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Assessment of Joint Space in Knee Osteoarthritis using Particle Swarm Optimization Technique

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Abstract: ***Osteoarthritis (OA) is one of the most common joint disorder which is debility seen in elderly & overweight people which affects the cartilage of bone joints like knee, feet, hip, and spine. In OA usually, cartilage is ruptured due to the kneading of bones with each other which will end up causing severe pain. In this condition, it is necessary to analyze the severity of OA which involves various medical imaging and clinical examination techniques. In this paper, automated analysis and detection of OA are proposed by calculating the thickness of cartilage which also helps to effectively detect and analyze the abnormalities in bone structures. Where we have considered various knee X-ray images. Initially, preprocessing and noise removal is performed. Further by implementing Particle Swarm Optimization (PSO) segmentation and thresholding, the specified knee region is cropped and analyzed to calculate the thickness of cartilage to detect the presence of OA.***

Keywords**:** ***Osteoarthritis (OA), Articular Cartilage, X-ray images, Segmentation, Particle Swarm Optimization.***

I. INTRODUCTION

Osteoarthritis is a type of arthritis that causes the breakdown of cartilage in one or more joints and eventually reduces the thickness of the cartilage. Cartilage is the protective tissue which is made of protein substance that covers the end of the bones and provides the cushion between bones joints reduces the friction. Degenerative change in the articular cartilage is one among the primary features of the knee OA disease [1]. Healthy cartilage will allow bones to glide easily at the joints and acts as a lubricant between bones and prevents the bone from rubbing each other. In osteoarthritis due to the breakdown of cartilage, the bones will rub each other which will end up causing the pain. It usually influences the knee joints, hip, spine and feet joints of the body. There are two types of osteoarthritis which are commonly Primary Osteoarthritis and Secondary Osteoarthritis. Primary OA which is caused by aging or genetic reasons that can be usually seen in aged people. Secondary OA may occur due to obesity, injury, diabetes or people who are suffering from rheumatoid arthritis. The images of normal knee image and osteoarthritis knee image are shown below [2].

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Medical imaging is the technique used to create visual portrayals of the inner structures of the body which are hidden by skin and bones. It is a part of biological imaging which involves radiology technologies like X-ray, MRI, Computed Tomography and Ultrasound, etc. But medical image segmentation is very difficult and requires a significant amount of knowledge and experience. Normally the physicians or radiologists use their experience to perform manual segment. But this will become a tough process if the amount of data is increases which will eventually create the demand for automatic detection [3]. In this paper, automated medical image segmentation is implemented which involves both shape and texture features. Where the required texture is efficiently designed using wavelet packet decomposition. Also, a prior shape model is created by analyzing a set of shapes by trailing and to describe the variation in object shape. Further, the PSO algorithm is used to precisely segment the medical image by implementing the prior shape model accordingly to image features. Finally, the knee region is extracted and the thickness of the cartilage is calculated.

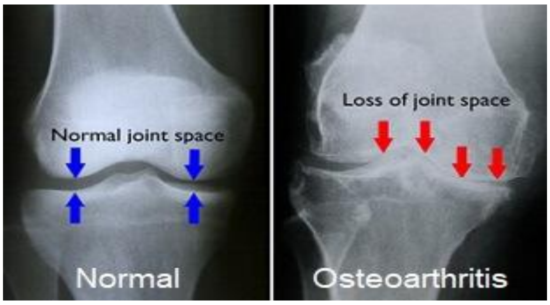

Figure. 1: A healthy knee and a knee joint affected with OA.

Source: https://www.knee-pain-explained.com/images/OA-knee-xray.jpg

II. LITERATURE SURVEY

Numerous researchers have proposed various medical image segmentation methods to detect and analyze Osteoarthritis by considering different images like MRI, X-ray, etc. Normally there are two types of medical image segmentation: Pixel-based which involves region growing, thresholding and region merging and Geometry (shape) based which involves active appearance models, deformable and active counter models [4]. As per the survey, Bindushree R et al. [5] have proposed a few image processing methods to detect the width of the joint space using knee x-ray images.

The different methods which are implemented to extract, analyze compute the width are canny edge-detection algorithm, contrast enhancement, thresholding, and histogram equalization.

Then the computed width of the input image is compared with standard width (5.7 for men and 4.8 for women) of the normal person to detect osteoarthritis. In [6] Subromonium.M et al, have proposed a technique to compute and classify the features of digital x-ray images by using LTP (Local Ternary Pattern) and SVM (Support Vector Machine) Classifier. To evaluate the performance of the proposed algorithm 50 X-ray samples images were considered. By implementing these techniques the authors have obtained 91.66% of specificity & 80% of sensitivity from Linear & Polynomial functions and 94.59% of specificity & 66.66% of sensitivity from RBF.G. W. Stachowiak et al. [7] have proposed an automatic framework buy using X-ray images of hand and Knee. In this approach, trabecular bone textures have been considered as a prime region. By using this technique it is appropriate to analyze of X-ray images we can differentiate pre-radiographic Osteoarthritis bone changes. In [8] Shamir et al. have proposed the Local Binary Pattern (LBP) vector algorithm to find the OA seriousness from the x-ray pictures, Where LBP vector algorithm involves the following steps. Initially, the analyzed window is divided into cells, and then every pixel in the cell is compared with each of its neighbor pixels. This is performed in a circular order for in either clockwise or anticlockwise for all the pixels. Further, the value of the central pixel is compared with neighbor pixel and an octa-binary value (eight-digit binary values) is assigned for each pixel and histogram is calculated for each cell and normalized to obtain the required results. But the obtained results are not accurate and the resultant images are not clear.

PSO segmentation is one of the advanced and efficient algorithms which is been used in image processing where a large amount of data need to be analyzed. Earlier, in [9] Yi et al. demonstrated a WBC image segmentation including an online trained neural network. Firstly, a mean shift algorithm [10] has been implemented to search the cluster center and uniform sampling is applied to reduce the size of the training set. With the help of this uniform sample, a subset of statistical data has been created which represents the entire set of data approximately. Then, the PSO algorithm has been applied to achieve faster convergence and help to escape from local optimum. In [11] Omran et al. have proposed a dynamic clustering by implementing PSO. Primarily, the algorithm divides the data set into a large number of clusters comparatively to reduce the effect of initial conditions. Then the binary PSO helps to select the best number of clusters. Finally, by using k-means clustering the centers of the chosen clusters are refined. The advantage of this method is that the user can choose any validity index for the given data.

III. PROPOSED METHODOLOGY

The proposed methodology comprises of three stages preprocessing, segmentation of region of interest and cartilage thickness measurement. In preprocessing stage Image filtering, Morphological operations and image sharpening is performed to the obtained grayscale image which improves the contrast of the image. Also, isotropic diffusion filter and Gaussian filter is used to remove the noise in the grayscale image in order to highlight the structure and border of bones and cartilage of grayscale knee image. The process of preprocessing is as follows.

A. Input Image

The input image of Osteoarthritis knee is usually in the RGB format and image Bit Depth is 24 before passing to the first stage of the proposed system, The Given RGB image is converted to Gray by taking the average of all three colors (bit depth of the gray image is 8) (Fig.4).

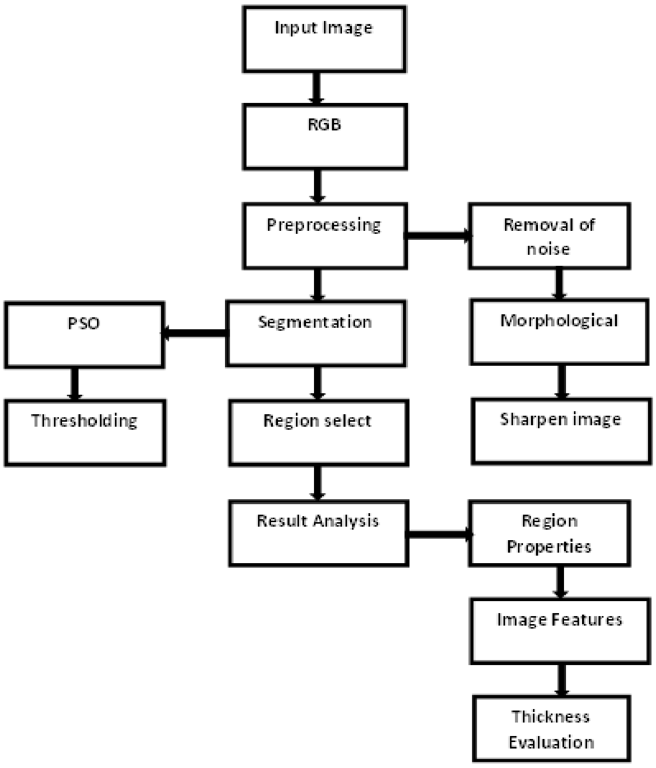

Fig.3. Block Diagram of Proposed System

B. RGB to Gray Conversion

An input image is converted in grayscale image as shown in fig 5. Where, triplet value equivalent to a red, blue and green color component at a specified spatial location of RGB image pixel is used to convert by calculating the weighted sum of RGB color [12].

Further, to analyze the grayscale image more efficiently preprocessing of an image has been implemented.

Fig.5.RGB to Gray Converted Image

C. Removal of Noise

In this stage, the anisotropic diffusion filter and Gaussian filter is used to remove the noise. Where, anisotropic diffusion which is also called as Perona–Malik diffusion is a method used to reduce noise without affecting important parts of the image contents like edges, lines or other details that are significant for the analysis of the image. The resulting image of this method is obtained by a convolution of the input image and a 2D-isotropic Gaussian filter, which increases the width of the filter along with the parameter. The resultant images are as shown below:

Fig.6. Anisotropic filtered image

Fig.7.Gaussian Filtered image

D. Morphological Operations

Morphology is a set of technique in image processing which is used to analyze medical images based on the shapes. In this technique, each pixel of the image is matched with neighbor pixels. By considering the size and shape of the neighbor pixel, we can construct morphological operation as per required specific shapes and size in the input image. In this paper, Dilation and erosion morphological operations are implemented. Where dilation is used to add pixels to the boundaries of objects and erosion is used to remove pixels on the boundaries object in the input image. Also in some cases, a combination of dilation and erosion is used in specific image preprocessing techniques to fill holes or remove small objects in the image.

Fig.8 Output of Morphological operations

E. Image Sharpening

In this stage, to highlight the edges of specific regions in the image, we have implemented unsharp masking (USM). In image processing, USM is an image sharpening technique which is used to sharpen the required region in a digital image. The "unsharp" is the name/code used to create a mask of the original blurred or negative image. Then the unsharp masked image is combined with the original (positive) image to create a comparatively less blurry image than the original. Even though the resultant image is clearer it may be less accurate concerning the image's subject.

Fig.9.Sharpen Image using unsharp masking

IV. IMAGE SEGMENTATION

In this stage, the PSO algorithm is implemented along with inertia weight to segment the specific region or object in the X-ray image. The required object is extracted by using PSO segmentation to obtain the level set function that precisely segments the image.

A. Particle Swarm Optimization (PSO)

Particle Swarm Optimization (PSO) is a segmentation algorithm which is developed by Eber hartand Kennedy in 1995. PSO performs searching via a swarm of particles that updates from iteration to iteration. To seek the optimal solution, each particle moves in the direction to its previous best (pbest) position and the global best (gbest) position in the swarm. One has:

$pb\ (i, t) = \arg\min\ k{=}1\ldots t\ [f\ (Pi\ (k))],\ i \in \{1, 2. . . NP\}$ (1)

$gb\ (t) = \arg\min\ i{=}1\ldots NP\ k{=}1\ldots t\ [f\ (Pi\ (k))]$ (2)

where i denote the particle index, N_p the total number of particles, t the current iteration number, f the fitness function, and P the position. The velocity V and position P of particles are updated by the following equations:

$Vi\ (t{+}1) = \omega Vi\ (t) + c1r1\ (pb\ (i, t) - Pi\ (t)) + c2r2\ (gbest(t) - Pi\ (t))$ (3)

$Pi\ (t{+}1) = Pi\ (t) + Vi\ (t{+}1)$ (4)

where V denotes the velocity, ω is the inertia weight used to balance the global exploration and local exploitation, $r1$ and $r2$ are uniformly distributed random variables within range [0, 1], and $c1$ and $c2$ are positive constant parameters called "acceleration coefficients."

PSO Algorithm Outline:

Step 1: Each pixel is allocated with an initial position and velocity

Step 2: Enhance the position and velocity values by classification

Step 3: The enhanced values for the position an velocity can be selected using the below equations (3) and (4).

Step 4: Until a convergence criterion is met step 2 and 3 are repeated.

After applying PSO we will get a gray image with low contrast, to increase the contrast and we are converting the gray image into black and white image based on thresholding, it helps to set the pixels in two range like black and white which means 0 is for black and 255 is white, thresholding helps to extract the object from the background.

B. Thresholding

Thresholding is a simple technique used in image processing segmentation. Segment and widely used method obtain a binary image from a grayscale image. In thresholding, we set a specific threshold value then all the gray level values which are less than the selected threshold value is considered as 0 (black i.e. background) and all the gray level value which is equal to or greater than the threshold value are classified as 1 (white i.e. foreground) [13].

$$g(x,y) = \begin{cases} 1 \ if \ f(x,y) \geq T \\ 0 \quad \text{otherwise} \end{cases}$$

Where, g(x, y) represents threshold image pixel at (x, y) and f(x, y) represents grayscale image pixel at (x, y) [14].

(a)

Fig.10: (a) Segmented images using PSO

(b)

(b) Thresholding

C. Region of Interest Selection

Once the segmentation is done using PSO algorithm, the OA knee region is highlighted and extracted with the help of thresholding. By using trial and error method outer border of the region is defined in the process, once the segmentation is done the region is cropped automatically. The required region is automatically cropped by setting the default region. Then finally measuring the distance between the articular surface the thickness of the cartilage is measured.

Fig 11. Cropped Region

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(A) (B) (C)

Fig 12: A- Input Image, B- Segmented Image and C- Resultant Image

D. Thickness Calculation

After cropping the region of interest of an X-ray image automatically thickness of the cartilage is calculated by measuring the distance between articular surfaces of the femur and tibia.

V. EXPERIMENTAL ANALYSIS

For the analysis of the proposed method various X-ray, knee images have been considered. The steps implemented in this process are as follows:

Step-1: Pre-processing of X-ray images that include grayscale conversion and image resize.

Step-2: Removal of noise using anisotropic diffusion and Gaussian filter

Step-3: Applying morphological operations and image sharpening methods to get a clear visual of the image.

Step-4: Segmentation of resultant image and thresholding.

Step-5: Region select and measurement of cartilage thickness using the distance between the articular surfaces. The standard thickness of the knee cartilage of a healthy person will vary in the range of 1.65mm to 2.65mm [15]. If the thickness of cartilage is less than the standard value i.e. 1.65mm then there is the maximum chance of osteoarthritis is possible. Fig 12 and Table 1 shows the results of different samples of X-ray images which are considered in this paper.

Table 1: Thickness Measurements

Images	Thickness (mm)	Status of OA
Image 1	0.6965	Yes
Image 2	0.5589	Yes
Image 3	0.6033	Yes
Image 4	0.57	Yes
Image 5	0.49	Yes
Image 6	0.6204	Yes

VI. CONCLUSION

Usually X-ray images of knee are very much affected with unwanted distortions and noise which creates problems to analyze the structures of bones effectively. To resolve these problems, in this paper an automated analysis and detection of the thickness of cartilage is proposed which also provides a quick and effective technique to detect and analyze the abnormalities in bone structures. Along with preprocessing and noise removal process, inertia weight particle swarm optimization method is implemented. PSO segmentation has better accuracy and it can preserve the detail information of the image. PSO segmentation is implemented which helps to efficiently search and analyze desired objects based on its parameters in an image. For analysis, various X-ray knee images have been considered to derive the thickness of cartilage which detects the presence of OA. In future, we intend to improve segmentation accuracy by employing still better pre-processing and segmentation techniques.

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