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Computer Assisted Automated Detection of Knee Osteoarthritis using X-ray Images

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ABSTRACT

Knee Osteoarthritis is a common disease of bones in human. Doctors check X-ray images manually for the identification of Osteoarthritis (OA) disease. Many researches till date have given some approaches to identify OA based on Kellgren-Lawrence (KL) classification but, they are manual or semi automated. Unlike KL grades we describe an automated computer assisted method to detect OA based on the Joint Space Width (JSW) of knee images. We used image processing method for clearing the image and extracting the JSW (pre-processing, segmentation, decision making etc) later compared with Ahlback Grading. We considered a dataset of 100 knee images of normal and OA. Our approach gave successful results in all images (excluding the damaged images).

Key Words: Kellgren-Lawrence classification, Osteoarthritis, Image Classification, Thresholding and X-ray.

1. INTRODUCTION

In recent years, medical image analysis had gained rapid development and popularity due to wide developments in computer technology, computer vision, image processing and pattern recognition and the related technologies. For medical diagnosis of a human body digitized imaging is the best media to detect the abnormalities, fractures etc in bones. X-ray [13], MRI (Magnetic

Resonance Imaging) [14] and CT (Computed Tomography)[15] are used for these tasks. Among all the above X-ray is the best image format to determine the exact location of bones, broken bones and diseased bones. Moreover X-ray is relatively less expensive compared to MRI and CT. Arthritis is a disease which affects only bone. So X-rays are must in this case. For automating the identification process of Joint Space Width calculation (JSW)[16] an X-ray images needs to be with proper contrast levels, oriented in proper direction, extracting the region of interest (ROI). Later the distance is measured between the femur and tibia bones. So, for accurate results the image processing methods are must.

A. Human Knee Anatomy:

Human body has many bone joints which play a major role in physical working. Among them knee joint is one of important joint, which allows legs to b end, rotate, carrying weight etc. At infant stage the conventional knee cap is not well developed. As the human grows to adult the knee cap develops with cartilage. Knee joint structure has two main bones femur and tibia. Patella which ossifies from infant to adult and joins with the femur bone. The pictorial representation is shown in Fig.1.

Osteoarthritis is a common disease in human body, which affects at various bone joints like knee, hip, hand, wrist, spine etc. OA causes bone swelling due to which the movement gets stopped and produces pain (cartilage gap becomes thinner). So using Joint space width the doctors identify whether it is in early stage or damaged stage (needs a surgery). Causes of this OA are age (due to calcium deficiency at above 40 years), overweight, joint injuries and hereditary etc [1][17]. Surveys by Arthritis Research UK Primary Care Centre Keele University [1] have shown that the OA also varies between male and females (as they have different skeleton growth rates). This study shows that females are the highest victims of OA. Fig. 2 shows the knee images before and after OA. Fig.2 (b) depicts OA effected in the right side joint cartilage.

In this paper we proposed an automated computer system for OA detection using the Joint Space Width as per the grading system of Ahlback for Osteoarthritis of knee [18]. This paper is organized as follows: Section-II describes the related work in this filed, Section-III describes dataset image description, Section-IV describes the proposed approach, Section-V describes experimental results and finally Section-VI describes conclusion and future scope.

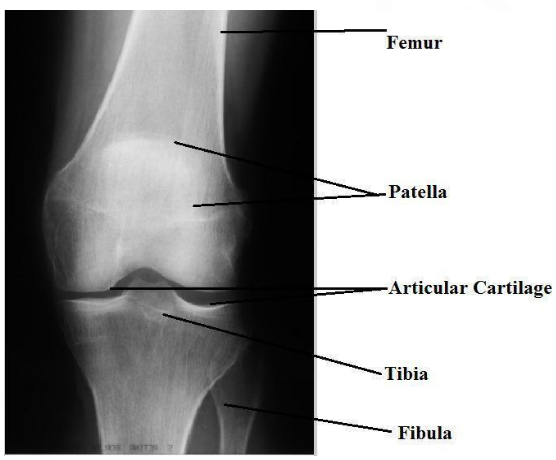

Fig.1. K nee Bone Image

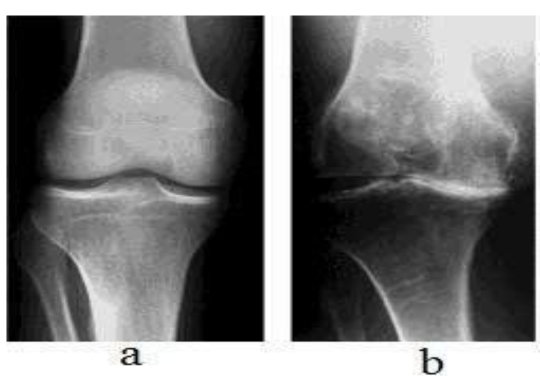

Fig.2. Comparison of radiograph with and without osteoarthritis

2. RELATED WORK

J.H. Kellegren and J.S. Lawrence (KL) [2] proposed four grades for OA identification on knee joints in the year 1957. Every human knee joints has four grades as per the disease stage they are: grade-0 for normal knee, grade-1 for doubtful (with narrow cartilage), grade-2 for staring stage of OA but definite OA and grade-3 for definite OA. Authors have proposed these grades for other bone joints also which includes hip, wrist and spine. Many researchers have classified the Knee OA according to this KL method. KL method doesn't specify the identification of arthritis diseases using cartilage thickness.

J Christopher Buckland-Wright and et al proposed a method using cartilage thickness by measuring the JSW in the year 1995[3]. Here the images are taken by injecting a 10ml local anesthetic at knee joint. Later the measurements are calculated using the x-ray image and categorized to the KL grades.

Tati and et al. proposed an automated technique for JSW calculations in the year 2005[5]. Here the image is rotated (if required), smoothed the image, boundary are extracted using Gaussian function in both vertical and horizontal directions. Later the image is cropped with 400*200 pixels which covers the boundaries of tibia and femur with cartilage. Thereafter the OA is classified using the neural network classifier. Lior Shamir and et al also proposed an automated system for detecting OA in the year 2008[6]. KL grades are used to classify the images. Here the success rate was different for each grade. The authors haven't explained the detailed description of image processing methods applied.

J.E. Schmidt and et al. have developed a semi automated design in the year 2005 using the cartilage thickness [7]. Femur and tibia edges with cartilage are identified by adjusting the intensities of image and canny edge operator. The ranges of cartilage width positions are chosen using manual intervention. Next the JSW is calculated. The designed system was to categorize the images to KL grades and to verify the mean error values in manual and automated approaches.

Philipp Peloschek and et al. have designed RAQuantify software in the year 2007. This software is used to measure the joint space width measurements for hand x-ray images [4]. Here an automated system is proposed for JSW measurements only. They can be further used for disease identification. The same approach can be applied for other bone images as well b y slightly modifying the software. Yinghe Huo and et. al. have also proposed another approach for JSW measurement for hand radiographs[12] in the year 2013. Most of the research was to categorize the images to KL grades.

3. DATASET FOR EXPERIMENT

The knee X-ray image are taken from Department of Medical Informatics, Aachen University of Technology, Germany entitled "10,000 IRMA images of 57 categories for Image CLEFmed 2005" that has been created by Dr. Thomas Deserno, Lehmann TM, Schubert H, Ott B and LeisenM.[11]. From this dataset we considered only the front viewed and clear images with our any distortion in pixels.

4. PROPOSED WORK

Joint space width calculation measurement is the major criteria for osteoarthritis (OA) identification and followed by diagnosis treatment (using radiographs and for monitoring of the disease). The proposed method has the following steps.

(i) *Proposed Algorithm: ROI Extraction*

Step 1: Read the X-ray Image.

Step 2: Enhance the image using Gaussian Low Pass Filter.

Step 3: Apply Contrast Stretch on the resultant image.

Step 4: Calculate the mean and variance for each pixel in the image.

Step 5: Convert the variance image to uint8 image.

Step 6: Identify the centre of the femur bone.

Step 7: Copy the cantered column values to an 1D array.

Step 8: Find the derivative for 1D array.

Step 9: Identify the maximum pixel variation locations from derivative result.

Step 10: Crop the image from pixel variation location.

Fig.3 ROI Extraction Algorithm

The proposed approach is divided into two algorithms one for ROI Extraction (as shown in Fig.3.) and second for thickness measurement analysis and decision making (as shown in Fig.4). These algorithms are implemented using MATLAB image processing tool box on windows environment. The considered images are clear without any distortion, damage etc. These two algorithms working are further divided into several stages to achieve the working steps of algorithms, which is depicted using a pictorial representation in Fig.5. The detailed descriptions of all the stages are explained as follows:

A. Pre-Processing the image:

Initially X-ray image is read and converted to gray-scale image. Then the image is smoothened using the Gaussian Low Pass filter in the frequency domain by converting image to double. Here the image is padded with zeros first and then a Fast Fourier Transform is applied using a Gaussian filter. The resultantant image is converted to uint8 image and then further enhanced using the contrast stretch function.

B. Segmenting the image:

After pre-processing the image is sufficiently clear as in Fig.5 with bone pixels enhanced. Later the mean and variance is calculated for each pixel using the neighboring pixels. The variance image results in clear boundary identification for femur and tibia bones. From the available boundary we identify the mid of the tibia bone. later the derivate is applied for this centered column values. The derivative shows the pixels sensitivity towards the edges with a peak indicators. Among these peaks we need to identify the cartilage thickness variation location peak and crop the image from this position. This final cropped image will show only the cartilage thickness with boundaries of tibia and femur (our ROI).

C. Thresholding the image:

Once the Cartilage ROI is extracted apply the threshold on this image and convert the image to binary format. Thresholding is chosen to remove the soft-tissue pixels and background pixels from the image.

D. Calculating the JSW:

Since the calculations are based on binary image, we identify the two locations from the edges of femur and tibia bone in the left side and also in the right side joints of cartilage. Then a Euclidian distance formula is used to calculate the distance d (any one side). This distance is measured in terms of millimeters. Finally these measurements are compared with the normal Joint space width given by Ahlback grading system [18] for decision making of OA disease identification.

5. EXPERIMENTAL RESULTS AND ANAYSIS

The proposed method was tested image IRMA dataset of 100 images. The dataset had more than 200 images of knee but, only 100 are clear images, the rest had some damaged data. So we considered only 100 images for processing. Among them our algorithm worked successfully on 80 images for perfect ROI extraction. The remaining 20 cases failed because of unclear boundaries obtained using the variance image. Further these 80 images are used for Joint Space Width measuring algorithm, where our success rate was 90%. Only 10% images have failed since the binary threshold cutoff was not identifying the cartilage boundary clearly (further needs a dynamic thresholding).

(ii) Proposed Algorithm: Joint Space Width Measurement

Step 1: Read the cropped image

Step 2: Convert the cropped image to binary.

Step 3: Calculate the distance 'd' between the JSW locations of cartilage joints.

Step 4: Compare this distances with the cartilage thickness criteria.

Fig.4. Joint Space Width Measurement Algorithm

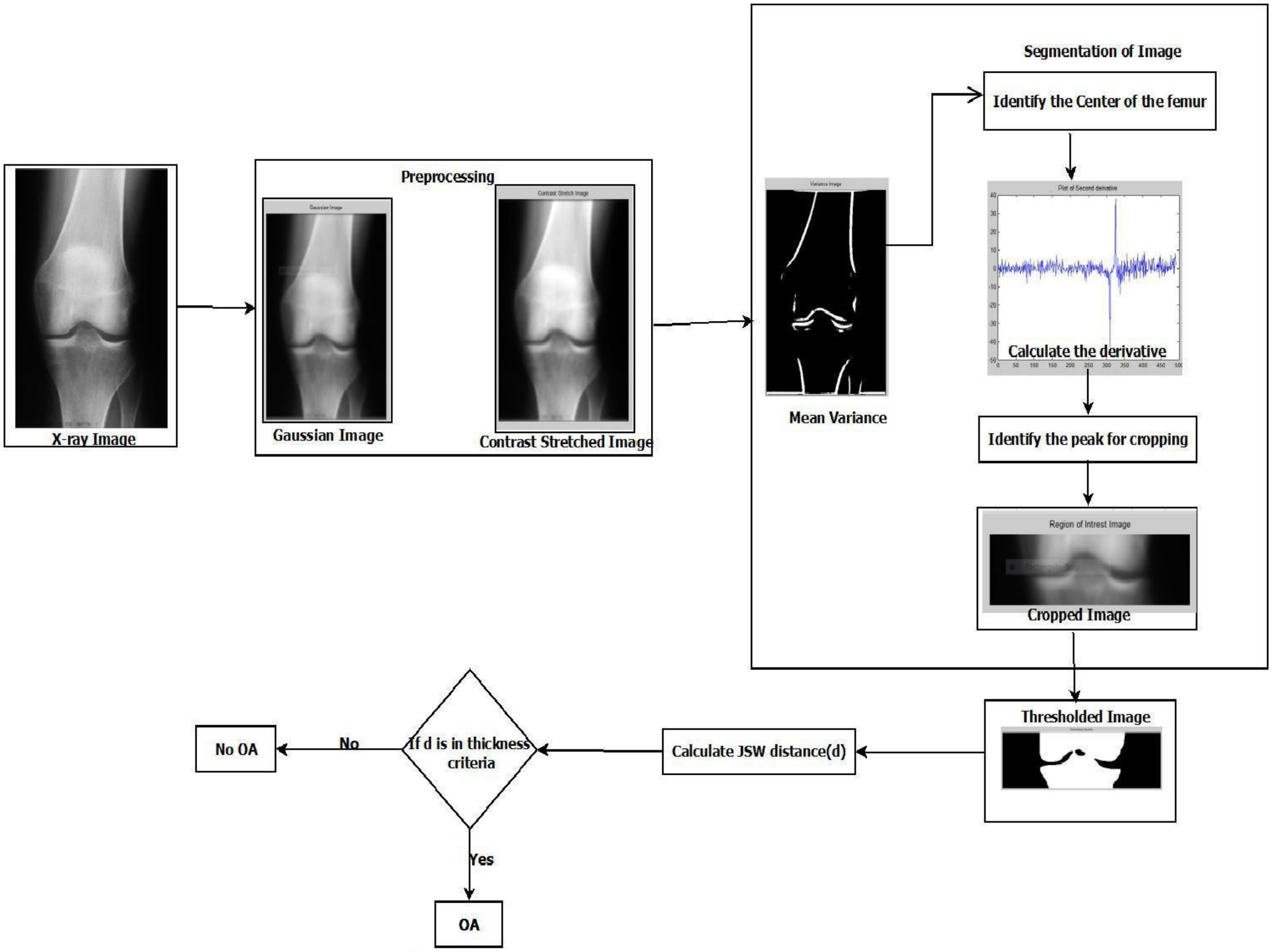

Fig.5. Automated System Design Architecture

Some of the results are depicted in the Table 1. This table shows the Joint Space Width of cartilage edge and the possibility of OA in the images.

Table 1: Results for Proposed System using 10 images

Image Number	Joint Space Width(mm)	OA Identification (Yes/No)
1	5.17	No
2	4.11	Yes
3	6.18	No
4	5.13	No
5	3.55	Yes
6	2.14	Yes
7	3.25	Yes
8	5.71	No
9	6.21	No
10	1.23	Yes

6. CONCLUSION AND FUTURE SCOPE

In this paper we described an automated method for the detection of OA using knee X-rays. The automated approach leads to accurate results in contrast to manual approaches (prone to mean errors for test to test). Our approach is a complete automated system including the pre-processing, ROI segmentation, threholding, distance calculations and decision making. The automated system worked well on clear images of knee. We gave the OA identification using the cartilage thickness unlike the KL grades classification. In future the ROI extraction algorithm must be further enhanced with a modified boundary extraction algorithm. In the current system this step failed in extracting the boundaries in some of the images (because of same/low intensities at the boundaries of bone and soft-tissue pixels). Next in the second algorithm also binary thresholding must be modified for clear identification of cartilage edges. Moreover the image might not be in proper direction so, rotation of image is required as the initial step, which can be further extended for future research.

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