CHAPTER 2

BACKGROUND AND LITERATURE REVIEW

2.1 Introduction

A review of the background and previous work with reference to the research illustrated in thesis is presented in this chapter. The content of this chapter is organised as follows Section 2.2 Medical Image, a brief history of medical image technology and the implementation of medical image in human debases diagnose, typically Knee-OA is presented. Section 2.3 Image Processing, the basic idea of image processing technology is described. There are three image processing techniques: (i) Image Segmentation, (ii) Image Enhancement and (iii) Feature Extraction/Image Representation. The brief detail of each technique is presented in Sub-section 2.3.1, Sub-section 2.3.2 and Sub-section 2.3.3, respectively. The summary information of image classification is suggested in Section 2.4. The detail of the section is described as follows: (i) the fundamental idea of data mining (ii) the detail of image classification and (iii) the classification learning methods are presented Sub-section 2.4.1 to 2.4.3, respectively. The feature selection techniques which apply to select the feature vector are described in Section 2.5. Section 2.6 points out of the brief information of Convolutional Neural Network (CNN) applying in medical imaging. The evaluation measurement methods which is used to evaluate the classification result is discussed in Section 2.7, in this section there are six measure parameters including: (i) Accuracy (AC), (ii) Sensitivity (SN), (iii) Specificity (SP), (iv) Precision (PR), (v) F- Measure (FM), and (iv) Area under the ROC Curve (AUC). In case of AC, SN, SP, PR, and FM can be calculated from Confusion Matrix which is presents in Sub-section 2.7.1. While AUC can calculates from the Receiver operating characteristic (ROC) curve which is presented in Sub-section 2.7.2. The comparison of some related works are presented in Section 2.8. Finally, the summary of this chapter is described in section 2.9.

2.2 Introduction

Medical image has spread widely and has been an interdisciplinary to many research fields, for example, computer science, computer vision, engineering, statistic, biology, and medicine. The technology in computer-aided diagnose processing has become an important for clinical healthcare. The medical image is used to diagnose inside human structure such as bone, brain and renal system. There are various types of medical image with respect to image capturing mechanisms including (i) X-ray (radiography), (ii) Computed Tomography (CT), (iii) Magnetic Resonance Imaging (MRI), (iv) Ultra-sound, (v) Positron Emission Testing (PET) and (vi) Single Photon Emission Computed Tomography (SPECT). With respect to the work presented in this research, to act as a focus for the work X-ray image is considered. However, there is three medical image capture mechanisms are presented in this section including (i) X-ray, (ii) CT and (iii) MRI.

2.2.1 X-ray Image

German physicist Wilhem Rontgen discovered X-ray image in 1895 [6]. The first medical image of X-ray image was taken from his wife’s left hand. Wilhelm Rontgen took this radiograph of his wife's left hand on 22 December 1895, shortly after his discovery of X-rays. The image of Wilhelm’s wife’s hand is shown in Figure 2.1.

Figure 2.1 The image of Wilhelm wife left hand [6].

X-ray is a form of electromagnetic radiation which can pass through the human body with producing the internal structure image, the resulting of X-ray is an image, and this image is called a radiographic, also known as "X-Ray" or "plain film".

Figure 2.2 An example of X-ray image with different radiographic density [7].

There are five categories depending on radiographic densities in X-ray image. The Figure 2.2 illustrates the difference of X-ray radiographic density indicating by the number including (i) number 1 is air (the darkest area), (ii) number 2 presents fat (the dark grey), (iii) number 3 is the soft tissue (grey), (iv) number 4 illustrates bone (bright grey) and (v) number 5 is the contrast material [7].

X-ray images have been used to diagnose Knee-OA which presented in many works [8,9,10,11,12,13,14,15]. There are two main objectives for Knee-OA research: (i) X-ray image was used to detect OA and non OA [9,11], while the second one is more advance than the first one because the X-ray image has been used to detect the OA stages as reported in [10,12,13,14,215].

On the purpose of the detection of the OA stage, the Kellgren-Lawrence (KL) system [16,17] is considered. The KL standard is a five stages indicating using *stage 0* to *stage 4*. '*Stage 0*' represents no OA symptom while '*Stage 4*' represents the most serve radiographic disease. The summary of the OA stage is shown in Table 2.1. There are five stage of OA has shown in the table which rank from zero to fourth stage. The *stage 0* refers to the normal case, within this stage the sign of OA cannot detect because there is no sign of OA has happened. The second stage of OA is the doubtful stage sometime called *stage 1* of knee OA; in this stage there is a little sign of OA has appeared. In other words, in the *stage 1* of OA there is a sign to show very minor bone spur growth. The next stage is the *stage 2* are considered as the minimal stage, the knee joints in this stage will reveal greater bone spur growth, but the cartilage is usually still at a healthy size, i.e. the space between the bones is normal, and the bones are not rubbing or scraping one another. At this stage, synovial fluid is also typically still present at sufficient levels for normal joint motion. However, this is the stage where people may first begin experiencing symptoms; pain after a long day of walking or running, greater stiffness in the joint when it's not used for several hours or tenderness when kneeling or bending. *Stage 3* of OA is considered as "moderate" stage. In this stage, the cartilage between bones shows obvious damage and the space between the bones begins to narrow. People with *stage 3* OA of the knee are likely to experience frequent pain when walking, running, bending, or kneeling. They also may experience joint stiffness after sitting for long periods of time or when waking up in the morning. Joint swelling may be presented after extended periods of motion. *Stage 4* OA is considered as "severe." People in *stage 4* OA of the knee experience great pain and discomfort when they walk or move the joint. This is because the joint space between bones is dramatically reduced; the cartilage is almost completely gone, leaving the joint stiff and possibly immobile. The synovial fluid is decreased dramatically, and it no longer helps reduce the friction among the moving parts of a joint.

Table 2.1 The summary of the knee OA stages

Knee OA Stage	*Stage 0* (Normal)	*Stage 1* (Doubtful)	*Stage 2* (Minimal)	*Stage 3* (Moderate)	*Stage 4* (Severe)
Properties	No sign of OA	Show very minor bone spur growth	Reveal greater bone spur growth	Cartilage was damage and narrowing of joint space	Great pain and discomfort when walking

Figure 2.3 shows the X-ray image of each OA levels Figure 2.33(a) presents *stage 0* OA or normal, Figure 3 (b) illustrates *stage 1* OA (doubtful), Figure 3(c) shows *stage 2* OA the minimal level and Figure 3 (d) presents *stage 3* moderate level.

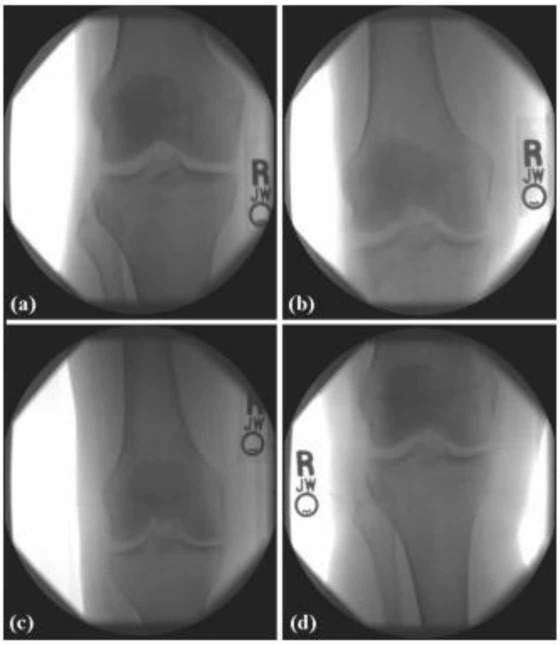


Figure 2.3 X-ray image of four different KL grade [14]

The work of OA stage detection using X-ray offers the benefit over the detection the OA and non-OA because knowing the level of OA can make orthopaedic doctor easy to prevent and slow down the OA speed to the OA patient. The most important is the cost because the price of X-ray image is unexpansive compare to the others.

2.2.2 Computed Tomography

Computed Tomography (CT) is one of the well-known medical imagery for disease diagnosis. A CT scan uses a collection of X-ray images taken from different angles to produce cross-sectional image using the computer processing. Thus the structures inside of the body can be presented without cutting. CT provides the clear image so the medical doctor can be used to analyse or diagnose the disease.

2.2.3 Magnetic Resonance Imaging

Magnetic Resonance Imaging (MRI) uses the magnetic properties of spinning hydrogen atoms to make the internal structure image. It makes the powerful image of human bone structure and create a very clear image. With respect to OA detection, the MRI images were also applied as presented in [18,19,20,21]. The works show the benefit of OA analysis with short time consuming and produce a good result. The example of MRI image of human knee is shown in Figure 2.4.

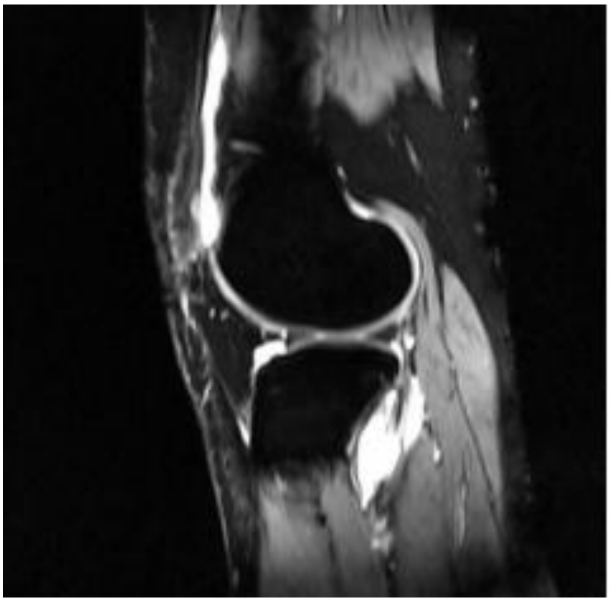


Figure 2.4 Human knee image using MRI [18]

To summarise, OA detection is the challenge task in medical and computer science. The image processing is applied to OA detection using medical image is the best solution as well as to analyse the OA stage. With the respect to this research to act as a focus in Thailand, so the medical X-ray image is considered with low cost of processing. With X-ray image apply with image processing to diagnose OA stage, the image processing technique is presented in the next section.

2.3 Image Processing

The fundamental concepts of image processing is discussed in this section. Image processing is a challenge area in computer science. The aims of this method is to analyse and manipulate the digital image. In addition image processing has been applied to improve the image quality. There are main three key words in image processing that can be listed as follows:

(i) Image processing (input as image and output as image)

(ii) Image analysis (input as image and output as the measurement)

(iii) Image understanding (input as image and output as the high-level description)

An image is a set of array, a matrix, a square of pixel which arrange in columns and rows. In 1920s, the first image processing was discovered and it was called Bartlane cable picture transmission system. Nowadays, image processing has been applied in various applications such as education, engineering and medical. To get the deep meaning of image processing, the definition of an image should be known clearly first. An image is considered of two real variable, for example I(x,y), with I as the amplitude of the image at the real coordinate position (x,y). Sub-image is the sub set of image, sometime it considers as the region of interest (ROI). The smallest element of image is pixel. Image processing generally separate into two main categories: (i) digital image processing and (ii) medical image processing [91].

In general the medical image processing provides the image in white and black colour, or greyscale image in technical word. An 8-bits greyscale image has which picture element has an assigned intensity that ranges from 0 to 255. Figure 2.5 shows each pixel of greyscale image with the value from 0(black) to 255 (white) because 8 bit equal to 256 greyscales.

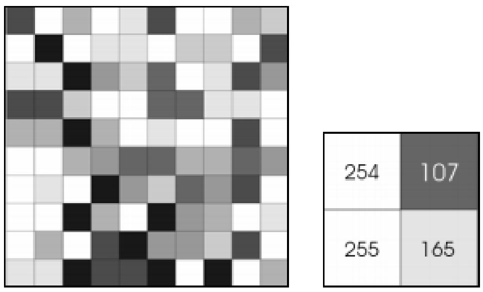


Figure 2.5 Each pixel has a value from 0 (black) to 255 (white) [22]

There are three image processing processes including: (i) image segmentation, (ii) image enhancement and (iii) image representation/image feature extraction. The detail of each process is discussed in the Sub-section 2.3.1 to 2.3.3 respectively.

2.3.1 Image Segmentation

Image segmentation is one of the most important processes of the image processing. The main objective of image segmentation is to divide the given image in to salient image regions, meaningful region, and homogeneous with specific cluster pixel. In addition, the image segmentation is applied to various application domains includes: object recognition, occlusion boundary estimation within motion or stereo systems, image compression, image editing, or image database look-up. A good segmentation of an image can be defined by: (i) pixel in the same region or categories has similar or equal pixel colour/intensity and (ii) the neighbouring pixel in different categories has different values or dissimilar values.

Although image segmentation is one of the main process in image processing, but it has many algorithms to apply with based on the different kind of work. Some of existing image segmentation methods are presented here: (i) threshold-based segmentation, (ii) region-based segmentation and (iii) edge-based segmentation. The brief detail for each method is discussed as follow:

Threshold segmentation

Threshold-based segmentation is one the existing methods for image segmentation. The separation of bright and dark region is the main objective of threshold segmentation. In general, thresholding is applied to create the binary image. For all pixel of greyscale image is calculated by comparing each pixel with threshold (T). If the intensity values is below than threshold the pixel which make from grey-level ones by turning all pixels that below threshold become zero (0) and if pixel is above threshold the pixel become one (1). For example: if I(x,y) is a threshold version of i(x,y) at some global threshold T, as Equation 1.1 belows:

$$I(x,y)=\begin{cases} 1 \text{ if } i(x,y) \geq T \\ 0 \quad \text{otherwise} \end{cases} \qquad 1.1$$

Threshold-based segmentation has a drawback which is only the pixel value is used to consider on other hand no relationship between the pixels is examined. Therefore, there is no any guarantee that the pixels identified by the thresholding process are contiguous.

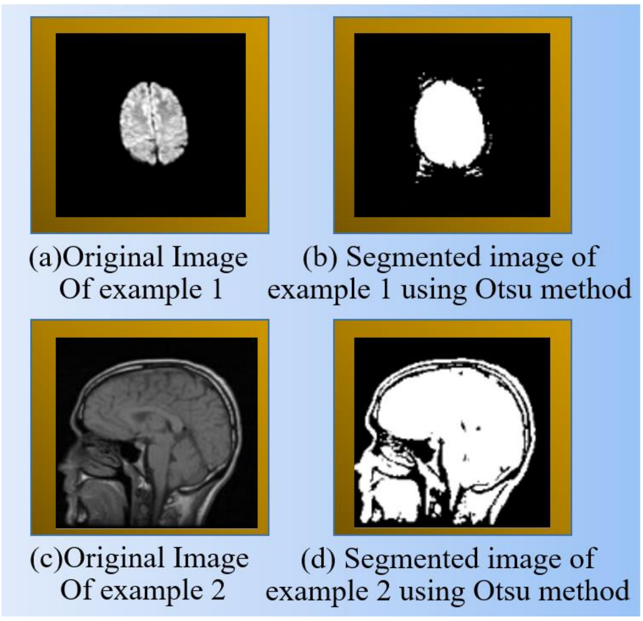


Figure 2.6 The human brain scan using Otsu method [20].

There are many applications using threshold mechanisms were proposed for medical image segmentation. In [20] the implementation of Otsu method to improve medical image segmentation. Otsu method is a method to reduce the greyscale to a binary image, the result shown that the method performs better than other thresholding methods with a good binary images. Otsu threshold method is a very good and efficient method to threshold the greyscale image. However, the drawback of this method is high complexity of the computation. Figure 2.6 (a) and Figure 2.6 (c) shows the original of human brain scan, while Figure 2.6 (b) and Figure 2.6 (d) presents the corresponding segmented image using Otsu method.

Local adaptive thresholding also is applied in [21]. The work reported the implementation of local adaptive threshold technique to removes background using local mean and standard deviation. The comparative study between Niblack and Sauvola local thresholding had been evaluated. The results shown that the Niblack local threshold algorithm reduced the background noise better than Sauvola local threshold algorithm. Figure 2.7 shows the difference of five sample sub-images between two different methods: Niblack technique and Sauvola technique.

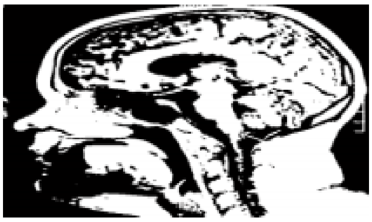
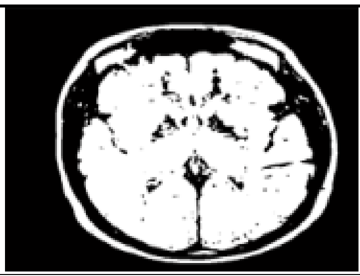
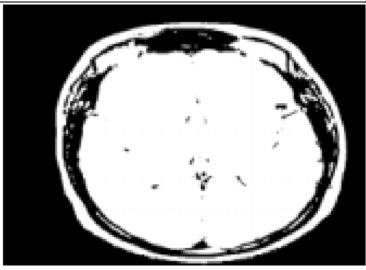
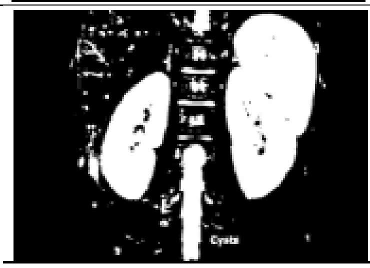
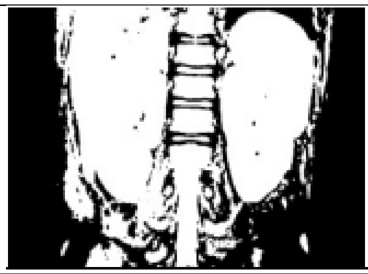
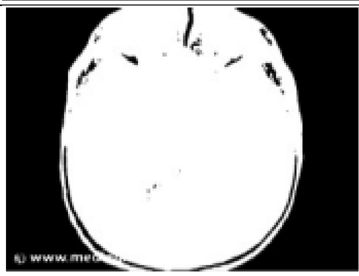
Images	Using Niblack Technique	Using Sauvola Technique
Image 1		
Image 2		
Image 3		
Image 4		
Image 5		

Figure2. 7 Example of The comparison of five medical images by using Niblack and Sauvola Technique [21].

Region based segmentation

Region-based segmentation is one of image segmentation techniques. The main objective is to find coherent regions in the image. The coherent region contains pixels that has same or some similar property. The transitivity of the similarity relationship in the image is considered. Region-based segmentation offers the advantages on (i) fast processing and (ii) more efficient than edge-based and threshold-based method. However the region-based also has the drawback concerning it probably grow further away from global pixel because it drifts as one. There are many existing region-based segmentation algorithms for example watershed segmentation, flooding-based watershed segmentation, marker-controlled watershed segmentation and inter-pixel watershed segmentation. The implementation of watershed segmentation in the context of medical image with texture-based region merging was proposed in [23]. The work in [33] reported the texture-based region merging was applied to MRI images in order to improve the segmentation efficiency. The comparison of images using watershed segmentation with/without text-based region merging and with texture-based region-based region merging is illustrated in Figure 2.8.

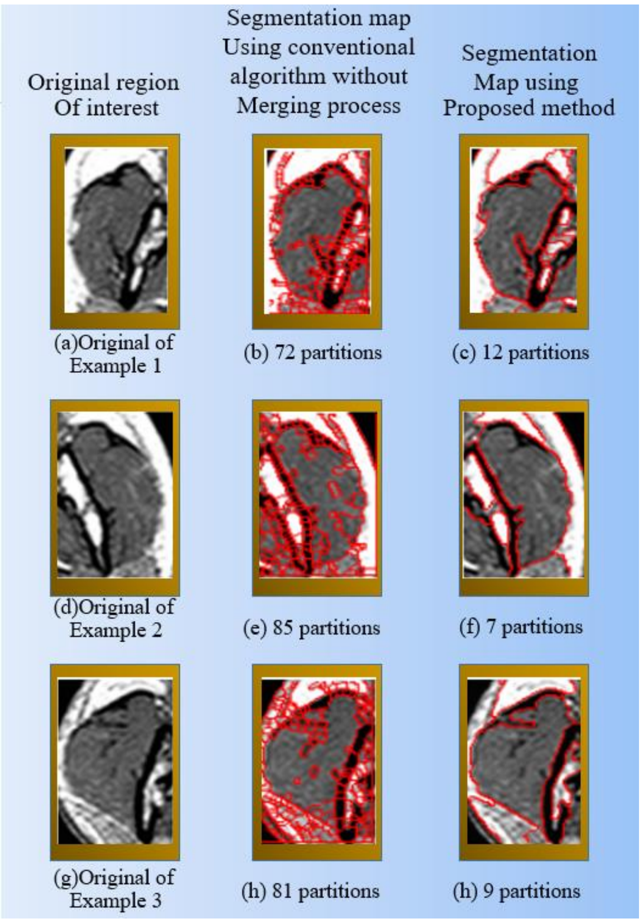


Figure 2.8 The comparison of image using watershed segmentation with/without texture-based [23]

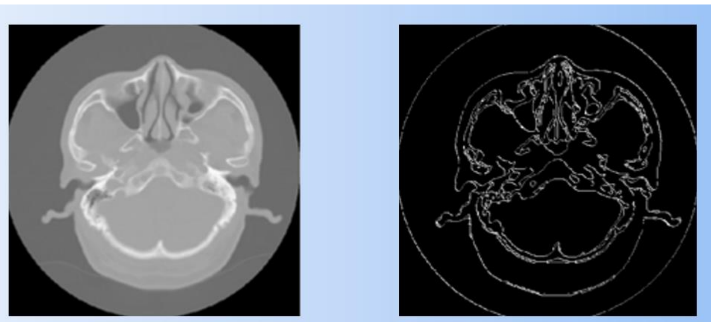
Edge based segmentation

In edge-based segmentation mechanism focuses on the edge in an image. The edge corresponds to singularities in the images. The edge in image generally represents as the shape of objects in the scene. The purpose of edge-based segmentation is to extract the edge or line in the image with good orientation. There are some existing edge operators for example Gradient operator, Prewitt operator, Sobel operator, Compass operators and Laplacian operator. Figure 2.9 shows the Prewitt and Sobel operator.

	(a) Prewitt operator	(b) Sobel operator
Verticel	$\begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix}$	$\begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}$
Horizontal	$\begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix}$	$\begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix}$

Figure 2.9 Prewitt and Sobel operator for edge detection

With the respect to the edge detection in the context of medical image segmentation, it can be found in [24]. The edge detection was applied to the brain scan images to detect the tumour regions based on the gradient magnitude information. The example image after applied the edge detection is shown in Figure 2.10.



(a) Original brain scan image

(b) The processed image using edge detection

Figure 10 The examle of brain scan image using edge detection [24]

From Figure 2.10 (a) shows the original brain scan while Figure 2.10 (b) illustrates the brain scan image after the edge detection was applied.

2.3.2 Image Enhancement

Image enhancement is one of the most important and complex techniques in image processing. The fundamental idea of image enhancement mechanism is to improve visual appearance of an image, or to present a better transform representation of the image. The main challenge in image enhancement is quantifying the criterion for enhancement.

There are some varies types of image such as personal images, medical images, satellite images and aerial images. The photographers/users/viewers probably suffer from some image quality problems such as poor contrast and noise. Therefore image enhancement plays the main role to enhance the contrast and remove the noise to increase image quality. During image enhancement process an input is an original image and the output also an image with better than the input image by changing the pixel intensity. Furthermore, image enhancement works as the important roles in many kinds of image for example hyper spectral image processing, remote sensing, high definition television (HDTV), industrial X-ray image processing, microscopic imaging, other image/video processing applications and medical image processing [25].

In addition image enhancement technique can be used to increase dynamic range of the chosen features in of an image such as point operation, spatial operation, transform operation and pseudo colouring. There are some existing methods of image enhancement for example: filtering with morphological operators, histogram equalization, noise remove using a Wiener filter, linear contrast adjustment, median filtering, unsharp mask filtering, contrast-limited adaptive histogram equalization (CLAHE) and decorrelation stretch.

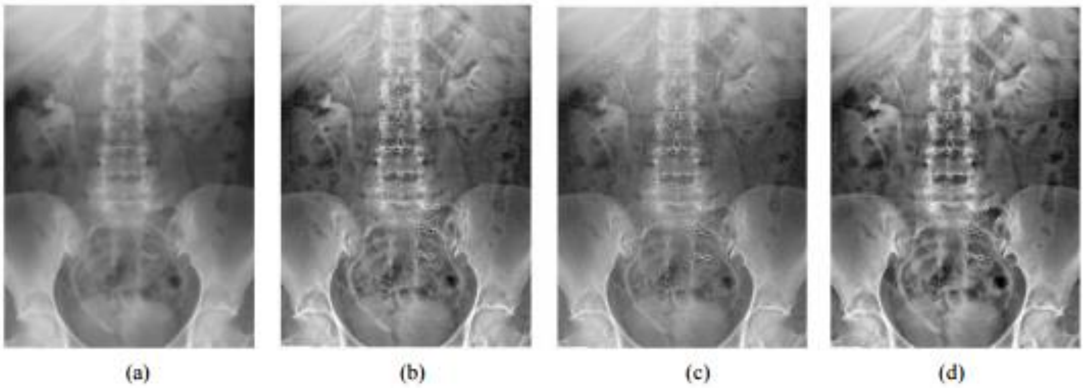


Figure 2.11 The example of X-ray image of renal system using morphological transform [26]

In the context of medical image, image enhancement also applied in many applications. Morphological transform was applied to medical images [26]. The work reported on using a disk shaped mask is used in Top-Hat and Bottom-Hat transform in order to remove noise and increase the contrast quantity in medical images. Figure 2.11 shows the morphological transform was used in X-ray of renal system. Figure 2.11 (a) presents the original image. Figure 2.11 (b) illustrates optimum enhanced image. While Figure 2.11 (c) and Figure 2.11 (d) shows the transformed image with different radius using Carrier-to-noise ratio (CNR) and Peak signal-to-noise ratio (PSNR), respectively.

2.3.3 Feature Extraction or Image Representation

The fundamental information of feature extraction or image representation is presented in this sub-section. In image processing, feature extraction is the main rule for measuring the data and builds derived values (features) in order to find a good data representation. The objective of feature extraction in digital image is to reducing the amount of resources which required to describe a large set of data. Feature extraction is directed relation to dimensional reduction; dimensional reduction is the process of reducing the number of random variables under consideration [27]. With the respect to dimensional reduction there are some existing techniques including: Independent component analysis, isomap, principal component analysis (PCA), kernel principle component analysis, latent semantic analysis, partial least squares, multifactor dimensionality reduction, nonlinear dimensionality reduction, multilinear principal component analysis, multilinear subspace learning, Semidefinite embedding, autoencoder and deep feature synthesis.

However in the context of image representation or feature extraction in digital images can be done using various using image properties. There are three main image properties including: (i) colour, (ii) texture and (iii) shape. The detail of each image feature extraction technique is described as follows:

Colour analysis

Colour is simplest features in digital image. It makes an image is more colourful and more interesting to human view [92]. The colour analysis for image representation is a technique that can use widely with RGB image. RGB image is one type of digital image which contain RGB color system; RGB system refers to the system that representation in Red, Green and Blue through computer display view. The level of red, green and blue can range from 0 to 100 percent of full intensity. For each level of red, green and blue is represented by the range of decimal numbers from 0 to 255 (256 levels for each colour), or to be a binary is 00000000 or 11111111. RGB also know as true colour image. With respect to digital image which store as an m-by-n-by-3 (m x n x 3) data array that defines red, green, and blue colour components for each individual pixel. The purpose of colour image analysis is to define or calculate the percent of each colour has contained in an image.

Texture analysis

The texture analysis concerns with description of characteristic image properties by textural features. Texture analysis [28,29] is an important approach for describing the region. Texture can be divided into three categories: (i) statistical methods (a collection of statistic that used to described of texture), (ii) structural methods (texture is viewed as consisting of many texels arranged according to some placement rules) and (iii) model based methods (used probability model to modelled the image textures). A number of existing texture analysis models has been proposed including autoregressive model, Gausian Markov random field, Gibbs random fields, Wold model, wavelet model, multichannel Gabor model and steerable pyramid.

Texture analysis is also implemented in the context of medical image. The example is found in [11] the long rage, standard deviation and greyscale entropy texture analysis techniques were applied to X-ray images to detect OA and non-OA, the Haralick feature was calculated in order to measure the texture image in term of contrast, correlation, sum of square, sum of average and homogeneity.

In [19], Frequency Filtering texture analysis was applied using Fourier transform to calculate filter data as the Equation 2.2

$$V\tilde{D} = F * VD \qquad 2.2$$

where

$V\tilde{D}$ is the filter data from the convolution theorem.

F is the filter in the spatial domain.

The examples various filters are illustrates in Figure 12 including: (i) Low pass filter (Figure 2.12 (a)), (ii) High pass filter (Figure 2.12 (b)) and (iii) Band pass filter (Figure 2.12 (c)). The results after applied given filters to human knee MRI image are presented in Figure 2.12 (d), Figure 2.12 (e) and Figure 2.12 (f), respectively.

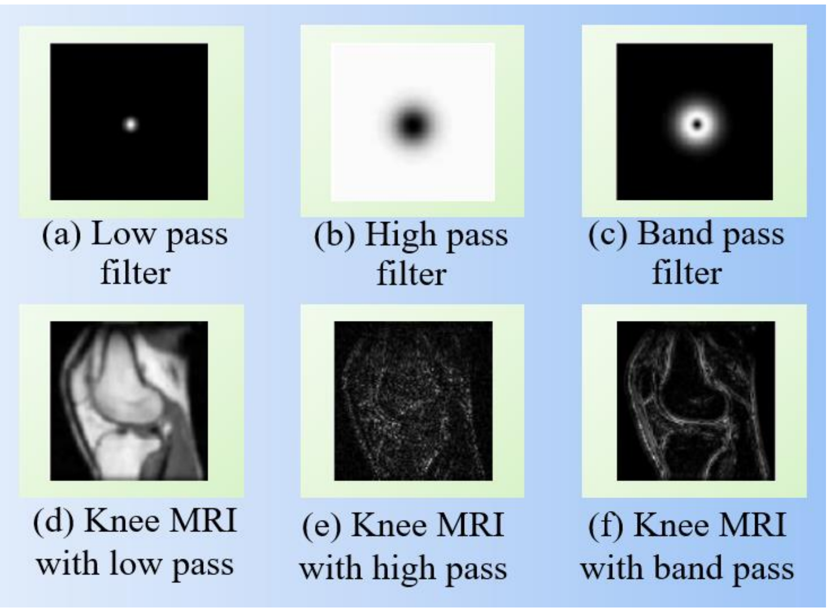


Figure 2.12 The example of various filters applied to MRI of human

Texture analysis

Shape analysis is directed to study the edge of shape feature in image. Shape refers to all the geometrical information that remains when location, scale and rotational effects are filtered out from an object [30]. Shape is any connection of point in the image. The example of the existing shape analysis mechanisms including: point distribution, active shape, active appearance models, Fourier Snakes, active contours and parametrically-deformable models. The shape analysis was applied in the context of medical image in many literatures. With respect to the work in this research is directed to Knee OA. There are some examples found in [9, 18, 31].

In [9] the shape analysis was used to calculate the thickness between the bone and joint space in knee. Thickness was calculated and found that in the range of 1.69 mm to 2.55 mm was non-OA. In contrast if the thickness is less than 1.69 mm then the symptom of OA was possible. Figure 13 shows the cropping image and applies with binary operation to make edge detection in order to detect the boundary between the bone and joint space.

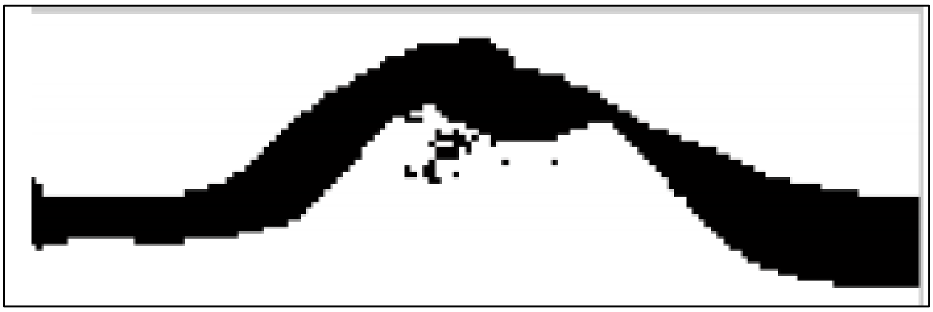


Figure 2.13 Cropping the image and apply in binary operation [9]

With the respect to the work presented in [31], the shape analysis was applied to calculate the area of cartilage. The initial step was the pixel-based segmentation is used to segment the cartilage. The texture filtering was then applied to calculate the area of cartilage by the number of pixel as presented in Figure 2.14.

Figure 2.14 MRI image of knee after the texture filtering [31]

In summary, the image segementation, image enhancement and image representation are the three main process in digital image processing. With the respect to the work presented in this thesis the image segementation, enhancement and representation were applied as the pre-procesing process. The next section is 2.4 image classification is discussed.

2.4 Image Classification

The basic information of image classification is presented in this section. With the respect to this work in this thesis the image classification mechanism is commenced. The fundamental idea of data mining is presented in Sub-section 2.4.1. Sub-section 2.4.2 suggests the detail of image classification and finally, Sub-section 2.4.3 presents the brief detail of classification learning methods.

2.4.1 Data Mining

Data mining is the process of discovering and searching insightful, interesting, useful, as well as descriptive, understandable and predictive models from large-scale data [32]. Data mining considered as the non-trivial of novel, implicit and actionable knowledge from large datasets. The alternative terms refer to knowledge mining from database, knowledge extraction, data analysis and data archaeology.

In addition, data mining is considered as the core element in the knowledge discovery in database (KDD) process .The phase knowledge discovery in database was suggested in the first KDD workshop in 1989. The KDD processes including data selection, data cleaning, data transformation, pattern searching (data mining), patterns/finding evaluation, data visualization and knowledge representing.

In [33] KDD consists of five processes: (i) Selection, (ii) Preprocessing, (iii) Transformation, (iv) Data mining and (v) Interpretation and evaluation as shown in Figure 2.15. From the Figure 2.15 can be observed that the KDD is a five-process mechanism. During selection process a large collection of data is selected. Once data selection is completed, the transformation process is then concerned in order to prepare appropriate data format to be ready for the data mining process [33]. During the data mining process, the data mining algorithms or techniques are implemented. When the pattern or hidden information is delivered the interpretation and evaluation process is applied to get the accurate knowledge.

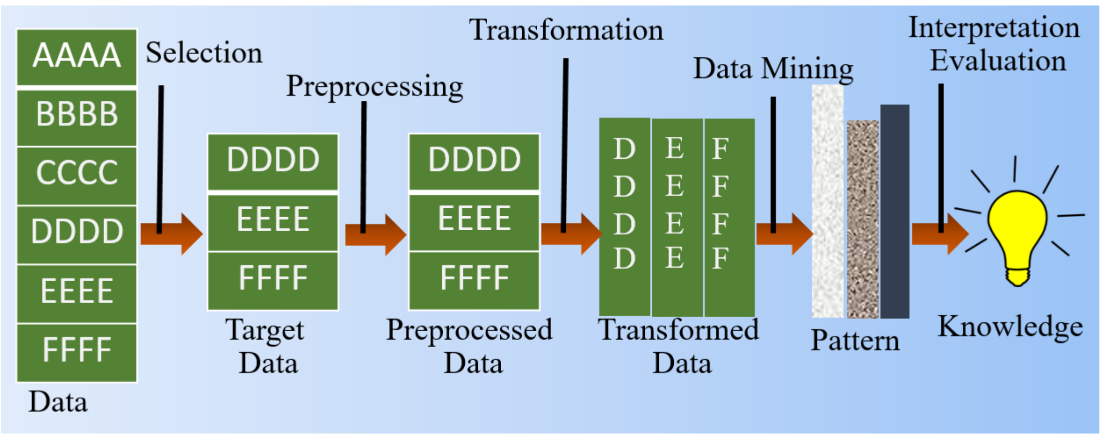


Figure 2.15 KDD process for producing the knowledge.

Data mining can be divided into two categories: (i) predictive data mining and (ii) descriptive data mining. Predictive data mining concerns with the prediction of behaviour based on historical data. In contrast descriptive data mining is directed at the discovery of patterns in existing data in order to use as the guideline for making the decision in the future.

In [34] presented the tasks of data mining. In general data mining task is divided into three main categories: (i) Classification, (ii) Association and (iii) Clustering.

Classification is the process of finding a model that describes the data classes or concepts based on its properties. The aims of classification is to be able to use the derived model in the prediction of unknown objects. More spacifically, classification model can be used to classify the unknown class or future object and develop the classes of the objects in the database in order to get more understanding.

Association is the discovery which use to find the familiarity of identified patterns that are frequently occur together. Association rule reveals the associative relationship among the objects [34], for example: Tesco Lotus Phuket generates an association rule that shows that 50% of time milk is sold with bread and only 20% of times biscuits are sold with bread.

Clustering is the process to group of similar kind of objects. Clustering analysis refers to forming group of objects that are very similar to each other. On the other hands, they are highly different from the objects in other clusters.

In the context of image data, image mining is then suggested. Image mining is one of a form of data mining which dealing with the extraction of implicit knowledge, image data relationship or other patterns not explicitly stored in a collection of images [35]. Image mining consists of multiple components [35] such as: image analysis, image classification, image indexing, image retrieval and data management. The component of image mining is presented in Figure 2.16.

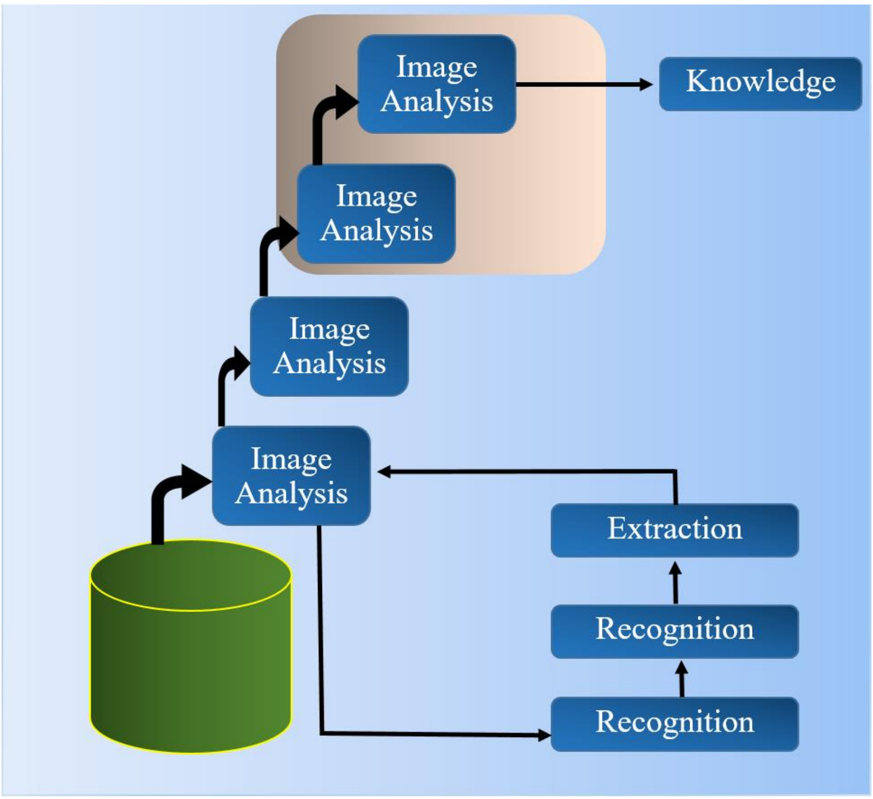


Figure 2.16 Traditional image mining process

2.4.2 Image Classification

Image classification is a branch of image analysis. It refers to classify an image by separate or group the similarity properties from the image into the same category.

With respect to digital image the image classification technique is applied to assign digital image to classes or categories using the image properties. Image classification is also widely used in medical image and remote sensing. Pattern recognitions is another cornerstone in computer science to help image classification classify an image, p¬attern recognition can be finding the similarities or patterns among small, decomposed problems that help to classify the complex image. In general, pattern recognition consists of three steps: (i) spectral pattern recognition (use spatial context to distinguish between different classes), (ii) spatial pattern recognition (used spectral reflectance in the different waveband to distinguish between different classes) and (iii) temporal pattern recognition (use variations in image over time to distinguish between different classes).

Image classification process, the initial step is a collection of image (known-classes) is used as input data to generate the classification model which can be used to predict the class of unseen data in the future.

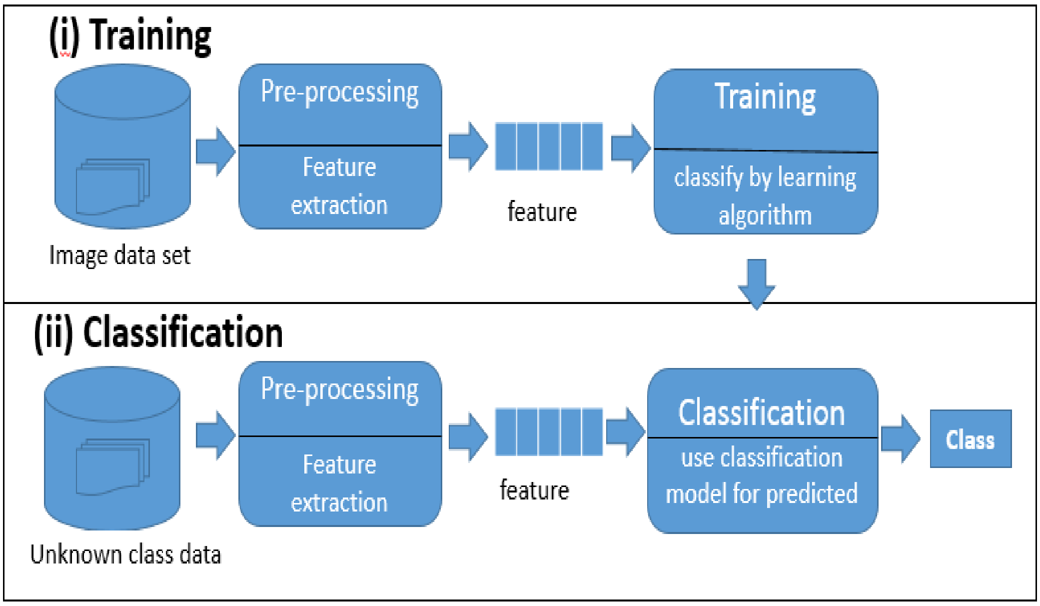


Figure 2.17 Image classification process

Image classification process is presented in Figure 2.17. From the Figure 2.17, image classification is a two sub-process: (i) training and (ii) classification.

During the training process a collection of image data is applied using pre-processing process to enhance the quality of image and segment the area of interest. The feature extraction is then applied resulting in a feature vector format. The next step is a classifier generation, which classification learning methods are applied to construct the desired classifier. The training data set used in training process, the pre-label record that typically represented by using an n-dimensional feature vector representation which in turn a set of attribute values and a class label $\{i_1, i_2, \ldots, i_{n-1}, c_n\}$ where i_i is an attribute value and c_n is a class label that $c_n \in C$.

Once the classifier has been generated, the second process is classification. In this process the generated classifier from training process is applied to the unknown/unseen image data in order to classify/predict the data class.

As noted above image classification technique consist two main processes where in the classification application process need to predict on the usage of discrete class label.

2.4.3 Classification Learning Methods

As mentioned before the work presented in this thesis is concerned to image classification. There are nine classification learning methods are presented in this sub-section: (i) Decision Tree, (ii) Binary Split Tree, (iii) Average One-Dependence Estimators, (iv) Bayesian Network, (v) Naïve Bayes, (vi) Support Vector Machine, (vii) Logistic regression, (vii) Sequential Minimal optimization, and (ix) Back Propagation Neural Network.

Decision Tree

Decision Tree [37] is considered as the most popular and widely use for classification learning methods. A decision tree is a mechanism to classify which is a recursive partition a collection of instances. Root tree is considered as the top node of the decision tree. In other words, decision tree is a classifier which instance by sorting them downs the tree from the root to some leaf node (also known as terminal or decision nodes). Root node is a direct tree with a node that has no coming edges. Every other node has exactly one coming edges. An internal or test node is the node that outgoing edge. In general, test node splits the instance space into two or more sub-spaces according to a certain discrete function of the input attributes values. Figure 2.18 illustrates the decision tree for the direct mailing response.

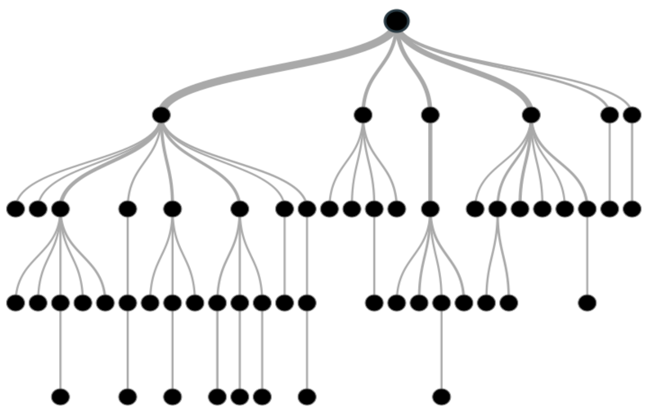


Figure 2.18 Response to Direct Mailing Decision Tree.

Binary Split Tree

Binary split is the improvement of decision tree. Each node of binary split tree contains only two values (binary 0-1). The purpose of designing binary split tree is to store the statistic datasets. The split tree is a subset of decision tree while each node of a decision tree contain multiple values. The further search in the tree is used by the split value in the split while the key value is not matched to the search value. The example of binary split tree is presented in Figure 2.19:

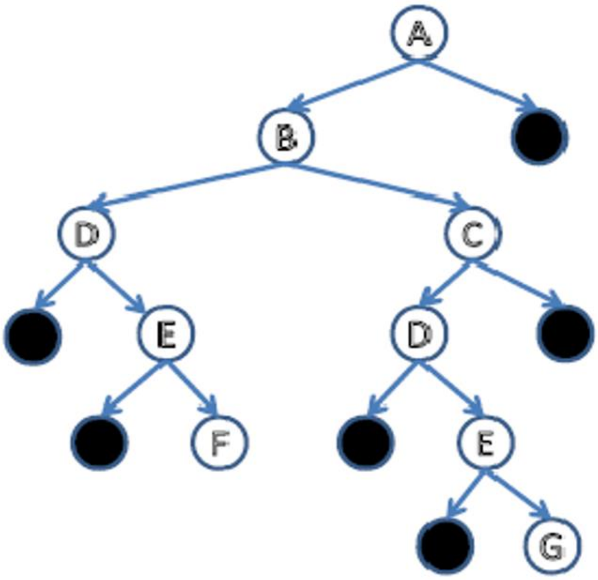


Figure 2.19 Binary Split Tree

Average One-Dependence Estimators

Average One-Dependence Estimators (AODE) is presented in this subsection. AODE is a probabilistic classification learning technique, AODE has improved from the Naïve Bayesian classifier [38] by addressing the problem of attribute-independence. For example, in the class of y, which has a set of features $x_1,...,x_n$, AODE can be applied to find the probability of each class y by using the following equation:

$$\hat{P}(y|x_1, \dots, x_n) = \frac{\sum_{i:1\le i\le n \wedge F(x_i)\ge m} \hat{P}(y,x_i) \prod_{j=1}^{n} \hat{P}(x_i|y,x_i)}{\sum_{y'\in Y} \sum_{i:1\le i\le n \wedge F(x_i)\ge m} \hat{P}(y',x_i) \prod_{j=1}^{n} \hat{P}(x_i|y',x_i)} \quad 2.3$$

where

$\widehat{P}$ is an estimate of P

F is the frequency

m is a user specified minimum frequency.

Bayesian Network

Bayesian Network (BN) or Probabilistic Networks (PNs) is discussed in this subsection. BN is consider as a graphical probability model which can be used for reasoning and the decision making in uncertainty [39]. In addition, the BN have been applied as a directed acyclic graph (DAG) and each node of BN represents a domain variable or dataset attribute. BN formally work depend on the Bayes rule while the The Bayes' rule can be written as the equation below:

Assume, there are Ai attributes where i= 1,...,n, and take value a_i where i= 1,...,n . Assume there is C as class label attribute and U= (a_1,..., a_n) as unclassified test instance. Hence, U will be classified into class C based on Bayes rule is represented as:

$$P(C|U) = \arg\max P(U|C) \qquad 2.4$$

Naïve Bayes

Naïve Bayes has been widely implemented in clustering and classification. Naïve Bayes sometime called idiot Bayes, simple Bayes or Bayes classifier. The Bayes theorem is used in Naïve Bayes for prediction both in classification and clustering. The Bayes theorem is shown as the equation (6) below:

$$\mathrm{P} = \frac{p(d|\, c_i)\, p(c_i)}{P(d)} \qquad 2.5$$

where

$p(c_i|d\ )$ is the probability of instance d being in class c_i,

$p(d|\ c_i)$ is probability of generating instance d given class c_i,

$p(\ c_i)$ is the probability of occurrence of class c_i

$p(d)$ = probability of instance d occurring.

Support Vector Machine

Support Vector Machine (SVM) is a popular classification method that has been widely applied for the classification task. The main used of SVM is to separate instances of two classes by constructing an N-dimensional hyperplane amount of two training sample classes in the feature set for the most optimal way[40]. SVM classifiers formally divided into two groups: (i) linear and (ii) non-linear.

- Linear Classification

  In linear classification, the SVM can be divided into two types of classification: (i) linearly separable case, and (ii) non-linearly separable case. In the linearly separable case, SVM with the training data x_i, y_i, $y_i \in$-1,+1, i = 1,...,n, can be written as the equation below:

$$\begin{cases} x_i.\omega + b \ \geq +1 & for\ y_i = +1 \\ x_i.\omega + b \ \leq -1 & for\ y_i = -1 \end{cases} \qquad 2.6$$

  For non-linearly separable, the SVM is defined as below equation:

$$\begin{cases} x_i.\omega + b \ \geq +1 - \xi_i & for\ y_i = +1 \\ x_i.\omega + b \ \leq -1 + \xi_i & for\ y_i = -1 \\ \xi_i \geq 0, \quad i = 1, n & \end{cases} \qquad 2.7$$

- Non-Linear Classification

In non-linear SVM classification, SVM is defined as:

$$f(x) = \sum_{i=1}^{n_s} \alpha_i y_i \, P(x_i, x) + b \qquad 2.8$$

where

n_s is the number of support vector.

α is non-negative Lagrange multipliers

P (x, y) is Polynominal of degree m: $k(x,y)=(x.y+1)^m$

Logistic Regression

Logistic regression is a statistical method which used to analyse a dataset. The dataset can be one or more independent variables which determine an outcome. The outcome is measured with a dichotomous variable (dependent variable normally is binary or dichotomous). The purpose of logistic regression is to discover the best fitting model for evaluating the relationship between a set of independent variables (predictor) and the dichotomous characteristic of interest (Outcome variable). Logistic regression provides the formula to predict a logit transformation of the probability as the Equation 2.9, where p is the probability of presence of the characteristic of interest.

$$logit(p) = b_0 + b_1X_1 + b_2X_2 + b_3X_3 ... + ... b_kX_k \qquad 2.9$$

Sequential Minimum Optimization

Sequential Minimal optimization (SMO) is a computer algorithm which is used to solve the quadratic programming (QP) problem that happen during the training of support vector machines (SVM). In order to solve the SVM QP problem, SMO decomposes SVM QP problem into QP sub-problems then solves the smallest possible optimization problem which involves two Lagrange multipliers, at each step. In other words, SMO algorithm can search with feasible region of two kind or type of problem then maximize the objective function. In other words, by using Lagrangian, this QP problem can be converted into a dual where the objective function Ψ is solely dependent on a set of Lagrange multiplier α_i. The equation of Lagrange is presented in Equation 2.10:

$$\min \Psi(\vec{\alpha}) \equiv \sum_{i=1}^{N} \alpha_i - \frac{1}{2}\sum_{i,j} \alpha_i\alpha_j y_i y_j x_i x_j \qquad 2.10$$

where

N is the number of training examples

Back Propagation Neural Network

Back Propagation Neural Network or Back Propagation is a computer algorithm/system which sets the model design as the human brain and nervous system. Back propagation is a mechanism used in artificial neural networks to calculate a gradient that is needed in the calculation of the weights to be used in the network. Back propagation is commonly used to train deep neural networks,[41] a term referring to neural networks with more than one hidden layer. Figure 2.20 is illustrated the general mechanism of Neural Network that has Back propagation to train in deep neural network:

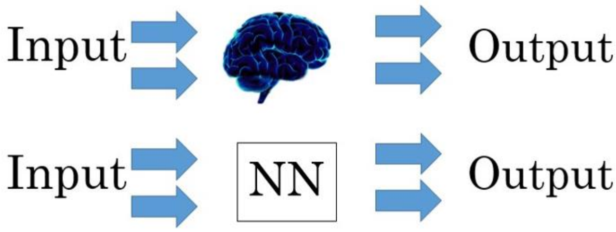


Figure 2.20 The example of Neural Network mechanism

In the Neural Network (NN) consists of three layers: (i) input, (ii) hidden, and (ii) output. For Back propagation is use to train in neural for learning. In other word, in the case of learning in NN, back propagation is commonly applied by the gradient descent optimization algorithm in order to adjust the weight of neurons by measuring the gradient of the loss function. This method is sometime known as backward propagation of errors, because the error is measured at the output layer and distributed back through the network layers.

2.5 Feature Selection Methods

In this section feature selection is described. Feature selection consider as the main process in the research study in order to make a feature vector which is very important for the classification process. The main use of feature in the research study is to reduce data dimensionality for making the feature vector. In the study, there are five feature selection techniques are applied, including: (i) Correlation-based Feature Selection (CFS), (ii) Chi-Squared, (iii) information gain, (iv) Gain Ration, and (v) Relief feature selection.

1. **Correlation-based Feature Selection**

Correlation-based feature selection is a techniques used to reduce the feature space that applied a heuristic search for evaluation the worth of feature subsets. In work [56] and [57] reported that CFS used the heuristic search for calculation the evaluation of feature subsets that based on the hypothesis “Good feature subsets contain features highly correlated with the classification, yet uncorrelated to each other”. In order to reduce the feature space, CFS used Symmetric Uncertainty. The fooling equation is defined as the Symmetric Uncertainty equation of two nominal attributes A and B:

$$U(A,B) = 2\,\frac{H(A)+H(B)-H(A,B)}{H(A)+H(B)} \qquad 2.10$$

where

H is the function of entropy

With the reference to Equation 2.10, CFS can be forms as the equation below:

$$CFS = \frac{\sum_{i=1}^{n} U(A_i,C)}{\sqrt{\sum_{i=1}^{n}\sum_{j=1}^{n} U(A_i,A_j)}} \qquad 2.11$$

where

C is the class of the feature

(A_i,A_j) is the indicates a pair of attributes

2. Chi-squared

Chi-squared is used to measure the relationship of dependency between a feature and a class [58]. Chi-squared is represented as χ^2 symbol and defined as the equation below:

$$\chi^2 = \sum_{i=1}^{c}\sum_{j=1}^{r} \frac{(O_{ij} - E_{ij})^2}{E_{ij}} \qquad 2.12$$

where

O_{ij} represent as the observed frequency

E_{ij} represent as the expected frequency

3. **Information Gain**

Information gain or IG is considered as one of the popular feature selection techniques. The implementation of IG is for selecting the test attribute at each node. IG can measure the number of information in bits to the class prediction while the available information present as a feature and class distribution [59]. For instant, if IG of a feature s directly related to a collection aspects B, thus IG can be represented as the equation below:

$$IG(B,s) \sum_{v \in Values(s)} \frac{|B_v|}{|B_s|} Entropy(B_v) \qquad 2.13$$

where

Values(s) presents as the set of all possible feature values s

$|B_v|$ presents as the cardinality to the subset of class related to feature s

$|B_t|$ presents as the cardinality to the set of aspects belonging to feature s

4. **Gain Ratio**

Gain ration (GR) is presented in this sub-section, an extension of IG is considered as gain ration technique. The implementation of decision tree in IG for one reason is to select the test attribute of each node [60]. Thus, the applying of GR to make IG better performance by choosing an attribute by token number and size of branches. In other words, GR is implemented to IG in order to reduce the bias of IG on each branch. GR is written as the equation below:

$$GR(attribute) = \frac{Gain(attribute)}{Entropy(attribute)} \qquad 2.14$$

5. **Relief**

Relief feature is considered as the last technique is presented in this sub-section. Relief first introduce in work [61]. Relief is the weight based algorithm that the related features are consider as the one who has a better distinction between the classes [62]. In order to understand the relief, a sample of dataset is selected, the nearest neighboring sample that belongs to the same class is called ‘Near-hit’. On the contrary, the nearest neighboring sample that belongs to the opposite class is called ‘Near-miss’. The relief measure these two weights: (I) Near-hit and (ii) Near-miss. In addition, all reiterations of M times, relief takes the feature vector of X that belong to random sample of Near-hit and Near-miss. After M iteration has gone, relief separates each item of the weight vector by M, thus, the relevance vector is created. Finally, the selected feature gets from the features that have relevance value greater than a threshold T value.

2.6 Deep Learning using Convolutional Neural Network

The implementation of deep learning in medical image analysis is presented in this sub-section. Deep learning is one of the mechanism in machine learning which is directed to the algorithm of brain structure and function called artificial neural networks. In other words, deep learning is considered as a technique developed from the artificial neural network which was inspired from human brain neurons connected system. The application of deep learning has been widely use in computer vision technology including: image classification, object detection, and image segmentation. Deep learning model is known as the well-known applications of deep learning, of those deep learning model is Convolutional Neural Network (CNN) [42]. CNN is a deep learning techniques that used for image classification. With the respect to the purposed of study, CNN have been applied to various type of medical image. For example, the latest study have been shown that deep learning are very efficient to medical image approach [8, 43, 44, 45, 46]. The Implementation of CCN to brain MR image for segmented brain into a number of classes is presented in [47]. In work [48] presented the brain tumors segmentation with MR image with small 3x3 kernel of CNN. For knee application, in work [49] have presented the knee tibia cartilage segmentation from MR image scan and tested on 114 unseen scans. The further information of CNN used with respect to work in this thesis is discussed in Chapter 6.

2.7 Evaluation and Measurement

To evaluate the classification performance for the generated classifier, the evaluation measure is applied. With the respect to the work presented in this thesis, the classification performance was recorded in term of (i) Accuracy (AC), (ii) Sensitivity (SN), (iii) Specificity (SP), (iv) Precision (PR), and (v) F-Measure (FM). The evaluation measurement is discussed further detail as follow. The confusion matrix and some evaluation measures calculating from confusion matrix is presented in 2.7.1. The basic idea of AUC is discussed in 2.7.2.

2.7.1 Confusion Matrix

The confusion matrix is used to measure how well of applied data mining algorithm perform on a given data set. It can help to find out which data mining algorithm give the best performance or the worst performance. The confusion matrix is performed about the predict class (predict value) and actual class (actual value), Table 2.2 presents the confusion matrix.

Table 2.2 Confusion Matrix

		Predicted Class	
		True	False
Actual Class	True	TP	TN
	False	FP	FN

From the Table 2.2, TP stands for True Positive rate used to measure the proportion of correctly identified positive test records. TN refers to the True Negative which used to measure the proportion of correctly identified negative test records. The FP is False Positive rate which used to measure the proportion of incorrectly identified positive test records and FN stands for False Negative which use to measure the proportion of incorrectly identified negative test records. There are a number of evaluation measures based on the confusion matrix including: (i) Accuracy, (ii) Sensitivity, (iii) Specificity, (iv) Precision, and (v) F-measure. The equation for each measure is presented in the Equation 2.11 to Equation 2.15, respectively.

$$Accuracy = \frac{TP+FN}{TP+TN+FP+FN} \quad 2.15$$

$$Sensitivity = \frac{TP}{(TP+FN)*100} \quad 2.16$$

$$Specificity = \frac{TN}{(TN+FP)*100} \quad 2.17$$

$$Precision = \frac{TP}{TP+FP} \quad 2.18$$

$$F - measure = 2\frac{Precision*Recall}{Precision+Recall} \quad 2.19$$

where $$Recall = \frac{TP}{TP+TN} \quad 2.20$$

2.7.1 Area Under Curve

Area under curve (AUC) is considered as the best method for indicating the overall quality of the classifier [36]. The AUC can be calculated from Receiver operating characteristic (ROC) graph. ROC graph is a two-dimensional plot of the TP rate as the y-axis and the FP rate as the x axis [36]. The ROC graph is shown in Figure 2.21.

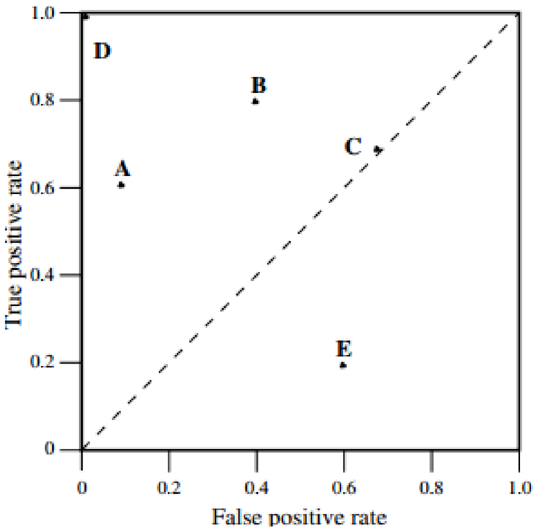


Figure 2.21 The ROC graph with five discrete classifiers [36]

From Figure 2.21 the lower left point (0, 0) is the point that a classifier perform no false positive errors but also gets no true positives. On the contrary, the upper right point (1, 1) is the point that a classifier perform full false positive errors but also gets full true positives. Thus, amounts five classifiers A-E, D's perform the best one due to the full of true positive rate.

AUC refers to the area under the ROC curve. Figure 2.22 presents the AUC in ROC graph which the random value from 0.0 to 1.0 in probabilistic classifier.

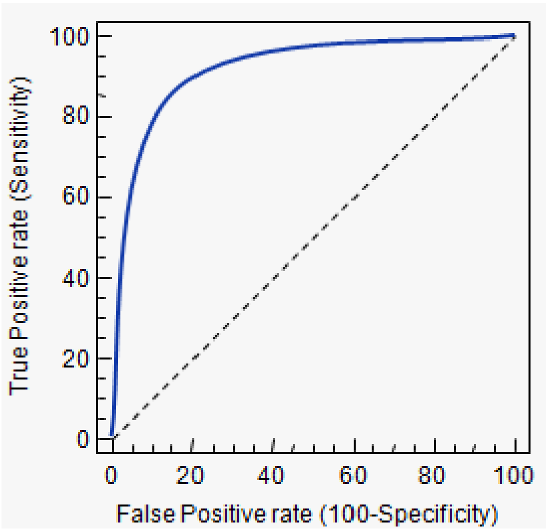


Figure 2.22 Area Under ROC Curve (AUC) [36]

2.8 The Comparison of related work

This section the comparison of previous or related works, typically OA detection, is discussed in this section. Table 2.3 presents the comparison of related works in this research study:

Table 2.3 The comparison of related works

Previous work	**Image Types**	**Osteoarthritis detection**	**Osteoarthritis Stage Detection**	**Accuracy/result, methodology**
Sanjeevakumar Kubakaddi [18]	MRI		Just classified (KOA, Normal and Doubtful KOA)	Calculate the thickness of cartilage (Shape analysis).
Mahima Shanker Pandey [9]	X-ray	Detect by shape analysis		Calculate the thickness of cartilage with the rate of result is higher than 65% (Shape analysis).
Lior Shamir [10]	X-ray		Bone texture of cartilage	by comparing the value of each stage and another prediction use the values of predicted example to lower than the certain value.

Table 2.3 The comparison of related works (Continue)

Shivanand [11]	X-ray	OA/ Non OA detection by using different technique of classification		The result provides 87.92 % by using different features calculations such as shape, statistical, first-four moment texture and Haralick texture.
Chao Jin [50]	Infrared	OA/Non OA by extraction the patella-centering of knee feature.		The result provides 85.49% of accuracy rate, 85.72% of sensitivity and 85.51% of specificity buy using SVM classifier.

2.9 Summary

In conclusion, many kinds of medical images have been applied to diagnose OA disease with image processing technique as mention above. As an example [9-18] have been applied the to various of medical image to analyse OA/non-OA and OA stage using image classification and image procession technique. To summarise of this chapter is to tell a brief of each previous work had implemented in image processing technique such as image enhancement, image segmentation, feature extraction, feature selection, evaluation and measurement. Some techniques for image processing. There were some brief study for machine learning algorithms for example, neural network, decision tree and logistic regression could be used for classification process. The detailed of each process work in medical X-ray image analysis is discussed in Chapter 3.