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Thermal Image Analysis and Segmentation of Hand in Evaluation of Rheumatoid Arthritis

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Abstract— **Rheumatoid arthritis (RA) is a chronic inflammatory disease that affects and destroys the joints of fingers, wrist and feet. Although different imaging modalities like x-ray, magnetic resonance imaging and ultrasound are available for diagnosing the RA. Thermal imaging is considered as a novel imaging technique for diagnosing the RA.Thermal imaging technique is based on infrared Thermograms depicting the temperature variations in abnormal region of interest. The objectives of this study was i) to evaluate the rheumatoid arthritis based on heat distribution index and skin temperature measurements and to analyse the difference in skin temperature measurement in hand for RA patients and normal persons.ii) to automatically segment the abnormal regions of the hand especially for arthritis patients using fuzzy c means algorithm and Expectation Maximization (EM)algorithm. In this paper ,thermal image analysis was done based on heat distribution index(HDI) and skin temperature measurement .The heat distribution value is obtained as 1.53±0.5 From the temperature analysis the results predicted was there is an increase in temperature of 0.96^0 c in hand region of RA patients compared to normal patients. The correlation between HDI and skin temperature measurement was statistically significant ($r=0.63$, $p<0.05$). Fuzzy c-means algorithm has better results compared to EM Algorithm in evaluating the disease.**

Keywords—*Rheumatoid arthritis, thermography, thermal imaging, heat distribution index, fuzzy c means algorithm, Expectation minimization algorithm*

I. INTRODUCTION

Rheumatoid arthritis (RA) is a chronic autoimmune inflammatory disease that affects the primary peripheral joints like fingers, wrist and feet. This disease results in joint pain, stiffness, swelling of the joints which showed deformity and ankylosis in the late stages of the disease. The risk factors of RA include high number of joints involved at onset, marked disability, elevated acute phase reactants, a positive finding of rheumatoid factor, female gender, advanced age, presence of certain human leukocyte antigens (HLA) class II antigens, early x-ray changes, low bone mineral density and job-related physical requirements. Earlier diagnosis of the disease is essential to avoid substantial morbidity and mortality. The various imaging technologies were studied in order to evaluate the severity of disease. But, limitation exists in all the current technologies. Although conventional radiography remains the standard method for assessing joint erosion and joint destruction, it lacks sensitivity in depicting early erosive changes.[1]. However, the assessment of multiple joints with magnetic resonance (MR) imaging is time-consuming and too expensive for routine use [1]. Ultrasound is a user dependent imaging modality that could quantify changes in effusion and synovitis. Hence Thermal imaging technique is considered as a useful tool in evaluating the rheumatoid arthritis.

Thermal imaging is a non invasive, non-contact type, radiation free imaging method in the diagnosis of RA. Infrared thermography provides directly a digitized output called thermogram. Thermogram is defined as a 2D radiance function r (x, y), where x and y denote spatial coordinates and the value of r at any point is proportional to the radiance. It provides a thermal pattern of the skin temperature at the area of observation. For a normal person, the thermogram shows uniform and symmetric temperature variations [2-3]. In case of abnormality, abnormal regions show abrupt variations in temperature. Traditionally, lower gray levels are represented by dark shades and higher gray level by bright shades. The RA region appears as hot spot in the thermogram [4].

Fuzzy algorithm is an image segmentation process widely used in segmenting the medical images. Fuzzy clustering plays a vital role in solving problems in the areas of pattern recognition and fuzzy model identification A variety of fuzzy clustering methods have been proposed and most of them are based on distance criteria. One of the most widely used algorithms is the fuzzy c-means (FCM) algorithm. It uses reciprocal distance to compute fuzzy weights [5]. A more efficient algorithm is the new FCFM. It computes the cluster centre using Gaussian weights and uses large initial prototypes, and adds processes of eliminating, clustering and merging.

The Expectation-Maximization (EM) iterative algorithm is a broadly applicable statistical technique for

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maximizing complex likelihoods[6] and at each iteration of the algorithm, two steps are performed: (i) E-Step consisting of projecting an appropriate function containing the augmented data on the space of the original, incomplete data, and (ii) M-Step consisting of maximizing the function. The main applications of the EM algorithm are i) the first occurs when the data has missing values, due to problems with or limitations of the observation process. ii) the second occurs when optimizing the likelihood function is analytically intractable but when the likelihood function can be simplified by assuming the existence of and values for additional but missing (or hidden) parameters.

Horvath [7]in his paper used fuzzy c means algorithm as pre-processing steps for region growing segmentation. Padmavathi and their co author [8] indicated that fuzzy c means algorithm with thresholding is an effective algorithm in segmenting underwater images. Zhou et al [9] in their study indicated that fuzzy c means algorithm has been shown to be work well for clustering based segmentation. Belongie et al [10] used EM algorithm to perform automatic segmentation based on image features.Farnoosh [11] et al in their paper used EM algorithm in combination with Gaussian mixture model for automatic image segmentation and noise reduction.

The aim of this study was to evaluate the rheumatoid arthritis based on heat distribution index and skin temperature measurements, and to automatically segment the abnormal regions of thermogram using fuzzy c-means and EM algorithm.

II.METHODOLOGY

A. *Patients*

Ten outpatients with definite Rheumatoid Arthritis (satisfying American Rheumatism Association criteria) and ten normal persons were included for this study. The mean age of the patients was 45.3±11.4 years and they had the disease duration of a mean of 4.3±2.53 and the ten age-matched healthy controls mean age was 45.5±11.8 years. The male/female ratio was 1:5. This study was approved by our institutional ethical committee and informed consent statement was signed by each patient.

B. *Thermal imaging*

Thermal image of the hand region of both the posterior and anterior view of RA patients and normal participants was obtained using a hand held thermo camera ThermaCAMT400). Participants were asked to sit with their hand exposed for 10 minutes in a temperature controlled room set at 20^0 c. The camera was placed at distance of 1.0m to obtain a thermogram of posterior and anterior views of hand in neutral position. The image was analysed by FLIR software version 1.2 and further processed by Matlab version 7.1. For a normal person, the thermogram showed uniform and symmetric temperature variations. In case of abnormality, there was an abrupt variations in the temperature in the abnormal region.

C. *Heat Distribution Index*

The Heat distribution index (HDI) reflects the pattern and the spread of temperature over joints. A region of interest on the thermogram was chosen to correspond to fixed area over the hand. Then HDI was calculated using the formula as follows

HDI= (No of pixels which occur at each Gray level / Total no of pixels in the given area of interest giving relative frequency distribution (RFD)).The calculation of width of RFD is made as ±SD from the mean frequency =heat distribution index [12].The HDI is thus an approximation to the width of the major components of RFD curves and has been found to be a useful parameter in arthritis patients.

D. *Image processing by Fuzzy c –means algorithm*

For each point x we have a coefficient giving the degree of being in the kth cluster $u_k(x)$. Usually, the sum of those coefficients for any given x is defined to be 1:

$$\forall x \left(\sum_{k=1}^{num.clusters} u_k(x) = 1 \right) \qquad \textbf{(1)}$$

With fuzzy c-means, the centroid of a cluster is the mean of all points, weighted by their degree of belonging to the cluster:

$$\text{Center}_k = \frac{\sum_x u_k(x)^m x}{\sum_x u_k(x)^m} \qquad \textbf{(2)}$$

The degree of belonging is related to the inverse of the distance to the cluster center.

$$u_k(x) = \frac{1}{d(center_k, x)'} \qquad \textbf{(3)}$$

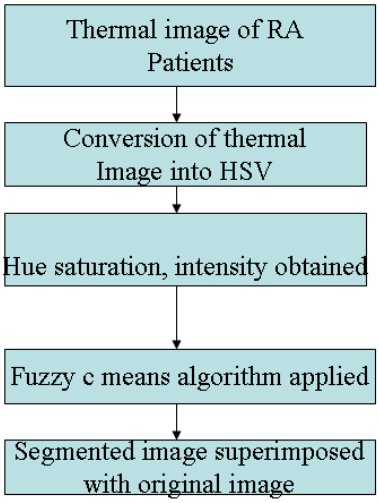
then the coefficients are normalized and fuzzyfied with a real parameter $m > 1$ so that their sum is 1. So

$$u_k(x) = \frac{1}{\sum_j \left(\frac{d(center_k, x)}{d(center_j, x)} \right)^{2/(m-1)}} \qquad \textbf{(4)}$$

The steps involved in fuzzy c means algorithms [13] are as follows:

- Choose the number of clusters.
- Assign the co-efficients randomly to each point in the cluster
- Choose the exponent weight m.
- Initializing the membership function u_k
- Find the centroid for each cluster, using the equation (2).
- Compute the coefficients for each points in the clusters, using the equation (3) and (4).

The overall algorithm implemented using fuzzy c means are as follows



E. EM Algorithm

EM algorithm is an iterative optimization method to estimate |marginal likelihood by iteratively applying the following two steps [14]:

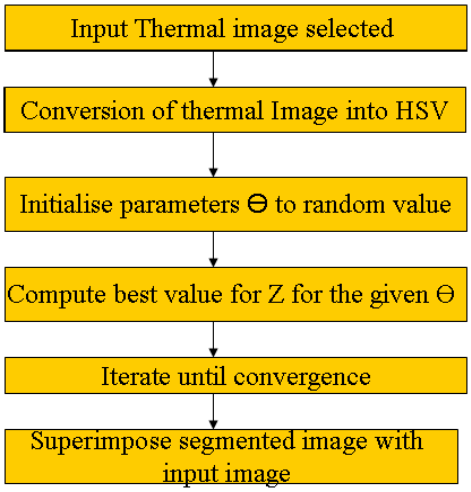
Expectation step (E-step): Calculate the expected value of the log likelihood function, with respect to the conditional distribution of Z given X under the current estimate of the parameters $\theta^{(t)}$:

$$Q(\theta|\theta^{(t)}) = E_{Z|X,\theta^{(t)}}[\log L(\theta; X, Z)] \text{ -------(5)}$$

Maximization step (M-step): Find the parameter that maximizes this quantity:

$$\theta^{(t+1)} = \arg_\theta \max Q\left(\theta|\theta^{(t)}\right) \text{ --------(6)}$$

The algorithm used is given as follows



F. Statistical Analysis

Data was analysed using SPSS software package version 10.0 (SPSS Inc., Chicago, USA). The skin temperature Measurement of RA patients and normal participants were compared using Student's t-test. Pearson correlation co-efficient was used to correlate the HDI and skin temperature measurements.

III. RESULTS

G. Skin Temperature Measurements

The calculated mean ±SD values of skin temperature of RA patients and normal participants at two sites metacarpals joints and palm from the thermal image is listed in the Table-I

TABLE I : SKIN TEMPERATURE MEASUREMENT

Region of interest	*Normal n=10, mean age±std 45.3±11.4 years Avg °c*	*Rheumatoid arthritis n=10, mean age±std 45.5±11.8 years Avg °c*
Metacarpals joints	32.68±0.52	*35.28±0.83 (P<0.001)
Palm	34.43±0.23	*35.39±0.71 (P<0.001)

* Significance when compared with normal

Fig 1 represents thermal image of rheumatoid arthritis patients showing skin temperature higher in abnormal regions than the normal regions and also indicates the region of interest measuring the skin temperature in the abnormal areas.fig 2 shows the thermal image of the skin temperature for a normal patient in an area of interest.

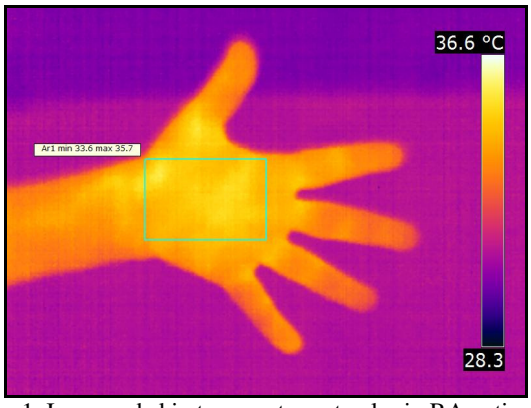


Fig. 1 Increased skin temperature at palm in RA patients.

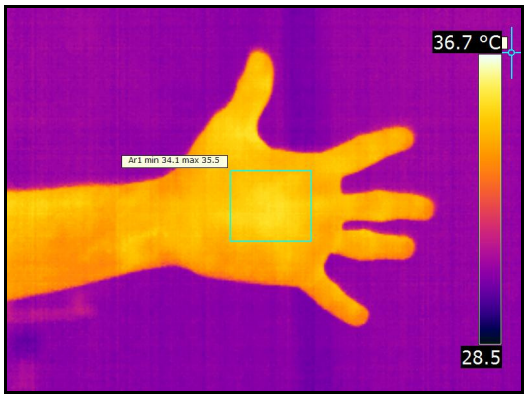


Fig. 2 Skin temperature distribution at palm in normal individual.

The bar graph (fig-4) illustrates the variations in the measured average skin temperature for rheumatoid arthritits patients comapared to the normal participants .

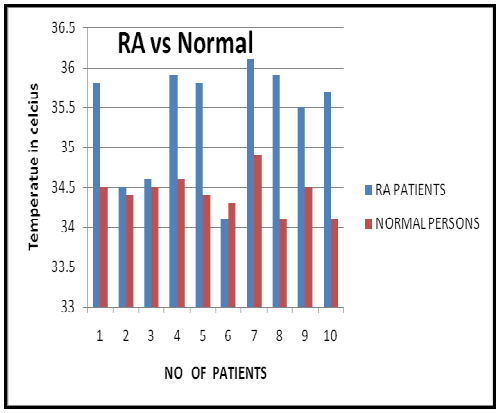


Fig. 3 Skin temperature of the palm in RA patients showing higher temperature compared to normal participants.

H. Heat Distribution index curve

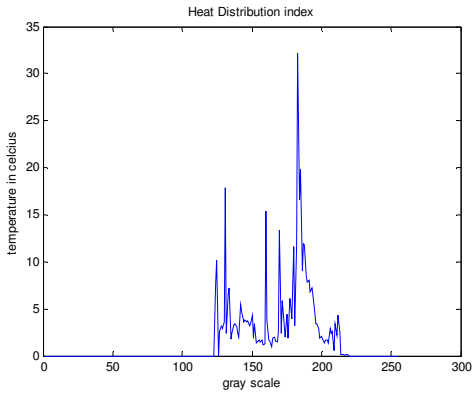


Fig. 4 Heat distribution index curve of the palm showing relative frequency distribution of Skin temperature of the RA patients.

The HDI curve in fig 5 reveals that the higher temperature attained for pixel intensity level between the gray scale 175-210.The heat distribution value for RA patients (N=10) obtained as 1.53±0.5.

There was a positive correlation exists between HDI and skin temperature measurements and the value found to be r=0.63 ($p<0.05$) as indicated in fig 6.

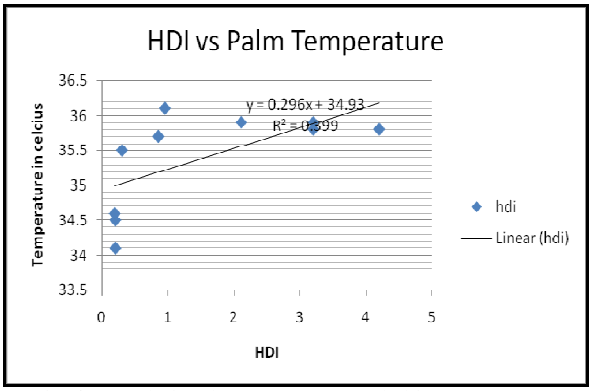


Fig 5 Correlation between HDI and skin temperature

I. Thermal image segmentation

Fig 6(a) indicates Thermography of rheumatoid arthritis patients and fig 6(b) shows the segmented image obtained by using the fuzzy c means algorithm. The segmented image depicts the abnormal region showing higher temperature segmented from the normal regions.fig 6(c) reveals the input thermal image superimposed over the segmented image.fig 6(d) indicates the thermal image segmented by using EM algorithm. Fig 6(e) shows the superimposed image of input thermal image and segmented image .By viewing the results of superimposed images of two algorithms; fuzzy c means algorithm produced better results compared to EM algorithm.

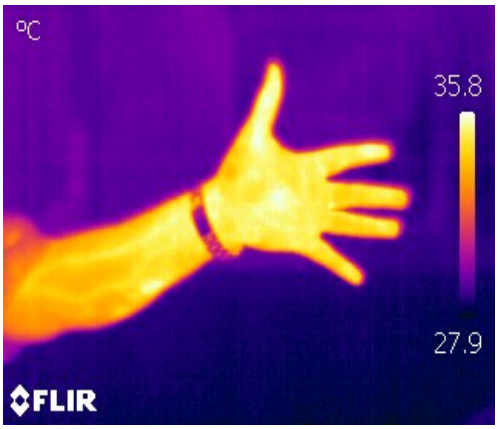


Fig 6 (a) Input Image

Fig 76(b) segmented Image using Fuzzy c means Algorithm

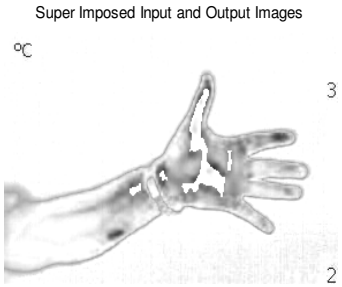


Fig 6(c) super imposed image using Fuzzy c means Algorithm

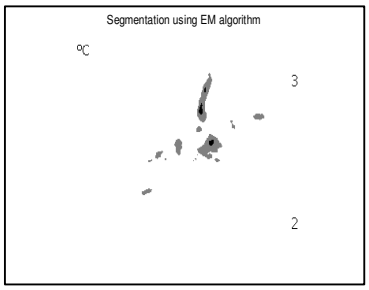


Fig 6(d) segmented image using EM algorithm.

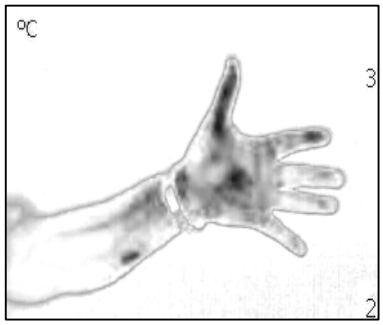


Fig 6 (e). Super imposed image using EM algorithm

IV. DISCUSSION AND CONCLUSIONS

Thermography appears to be an effective research tool for determining thermal changes. Thermal imaging modality is used to identify and quantify the severity of arthritis. Evaluation of the severity of disease in RA using thermography is reflected by inflammation in the hand and the wrist. In this paper the average skin temperature of the RA and the hand and the wrist of the normal participants were measured in the region of interest. Salisbury et al [12] introduced a heat distribution index and showed that HDI correlated better with clinical assessment than the thermographic index (TI).Even though skin temperature measurements showed the variations in temperature in the abnormal regions compared to normal regions, heat distribution index reflects the pattern and spread of heat over the abnormal regions that was indicated clearly in the HDI curve. In this study, Heat distribution index was calculated for RA patients and there was a significant positive correlation exists between HDI and skin temperature measurement. The heat distribution curve showed that the increase in temperature distribution in the arthritis affected region of the palm.

The segmentation algorithms not only identify the abrupt temperature variation but also provide features for quantitatively characterizing the defect. Tavakol et al [15] in their study indicated that the fuzzy c means algorithm provided better accurate results with no empty clusters for segmenting the thermal infrared breast cancer images. In this paper two segmentation algorithms like fuzzy c-means algorithm and EM algorithm were applied for extracting and quantifying the abnormality of RA patients. The fuzzy clustering algorithm compares the colors in a relative sense and groups them in clusters which are not with crisp boundaries and data point can belong to more than one cluster. [16]. EM algorithm is an iteration algorithm of first order [17], so it has slow convergence .The EM algorithm applied for the thermal image of hand region has not provided the accurate and better results. The fuzzy c-means algorithm produced better segmentation results compared to EM algorithm. The segmented image using fuzzy c means indicated the abnormal region which predicted the heat sensitive regions depicting the arthritis.

Thermography is a noninvasive technique that detects infrared radiation to provide an image of the temperature distribution across the body surface [18]. The reproducibility and sensitivity of thermography proven to be adequate for measuring disease activity in RA patients [19]. Some of the clinical applications of thermography in rheumatology reported so far were the assessment of inflamed joints [20], the response to cold challenge of the hands in Raynaud's phenomenon [21] and the evaluation of skin surface temperature in Paget's disease [22]and

algodystrophy[23].This technology is used as a valuable tool for diagnosing the rheumatoid arthritis patients. The thermographic method is extremely suitable for the assessment of response to therapy in patients with rheumatoid arthritis.

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