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Detection of Osteoarthritis in Knee Radiographic Images using Artificial Neural Network

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***Abstract:** In this paper, the Osteoarthritis (OA) analysis in knee radiographic images using artificial neural networks (ANN) is considered. In Osteoarthritis, mobility is restricted and bones rub each other causing extreme pain in knee due to cartilage disintegration. The cartilage destruction is minimal in the initial stage of OA. It is observed that a small number of researchers have implemented identification and grading of Osteoarthritis utilizing their own datasets for experimentation. However, there is still need of automatic computer aided techniques to detect Osteoarthritis for early recognition. In this work, a dataset of 1650 radiographic images of knee joints of OA patients are collected from different hospitals and have been annotated by two different orthopedic surgeons as per the Kellgren and Lawrence (KL) grading system. To automate this grading procedure, the local phase quantization and multi-block projection profile features are computed from the images and then presented to artificial neural network to classify the images based on the KL grading of the severity of the disease. The classification accuracy of 98.7% and 98.2% with reference to surgeon-1 and surgeon-2 opinions, respectively, is achieved.*

***Keywords:** Knee Radiography, Osteoarthritis (OA), Local phase quantization (LPQ), Multi-block Projection Profile (MB-PP), Artificial Neural Network.*

I. INTRODUCTION

In a knee anatomy, cartilage holds important role in leg mobility. Cartilage is a bouncy material at the ends of the bones that helps easy movement and abides as a shock absorber. In Osteoarthritis (OA), cartilage is disintegrated because of which bones rub each other causing extreme pain and restricted mobility. The cartilage destruction is minimal if the disease is diagnosed in the initial stage and analyzed properly. The important clinical symptoms of OA in the initial stage are joint pain in knee, hip, ankle, spine etc. If any of these indications are experienced, the patients have to immediately consult the doctor/experts preferably Rheumatologists/Orthopedicians for diagnostic analysis. The experts examine the patient clinically and may recommend for a radiographic examination.

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Some of the important radiological parameters are cartilage disintegration, reduced joint space width, formation of osteophytes, loose bones and bone deformation [8]. Depending on the radiological parameters and severity level, the individual joint is categorized into five different grades based on Kellgren and Lawrence (KL) grading system [15] depicted in Table 1.

Table.1. Grading framework by Kellgren and Lawrence [15]

KL Grades	OA Analysis
Grade0 (Normal OA)	Radiographic parameters related to OA are absent
Grade1 (Doubtful OA)	Reduced joint space width
Grade2 (Mild OA)	Clear/ visible narrowing of joint space
Grade3 (Moderate OA)	Numerous bony outgrowths, sclerosis
Grade4 (Severe OA)	Massive bone spurs, extreme sclerosis, bone deformity

Generally, analysis of X-ray images is done manually by the medical expert, which is time consuming, subjective and sometimes unpredictable. The complexities related to the medical images make it hard to examine them in an effective way. Thus, to overcome these difficulties, an automated method is proposed for early evaluation of Knee OA to protect the cartilage and other tissues from the damage and make the treatment more effective.
The rest of the paper comprises related work, proposed methodology, experimental results and discussion along with the summary.

II. RELATED WORK

Radiological parameters like joint space width, sclerosis and osteophytes play very important role in assessment of Osteoarthritis [15]. Based on these parameters, the medical experts classify OA through manual inspection. From the literature, it is found that numerous researchers have utilized these radiological parameters for the detection of OA using various machine learning and computer vision techniques. Joseph Antony et al. [2] have used a method to localize knee joint and classify the joint OA using fully convolutional neural network and obtained better results. Jihye Lim et al. [3] have used deep learning neural network for OA detection using subjects' statistical and behavioral data. The result of 76.8% is achieved under the curve with scaled PCA. Yoo et al. [1] developed a scoring system to predict radiographic knee OA using KNHANES V-1 data and ANN. The results attained were helpful in early prediction of Knee OA. Lior Shamir et al. [4] have used WND-CHRM algorithm for the early detection of Knee OA using computer aided analysis. The classification rate of 91.5% for Moderate OA and 80.4% for Minimal OA was achieved.

Shivanand Gornale et al. [9-14] have used contour based segmentation method to detect the cartilage region using Knee X-ray images [9-11].
Multiple statistical features like texture based, shape based and first four moment features were computed and classified using Radom forest and K-NN classifier with classification rate of 87.92% and 88.88%, respectively [9-10]. Further, the computational part was modified using histogram of gradients which were classified using multiclass SVM by achieving the enhanced accuracy of 95% [11]. Later, the implementation was carried out to automatically detect the region of interest using different segmentation methods. The methods like Sobel, Prewitt, Texture and Otsu's methods were used and it is found that Prewitt method performed better with an accuracy of 97.55% compared to other segmentation methods [12]. Additionally, a novel pixel density based approach of automatically identifying the region of interest was developed that demonstrated a classification rate of 97.86% [13]. Lastly, in [14], cartilage thickness was calculated using various shape descriptors and the accuracy of 99.81% was attained, that was validated by medical experts.
The majority of the earlier works are concentrated on the early prediction of OA using machine learning/computer aided methods, but very little study has been carried out for OA classification as per KL grading system. Thus, in this work, the focus is on early analysis as well as grade-wise classification of Knee OA using X-ray images.

III. PROPOSED METHODOLOGY

The proposed methodology comprises four main steps as depicted in Fig.1: preprocessing, identification and extraction of region of interest, feature computation and fusion and, lastly, classification using artificial neural networks.

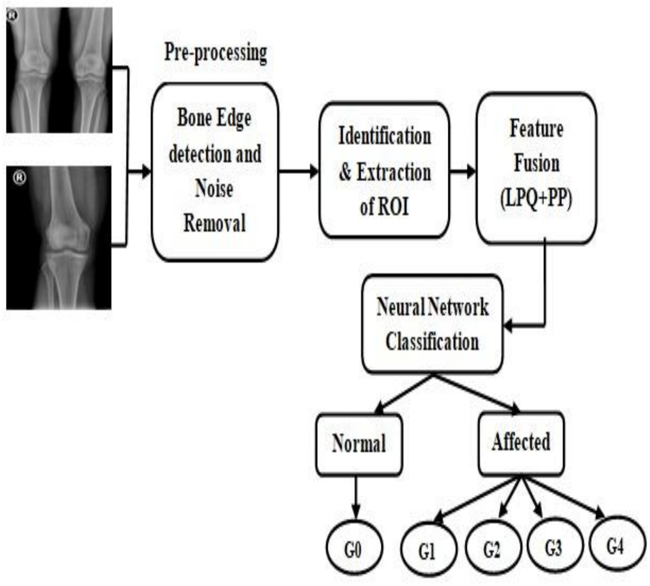

Fig.1. Block diagram of proposed methodology (G-0: Normal, G-1: Doubtful, G-2: Mild, G-3: Moderate, G-4: Severe)

A. Dataset

A dataset of 1650 knee radiographic images is considered for the experimentation, which were collected from different hospitals. All the images are of DICOM standard with size 255x255. The entire dataset is annotated or classified into KL grades by two different ortho-surgeons who examine 85 to 95 radiographic images per day. For all 1650 images, the grade-wise annotations made by two ortho-surgeons as per KL grading framework are summarized in Table 2.

Table2: Grade-wise annotations by two different surgeons

KL Grade	Surgeon-1	Surgeon-2
Normal(G-0)	514	503
Doubtful(G-1)	477	488
Mild(G-2)	232	232
Moderate(G-3)	221	221
Severe(G-4)	206	206
Total	1650	1650

B. Pre-processing

The pre-processing of knee X-ray images is performed for noise removal and detection of bone edges that are represented by salient shape features of a particular image. The knee radiography images contain prominently salt and pepper noise, which is filtered by using adaptive median filter that are beneficial in preserving edges of an image [12-13]. The difference of the neighboring pixel is helpful in detecting the bone edges at pixel (i, j) for input image X with respect to row and column is given in equations (1) and (2). The bone edges of knee radiography images are shown in Fig. 2.

$$X(i,j) = X(i,j) - X(i-1,j) \quad (1)$$

$$X(i,j) = X(i,j) - X(i,j-1) \quad (2)$$

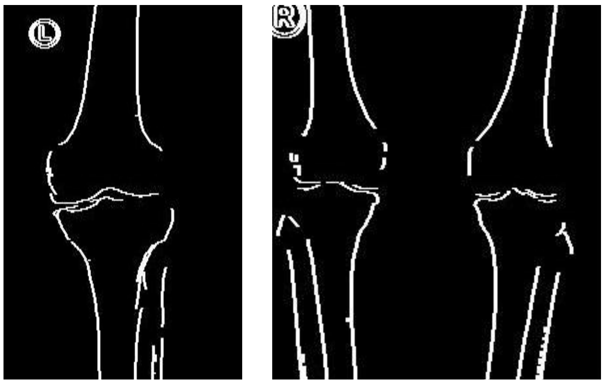

Fig.2. Bone edges of knee radiography image

C. Identification and Extraction of Region of Interest

The identification process is carried out in four steps: Firstly, partition the entire image into many parts row wise along the axes. Secondly, extract the region of interest (ROI) from each part. Thirdly, estimate the area of each part to detect the bone density [16]. The region in the image that is denser (or thicker), results in high density value. Lastly, extract the region with high density value and enhance it using sine adaptive filter [14]. The steps used by sine adaptive filter are given in equations (3) to (6)

$$CF = 0 : \frac{\Pi}{2} : 0 \quad (3)$$

$$K = \frac{\Pi}{2} - FW * \frac{\Pi}{2} \quad (4)$$

$$CF(CF > K) = \frac{\Pi}{2} \quad (5)$$

$$I_{out} = I_{in} \sin(CF) \tag{6}$$

Where, CF is a filter co-efficient and FW is Filter Width, which are calculated based on the X-ray reconstructed image characteristics. Images recorded from X-ray detectors always have the data in the centre portion of the image. Therefore, by defining the filter co-efficient as a sine wave, more weight is being added to the data in the middle of the image. Adaptive sine filter is used for allocating weights based on the geometrical axis of the reconstructed image [12]. Thus, the region of interest is accurately extracted, that can be further used for the medical examination [17]. The identification of ROI is shown in Figs. 3(a) and 3(b).

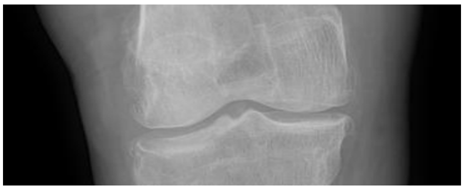

Fig.3(a)

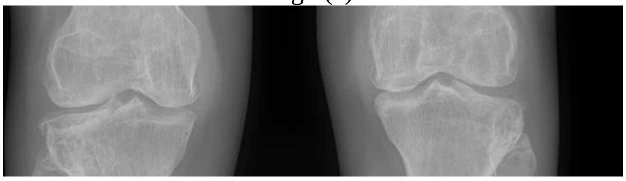

Fig.3(b)

Fig.3: Identification of Region of Interest: (a) Single knee (left/right) image (b) ROI identification in both left and right knee.

D. Feature Extraction

Local phase quantization and projection profile features are independently computed, which yield good results. Further, these features are fused to enhance the outcomes.

Local phase quantization (LPQ): The purpose of LPQ operator is the identification of texture by figuring it locally at each pixel area and exhibiting the subsequent codes as a histogram. LPQ is, moreover, a generalization of LBP and BSIF [18]. Additionally, LPQ can discriminate phase information from an image without losing the data at high frequencies. Here, the Discrete Fourier Transform is applied on the entire image linearly by considering image patch for the extraction of local phase information [20]. Taking into account linear filtering technique based on weighted sum of the image, phase of local frequency transform FT(u,v) is calculated in N x N neighborhood for every pixel in image M(i,j). The scalar quantization is defined by equation (7).

$$u(x) = \begin{cases} 1 & if \quad u_x \geq 0 \\ 0 & otherwise \end{cases} \tag{7}$$

Where u(x) is the x^{th} component of the FT. The single frequency component is represented by a scalable quantizer element at the point i. Finally, the quantized coefficient values are presented to histogram according to the binary coding generated as shown in equation (8).

$$b = \sum_{x=1}^{8} u_x 2^{x-1} \tag{8}$$

This ranges between 0 and 255 and describes the local phase information at each image positions and generates 256 dimensional feature vector [21].

Multi-block Projection Profile (MBPP): The alternate runs of white and black pixels in Knee X-ray motivated us to study and examine the projection profile features. The X-ray image, in either vertical or horizontal direction independently, is represented using projection profile feature [6]. This feature computation mainly aims to represent the distribution of dark and bright pixels of an image. A Projection Profile is a histogram of number of black pixel values gathered parallel in an image I(x,y), which may be denoted by:

$$MB - PP(I) = \sum_{1 \leq y \leq n} F(x, y) \tag{9}$$

Where x and y are rows and columns for an image. The knee X-ray images are resized to 255x255 to get the uniform feature vector and then each image is successively split into non-overlapping sub-blocks Nblk1, Nblk2, …, Nblkn (r x r) [23]. Further, horizontal projection profile features are computed on each sub-block by using the equation (9). Features are calculated by alternative runs of either black or white pixels, by adding all white pixels column-wise and skipping the alternative black pixels [19]. Finally, resulting features from each sub-block are integrated and stored in the form of final feature vector that contains 9 features from each of the images.

E. Classification

In ANN, to process a specific data or information three main processing elements are considered, namely, weighted inputs, target functions and outputs. ANN is composed of single-layer or multiple layer neurons based on the connection formula, training provided and functions that are used to process the neurons [7]. The diverse training algorithms are used on a set of input knee X-ray images. Herein, three types of training algorithms comprising eight training functions have been assessed for classification of Knee Osteoarthritis. The training algorithms are Gradient Descent algorithms (traingd, traingdm, trainrp), Conjugate Gradient algorithms (trainscg, traincgf, traincgp), Quasi-Newton algorithms (trainbfg, trainlm) [8]. The gradient descent function calculates the gradient of the error by adjusting the weights in the descending gradient direction and the performance function is biased towards the negative gradient. The conjugate gradient algorithms have increasingly rapid convergence as compared to gradient descent by performing the search along the conjugate directions [5]. The fundamental step used by Newton's method is Hessian matrix (second derivatives) which confers enhanced and speedy optimization over conjugate gradient methods. These methods consume more time for computations and are highly intricate. In Newton's method, there is a group of algorithms that do not require Hessian matrix computation and are called Quasi-Newton methods. They update an estimated Hessian matrix at every cycle of the calculation. The update is processed as a gradient function [5].

IV. EXPERIMENTAL RESULTS AND DISCUSSION

A dataset of 1650 knee radiographic images are considered for the experimentation. All the images are of DICOM standard with same quality.

The entire dataset is annotated or classified into KL grades [15] by two different ortho surgeons. In this work, initially, local phase quantization and multi-block projection profile features are individually computed, that demonstrated good results. Further, to enhance the results, the experiment was conceded with fusion of local phase quantization and multi-block projection profile features for each image, which is presented to artificial neural network with 10 neurons in hidden layers. The various steps of the proposed methodology are given below:

Input: Radiographic Knee Image
Output: Normal or OA affected image (grade wise)
Step 1: Input a knee X-ray image.
Step 2: Perform pre-processing that includes noise removal and edge detection.
Step 3: Identify and extract ROI based on pixel density.
Step 4: Compute features:
(i) Local phase quantization and multi-block projection profile features individually.
(ii) Fusion of local phase quantization and multi-block projection profile features.
Step 5: Grade-wise classification using artificial neural network.
End

For the classification of knee radiographic images, mainly three categories of learning algorithms are considered with eight training functions. To understand the process clearly, 70% of images are used for training initially, 15% are used for validation and rest 15% of images are utilized for testing. The Table 3 gives the overall classification percentage for each training function with reference to opinions/annotations made by two different surgeons for same dataset.

Table 3. Overall classification rate (%) for each training function according to the opinions of two different ortho-surgeons.

Algorithm	Training function (ANN)	Feature Fusion (LPQ+PP)	
		Surgeon-1	Surgeon-2
Gradient descent	traingd	81.8 %	71.9%
	traingdm	81.2%	77.3%
	trainrp	97.5%	97%
Gradient conjugate	trainscg	**98.7**%	**98.2**%
	traincgp	98.1%	98%
	traincgf	98.3%	98%
Quasi Newton	trainlm	98.5%	98%
	trainbgf	97.9%	94.5%

A simple gradient descent function traingd is more complex to execute than the function traingdm due to high learning rates [5]. The time taken by the function trainscg and trainlm for execution is similar to trainrp function with less number of iterations. Time complexity of trainbgf and trainlm are found to be high for our dataset; however, for the smaller number of neurons and smaller feature set, these functions give efficient results with minimum iterations. From the Table 3, trainscg function has outperformed other functions by achieving the accuracy of **98.7%** for labeling made by surgeon-1 and **98.2%** for labeling made by surgeon-2, respectively. The comparative analysis of proposed algorithm results (pertaining to trainscg function) with the annotations of Surgeon-1 and Surgeon-2 is graphically shown in Fig.4.

Statistical Test of Significance: To test the 'goodness of fit' between the results of proposed algorithm and the annotation results by each of the two medical experts, the Chi-Square test (at 5% of significance level) [22] is performed. The test demonstrated that there is a close agreement between the proposed algorithm results and the annotations made by both the medical experts (surgeons).

Further, t-test (at 5% of significance level) was performed between the annotation results of the two surgeons, i.e. surgeon-1 and surgeon-2, and it is found that the difference in their annotations is due to random variations in sample inspections and not due to medical experts [22].

From both the statistical tests, the proposed algorithm is found to be effective significantly and thus provide computer-aided assistance to doctors for rapid assessment of the knee OA severity level from knee X-ray images so that the patients get better and accurate timely treatment.

V. SUMMARY

In this work, a dataset of 1650 knee radiographic images is manually annotated/labeled by two different orthopedic surgeons. The small amount of discrepancy was observed between the opinions/annotations made by two surgeons in case of Normal (G-0) and Doubtful (G-1) grades. This could be due to minimal resolution of bone structures, low contrast images or may be due to the other distortions present in the knee radiographs. These intricacies create problem in examining the X-rays effectively. Thus, to overcome these difficulties, the objective of the proposed methodology is early evaluation of Knee OA to protect the cartilage and other tissues from the damage and make the treatment more effective. In the proposed method, local phase quantization and multi-block projection profile features are computed that are presented to artificial neural network for grade-wise knee OA classification. For the collected dataset, the proposed algorithm demonstrated accuracy of 98.7% for labeling made by surgeon-1 and 98.2% for labeling made by surgeon-2. The results are promising and competitive, which are validated by medical experts and statistical tests of significance. In future, the work can be extended for osteoarthritis evaluation by considering some more radiological parameters like sclerosis and osteophytes.

CONFLICT OF INTEREST

The authors declare no conflict of interest regarding the publication of this work.

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