IMAGE SEGMENTATION METHODS AND EDGE DETECTION: AN APPLICATION TO KNEE JOINT ARTICULAR CARTILAGE EDGE DETECTION

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ABSTRACT

Image segmentation is the process of partitioning a digital image into multiple segments and regions for further processing. Edge detection methods are widely used in the area of image processing for feature detection and extraction. In this paper we use human's Knee MRI (Magnetic resonance imaging) images of patients and applied various image segmentation and edge detection methods for knee cartilage visualization. Also this paper focuses on providing an overview of important concepts, methods and algorithms commonly used for image segmentation and edge detection with focus on knee joint articular cartilage image segmentation and visualization.

Keywords: *Image Segmentation, Feature Deduction, Feature Extraction, Edge Detection, Cartilage Visualization*

1. INTRODUCTION

Image enhancement techniques play a significant role in digital image processing [1]. Image enhancement methods improve the quality of the digital image for further processing. Image segmentation is the process of partitioning a digital image into multiple segments for better understanding and processing [2]. The partition of the image is domain independent and divided into regions. Normally, the regions may be distinct in terms of visual content and with respect to certain image features such as pixel intensity, texture and color. Image segmentation simplifies the representation of a digital image by identifying regions for further analysis [3].

The advent of modern Information and Communication Technologies (ICT) in the last two decades is phenomenal. Application of ICT in medical and health domain is ever increasing and the merger of ICT and medical domain is term as medical or health informatics [4]. Medical data related to patients in terms of lab reports, diagnosis, treatment, X-Rays, ECG (Electro Cardio Gram), CT (Computerized Tomography) scans and MRI's

(Magnetic Resonance Imaging) are stored in a digital format (DICOM) and can be accessed and processed within health information system. In practice physician assess X-Rays and MRI's of patients manually and reach to conclusions on the basis of their expertise. If they have any doubts they go for other opinion or further consultation. Manual decision making process is not error free as humans make judgment error which is very costly in medical domain because the life of human is on risk. In comparison, an automated decision support system (DSS) based on software solution if carefully developed are more reliable and consistent as compare to manual decision making process. DSS is a computerized system that gathers, process and presents data in an effective manner which significantly improves the decision making process. DSS developed with the active participation of domain experts and carefully tested. It can also help physician to validate his findings and feel more confident in diagnosing the correct problem of a patient.

MRI is a standard medical imaging technique for visualization of internal body structure used in radiology [5]. MRI provides more detail and clear

images of the human body as compare to CT scans and X-Rays. Knee joint is a very important joint of human body, in fact the whole weight of the body lies on the knee whether we are standing, walking or running. It is very vulnerable joint, and more often at some stage of the life many people have knee related problems. Whenever a patient arrives to orthopedic he/she advised to bring his/her knee MRI scan for further evaluation because it gives a more detailed view of the knee joint [5].

Important contributions are being made by the research community in medical image processing by applying various image processing algorithms and techniques [3]. Number of image segmentation methods and edge detection algorithms are being proposed [6][7][8]. Shrivakshan [9] and Senthilkumaran [10] provide a comprehensive review on existing image segmentation and edge detection algorithms.

In this paper we have analyzed knee MRI cartilage images of different patients obtained from Dow medical hospital and applied different image enhancement techniques and edge detection methods using MATLAB. In the first step image enhancement techniques such as histogram equalization, gray scale enhancement and adaptive histogram equalization are applied to scanned MRI images. PSNR and MSE values are obtained using algorithm. Sobel, Prewitt, Robert, Laplacian of Gaussian Method, zero cross method and Canny edge detection method are being applied to the given MRI images for knee articular cartilage edge detection.

2. ANATOMY OF KNEE

Knee joint is a critical joint in a human body. Most of the time knee absorbs maximum weight of the body. According to a study human knees sustain half times of the body weight and in case of climbing high or going upstairs it raises up to three fourth times of body weight. It is considered to be one of the most vulnerable bodies joint and there are increasing numbers of patients with problems in knee joints.

The knee joint is a synovial joint which connects the femur (thigh bone) to the tibia (shinbone) shown in Figure. 1 [11]. Knee have two important joints, the tibiofemoral joint, which joins the tibia to the femur and the patellofemoral joint which joins the kneecap to the femur. The movement in the knee joint (bending or straightening) is totally dependent on tibiofemoral and patellofemoral joints [11].
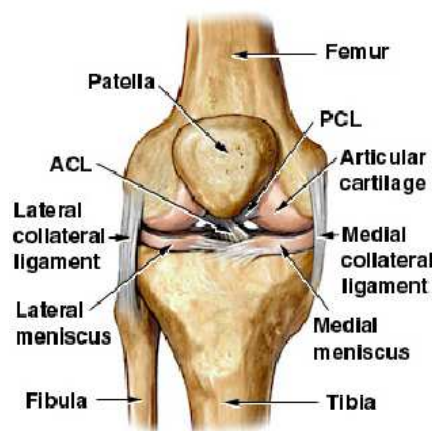

Figure 1: Knee Joints: Posterior View

Cartilage of Knee Bone:

Articular cartilage is a connective tissue kept with synovial fluid, which protects the bones and ensures the smooth and friction free movement of the knee joints. The articular cartilages of the knee cover the ends of the femur, the top of the tibia and the back of the patella (Figure 2) [11]. In many cases like arthritis, knee joint inflammation, physical stress and aging the articular cartilage losses its concentration or thickness on the knee joints and patients start feeling pain in knees.
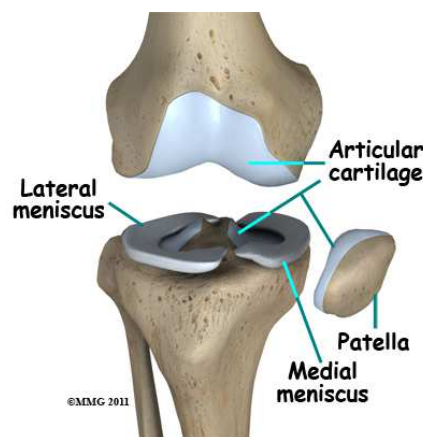

Figure 2: Cartilage of Knee Bone [MMG 2011]

3. MEDICAL IMAGE FORMULATION

3.1 The DICOM Format

DICOM (Digital Imaging and Communications in Medicine) [12] is an international health standard for storing and managing medical images (X-Rays, MRI, CT Scans) in health information systems. It is developed by NEMA [5][13]. DICOM is different in its definition compare to other image data

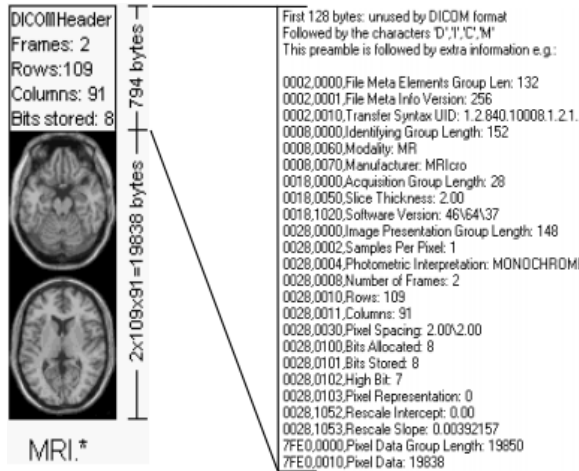formats (jpeg, gif and bmp) as it clusters information into data sets [12].

Figure 3: DICOM Image

A DICOM data set composed of number of attributes related to patient identification, name, type of image and image pixel data (Figure 3). For example, a knee X-Ray image contains the patient identification within image and this information cannot be separated for any kind of data loss.

DICOM has its own file format and network protocol which uses TCP/IP protocol to connect and establish communication between systems. It is important for sender and receiver to have compatibility for exchanging and processing DICOM images. Digital computer devices (scanners, printers, network cards, workstations) are fully integrated to process DICOM images

through a system called PACS (Picture Archiving and Communication System). DICOM uses three different data element encoding schemes [13]. It provides data representation by introducing a lookup table to display digitally assigned pixel values for identical gray scale image on different types I/O devices.

3.2 Controlling DICOM Images Using MATLAB

The 'dicomread' command in MATLAB is used for reading a DICOM image using the following syntax and shown in Figure. 4.

```
X = dicomread(filename)
X = dicomread(info)
[X,map] = dicomread(...)
[X,map,alpha] = dicomread(...)
[X,map,alpha,overlays] = dicomread(...)
[...] = dicomread(filename, 'frames', v)
```

The 'imadjust' function in MATLAB is used to adjust intensity values and colormap of the DICOM images shown in the following syntax. Output for adjusting image intensity and colormap is represented in Figure. 5 and an output for image stretching is shown in Figure. 6.

```
K = imadjust(I,[0.3 0.7],[]);
L = imadjust(K);
P = imadjust(L,stretchlim(L),[]);
```

4. IMAGE ENHANCEMENT

Image enhancement techniques improve the quality of the given digital image to great extent depending on the type of the image. It is an automated process based on mathematical
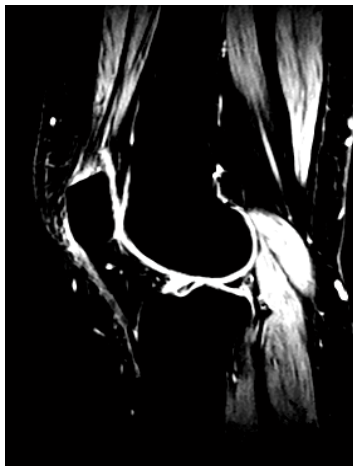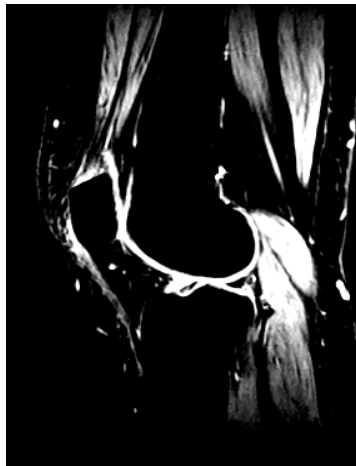

Figure 4: Acquiring DICOM image
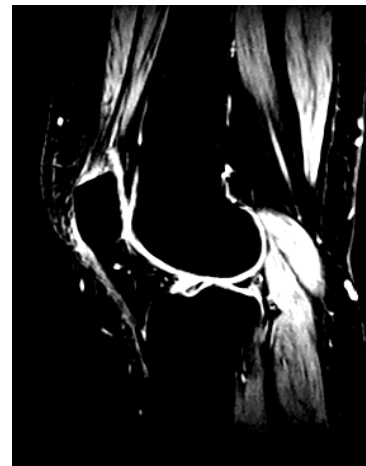

Figure 5: Adjusting DICOM Image

Figure 6: Stretching DICOM Image

functions. These techniques can improve the image quality in terms of shading (light or dark), contrast and color [14][15]. Image enhancement techniques transform a low quality image to an enhanced (high quality) image for further information processing. Furthermore, it refines and sharpen image features to obtain a visually more pleasant and less noisy output image [16]. The aim of image enhancement is to improve the image information for better perception of information as per the requirement of user (Figure 7).
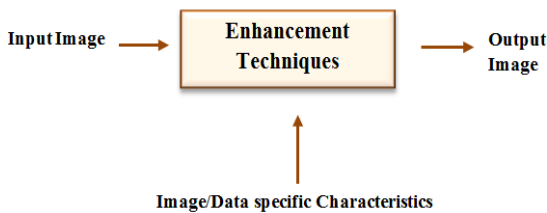

Figure 7: Image Enhancement

There are number of image enhancement techniques proposed in the literature which can improve the quality of an image without distorting image information. These techniques are divided amongst two major domains that are frequency domain methods and spatial domain methods [14].

4.1. Frequency Domain Methods

Image enhancement in the frequency domain is easy and simple. First, compute the Fourier transform [15] of the given image then multiply the result by a filter and in the last step take the inverse transform to produce the enhanced image (Figure 8). These functions (computations) are performed in order to modify the brightness, contrast level and distribution of the frequency level of a given image. Hence, the output image is modified in terms of pixel value in accordance with the transformation function applied to the input values.

Image enhancement under this domain usually means transforming an image F, to an image G using a function T. Pixel values in F and G are represented by "s" and "r" respectively. An expression representing pixel values in "r" and "s" is:

$$S = T(r) \qquad (1)$$
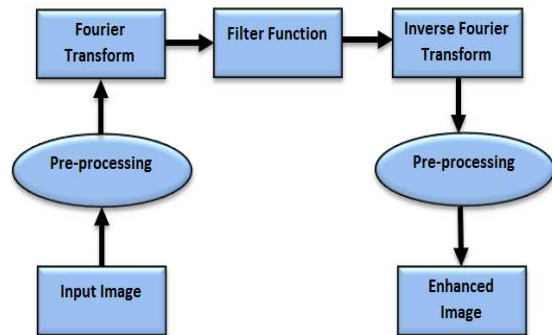
Where, T is the transformation function.

Figure 8: Image Enhancement Using Frequency Domain Method

4.2. Spatial Domain Methods

The term spatial domain refers to the aggregate of pixels composing an image. Spatial domain methods operate directly on these pixels [14]. It is denoted by expression (2):

$$G(x,y) = T[F(x,y)] \qquad (2)$$

Where F(x,y) is the input and G(x,y) is the processed image (output) and T represents an operator.

The methods in spatial domain are further divided into point processing and mask processing. Following section describes some of the important techniques of spatial domain method.

4.2.1. Contrast stretching

Contrast stretching [1] technique uses the range of intensity values it possess and span it to desired range of values using point pre-processing to improve the contrast of a given image. Contrast stretching only applies a linear scaling function to the image pixel values as compared to histogram equalization method as shown in Figure 9.
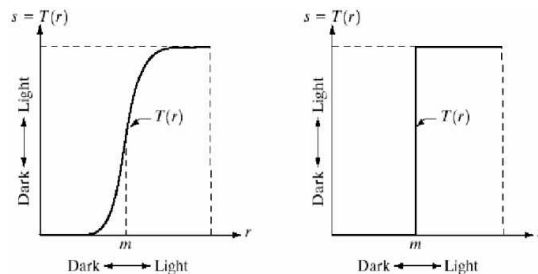

Figure 9: Gray level Transformation Function for Contrast Enhancement

It is important to set the pixel value limits (upper and lower) for the image is to be normalized. These limits correspond to the minimum pixel value and

maximum pixel value of given type of the image. For instance, the lower and upper limits for eight-bit gray level images might be 0 and 255 respectively.

The simplest contrast stretch is a linear transform that maps the lowest gray level GLmin to "0" and the highest value GLmax to 255 for an (eight-bit gray level) image. All other gray levels of an image remapped linearly ($0 \geq GL \geq 255$); to produce a high-contrast image that spans the full range of gray levels. This linear transform is given by equation (3).

$$g'(x,y) = INT \left\{ \frac{255}{GL_{max} - GL_{min}} \left[g(x,y) - GL_{min} \right] \right\}$$

(3)

We have applied contrast stretching to MR images of Knee and following results are illustrated shown in Figure 10 and 11.
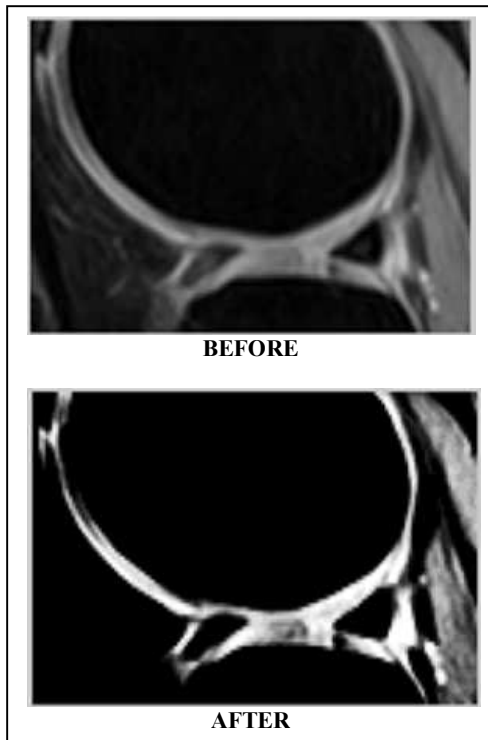

BEFORE

AFTER

Figure 10: Contrast Enhancement for MR Images of Knee
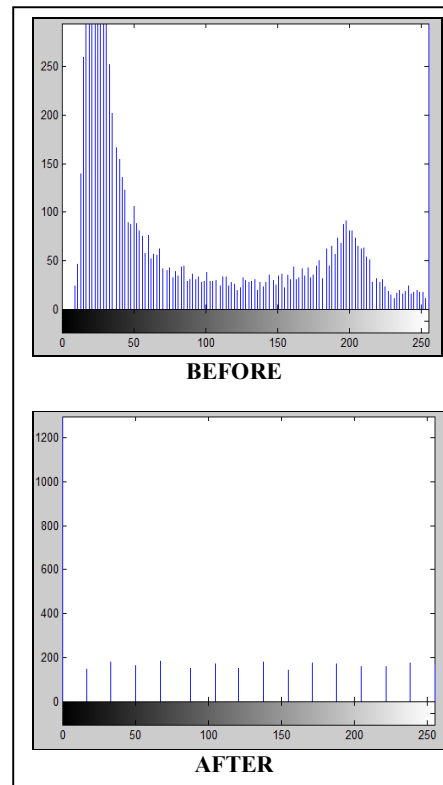

BEFORE

AFTER

Figure 11: Histogram Comparison of Contrast Enhancement on MR Images of Knee

4.2.2. Histogram equalization

Histogram equalization is an effective method for the adjustment of contrast in digital images. It uses image histograms for contrast adjustment [16]. This method is extremely useful in increasing the global contrast of images, provided the input image is represented by close contrast values. Due to this contrast adjustment, the intensities can be better distributed on the histogram. Therefore, areas of low contrast in resultant image can gain a higher contrast. Histogram equalization achieves this by successfully spreading out the most frequent intensity values.

It is more effective where there is a variation in the color contrast of an image. For instance an image background is very dark or bright. Therefore, histogram equalization method provides better view of X-Ray and MRI scans of bones. One of the important benefits of this method is its simplistic approach and an invertible operator. The calculation is not computationally intensive. Indiscriminate behavior is one of the limitations of this method as it may amplify the contrast of noise element in the background at the cost of actual signal.

4.2.3. Adaptive histogram equalization

Adaptive Histogram Equalization (AHE) [6] is very effective method to enhance color contrast in digital images. Unlike, ordinary histogram equalization method, AHE computes series of histograms for different regions (sections) of the image. This information is used to reallocate the lightness values of the image and hence improves the local contrast of an image with more detailed information.

One of the disadvantages of AHE is the noise amplification in relatively homogeneous regions of an image. This deficiency is removed by limiting the amplification in a modified version of AHE called Contrast Limited Adaptive Histogram Equalization (CLAHE) [6].

4.2.4. Gray scale enhancement

Gray-scale modification and gray-level scaling methods uses different point operations and function to make changes in the pixel's values with the help of a linear mapping equation. However, it can also be used with nonlinear equations by modeling stepwise linear models. It maps the original gray-level pixel values to the specified values shown in Figure 12.
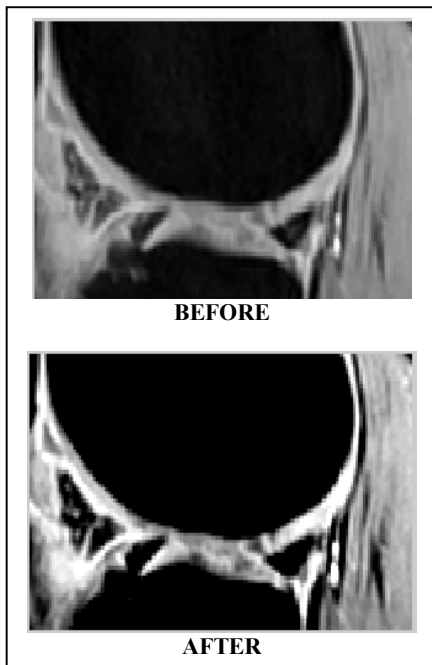

Figure 12: Gray Scale Adjustment of Knee MR Images

We have applied gray scale enhancement since its shows the maximum PSNR and minimum Mean Square Error (MSE) when applied on MRI images of knee (Table 1).

Table 1: PSNR and MSE Calculations

PSNR & MSE CALCULATIONS		
TECHNIQUE	**PSNR**	**MSE**
Histogram Equalization	16.7820	1364.2
Enhanced Gray Scale	18.1862	987.3150
Adaptive Histogram Equalization	16.9998	1297.5

5. EDGE DETECTION TECHNIQUES

Edges correspond to object boundaries of objects in images. It is the outside region of image represented by pixels where there is abrupt change in brightness. An edge is a vector variable and an implicit characteristic attached to each pixel and is computed by the image function behavior in a neighborhood of the pixel. Edge detection techniques are extensively used in image processing to identify changes in the image brightness.

Edge detection process can be divided into four phases smoothing, enhancement, detection and localization (Figure 13). It is based on mathematical methods and functions which calculates the image strength in terms of sharpness and discontinuities. The points at which image brightness changes sharply are represented into a set of curved line segments called edges. Edge detection is considered to be a fundamental tool in digital image processing for feature detection and extraction.
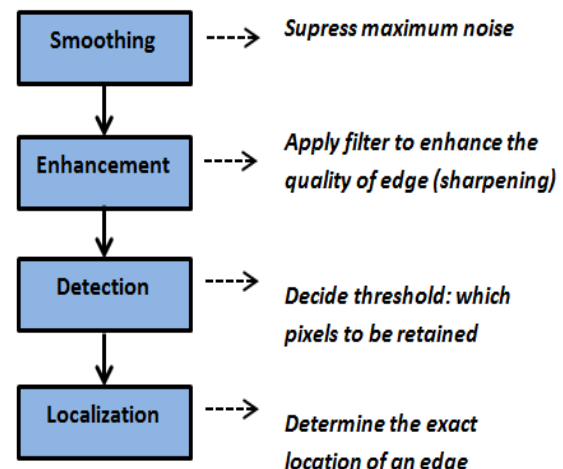

Figure 13: Edge Detection Process

5.1 Sobel Method

The Sobel operator [3][7] is a discrete differentiation operator commonly used for edge detection algorithms. This operator, when applied to a given image, calculates the gradient approximation of the image intensity function. It generates the gradient vector when applied to the given image. Sobel operator is applied to a given MRI knee cartilage image shown in Figure 14.
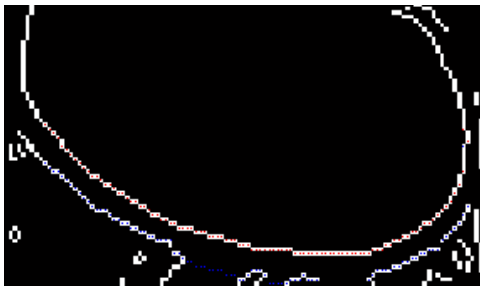

Figure 14: Sobel Edge Detection

The advantage of Sobel operator is that it uses an integer valued filter for image and it is less expensive. One of the drawbacks in this approach is the consistency in application of the gradient approximation especially in the case of high frequency variations in the image. Mask coefficients of Sobel method are given in 4 & 5:

Edge Magnitude= $\sqrt{x^2 + y^2}$ (4)

Edge Direction = $\tan^{-1}\frac{y}{x}$ (5)

5.2 Prewitt Method

The Prewitt operator is a discrete differentiation operator used for edge detection algorithms in digital image processing. It approximates the gradient of the image intensity function. This method detects edges of a given image both horizontally and vertically. It converts the pixel information into a metric. Figure 15 shows the result of the application of Prewitt operator on a given MRI of knee cartilage.
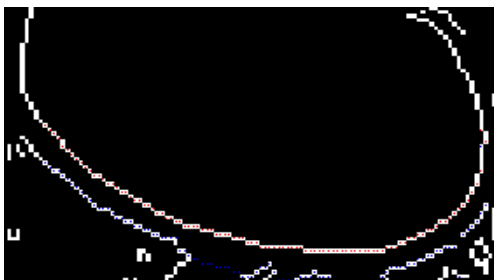

Figure 15: Prewitt Edge Detection

5.3 Robert Method

The Roberts cross operator [3] and [16] proposed by Lawrence Roberts is considered to be the first edge detector, which is used in digital image processing. Robert used discrete differentiation to approximate the gradient of an image by calculating the sum of the squares of the differences between diagonally adjacent pixels. It gives best results in the case of binary images. One of the limitations of Robert cross operator is that it doesn't give information about edge orientation. The operator consists of a pair of 2×2 convolution kernels (Figure 16). The output through Robert method is shown in Figure 17.

Figure 16: 2 x 2 Convolution Matrix

The convolution kernels, when applied to input image calculates the measurements of the gradient component in each orientation (Gx and Gy) shown in 6 & 7.

$$|G| = \sqrt{Gx^2 + Gy^2}$$ (6)
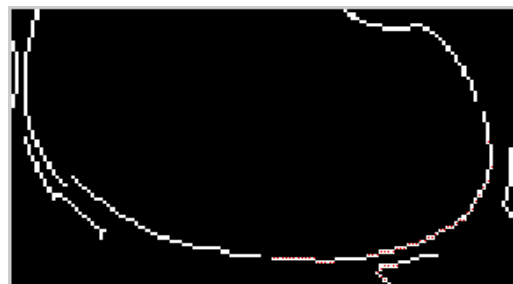
$$|G| = |Gx| + |Gy|$$ (7)

Figure 17: Robert Edge Detection

5.4 Laplacian of Gaussian Method

This method finds edges by looking for zero crossings after filtering "I" with a Laplacian of Gaussian filter [8]. A convolution sum (approximation) is computed for edge magnitude in images. Plus "+" or minus "-"signs in the result obtained from two adjacent pixels provide better edge orientation. It indicates the brighter side of the edge in a given image as shown in Figure 18. The

Laplacian L(x,y) of an image with pixel intensity values I(x,y) is given by (8):

$$L(x,y) = \frac{\partial^2 I}{\partial x^2} + \frac{\partial^2 I}{\partial y^2}$$
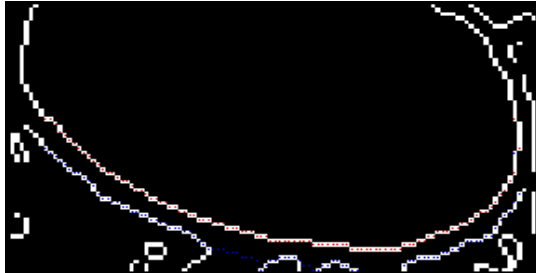
(8)

Figure 18: Laplacian of Gaussian Edge Detection

5.5 Zero Cross Method

Gradient filters (operators) are effectively used to detect edges in area of digital image processing [10]. A gradient filter identifies the regions in images in terms of rapid change in pixel value, which identifies edge or boundary. A Laplace filter does the same task but in a bit different way. It marks the potential edge point by looking out points in the signal stream where the digital signal of an image passes through a pre-set value '0'. Since, the signal crosses the point zero, it is called zero cross method. The output from zero cross method is given in Figure 19.
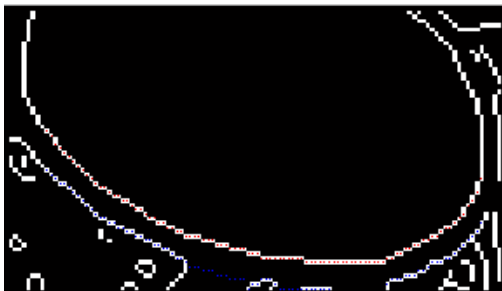

Figure 19: Zero Cross Edge Detection

5.6 Canny Edge Detection

The Canny edge detection process uses a multi stage algorithm for identification and detection of edges in images [17]. It is based on an edge detection operator. An edge is the outline boundary of a particular object in an image and point in a variety of directions. The Canny method [8][16] includes four different type of filters to locate vertical, horizontal and diagonal edges in the unclear image. Different edge detection operators such as Roberts and Sobel return a value for the 1st derivative in the horizontal and vertical directions,

represented by Gx and Gy respectively. In this way the edge gradient and direction can be calculated by using 9 and 10.

$$G = \sqrt{G_x^2 + G_y^2}$$

(9)

$$\theta = \arctan\left(\frac{G_y}{G_y}\right)$$

(10)

Following is the syntax of Canny Edge Detection in MATLAB

```
BW = edge(I,'canny')
BW = edge(I,'canny',thresh)
BW = edge(I,'canny',thresh,sigma)
```

The Canny method finds edges by looking for local maxima of the gradient of I. The gradient is calculated using the derivative of a Gaussian filter. One of the important highlight of this method is to maintain to two different thresholds to detect strong and weak edges of the input image. Output image includes only those weak edges which have connections with strong edges. Therefore, Canny method is performs relatively better than other methods and not confused with noise element and detects right edges. The result for canny edge detection is shown in Figure 20.
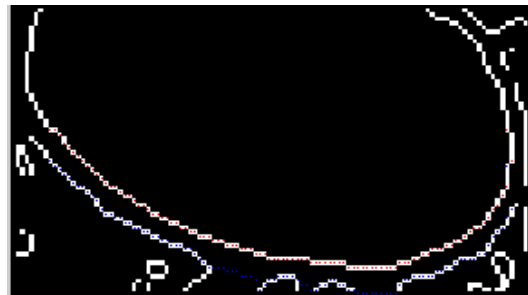

Figure 20: Canny Edge Detection

5.6.1. Noise removal

The function Bwareaopen() removes all small objects from binary image. Following is the syntax of Bwareaopen function in MATLAB and output is represented in the Figure 21.

```
BW2 = bwareopen (BW, P)
BW2= bwareopen (BW, P, conn)
```

Figure 21: Applying Noise Removal Technique

Connectivity can be defined for a given dimension by using 3 x 3 matrix of zeros and ones. The one-valued elements define neighborhood locations relative (symmetric) to the central element of conn.

6. RESEARCH ISSUES AND FUTURE DIRECTIONS

There are some important research issues related to image segmentation and edge detection techniques, which includes fuzzy boundaries, high dimensional indexing, multi-dimensional images, hybrid techniques, parallel and Grid computing, complete noise removal, performance evaluation metrics, reconstructing images and real time image processing. This work may further be extended to fuzzy based edge detection to extract important features of given images.

7. CONCLUSION

In this paper, we have discussed various important methods of image segmentation with specific focus on the knee joint image segmentation for articular cartilage. The knee joint articular cartilage (2D view) MRI scans of patients have been used for articular cartilage edge detection. Different edge detection techniques are applied using MATLAB and results are analyzed. The advantages and disadvantages are also discussed. It is observed that gradient based algorithms are more sensitive to noise compare to Canny, Sobel, Prewitt, Robert and zero cross method. The outcome of the Canny method depends on changing values of parameters which are standard deviation from the Guassian filter. In terms of performance evaluation Canny algorithm is more costly as compare to Robert, Prewitt and Sobel methods. The results showed that Canny edge detection algorithm works well with the given images as compare to other approaches.

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