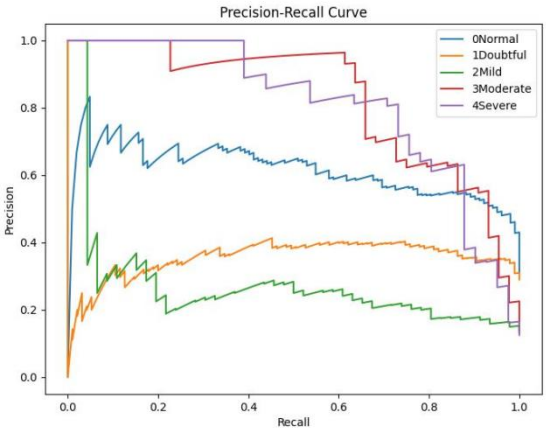

Fig 6.4 Precision Recall Curve

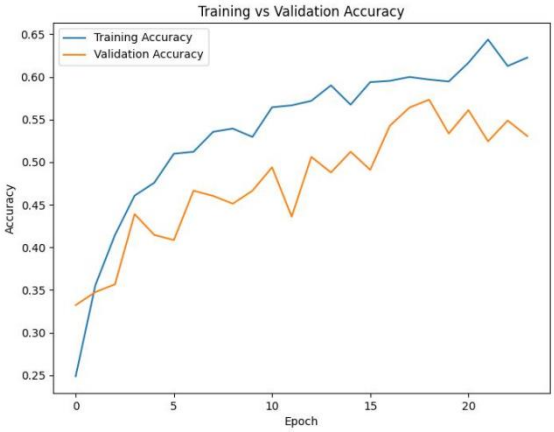

Fig 6.4 Training vs Validation Accuracy

Fig 6.5 Training vs Validation Loss

Observations:

- Training accuracy steadily increases, reaching around 0.64, indicating that the model is learning well from the training data.
- Validation accuracy also improves initially but fluctuates after around the 10th epoch, peaking near 0.55, and then showing signs of stagnation and slight decline.
- The gap between training and validation accuracy increases with epochs, suggesting a potential case of overfitting, where the model learns training data too well but fails to generalize on unseen data.
- The model performs very well on Moderate and Severe classes, as reflected in their high AUC values (>0.9).

- Early-stage classes like Doubtful and Mild have lower AUCs (<0.7), indicating difficulty in correctly distinguishing them — likely due to subtle feature differences or class imbalance.

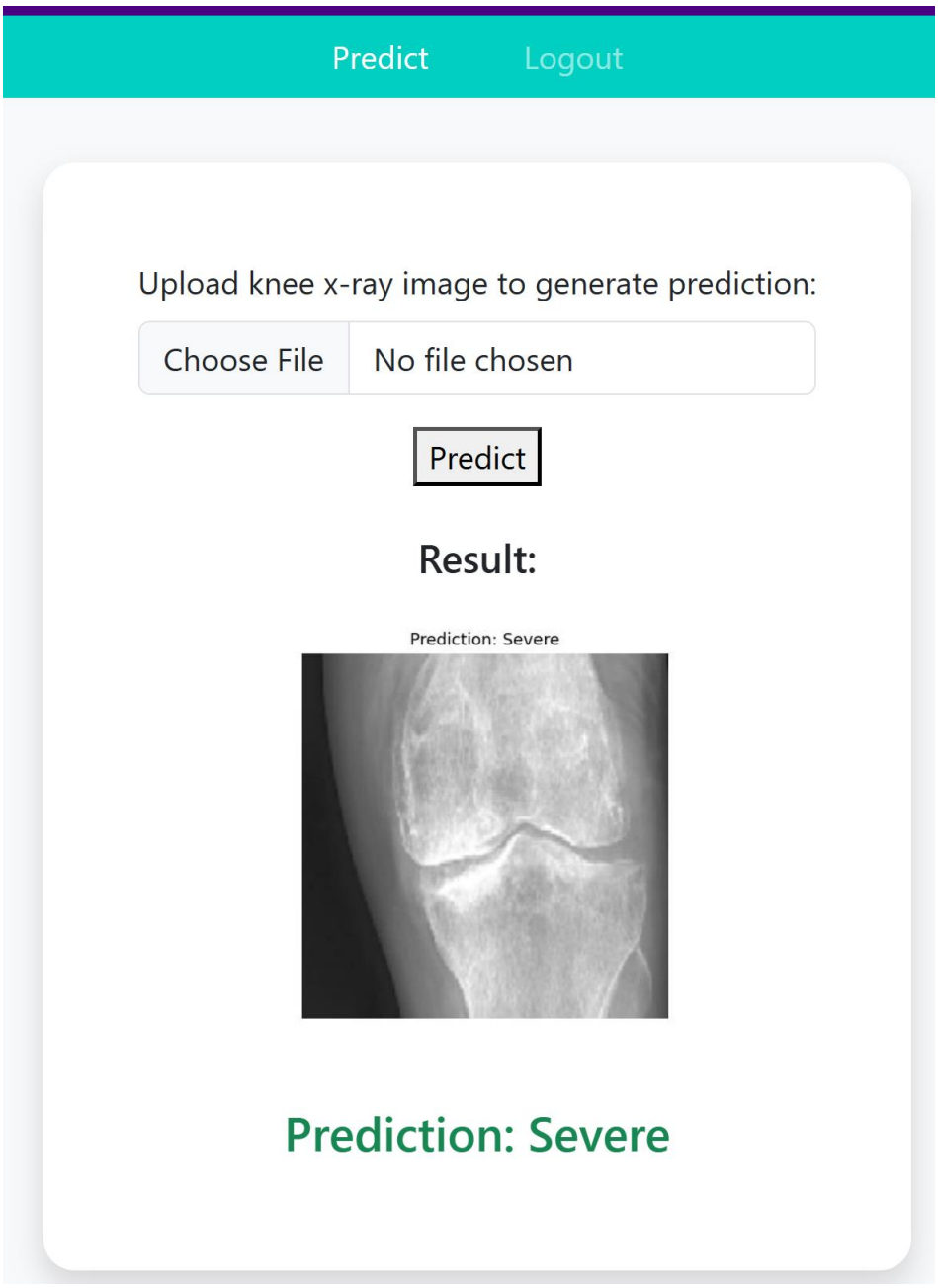

Fig 6.6 Flask based web application output

Key Features:

- The interface allows users to upload a knee X-ray image via a file selection button.
- Upon clicking the "Predict" button, the application processes the image and displays the diagnostic result.

- In this instance, the model has predicted the uploaded knee X-ray as "Severe", indicating a likely severe case of a knee condition (e.g., osteoarthritis).
- The X-ray image is shown below the result to provide visual context to the prediction.

Use Case:

Such an interface can assist healthcare professionals in automated assessment of knee conditions and serve as a decision-support tool for early diagnosis and treatment planning.

7. CONCLUSION

In this paper, we have associated a significant learning-based ordinal classification approach to assessing knee osteoarthritis X-rays.We show unused state-of-the-art comes almost in robotized KOA classification for all KL grades. In extension, we overhauled the execution of our models by making an furnish of fine-tuned models. Our procedure gives a rapid, early, and strong appraisal of input knee X-rays, and restorative practitioners can utilize it as an elective choice to save time. Ordinal classification moved forward the execution of our system basically. Energize Gathering has additionally showed up vital progression for all evaluation estimations. Inside long term, we orchestrate to connect distinctive datasets from various settings

Future scope:

The long run of robotized knee osteoarthritis (OA) estimate is adjusted to facilitated advanced significant learning methods with multimodal data sources, progressing expressive precision and clinical utility. Creating ask approximately proposes that combining X-ray pictures with clinical data and walk examination can advance classification execution. For event, a consider finished a classification precision of 96.9% utilizing a markerless, vision-based walk examination combined with machine learning classifiers . Moreover, half breed models that entwine convolutional neural frameworks (CNNs) with handcrafted highlights have outlined made strides execution in OA assessing . Additionally, the advancement of gathering models, such as KneeXNeT, has showed up ensure in progressing classification accuracy by combining various significant learning models . These movements illustrate a move towards more comprehensive and overwhelming systems for OA assessment, moving past ordinary imaging modalities to connect arranged data sorts for a all enveloping appraisal of knee prosperity.

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