

**MAR ATHANASIUS COLLEGE OF ENGINEERING, KOTHAMANGALAM**

**Initial Project Report**

**AUTOMATED DETECTION AND CLASSIFICATION OF KNEE OSTEOARTHRITIS USING DEEP LEARNING**

Done by

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**ABSTRACT**

# Topic: Automated Detection and Classification of Knee Osteoarthritis Using Deep Learning

Knee osteoarthritis (OA) is a prevalent joint disorder causing significant pain and disability. Early detection and accurate grading of OA severity are crucial for effective treatment planning and management. Traditional methods of OA assessment rely heavily on expert radiologists interpreting X-ray images, which can be time-consuming and subject to inter-observer variability. This project aims to develop an advanced deep learning model for automated detection and classification of knee OA using X-ray images.

The project utilizes a comprehensive dataset from the Osteoarthritis Initiative (OAI), comprising thousands of knee X-ray images labelled according to the Kellgren and Lawrence (KL) grading system (0-4). This dataset includes healthy, minimal, moderate and severe stages of OA severity

The proposed approach involves preprocessing the X-ray images, addressing class imbalance through data augmentation techniques, and developing a novel hybrid deep learning model. This model combines the strengths of Convolutional Neural Networks (CNNs) and pre-trained architectures like VGG16, leveraging transfer learning to enhance feature extraction and classification accuracy.

**Dataset link:** <https://www.kaggle.com/datasets/shashwatwork/knee-osteoarthritis-dataset-with-severity>

**References:**

1. T. Tariq, Z. Suhail, and Z. Nawaz, "Knee Osteoarthritis Detection and Classification Using X-Rays," in IEEE Access, vol. 11, pp. 48292-48303, 2023, doi: 10.1109/ACCESS.2023.3276810.
2. J. H. Cueva et al., "Detection and Classification of Knee Osteoarthritis," in Diagnostics, vol. 12, no. 10, p. 2362, Sep. 2022, doi: 10.3390/diagnostics12102362.
3. . S. U. Rehman and V. Gruhn, "A Sequential VGG16+CNN-Based Automated Approach With Adaptive Input for Efficient Detection of Knee Osteoarthritis Stages," in IEEE Access, vol. 12, pp. 62407-62415, 2024, doi: 10.1109/ACCESS.2024.3395062.

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**INTRODUCTION**

Knee osteoarthritis (OA) is a prevalent degenerative joint disorder that affects millions of people worldwide, causing significant pain, disability, and reduced quality of life. Early detection and accurate grading of OA severity are crucial for effective treatment planning and management. Traditionally, the assessment of knee OA relies heavily on expert radiologists interpreting X-ray images, a process that can be time-consuming and subject to inter-observer variability. In recent years, there has been a growing interest in leveraging advanced machine learning and deep learning techniques to automate and enhance the accuracy of knee OA detection and classification.

The Kellgren and Lawrence (KL) grading system is widely used to assess OA severity, categorizing it into five grades (0-4) based on radiographic features such as joint space narrowing, osteophyte formation, and bone deformities. However, distinguishing between these grades, especially in early stages, can be challenging even for experienced radiologists. This challenge has motivated researchers to explore various computational approaches to improve the accuracy and consistency of OA assessment.

Recent studies have demonstrated the potential of deep learning models in automating the detection and classification of knee OA. Convolutional Neural Networks (CNNs) have shown particular promise in this domain due to their ability to learn hierarchical features from image data. Researchers have explored various CNN architectures, including VGG16, VGG19, ResNet, and DenseNet, often employing transfer learning techniques to leverage pre-trained models. These approaches have yielded impressive results, with some models achieving accuracies exceeding 90% in classifying OA severity.

However, the field continues to face challenges, particularly in accurately differentiating between adjacent KL grades and handling class imbalance in datasets. To address these issues, researchers have proposed innovative solutions such as hybrid models, ensemble methods, and custom loss functions designed for ordinal classification tasks. For instance, the combination of VGG16 for feature extraction with a custom CNN for classification has shown promising results, outperforming individual architectures in some studies.

The development of automated OA detection and classification systems has far-reaching implications for clinical practice. These systems can potentially reduce the workload on radiologists, provide more consistent assessments, and enable earlier detection of OA. Moreover, the integration of these models into user-friendly interfaces allows for wider accessibility and practical application in clinical settings. As research in this field progresses, there is a growing focus on not only improving model accuracy but also on developing interpretable models that can provide insights into the decision-making process, thereby fostering trust and adoption among medical professionals.

**LITERATURE REVIEW**

## Paper 1: Knee Osteoarthritis Detection and Classification Using X-Rays

The paper "Knee Osteoarthritis Detection and Classification Using X-Rays" by T. Tariq et al. explores enhancing knee osteoarthritis (OA) detection through deep learning. Using 9,786 X-ray images from the Osteoarthritis Initiative (OAI) and the Kellgren and Lawrence (KL) grading scheme, the authors address class imbalance and improve model performance with data preprocessing and augmentation.

The study fine-tunes four pre-trained models—ResNet-34, VGG-19, DenseNet 121, and DenseNet 161—and combines their predictions in an ensemble model. A key innovation is the use of a customized ordinal loss function (CORN) to handle the ordinal nature of KL grades.

The ensemble model achieves 98% accuracy and a 0.99 Quadratic Weighted Kappa, outperforming previous studies, particularly in early-stage OA classification. The authors suggest incorporating multiple datasets to improve generalizability in future work. This study significantly advances automated OA detection by demonstrating the effectiveness of ensemble deep learning models and ordinal classification.

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| **Title of the paper** | T. Tariq, Z. Suhail, and Z. Nawaz, "Knee Osteoarthritis Detection and Classification Using X-Rays," in IEEE Access, vol. 11, pp. 48292-48303, 2023, doi: 10.1109/ACCESS.2023.3276810. |
| **Area of work** | Automated detection and classification of knee osteoarthritis using X-ray images. |
| **Dataset** | OsteoArthritis Initiative (OAI) dataset  Kaggle: https://www.kaggle.com/datasets/shashwatwork/knee-osteoarthritis-dataset-with-severity |
| **Methodology/Strategy** | Fine-tuning of pre-trained models, ensemble learning, ordinal classification, data augmentation |
| **Algorithm** | ResNet-34, VGG-19, DenseNet 121, DenseNet 161, Ensemble model |
| **Result/Accuracy** | 98% overall accuracy |
| **Advantages** | High accuracy across all KL grades, effective handling of class imbalance, improved early-stage OA detection |
| **Limitations** | Limited diversity in dataset |
| **Future Proposal** | Incorporate multiple datasets from various settings to improve generalizability |

### Paper 2: Detection and Classification of Knee Osteoarthritis

The paper "Detection and Classification of Knee Osteoarthritis" by J. H. Cueva et al. introduces a computer-assisted diagnostic (CAD) system for detecting and classifying knee osteoarthritis (OA) using X-ray images from the Osteoarthritis Initiative (OAI) dataset. The system analyzes both knees simultaneously.

The methodology features a two-step approach: first, a customized YOLOv2 network for automated knee joint detection, and second, Deep Siamese convolutional neural networks combined with a fine-tuned ResNet34 for OA classification based on the Kellgren-Lawrence (KL) grading system. A key innovation is the use of transfer learning to address class imbalance, improving model performance across OA severity levels.

The model achieves a multiclass accuracy of 61% for KL grading. Despite lower accuracy compared to other methods, the study's simultaneous analysis of both knees and effective handling of class imbalance through transfer learning offers valuable insights for future research. The combined approach of object detection and classification in a single model could be especially useful in clinical settings where efficiency is essential.

in a single model. This could be particularly valuable in clinical settings where efficiency is crucial.

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| **Title of the paper** | J. H. Cueva et al., "Detection and Classification of Knee Osteoarthritis," in Diagnostics, vol. 12, no. 10, p. 2362, Sep. 2022, doi: 10.3390/diagnostics12102362. |
| **Area of work** | Computer-assisted diagnosis (CAD) system for knee osteoarthritis detection and classification |
| **Dataset** | Images were gathered from renowned hospitals and reputable diagnostic centres. |
| **Methodology/Strategy** | Two-step approach: knee joint detection followed by OA classification, transfer learning for class imbalance |
| **Algorithm** | YOLOv2 for knee detection, Deep Siamese CNN and ResNet34 for classification |
| **Result/Accuracy** | 61% multiclass accuracy for KL grading |
| **Advantages** | Simultaneous analysis of both knees, addressing class imbalance through transfer learning |
| **Limitations** | Relatively lower accuracy compared to other methods |
| **Future Proposal** | Improve model performance, potentially incorporate additional clinical data |

**Paper 3: A Sequential VGG16+CNN-Based Automated Approach With Adaptive Input for Efficient Detection of Knee Osteoarthritis Stages**

The paper "A Sequential VGG16+CNN-Based Automated Approach With Adaptive Input for Efficient Detection of Knee Osteoarthritis Stages" by S. U. Rehman and V. Gruhn proposes a hybrid model that combines VGG16 and a custom Convolutional Neural Network (CNN) to improve knee osteoarthritis (OA) detection and classification. The study uses a dataset of 1,650 X-ray images annotated according to the Kellgren-Lawrence grading system by two medical experts.

The key innovation is the hybrid model, which leverages VGG16's feature extraction and the custom CNN's task-specific learning. The authors also emphasize data preprocessing and augmentation to address class imbalance, which is crucial in medical imaging datasets.

The VGG16+CNN hybrid model achieves a 93.27% accuracy in classifying OA stages, surpassing other models like CNN, VGG16, VGG19, and ResNet50. The study demonstrates the effectiveness of combining established architectures to create a more robust model and highlights the importance of data augmentation in improving performance. This research provides valuable insights into enhancing automated OA detection through advanced deep learning techniques.

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| **Title of the paper** | S. U. Rehman and V. Gruhn, "A Sequential VGG16+CNN-Based Automated Approach With Adaptive Input for Efficient Detection of Knee Osteoarthritis Stages," in IEEE Access, vol. 12, pp. 62407-62415, 2024, doi: 10.1109/ACCESS.2024.3395062. |
| **Area of Work** | Automated detection of knee osteoarthritis stages using X-ray images |
| **Dataset** | 1,650 digital X-ray images of knee joints |
| **Methodology/Strategy** | Hybrid model combining VGG16 and CNN architectures, extensive data augmentation |
| **Algorithm** | VGG16+CNN hybrid, compared with CNN, VGG16, VGG19, and ResNet50 |
| **Result/Accuracy** | 93.27% accuracy in detecting various grades of OA |
| **Advantages** | High accuracy across all KL grades, effective handling of class imbalance, improved performance compared to individual models |
| **Limitations** | The computational effort required for training and optimizing both the models can be significant. |
| **Future Proposal** | Integrate additional imaging modalities, incorporate knee joint space measurement for enhanced accuracy |

**LITERATURE SUMMARY**

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| **PAPER** | **TITLE** | **DATASET** | **ALGORITHM** | **ACCURACY** |
| PAPER 1 | T. Tariq et al., "Knee Osteoarthritis Detection and Classification Using X-Rays," in IEEE Access, vol. 11, pp. 48292-48303, 2023, doi: 10.1109/ACCESS.2023.3276810. | OsteoArthritis Initiative (OAI) dataset: 9,786 X-ray images | ResNet-34, VGG-19, DenseNet 121, DenseNet 161, Ensemble model | 98% (Ensemble model) |
| PAPER 2 | J. H. Cueva et al., "Detection and Classification of Knee Osteoarthritis," in Diagnostics, vol. 12, no. 10, p. 2362, Sep. 2022, doi: 10.3390/diagnostics12102362. | X-ray images gathered from renowned hospitals and reputable diagnostic centers | YOLOv2 for knee detection, Deep Siamese CNN and ResNet34 for classification | 61% (multiclass accuracy for KL grading) |
| PAPER 3 | S. U. Rehman and V. Gruhn, "A Sequential VGG16+CNN-Based Automated Approach With Adaptive Input for Efficient Detection of Knee Osteoarthritis Stages," in IEEE Access, vol. 12, pp. 62407-62415, 2024, doi: 10.1109/ACCESS.2024.3395062. | 1,650 digital X-ray images of knee joints | VGG16+CNN hybrid, compared with CNN, VGG16, VGG19, and ResNet50 | 93.27% (VGG16+CNN hybrid model) |

**PROJECT PROPOSAL**

Based on the findings from previous studies, the hybrid model combining VGG16 and CNN, as well as ensemble methods, have shown promising results in knee osteoarthritis (OA) detection and classification. This project aims to develop a deep learning model to accurately detect and classify knee OA using X-ray images. The project will utilize a hybrid approach combining VGG16 for feature extraction and a custom CNN for classification. Additionally, a web interface will be created to allow medical professionals to upload X-ray images and receive instant OA severity predictions.

**Objectives:**

* Develop a hybrid deep learning model (VGG16+CNN) for knee OA detection and classification.
* Compare the performance of this hybrid model with standalone VGG16, VGG19, and ResNet50 models.
* Create a user-friendly web interface for medical professionals to upload X-ray images and obtain OA severity predictions.

**Motivation for Choosing Hybrid VGG16+CNN Model:**

1. **Complementary Strengths:** VGG16 excels in feature extraction from images, while custom CNNs can be tailored for specific classification tasks. Combining these approaches leverages the strengths of both architectures.
2. **High Accuracy:** Previous studies have shown that hybrid and ensemble models often outperform standalone architectures in medical image analysis tasks, including OA detection.
3. **Handling Complex Patterns:** Knee OA presents subtle changes in X-ray images, especially in early stages. The hybrid model's deep architecture can capture these intricate patterns more effectively than simpler models.

**Methodology**

1. **Data Preprocessing:**

* Data Augmentation: Techniques such as rotation, flipping, and contrast adjustment will be applied to address class imbalance.
* Normalization: Images will be normalized to ensure uniformity and improve model performance.
* Segmentation: Knee joint areas will be segmented to focus the model on relevant regions.

1. **Model Development:**

* Feature Extraction: Implement VGG16 architecture for extracting relevant features from X-ray images.
* Classification: Develop a custom CNN for classifying the extracted features into OA severity grades.

1. **Model Training:**

* The dataset will be split into training, validation, and testing sets (70%, 20%, and 10% respectively).
* Transfer learning will be applied to the VGG16 component to leverage pre-trained weights.

1. **Model Evaluation:**

* Models will be evaluated using accuracy, precision, recall, F1-score, and Quadratic Weighted Kappa.
* Comparative analysis with standalone VGG16, VGG19, and ResNet50 models will be conducted.

1. **Model Deployment:**

* Web Interface Development: A user-friendly web interface will be created using Flask or Django. This interface will allow medical professionals to upload knee X-ray images and receive OA severity predictions.
* Backend Integration: The trained model will be integrated with the web application backend to process uploaded images and generate predictions.

**DATASET**

The dataset used in this project is sourced from the Osteoarthritis Initiative (OAI), a multi-center, longitudinal, prospective observational study of knee osteoarthritis. This comprehensive dataset includes:

* Total Images: 9,786 knee X-ray images
* Image Type: Digital radiographs in 8-bit grayscale format
* Image Size: 224 x 224 pixels

The dataset is annotated according to the Kellgren and Lawrence (KL) grading system, with the following distribution:

* Grade 0 (Normal): 3,857 images
* Grade 1 (Doubtful): 1,770 images
* Grade 2 (Minimal): 2,578 images
* Grade 3 (Moderate): 1,286 images
* Grade 4 (Severe): 295 images

Each X-ray image in the dataset has been independently graded by two medical experts to ensure accuracy in labeling. The images were captured using standardized protocols to maintain consistency across different medical centers.

This dataset provides a rich source of information for developing and evaluating machine learning models for knee osteoarthritis detection and classification. It captures a wide range of OA severities, from normal knee joints to severe cases, allowing for comprehensive model training and robust performance evaluation across all stages of the disease.

**Conclusion**

This project leverages the power of hybrid deep learning models to enhance knee OA detection and classification accuracy, supported by a user-friendly web interface for practical applications. By building on the insights from recent studies and employing a comprehensive methodology, the proposed system aims to offer a significant improvement in OA assessment, addressing the needs of healthcare professionals and potentially improving patient outcomes through earlier and more accurate diagnoses.