

Detection of Knee Osteoarthritis Using Image Segmentation and Artificial Neural Networks

Abstract

Background: Knee osteoarthritis is one of the common diseases in humans and due to its increasing spread, early diagnosis of this disease is very important. Consideration of cartilage volume in knee osteoarthritis studies from radiological images is very necessary. The aim of this study is to help improve the diagnosis of knee osteoarthritis with the help of artificial intelligence and image processing techniques.

Methods: This is a diagnostic study that has been evaluated on 957 MRI images. Images were collected from Tehran Hospital database, such that 111 samples were related to healthy individuals and 48 samples to people with knee osteoarthritis. In this study, in order to diagnose osteoarthritis automatically, a new method called "image distinguishing and teaching it to artificial neural network", using MATLAB software was used. MRI images were received and after pre-processing they were processed to diagnose osteoarthritis conditions with the help of artificial neural networks.

Findings: Experiments show acceptable performance of the proposed method, such that using this technique the diagnose of knee osteoarthritis was possible, with 93% accuracy.

Results: the proposed model can be used in screening plans in order to identify people in danger of developing osteoarthritis and can serve as doctor assistants.

Keywords: Digital Image Processing, Osteoarthritis of Knee, MRI, Computational Neural Networks, Knee

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Introduction

The knee osteoarthritis¹ is a destructive disease of the synovial joints that affects the articular cartilage and leads to loss of articular cartilage and changes in other tissues including inflammation of the synovial membrane, thickening of the joint capsule, muscle weakness and new bone formation. Therefore, knee osteoarthritis has an effect not only on the tissues inside joint capsule but it has effects on tissues around the joint, including the ligaments² Joint capsules, tendons and muscle⁽¹⁾. This disease causes more disability and clinical symptoms in the knee than other joints and, based on existing evidences from around the world, it is a major health problem⁽²⁾. In people with this disease as a result of pain and decreased movements, the quadriceps muscle becomes atrophic and weak. With the progression of arthritis, degeneration of cartilage, bone, and adjacent soft tissue occur, and eventually the disease causes the knee to deform and loosens or destabilizes ligament⁽³⁾.

Unfortunately, the lesions of articular cartilage due to not having blood vessels and nerve fibers have a limited ability to heal, and because there is no cure for the disease, it is a major problem for physicians. But if detected early it can be controlled⁽⁴⁾.

In United states about one hundred thousand people, due to osteoarthritis of the knee or pelvis, are unable to move for even a short distance without assistance. Early diagnose of this disease and preventive methods slow down its progression⁽⁵⁾. The prevalence of this disease in Iran is not very precise, but according to the study of Izadpanah et al⁽¹⁾, its prevalence Was 17.87%, of which 86.4% were only one knee involved and 13.6% were generalized. Considering the new diseases and improvement and spread of technology, diagnosing illnesses based on artificial Intelligent diagnostic methods are increasing. Using these methods for images of knee osteoarthritis is possible with the help of processing MRI³ image from inside the body⁽⁶⁾. MRI scan considers the distance between the joints and the extent of cartilage damage and diagnoses osteoarthritis⁽⁷⁾. The potential problem is that most of the techniques are based on the analysis of MRI images in order to measure cartilage volume that contain different amounts of manual interventions so they make diagnostic process time taking and also includes human error⁽⁸⁾.

Methods

Nowadays, relying on techniques based on image processing and combining them with Data analysis like artificial neural networks, it is possible to detect a process automatically in less time and with more accuracy⁽⁸⁾. Artificial neural networks have been noticed by researchers in various studies for diagnosing many diseases such as coronary heart disease and breast cancer^(9 to 11). The aim of this study was to diagnose knee osteoarthritis using techniques based on machine and electronic vision and artificial neural networks. It is noteworthy that the data of this study are completely indigenous and have been collected by the project researchers themselves.

Osteoarthritis means inflammation of the joints; in other words, the part of the bone that is involved in the joint with another bone is covered with cartilage. If this cartilage is damaged, the knee will become abnormal and the distance between the joints will be minimized. Figure 1 shows an example of bone tissue with a healthy knee and a knee with osteoarthritis.

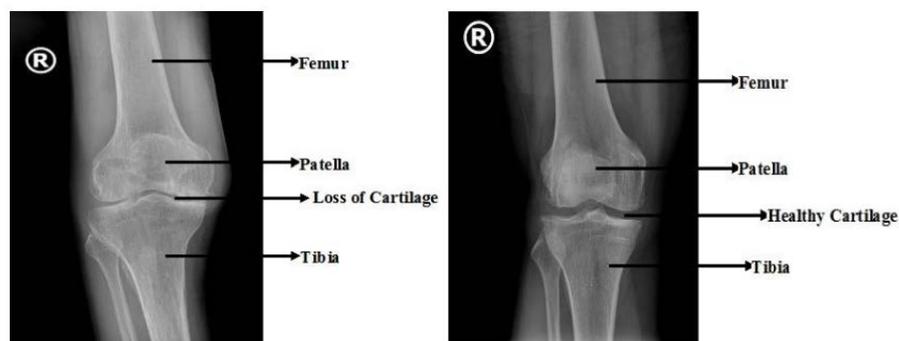


Figure 1- Difference between normal knee and a knee with osteoarthritis (left image is for a healthy knee and right image is a for knee with osteoarthritis)

This study is the result of a diagnostic study, based on MRI images, that differentiates the status of knee osteoarthritis in terms of health or disease. The database used in this study is a collection of data collected from patients with knee osteoarthritis. It should be noted that these data are non-attributable and there are no details of any of these patients recorded in the database. This resource database contains 158 samples. Of these, 47 had osteoarthritis and 111 were healthy. Figure 2 shows a sample of early MRI images. The following steps have been performed to diagnose osteoarthritis of the knee

1. Pre-processing of input images
2. Blocking images and actions to the first neural network
3. Creating a database of joints
4. Diagnosis of osteoarthritis with the help of the second neural network

Pre-processing input images

There are several ways to increase image quality in order to identify different areas of the image. In this study, first, by edge finding the input images, the knee part was extracted and changed to images with dimensions of 500 by 500 pixels. Then the input color images whose color combination range is zero to 255 were converted to a gray image. The input image was gray with a brightness level of 256 and each pixel ranged from zero to 255. Figure 2 shows a gray output image for two healthy people and two people with osteoarthritis

Histogram improvement

An image histogram is a graph that identifies the number of pixels of each brightness level in the input image. In this part, the images were normalized with different severities and their histograms were calculated. Normalizing the histogram causes the pixel values to change from the gray range of zero to 255 to the binary range of zero and one. This reduces the time of the image processing in later stages. The histogram of the gray image is shown in Figure 3, and after applying the changes and creating a binary image, a sample image of two healthy and sick people is shown in Figure 4.

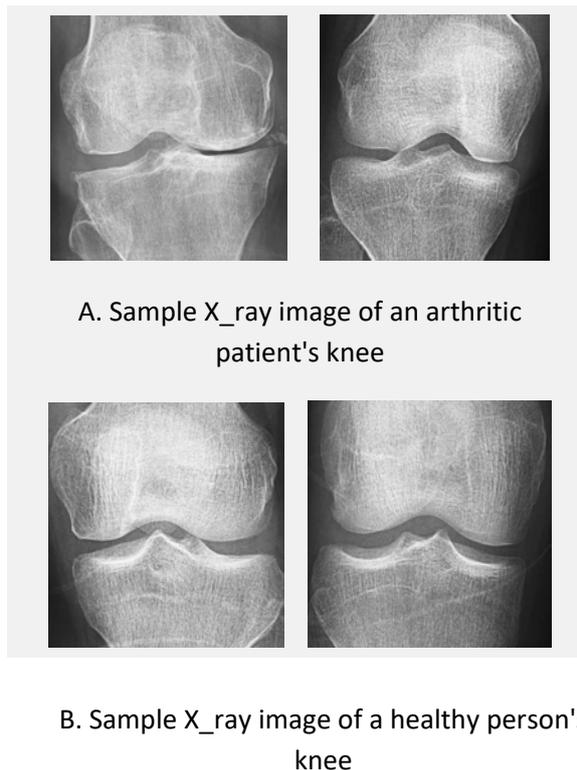


Figure 2- Pre-processed images of the knee joint in 2 people one healthy and one sick individuals

Blocking images to differentiate joints from non-joints with the help of Artificial neural network

One of the problems in intelligent analysis of knee MRI images is locating the joint. In this study, by inventing a method called image blocking, we tried to separate the knee joint from other parts primarily in the image segmentation phase, while preparing to apply to the neural network, to remove parts of the image that increased the processing cost. In this way, each image was divided into 7 separate blocks with dimensions of 150x500 and the network input had 75,000 features and there were the same number of neurons in the input layer of the neural network.

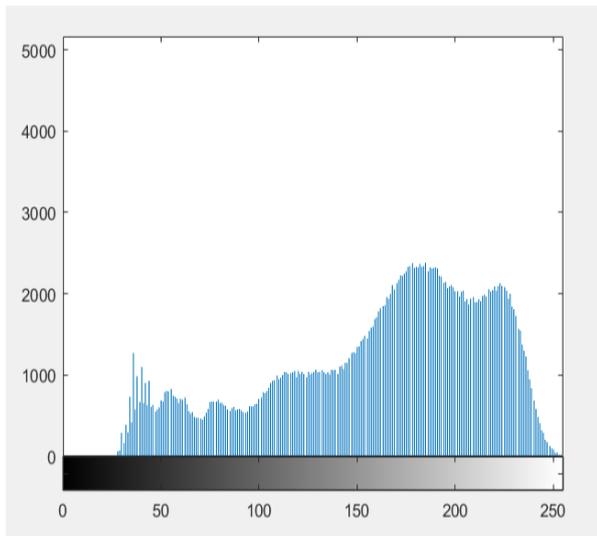


Figure (3) then histogram of image healthy and one sick

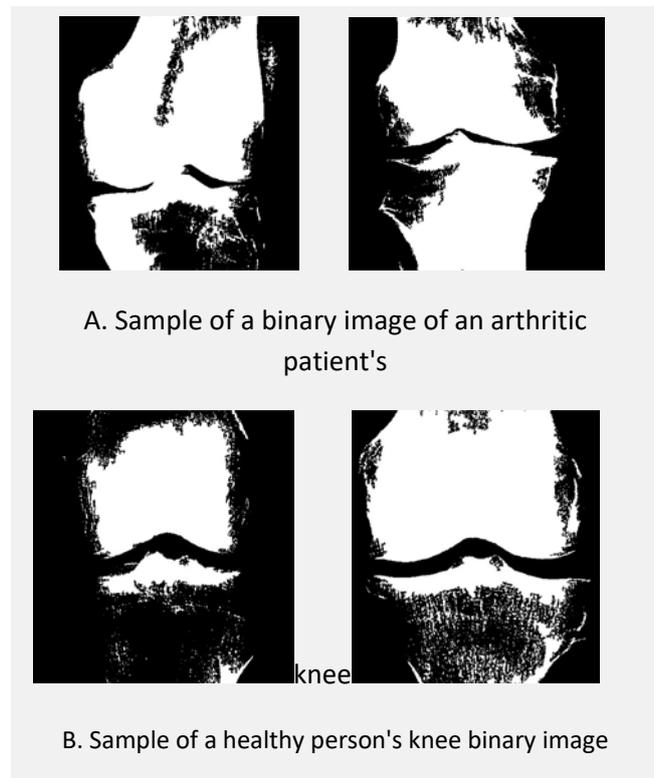


Figure 4- Binary images of the knee joint related to 2 people one healthy and one sick

Table (1) Determining the class of blocked images

Image Name	Joint status 1: joint 2: Non-joint
Figure 5-1 First block	2
Figure 5-2 Second block	2
Figure 5-3 Theird block	2
Figure 5-4 Fourth block	2
Figure 5-5 fifth block	1
Figure 5-6 Sixth block	1
Figure 5-7 seventh block	1

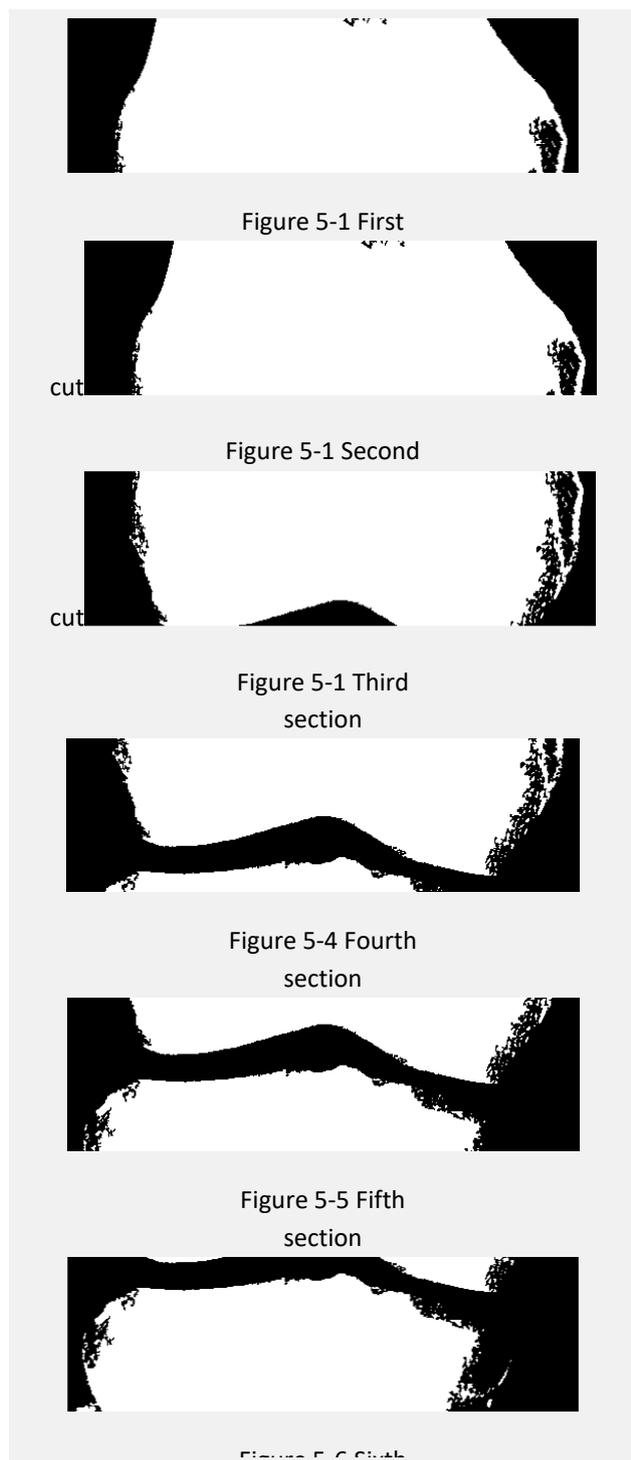


Figure 5 - Blocked images and extraction of the joint location

As shown in Figure 5. In this situation Images are divided into two classes, joint and non-joint, with codes 1 and 2, respectively. Table 1 shows the classification status of the related images in Figure 5.

At this stage, a classification system such as an artificial neural network should be used to distinguish the knee joint from the non-joint. Learning systems consist of layers, each of which consists of a number of neurons. More precisely, each layer consists of a weight matrix, a bias vector, and its own output vector. All preprocessed images were blocked and entered as input to the designed neural network. From the database images, 50 images were selected as a sample to apply the image blocking operation on them. As a result, a number of $7 \times 50 = 350$ blocks were made so, the input matrix p to be applied to the network had dimensions of 350×750 , then the matrix T was formed as a target matrix with two values of 1 and 2 as two classes of joint and non-joint for network output. These images were then applied to the neural network to automatically find the joint part.

Designing a second neural network to diagnose osteoarthritis

Now that the location of the joint has been determined, it should be examined for being osteoarthritis or non-arthrosis. Therefore, at this stage, the second neural network (nn2) was designed so that it shall diagnose osteoarthritis of the knee. This neural network was also designed as a multilayer perceptron. At this stage, 158 images representing the joint (as in the fifth block of Figure 6) as well as a matrix called Arthritis Target, indicating the type of arthritic or healthy image, were applied to the in order to teach it the difference between the healthy people and people with osteoarthritis.

Applying the captured images to the artificial neural network

Results

However, a neural network is very robust due to its parallel processing capability, and by properly adjusting the number of hidden layers and the appropriate number of neurons, it is able to approximate any nonlinear function; But if the accuracy of a classification is to be increased, one way is to reduce the number of classes in that classification and increase the number of learners. The proposed model in this study uses a combination of neural network divisors to diagnose osteoarthritis of the knee. This mechanism first divides the MRI images into sections using image blocking, then recognizes and classifies them. In this study, two neural networks n1 and n2 were designed. The task of the first neural network (n1) was to distinguish the joint from the non-joint. The n1 network was trained with 80% of the joint and non-joint images and tested with 20% of the data. Out of a total of 350 neural network images, it correctly classified 289 items in the relevant non-joint class and 44 items correctly in the joint class. In total, only 8 items were misclassified. Table 2 shows the learning status

of the n1 network. The second neural network called n2 was designed and trained similar to the first neural network. This network is also taught in two classes, meaning that joint images are applied to the network and the neural network learns whether this joint has osteoarthritis or not. In a similar way, the evaluation parameters for the second network were calculated, which are shown in Table 3

The algorithm used in this research is shown in Figure 6 and as can be seen, there are three general phases in this algorithm. In the first phase, the MRI images of the knee are pre-processed, and at the end of this phase, a database of images is formed to enter the next phase. In the second phase, the n1 neural network is trained with 70% of the blocked images in order to distinguish the joint images from the non-joint ones. At the end of this phase, a database of knee joints including arthrosis and non-arthrosis is formed. In the third phase, the n2 neural network distinguishes osteoarthritis of the knee from non-osteoarthritis

Table 2 - The state of learning of the first neural network in distinguishing joint images from non-joint

Number of all samples	Number of non-joint images	Number of joint images	Accuracy N1	Sensitivity N1	Specificity N1
350	300	50	97/7	95/7	98/0

Table 3 - The state of learning of the first neural network in distinguishing joint images from non-joint

Number of all images	Number of arthritic images	Number of healthy images	Accuracy N2	Sensitivity N2	Specificity N2
158	47	111	93/0	95/0	92/4

Discussion

In this study, to improve the diagnosis of osteoarthritis of the knee, the blocking method and the use of two neural networks with two different tasks were used. In the study of Kaufman et al, in order to improve the quality level of the images, an attempt has been made to increase the sharpness of the sharp edges of the bone. In this method, the edges of the femur are determined using a canny filter. In this study, the researchers proved that if the automated method is used with two different strategies to diagnose osteoarthritis, the mean error can be 0.006 and 0.004. While with the same strategies in manual mode, errors of 0.104 and 0.067 have been obtained⁽¹²⁾. In a study conducted in 2011, it was found that the use of neural network back propagation to classify and predict the severity of osteoarthritis based on the texture and color of joints reached an accuracy of 66.6% and this statistic showed that the probability of error occurs in 33.4% and this system faces many errors⁽⁶⁾.

In another study, Lilik et al, used four steps to diagnose osteoarthritis: Processing, zoning, feature extraction and grouping. Classification of osteoarthritis was divided into four categories, which included grade 1, grade 2, grade 3 and grade 4. In the first stage, the photos are normalized, their histogram is calculated and the image is improved. Then, the location of the joint space is determined and in the third stage, photo features are extracted and entered in a table to rank the rate of osteoarthritis. Finally, according to the extracted characteristics and by comparing the output information of the previous stage with the data, the degree of osteoarthritis is obtained⁽¹³⁾. In the field of knee osteoarthritis, Aka et al, developed a method called Koakad, in which the input image is first filtered. By finding the edge, the two ends of the bone are identified and the space between the two sides of the bone is obtained. Next, the distance between the upper and lower bones is calculated and compared With the other side, and knee osteoarthritis is diagnosed. Although in this method the final decision is with the physician and not by the system, but the researchers in this study were able to extract some important parameters for assessing the condition of knee osteoarthritis in less than 1 second. His study database consisted of 594 radiographic images⁽¹⁴⁾. Ababneh et al, used

segmentation using a graph cutter to automate bone sectioning. The segmentation algorithm consisted of a mixed block based on new content. The results showed that the automatic bone detection rate was 99% and the mean segmentation accuracy was 95% using the dice similarity index⁽¹⁵⁾. Also, the diagnosis of cartilage thickness has been suggested in the Article of Lee et al, the proposed method consists of three parts, which include the desired volume (voi)⁽⁶⁾ of initialization, bone segmentation and cartilage thickness of the visualization. Then, with a U-shaped filter, the object is automatically selected and provided with the classification algorithm for bone classification⁽¹⁶⁾. Data mining techniques can be used as a physician's assistant in diagnosing specific diseases and in order to predict the possibility of people contracting diseases. The model presented in this study can be used to identify people with osteoarthritis or at risk for osteoarthritis; In addition, it can serve the specialists as a physician's assistant. One of the most important limitations of the researchers in this study was the lack of local data. In this study, local data were collected by the researchers under the supervision of a specialist physician. The results were analyzed with the proposed model, which showed a favorable and acceptable diagnosis. The results of the study indicate that the method of blocking radiographic images of knee osteoarthritis can increase the accuracy of the learning system (in this study, neural networks) while reducing the computational volume of a learning system. It is suggested that this model be used experimentally as a physician's assistant by installing it in medical centers in order to finally reach the desired level of accuracy and lead to the creation of a comprehensive and appropriate model for the diagnosis of knee osteoarthritis.

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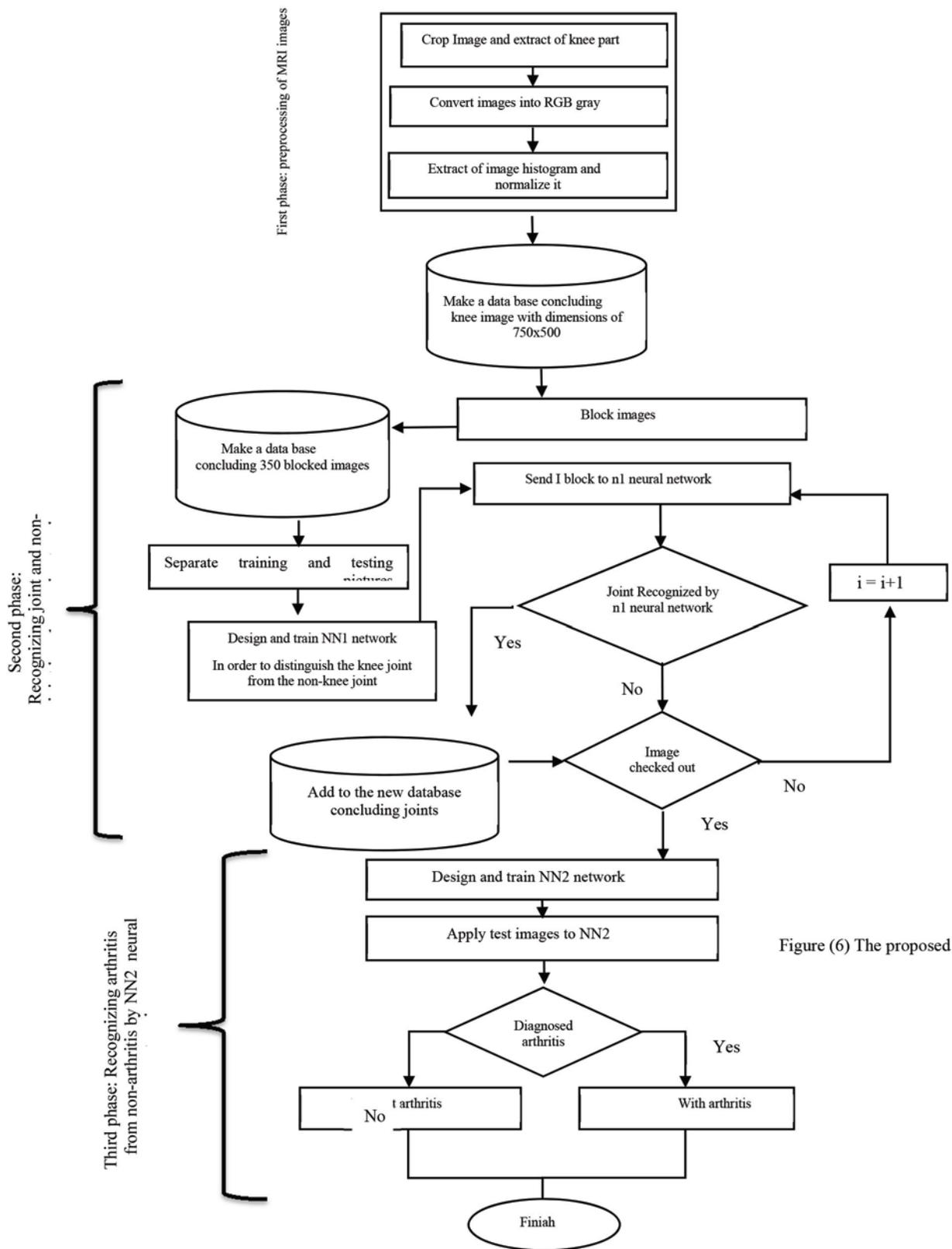


Figure (6) The proposed ethoc

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