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Effective Feature Extraction Based Automatic Knee Osteoarthritis Detection and Classification using Neural Network

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Abstract:

Osteoarthritis (OA) is the most common form of arthritis seen in aged or older populations. It is caused because of a degeneration of articular cartilage, which functions as shock absorption cushion in knee joint. OA also leads sliding of bones together, cause swelling, pain, eventually and loss of motion. Nowadays, magnetic resonance imaging (MRI) technique is widely used in the progression of osteoarthritis diagnosis due to the ability to display the contrast between bone and cartilage. Usually, analysis of MRI image is done manually by a physician which is very unpredictable, subjective and time consuming. Hence, there is need to develop automated system to reduce the processing time. In this paper, a new automatic knee OA detection system based on feature extraction and artificial neural network is developed. The different features viz GLCM texture, statistical, shape etc. is extracted by using different image processing algorithms. This detection system consists of 4 stages, which are pre-processing with ROI cropping, segmentation, feature extraction, and classification by neural network. This technique results 98.5% of classification accuracy at training stage and 92% at testing stage.

Keywords — Artificial Neural Network (ANN), Gray Level Co-occurrence Matrix (GLCM),Knee Joint, Magnetic Resonance Imaging (MRI), Osteoarthritis(OA).

I. INTRODUCTION

The knee joint is the largest and most complex joint of the human body. It is a major weight bearing joint which made up of condyles of femur, condyles of tibia and posterior surface of patella (knee cap). Articular cartilage covers ends of the femur and tibia bone. Cartilage is ultra-slippery thin layer of high-quality hyaline material between the femur and tibia bones and helps in smooth movement of knee joint [1].

Osteoarthritis (OA) is degenerative joint disease and occurs when cartilage becomes soft and gets damaged due to continuous wear and tear movements and with ageing. This reduces the ability of the cartilage to work as a shock absorber. It is growing common among women, obese and older people. OA situation also arises due to previous knee injury, repetitive stress on the knee, and obesity problem [2].

There are few methods that can be used for diagnosis of osteoarthritis but the most common diagnosis method which used newly is through magnetic resonance types [3]. MRI image is invasive and repetitive. It is most widely used because it is hazardless as well as noise free as compared to X- Rays and computer tomography (CT) images.

Usually, analysis of MRI images is done manually by physicians, which are very subjective, time consuming and inconsistent. The situation may become worst if patients exceed certain limit. Thus, there is a demand of automated knee osteoarthritis classifier, which able to reduce the time consumption for analysis as well as avoid the inconsistent of the interpretation.

In digital image analysis, feature selection/ extraction are used to extract or retain the optimum salient characteristics for proper analyse and classify the image [4]. This feature extraction process also able to reduce the dimensionality of the measurement space, thus minimize the timeconsumption of image processing. So in this paper,initially input MRI images are pre-processed using contrast enhancement, histogram equalization, thresholding, and canny edge detection etc.

Then these images are cropped to obtain ROI based masking images followed by segmentation using region based active contour algorithm to detect or segment cartilage from image. Then different features are extracted such as GLCM texture features, statistical features, shape features etc. A combined feature vector is formed. Finally, these features are passed as input to neural network to perform automated classification as normal vs. abnormal OA.The rest of the paper is organized as follows. Section II discusses related work. Methodology of knee OA detection Process is focused in Section III. Section IV presents results of experiment conducted. Finally Conclusion is specified in Section V.

II. Related Work

Many researchers have investigated various methods for knee joint image segmentation for detection of OA. Knee joint image segmentation is a very interesting task because of its complexity. Kshirsagar et al. [4] have used Canny edge detection and template matching techniques to locate the boundary of femur bone. Cashman et al. [5] have developed an algorithm using edge detection and thresholding. Poh et al. [6] have developed a radial search method in which a threshold method was used to detect the inner boundaries along the radial lines. Also for segmentation of cartilage one can use active contour methods, geometric active contours (GAC), Chan-Vese approach etc[7],[8]. Still maximum accuracy is not achieved. So there is better scope for segmentation of knee MRI image. In this project, active contour method is used.

Basically, classification approaches are divided into two category, which are supervised classification and unsupervised classification[9]. Supervised classification approach will classifies a set of images with certain pre-given images, references and template while unsupervised classification approach will classifies images based on their intrinsic grouping or clustering within the set. Examples of supervised classification approaches are feed-forward neural network (FNN), k-nearest neighbours (k-NN) and back propagation neural network while k-mean and self-organizing feature map (SOM) are unsupervised classification approaches. In this paper artificial neural network (ANN), which is the supervised classification approach, has been chosen as the classifier.

III. Methodology

Basically, this project is divided into four stages, such as preprocessing, cartilage segmentation, feature extraction and classification using neural network. The aim of first stage is to perform pre-processing with ROI based cropping of MRI image that useful for further process. Second stage is segmentation by region based active contour model to segment cartilage region. Third stage, feature extraction to extract out the essential features that needed for analyse and classify the MR image. Lastly, ANN based classification consist of training stage, to construct a model to describe a set of pre-determined classes and model testing stage is carried out for testing the accuracy and reliability of the model. Figure 1 show block diagram of knee OA detection system.

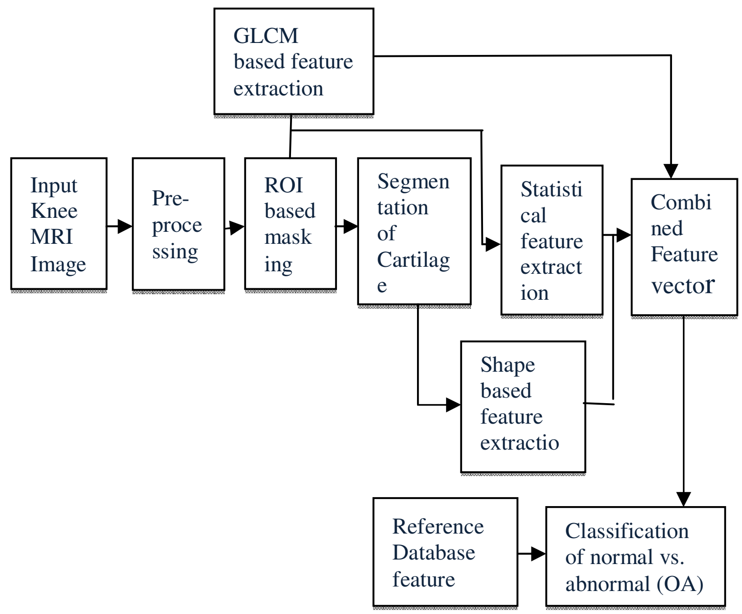
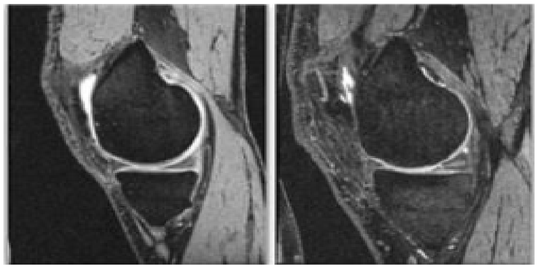


Figure 1: Block diagram of knee OA detection system

A. Input Datasets

The input datasets are collected from various Hospitals and diagnostic centers with required specifications. These images consist of 512 x 512 pixels which acquired from Siemens 3T MR system in fat suppressed spoiled gradient recalled (SPGR) image protocol in 2D Sagittal view. This has ability to provide clear cartilage delineation and it suitable for morphological measurement such as cartilage thickness and volume [12]. 100 images used in training stage, which consist of 50 normal knee and 50 osteoarthritis knee images. While in testing state, 50 MR images, which consist of 20 normal knee and 30 osteoarthritis knee is used. The images in training stage are independent to image in testing stage. Figure 4 shows the image of normal knee (Figure 2(a)) and osteoarthritis knee (Figure 2(b)). As shown in the figure, cartilage of the normal knee is thicker than osteoarthritis knee. Also in OA cartilage is degenerated.



(a) (b)

Figure 2: (a) Normal Knee, (b) Osteoarthritis Knee

B. *Pre-processing*

The input knee MRI images are preprocessed for type conversion, noise removal. It includes contrast enhancement, histogram equalization, Gaussian filtering, thresholding and canny edge detection etc.

1) Contrast Enhancement

Contrast enhancement is defined as to change the image value distribution to cover a wide range. In case of low contrastimage values concentrated near a narrow range. It is used for the better view of various anatomical boundaries of the knee.

2) Histogram Equalization

Histogram is plotted to understand number of gray levels into image. In the dark image components of the histogram are concentrated on low side of the gray scale. The components of the histogram are influenced towards the high side of gray scale of the bright image. Histogram equalization distributes pixels to different gray intensity levels.

3) Gaussian low-pass Filtering

Gaussian low-pass filter is created by using fspecial function. fspecial returns a correlation kernel, which is the appropriate form to use with imfilter function. It is used to remove unnecessary high frequency edges around the cartilage.

4)Thresholding

Thresholding is used to exclude pixels whose intensity are less than the half the average intensity of the image. Heregraythresh function calculates a global threshold that can be used to convert an intensity image to a binary image with im2bw. It uses Otsu's method, which selects the threshold to minimize intraclass variance of the black and white pixels.

5) Canny Edge Detection

The Canny edge detection method finds edges by seeing for local maxima of the gradient of image. The gradient is calculated using the derivative of a Gaussian filter. This technique detect strong as well as weak edges, and includes the weak edges in the output if and only if they are connected to strong edges. This method detects the boundaries of the femur, tibia, and cartilage from threshold image.

Figure 3shows histogram equalized plot of the image. Figure 4 shows threshold version of image. Fig.5 shows the canny edge detected image.

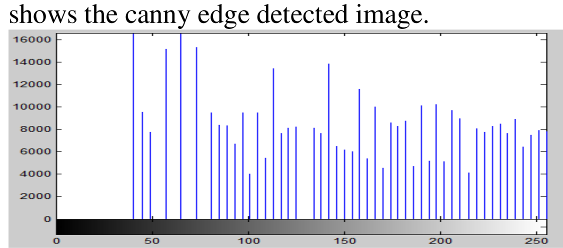


Figure 3: Histogram Equalization

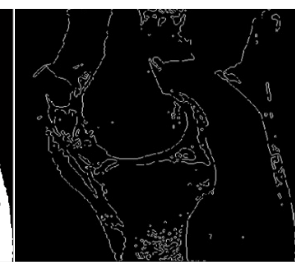


Figure 4:Thresholded imageFigure 5: Canny edge detected image

After pre-processing, image is cropped to obtain ROI based masking image which useful for further processing. Figure 6 shows cropped image.

Figure 6: Cropped image

C. *Segmentation*

The segmentation is performed by region based active contour method using Chan-Vese algorithm. It is powerful and flexible method to segment a variety of images which are difficult to segment using thresholding and utilizing gradients.This model is widely used in the

medical imaging field, especially for segmentation of the brain, heart and knee.
The objective of the Chan-Vese algorithm is to minimize the energy function F(c1,c2,C) defined by:

$$F(c1, c2, c) = \mu.Length(c) + v.Area\big(inside(c)\big) + \lambda 1 \int |u0(x, y) - c1|^2 \, dx \, dy + \lambda 2 \int |u0(x, y) - c2|^2 \, dx \, dy \quad (1)$$

Where, the first term stands for energy inside C, and the second term for the energy outside C. also, $\mu \geq 0, v \geq 0$, $\mu \geq 0, v \geq 0, \lambda 1, \lambda 2 \geq 0$ are fixed parameters. In this paper Chan and Vese, the preferred settings are v =0, $\lambda 1 = 1, \lambda 2 = 1$ This method is iteration based require iteration counts to given. Figure 7 shows segmented image after cropping.

Figure 7: Segmented image

D. *Feature Extraction*

The feature extraction is transforming the input data into the set of features. Here different features such as GLCM based texture features, statistical features and shape features are extracted.

1) *Gray level Co-occurrence Matrix (GLCM)*

The GLCM is a tabulation of how often different combinations of pixel brightness values (grey levels) occur in an image. According to the number of intensity points (pixels) in each combination, statistics are classified into first-order, second order and higher-order statistics. The Gray Level Co-occurrence Matrix (GLCM) method is a way of extracting second order statistical texture features. Following equations shows features extracted from GLCM Matrix.

Contrast= $\sum_{i,j}(i-j)^2 \, p(i,j)$ (2)

Correlation= $\sum_{i,j} (i-\mu)(j-\mu)/\sigma^2 p(i,j)$ (3)

Energy=$\sum_{i,j} p(i,j)^2$ (4)

Homogeneity = $\sum_{i,j} p(i,j)/\{1 + (i-j)^2\}$(5)

Entropy= $-\sum_{i,j} p(i,j) log\{p(i,j)\}$ (6)

2) *Statistical Feature Extraction*

Statistics is the study of the collection, organization, analysis, and interpretation of data. The various statistical measures include mean, variance, standard deviations, skewness and median. All of these measures were used in a wide range of various scientific and social researches. Following equations can describes some statistical features.

Mean $\mu = \sum_{i,j} p(i,j)$ (7)

Variance $\sigma^2 = \sqrt{\sum_{i,j}(i-\mu)^2 \, p(i,j)}$ (8)

Standard deviation $\sigma = \sigma^2$ (9) Skewness = $\frac{1}{\sigma^3} \sum_{i,j}(p(i,j) - \mu)^3 \; p(i,j)$(10)

Median = $\sum_{i,j} \{p(i,j)/\{(i,j)\}$(11)

3) *Shape Feature Extraction*

Basically, shape-based image consists of the measuring of similarity between shapes represented by their features. These shape parameters are Area, Eccentricity, Perimeter, Solidity, MajorAxisLength, MinorAxisLength etc. Described by following equations.

Area (A) = number of pixels of an object (12)

Eccentricity $(E) = \frac{\lambda 1}{\lambda 2}$ (13)

Perimeter (P) = number of boundary pixels (14)

Solidity (S) $= \frac{Area}{\text{Convex area}}$ (15)

Major Axis Length =longest straight line inside of object. It is measure of object length

Minor Axis Length = longest straight line inside of object perpendicular to major axis. It is measure of object width.

E. Classification by Artificial Neural Network

An artificial neural network is a non- linear network which is working like a human brain. This network consists of neurons which is working in parallel and communicating with each other through weighted interconnection. Generally, the neural network consists of 2 stages such as training and testing stage. In training stage, adjustment of weights is done. Also, in testing stage, input is received from external source and computes an output which is propagated to other units. Following Figure 8shows simple artificial neural network which consist of input layer, output layer and middle hidden layer. In this paper, the ANN is used for database in which feature extracted values are used as an input to train the network. For this purpose, 16*40*2 NN structure is used. These inputs are trained using back propagation training algorithm.

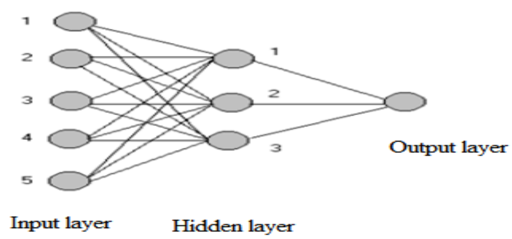


Figure 8: Simple artificial neural network

Back propagation neural network is the most commonly used method as a learning algorithm. During the training stage, the extracted feature values are used as inputs for neural network development. These inputs will continue to propagate along the network, from input layer to hidden layer until it reach output layer. The difference between actual output and target output is considered as error, thus back propagate to the earlier layer and updating the weights. Algorithm of BPNN is given below as

1. Initialize weight (W) and threshold.
2. Apply a sample (input pattern, Xk that had targeted output, Ti).
3. Propagate the signal through network and compute actual output, Oi.

$$\mathrm{Oi} \ = \ \mathrm{f}(\sum_{j=1}^{40} \mathrm{Wij\ Vj})$$

where

$$Vj = f(\textstyle\sum_{\mathrm{k}=1}^{16} \mathrm{WjkVk}\,)$$

4. Calculate the difference, E between actual and target output.

$$E = \frac{1}{2}\sum_{j=1}^{40}(\mathrm{Ti} \ - \ \mathrm{Oi})$$

5. Update weights.

Output layer weight can be updated by:

$$\Delta \mathrm{Wij} \ = \ -\eta \frac{\mathrm{dE}}{\mathrm{dWij}}$$

$W_{ij}{}^{new} = W_{ij}{}^{old} + \Delta W_{ij}$

Hidden layer weight can be updated by:

$$\Delta \mathrm{Wjk} \ = \ -\eta \frac{\mathrm{dE}}{\mathrm{dWjk}}$$

While η is the learning rate of the network

6. Repeat process 2-6 until difference is sufficiently small.

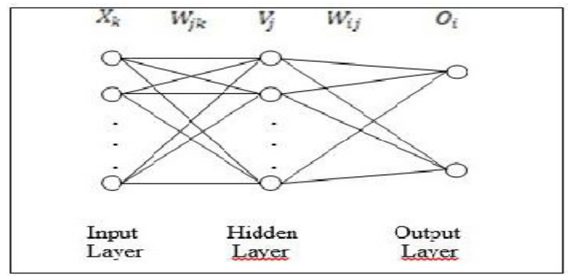


Figure 6: Back Propagation Neural Network structure.

IV. RESULT

Different features are extracted from input knee MRI image. These different features are beneficial for classification purpose. Following Table I illustrate values of different features after feature extraction step. Table II shows the result of classification of knee osteoarthritis detection.

Table I. Values obtained for different features

Matrix name	Feature name	Calculated Value
GLCM (Gray level co-occurrence matrix) Textural Features	Contrast	164.2389
	Correlation	20.1826
	Energy	6.0614
	Homogeneity	0.9976
	Entropy	1053
Statistical Features	Mean	149.8113
	Variance	128.3104
	Standard deviation	56.9044
	Skewness	0.7884
	Median	149.0000
Shape Features	Area	24.7000
	Eccentricity	0.7605
	Perimeter	567.8478
	Solidity	0.4715
	MajorAxisLength	104.9722
	MinorAxisLength	68.1564

Table II Details of neural network classification of knee OA

Hidden neurons:40	Learning rate: 0.0001
Activation function: $= \frac{1}{1+e^{-ka}}$	No. of trained samples: 100
NN Structure	Accuracy %
16*40*2	92%

V. CONCLUSION

This paper presents a method of classification and detection of KOA in patients based on segmentation, different features extraction and artificial neural network. Classification is done based on different feature vector values. This detection system yield 92% of classification accuracy. This ANN-based classifier can be used as computer aided tool to assist the physicians in knee osteoarthritis diagnosis.

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