Surface Temperature Distribution in Popliteal Region for Early Detection of Osteoarthritis

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Abstract:
Infrared thermography (IRT) is used to measure and analyze physiological functions and pathology which can be related to the body’s thermal homeostasis and temperature. Our goal is the early detection of Osteoarthritis (OA), with a narrow focus on skin surface temperature distribution around Popliteal (Posterior knee) region. The temperature distribution along the popliteal region was considered whereas previous works focused on the temperature elevation in the patellar region affected with OA [13-15]. The average temperature was found to be variable for different person. So it is difficult to detect early OA knee considering temperature elevation instead here temperature distribution in popliteal region is considered. Infrared thermography and radiography were done on 27 normal knees (Kellgren-Lawrence grade 0) and 34 early Osteoarthritis knee (Kellgren-Lawrence grade 1). When a vertical profile plot of popliteal region was considered surface skin temperature was found to be more distributed in entire region for early OA knee and peaked near knee joint for normal knee. Statistical measures that predict the temperature distribution in popliteal region were fed to a support vector machine (SVM) classifier to perform automated recognition of early OA knee. Experimental results indicate that the SVM classifier has an average accuracy rate of 86.65%, a sensitivity of 84.42%, and a specificity of 88.89% in detecting normal and early osteoarthritis cases. The proposed method for knee thermal screening can thus provide quantitative reference information in assisting clinical diagnosis.

Keywords: Popliteal region, Infrared Thermography, Radiography, Surface temperature distribution

I. INTRODUCTION
Osteoarthritis is a progressive form of arthritis which is characterized by breakdown of the cartilage in joints [1]. Osteoarthritis is abbreviated as OA and is also known as degenerative joint disease. OA will cause pain in the joints with activity. The knees and the hips are common joint locations affected with OA and are common in people over 60 years of age, but it can affect younger people when they have had joint injury or surgery [2].

OA develops over years, offering a long window of time to alter its course potentially. The etiology of OA shows strong associations with highly modifiable risk factors such as mechanical overload, obesity and joint injury. Osteoarthritis in its late-stage, modifying disease opportunities is limited. Radiographic joint-space narrowing is highly insensitive measure used for centuries to diagnose OA. Advances in optical imaging and magnetic resonance imaging (MRI) have permitted direct imaging of joint tissues that helps in quantitative assessment of joint tissue structure for identifying early OA [3]. But MRI require patient to stay still for a long time inside a machine. This can be uncomfortable. X-Ray and CT involve exposure to a small amount of radiation. IRT belongs to the functional imaging category; it provides a non-invasive and dynamic measure of the heat radiated from the 1–2 mm below the skin surface [4].

Infrared thermal imaging has been used in a range of clinical applications in rheumatology including; the monitoring of skin temperature elevations for pain assessment [5-7], evaluation of rheumatoid arthritis (RA) [8-11] hand OA [11,12] and knee OA[13-15], animal clinical trials[16].

Our goals were to standardize a method of knee infrared imaging to explore which distinct knee region provides the highest correlation of local temperature distribution with early radiographic findings of knee OA and to characterize osteoarthritis disease at early stage using Infrared Thermography which will allow a paradigm shift from palliation of late disease towards prevention. The early diagnosis and early treatment of joint injury and degeneration reduces osteoarthritis risk.

II. METHODS
A. Subjects
54 subjects participated in this study. An Arthritis Camp was organised on 30th Jan 2016 in association with Medical Electronics Department of BMS College of Engineering and Sagar Clinic (Banashankari, Bengaluru, India) and funded by Teqip Phase II. The entry criterion for OA participants chosen included definite x-ray evidence of knee OA of Kellgren-Lawrence (KL) [17] grade 1, 2 or 4 chosen on the basis of x-ray. Controls were required to have normal (KL0). As this study is about early diagnosis of OA, only knee with KL grade 0 and 1 was considered.

Participants were informed in detail of the study protocol, signed a consent statement and could at any time if they wanted to abort the protocol.

B. Knee Radiography
Posteroanterior digital x-rays were obtained at Sagar Clinic (Banashankari, Bengaluru, India). X-rays were read by a single radiologist (Dr. SrinivasMurthy) for evidence of OA using the Kellgren Lawrence (KL) grading system with a standard paper [17]; grade 0= No evidence of OA(normal);
grade 1=early OA changes noted(doubtful joint space narrowing); grade 2=OA changes noted(definite joint space narrowing); grade3 = OA changes with narrowing of intra condylar joint(moderate OA); grade 4= advanced OA changes with narrowing of intra condylar joint(severe OA)

C. IRT Procedure

The thermal image was taken using KT 640 from Sonel Test and Measurement Instruments. It is fully radiometric camera which records temperature at each point of the image - high resolution 640 x 480. Recording is in the extended jpg format. Infra Fusion technology of the camera used to view combined real and infrared image for effective locating of the measurement place.

The IR camera captures the emitted radiation. Therefore the consideration of the environmental condition is very critical if not the temperature measurement of the target object may be corrupted from other infrared sources. So the environment where the IRT was done had limited source that emits IR radiation and the room temperature was maintained at 24°C. All subjects underwent IRT in same room. Participants got an hour to rest in a comfortable position after X-Ray before IRT was conducted to ensure that the participants did not have any stressful physical activity that may increase their body temperature. During the camp no caffeine (tea or coffee) was served that may add to the body temperature instead non caffeine drinks were served. Infrared thermal images of the knees were acquired in four configurations (anteroposterior, posteroanterior, lateromedial, and mediolateral). The posteroanterior image was used for the analysis.

D. Image Preprocessing

The real image and thermal images obtained from the Sonel IR camera were not correlating with each other. For this purpose a Sub-Image matching algorithm was developed to match the real image with the thermal image.

1. Both IR and Visual image are converted to grey scale(Figure 1)
2. Edge detection of both IR and Visual image using Canny edge detection. Visual Images edge detection was done with higher sigma value to get a better correlation between two edge detected image (Figure 2)
3. All possible sub-image of Visual edge detected is correlated with the edge detected IR image using Pearson Correlation.
4. The Coordinates of sub-image with highest correlation value is used to crop the Visual image and resize to 640 x 480(Figure 3)

Figure 2: Canny Edge detection of IR image (Left, No smoothing is done i.e. Sigma=0) and Visual Image (Right, Smoothing is done i.e. Sigma=5)

Figure 3: Image Overlap by alpha blending technique. Before applying Sub-Image matching algorithm (Left). After applying Sub-Image matching algorithm Right

E. Automatic selection of ROI

For automatic selection of ROI the centre of popliteal region in real image was manually marked as seen in top left corner of Figure 5. Following are steps involved in the ROI extraction:

1. Separation of left and right posterior knee
2. Identify the Popliteal centre
3. Extract 30X90 rectangular region around the popliteal centre identified in previous step

Steps for separating left and right posterior knee:

1. IR image is converted to grey scale and segmented using otsu method
2. The profile change along the x axis at 60% (288th pixel) of Y axis is digitalised as shown in Figure 4
3. All the pixels at which the profile change is detected are saved as a list.
4. The middle point of 2nd and 3rd pixel stored in previous step is used as the crop axis for separating the two knees.
5. The real and IR image are cropped at crop axis estimated in previous step. The final result is shown in Figure 5.

Figure 1: Grey scale image of IR Image (Left) and Visual Image (Right)

Figure 4: Profile Change between two legs along x axis on 60% (288th pixel) of Y axis
After left and right knee separation, the manually marked popliteal centre is to be identified.

Steps to identify posterior knee (Popliteal) region:

1. The cropped visual image of right knee/left knee is converted to grey image and segmented using otsu method.
2. The profile change along the x axis for every pixel in y axis is digitalised. (Figure 6)
3. When 3 or more profile change is detected, all the pixels at which the profile change is detected are saved as a list.
4. Pixel between 2\textsuperscript{nd} and 3\textsuperscript{rd} profile change is stored as posterior knee centre.

After the identification of the posterior knee centre a rectangular region (30X90) around the popliteal centre is selected and saved from which features are extracted.

**G. Feature Extraction and Classification**

Attributed considered for classification are the statistical features extracted from the selected ROI i.e. the popliteal region. Statistical measures considered are:

1. Variance
2. Standard deviation
3. Average absolute deviation
4. Skew (3\textsuperscript{rd} order moment about the mean)
5. Kurtosis(4\textsuperscript{th} order moment about the mean)
6. Difference between Minimum and Maximum pixel value
7. Difference between Maximum and Median pixel value
8. Difference between Median and Minimum pixel value

The work here considers the grey values in feature extraction. It was found that the grey pixel value is directly proportional to temperature pixel value.

Among the classification methods available for solving pattern recognition problems, the SVM classifier has been proven to be an efficient way of obtaining good classification performance [18]. Therefore, the features extracted are fed to the SVM classifier to develop an automated early diagnostic method for knee OA.

The process of SVM classification involves two primary procedures, namely those of training and testing. Based on the training dataset (feature vector and class label contained in each dataset), the goal of the SVM classifier is to produce a decision model that can predict the class label of the test data.
given only the feature vector. The training data and test data was split into 75% and 25% ratio respectively. The Input details of SVM classification is given in Table 1.

Table 1: Input for SVM Classification

<table>
<thead>
<tr>
<th>Number of attributes</th>
<th>Number of instances</th>
<th>Associated Tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>61</td>
<td>Classification Class 0: Normal knee Class 1: Early OA knee</td>
</tr>
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III. RESULTS AND DISCUSSION

A total of 27 normal knees (KL 0) and 34 early OA knees (KL 1) were selected on the basis of Radiogaphical graphical findings. The majority of subjects were women (55%). Mean age was 48.675 year (range 19–68 year). Each knee was evaluated thermally and radiographically. Kurtosis of popliteal region is found to be more positive for normal knee and negative or less positive for early OA knee from image analysis.

The complete training and testing was performed randomly twice on the data collected. Figure 9 shows the confusion matrix for two trials performed. Table 2 shows the average statistical test data evaluation of diagnosis for the classified output after two trials.

From the results we can conclude that the temperature distribution in popliteal region significantly helps in diagnosis of knee OA at its early stage (i.e. radiographic findings with KL grade 1).

COMPETING INTERESTS

All authors declare that there is no conflict of interest.

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REFERENCE


