A quantitative analysis of severity grading of knee osteoarthritis

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***Abstract*—Knee Osteoarthritis (OA) is a common condition traditionally assessed using the qualitative Kellgren-Lawrence (KL) grading system. For better analysis it is important to have quantified value of the bone condition. We put effort to measure the knee joint space between the tibia and femur from frontal X-ray images. Our approach utilizes Sobel and FastSAM edge detection algorithms, enhanced with simulated annealing and local smoothing techniques. We find the effectiveness of our method as it requires minimal computational resources and no machine learning training. Preliminary results show that our method provides a reliable and precise tool for knee OA assessment, setting the stage for future clinical validation.**

***Index Terms*—Knee Osteoarthritis (KOA), Quantification, KL Grading, FastSAM, CNN, Fully Convolutional Network (FCN)**

I. Introduction

Knee Osteoarthritis (KOA) is a major global health issue, impacting millions and causing pain, stiffness, and reduced mobility [5]. The most standard knee OA assessment relies on the Kellgren-Lawrence (KL) grading system, which is subjective and usually leads to variability and inaccuracies in diagnosis [6]. Various methodologies have been developed to automate knee OA grading and assessment. Kondal et al. [1] used Convolutional Neural Networks (CNNs) in a two-stage model for KL grading, but it depends heavily on dataset's quality and lacks generalizability. Antony et al. The authors in [2] proposed a Fully Convolutional Network (FCN) for localizing knee joints and a CNN for severity quantification, requiring significant computational resources. Tiulpin et al. [3] employed Siamese network with an attention mechanism for KL grading, achieving high accuracy with the penalty of generalization issues. Brahim et al. [4] combined image pre-processing with machine learning for early OA detection, but relied on manual feature engineering and showed inconsistent performance across datasets. Despite these advancements, challenges such as low-quality of X-ray images, inaccurate detection, and reliance on subjective grading still persist. The main challenges involved in knee gap measurement are as follows.

1) Lack of Labeled Data: The absence of ground truth labels complicates the validation of edge detection and gap measurement techniques.
2) Low-Quality X-ray Images: Low-resolution and poor-contrast X-ray images create difficulties in accurately processing anatomical structures.
3) FastSAM and RGB Detection Challenges: FastSAM's lack of precision and RGB detection's sensitivity to light contrast hinder accurate knee gap measurement, necessitating more robust medical imaging methods.
4) Reliance on Opinion-Based KL Grading: Subjective KL grading introduces variability and potential bias, affecting the reliability of measurements.

Therefore, it is important to have grading based on quantitative assessment.

II. Proposed Approach

Our study aims to improve diagnosis of KOA by better assessment with quantified values computed from bone images.

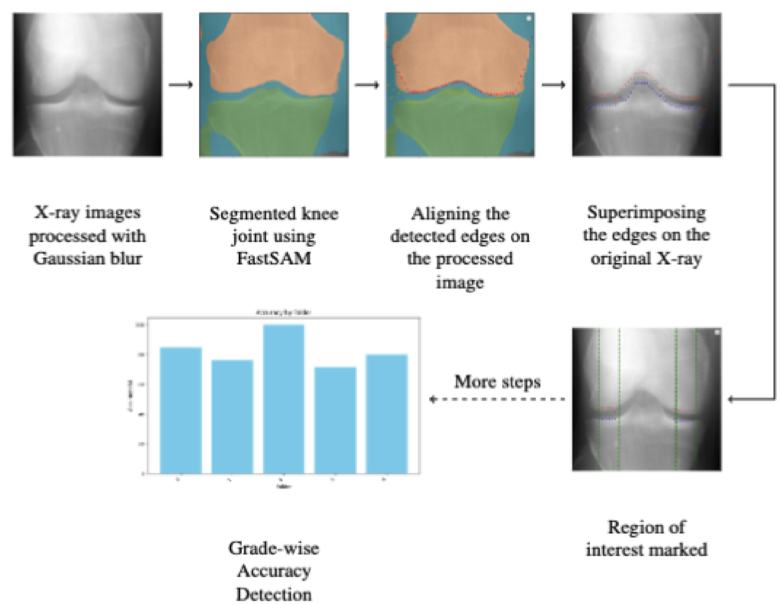

Fig. 1: The pipeline illustrating the knee OA assessment process.

A. Dataset

In this research, we have utilized two datasets: a real dataset (publicly available) from Kaggle and a synthetic dataset. The primary dataset from Kaggle consists of knee X-ray images graded according to the Kellgren-Lawrence (KL) system: 1000 images each for Grades 0, 1, and 2; 750 for Grade 3; and 150 for Grade 4. All images are grayscale with a resolution of 224 x 224 pixels. We have enhanced this dataset using the FastSAM image segmentation algorithm [7], which involved segmenting the knee joint, identifying tibia and femur boundaries, converting images to RGB format, and measuring knee gaps. This pre-processing improves edge detection accuracy.

B. Methodology

Our approach involves several key steps. Firstly, the quality of knee radiographs is enhanced using the Sobel operator, Gaussian blur, and adaptive thresholding to highlight edges and to reduce noise. Sobel and FastSAM algorithms are then used to detect the edges of the tibia and femur bones. Initial edges are identified by iterating through image columns to detect significant intensity changes. These detected edges are refined using simulated annealing, and further smoothed with a moving average filter to remove noise and improve precision.

After edge detection, the points are superimposed on the original X-rays, and the region of interest (ROI) is filtered out. The most accurate points representing the knee gap are identified within specified ranges, ensuring precise measurement. The knee joint space is then computed by measuring the distance between the detected upper and lower edges, providing a critical indicator of OA severity. This process ensures an accurate, objective, and reproducible assessment of knee OA from radiographs.

III. Results and Analysis

The performance metrics included metrics such as *percentage of joint space narrowing* and *accuracy* in detecting osteoarthritis. Implemented in Google Colab, the testbed used a dataset of knee joint images classified into five grades (KL grades 0 to 4).

By analyzing all images in the training dataset, we have determined the standard joint space widths for the left and right sides of the knee joint. This involved detecting edges, calculating the gap within the region of interest, and statistically determining the most probable gap value.

TABLE I: The width of joint space for different grades.

Grade	Joint Space Width (px)		Joint Space Width (%)	
	Left	Right	Left	Right
0	19	19	8.0	8.0
1	16	16	7.0	7.0
2	14	14	6.0	6.0
3	11	12	5.0	5.0
4	11	11	5.0	5.0

We have found that images with a joint space width of less than 7% of the image height (224 pixels) were detected as osteoarthritic, typically corresponding to Grades 4, 3, and sometimes 2. Images with joint space widths greater than 7% have been identified as non-osteoarthritic, corresponding to Grades 0, 1, and sometimes 2. Testing on 500 images, we have achieved 82.96% accuracy in detecting osteoarthritis.

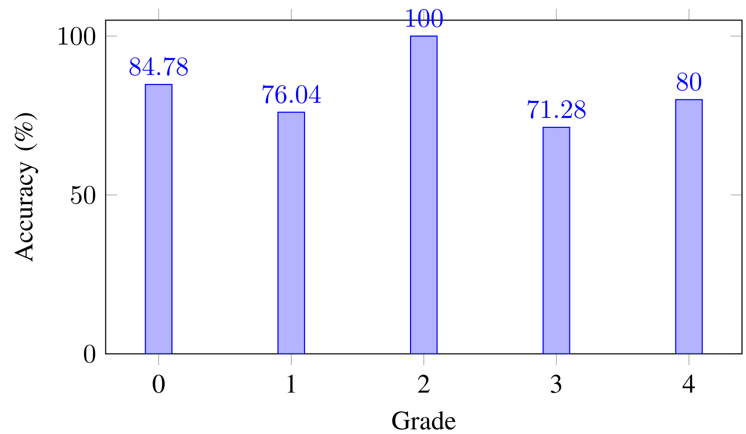

Fig. 2: Accuracy of Osteoarthritis detection

IV. Conclusion

Measuring the joint space between the tibia and femur for each grade and identifying the percentage range of joint space width for osteoarthritic knee joints will aid in decision making for advanced diagnosis and treatment. With an accuracy of 82.96% in detection provides the efficiency of our proposed framework. Besides, our approach is suitable for the low-resources and it is easy for clinical use. In future, identifying osteophytes will add value to our proposed framework.

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References

[1] Sudeep Kondal and Viraj Kulkarni and Ashrika Gaikwad and Amit Kharat and Aniruddha Pant, "Automatic grading of knee osteoarthritis on the Kellgren-Lawrence scale from radiographs using convolutional neural networks," eess.IV, 2020, pp. 1–6

[2] Antony, Joseph and McGuinness, Kevin and Moran, Kieran and O'Connor, Noel E., "Quantifying radiographic knee osteoarthritis severity using deep convolutional neural networks," Springer International Publishing, 2017, pp. 376–390.

[3] Tiulpin A, Thevenot J, Rahtu E, Lehenkari P, Saarakkala S.," Automatic Knee Osteoarthritis Diagnosis from Plain Radiographs: A Deep Learning-Based Approach.," Sci Rep., 2018 Jan 29, pp. 8(1):1727

[4] Brahim A, Jennane R, Riad R, Janvier T, Khedher L, Toumi H, Lespessailles E.,"A decision support tool for early detection of knee OsteoArthritis using X-ray imaging and machine learning: Data from the OsteoArthritis Initiative," Data from the OsteoArthritis Initiative. Comput Med Imaging Graph. 2019 Apr, pp. 73:11–18.

[5] Behzad Heidar, "Knee osteoarthritis prevalence, risk factors, pathogenesis and features: Part I,"Caspian J Intern Med. 2011 Spring, pp. 2(2): 205–212.

[6] Kohn MD, Sassoon AA, Fernando ND, "Classifications in Brief: Kellgren-Lawrence Classification of Osteoarthritis, " Clin Orthop Relat Res. 2016 Aug, pp. 474(8):1886-93.

[7] Xu Zhao and Wenchao Ding and Yongqi An and Yinglong Du and Tao Yu and Min Li and Ming Tang and Jinqiao Wang"Fast Segment Anything,", 2023