International Journal of Emerging Engineering Research and Technology
Volume 2, Issue 4, July 2014, PP 35-44
ISSN 2349-4395 (Print) & ISSN 2349-4409 (Online)

Segmentation of Thermal Images for Evaluation of Rheumatoid Arthritis Disease

Nizami Mohiyuddin

M.E Student
Department of Electronics and Telecommunication
M.I.T COE, Pune, India

Pradeepkumar Dhage

Assistant Professor
Department of Electronics and Telecommunication
M.I.T COE, Pune, India

Krishna K. Warhade

Professor
Department of Electronics and Telecommunication
M.I.T COE, Pune, India

Abstract: *Inflammatory joint diseases generally referred to as 'arthritis', are commonly indicated by increased temperature. Rheumatoid arthritis (RA) is an autoimmune disease that results in a chronic, systemic inflammatory disorder that may affect many tissues and organs, but principally attacks flexible synovial joints. In the last ten years, the infrared thermography has shown to be a promising technique to early diagnose the breast pathologies. We are using this for Rheumatoid Arthritis detection (RA). Although different imaging modules like x-ray, magnetic resonance imaging (MRI) and ultrasound are available for diagnosing RA. Thermography is a noninvasive, nondestructive method of scanning that does not require physical contact between measuring device (camera) and scanned object. Thermal imaging is considered as a novelistic imaging technique for diagnosing the RA. We had evaluated RA patients and normal subjects thermal images using EM and Fuzzy C-Means algorithm and experimental results show the effectiveness of these algorithms to detect Rheumatoid Arthritis.*

Keywords: *Rheumatoid arthritis, automatic joint detection, joint margin, hand bone segmentation, thermography, thermal imaging.*

1. 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 hand affected with Rheumatoid Arthritis with X-Ray image as shown in Figure 1. Heat is one of the oldest clinical signs of inflammation, and is efficiently recorded by infra red imaging techniques. Peripheral joints of the upper and lower limbs, e.g. knees, ankles, elbows and fingers, are subject to large changes in temperature from inflammatory conditions, i.e. up to 5°*C*. They are easily identified when the subject is examined in an ambient of 20°*C*, when the normal skin surface cools, increasing the temperature contrast from the persistent hot areas.

Fig1. *Hand affected with Rheumatoid arthritis*

Thermography can detect and measure infrared radiation emitted spontaneously from any object that is at a temperature above absolute zero. The term “thermal imaging” refers to the graphic representation of the electromagnetic radiation emitted by a surface, which is then turned into a visible image. The thermal energy, or infrared radiation, consists of electromagnetic waves whose length is too large to be detected by the human eye. It is, in fact, that portion of the electromagnetic spectrum that is normally perceived as heat. In the world of infrared energy, all items with a temperature above absolute zero emit heat; even objects that have a very low temperature, such as ice cubes, emit infrared radiation. The higher the temperature of the object the smaller the wavelength infrared radiation.

The various imaging technologies were studied in order to evaluate the severity of disease. But, limitation exists in all the current technologies. The assessment of multiple joints with magnetic resonance imaging (MRI) 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. Thermogram gives a thermal energy pattern of the skin temperature at the area captured by the camera. For a normal person, the thermogram gives uniform and symmetric temperature distributions [2-3]. In case of abnormal conditions, 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 red spot in the thermogram [4].

A number of internal and external factors affect the skin temperature. Despite a large number of the individual factors that affect the skin temperature, measurement of a mean skin surface temperature has a potential to be an indirect method for measuring an inflammatory disease activity. It is difficult to compare the thermographic research throughout the history due to the differences in sensitivity of the used equipment as well as the variability of skin surface temperature over different body parts.

Traditional assessment of the activity of the rheumatoid arthritis includes measurements of the subjective clinical variables, laboratory values and radiographic findings. Considering the change of temperature being basic physical characteristic of the inflammatory process and related reactions, it is justified to consider thermography as a potential, sensitive, noninvasive method for monitoring the severity of the inflammatory disease in both animal models and humans.

2. Related Work

Rheumatoid Arthritis (RA) results in pain of 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. So its detection is of at most important in early stages, Various researchers has proposed methods like MRI, X-Ray, Radiography, Thermography etc. for the detection of RA

Yinghe Huo et al. have proposed automatic joint detection in rheumatoid arthritis hand radiographs [5]. This method has focused on both joint location and joint margin detection. An automatic unsupervised joint location and joint margin detection method with a high detection rate was proposed. Secondly, the margin span is anatomically defined. The experiments are carried out on five 16-bit grayscale hand radiographs with resolution 2500 × 2000 pixels (0.1 × 0.1 mm). All detected joints are evaluated with the manual joint delineation.

Syaiful Anam et al. have proposed automatic bone boundary detection in hand radiographs by using modified level set method and diffusion filter [6]. The method proposed by them has shown good extraction performance. However, the mask operation in this method could not work well for some images because the pixel intensities of bone and the pixel intensities of other areas are similar in some parts.

Koay et al. [7] extracted ten features from thermal image for each quadrant of each breast. Quadrants were defined having nipple as a common point. Extracted features were skewness, standard deviation difference, mean temperature difference, entropy, maximum, median, minimum, kurtosis, area and heat content.. The SPSS statistical software was used to determine the correlation among the features after feature extraction.

Lipari and Head [8] used asymmetry between breasts and quadrants. The features extracted are: standard deviation median, mean, minimum and maximum value of temperature for each breast and quadrant. The paper didn't reflect any results in sensibility or specificity, some comparisons of values between features extracted from each breast and quadrant.

Kuruganti and Qi [9] segmented each breast in thermal images using generalized HT to extract parabolic curves defining the lower part of the breast. In return, the following features were extracted from the histogram of each breast region four moments mean, variance, skewness, kurtosis and entropy measures. They used six normal and eighteen cancer affected thermograms to validate the proposed classification method. It was observed by the authors that the high-order statistics skewness and kurtosis proved to be most effective features to measure asymmetry, while low-order statistics and entropy do not help in the detection of asymmetries. To validate their methodology, the authors had implemented the correlation measure to asymmetric analysis. From the set of features derived from the testing images, the existence of asymmetry is verified by computing the ratios of features of left to the right region of interest.

Table 1. *Comparative Analysis of Various Methods Implemented*

Paper	Feature extraction	Evaluation method	Characteristics
Yinghe Huo et al. [5]	This method has focused on both joint location and joint margin detection	An automatic unsupervised joint location and joint margin detection method	Detected joints are evaluated with the manual joint delineation
Syaiful Anam et al. [6]	Aautomatic bone boundary detection in hand radiographs	By using modified level set method and diffusion filter	Automatic bone boundary detection by modified diffusion filter
Koay et al. [7]	Mean, standard deviation, median, maximum, minimum, skewness, kurtosis, entropy, area and heat content	Artificial neural network (ANN) with back propagation	At end, they use just two features: mean and standard deviation
Lipari and Head. [8]	Mean, median, standard deviation, maximum and minimum value of temperature for each mama and each quadrant	An algorithm of semi-automatic segmentation	Four reference points Each of these points connected to the nipple separates the image into four distinct quadrants.
Kuruganti and Qi. [9]	Means, variance, skewness, and kurtosis, the peak pixel intensity of the correlated image, entropy and joint entropy	Correlation measure to asymmetric analysis	Segmented each breast in thermal images using generalized HT to extract parabolic curves defining the lower part of the breast.
Schaefer et al. [10]	Basic statistical features, moments, histogram features, cross co-occurrence matrix, mutual information, and Fourier analysis	Fuzzy rule-based classification system	Statistical methods and fuzzy classification to diagnose breast cancer
Padmavathi et al. [11]	This method had focus on ROI	Fuzzy c means algorithm in segmentation	Fuzzy clustering algorithm videlicet fuzzy c-mean and adaptive fuzzy clustering algorithm
Zhou et al. [12]	Pixel intensities	Fuzzy C-means algorithm	Clustering based segmentation
S. Belongie et al. [13]	Color and texture based image segmentation	EM algorithm	Automatic segmentation based on image features

Schaefer et al. [10] proposed an application of content- based image retrieval (CBIR) to thermal medical images. CBIR allows the retrieval of same images based on features extracted directly from the image data. Padmavathi et al. [11] indicated that fuzzy c means algorithm with thresholding is an effective algorithm in segmenting underwater images. Zhou et al. [12] in their study indicated that fuzzy c means algorithm has been shown to be work well for clustering based segmentation. S. Belongie et al. [13] used color and texture based image segmentation using EM and its application to content based image retrival.

The aim of this study was to evaluate the (RA) Rheumatoid Arthritis disease based on skin temperature measurements, and to automatically segment the abnormal regions of thermogram using fuzzy c-means and EM algorithm. As this technique is less expensive and involves non invasive testing procedures with less time in processing the results this testing methodology can be useful in detection of Rheumatoid Arthritis. Avoiding the routine diagnostic process like M.R.I, Ultrasound and CT scan which are of high cost.

3. METHODOLOGY

3.1. Patients/Subjects

Patients with definite Rheumatoid Arthritis (satisfying American Rheumatism Association criteria) and normal persons were included for this study. The mean age of patient was thirty five years and they had the disease duration of a mean six years. We have taken data of four subjects out of which two are healthy and two are affected with Rheumatoid Arthritis

3.2. Thermal Imaging

The imaging was performed using an infra-Rent LLC camera (Lakeland, FL 8007099565).The images were analyzed using MedHot pro IR version 2.0 REV 3 proprietary software at The Centre for Biofield Sciences, M.I.T College, Kothrud, Pune. Air temperature and humidity of the imaging room were stable, with maximum temperature oscillation of ±2°C. Thermographic images of both sides of both hands for each subject have been made. All thermographic images are captured in the same room at approximately same time of the day. A total of forty images were captured of healthy and unhealthy subject of various parts of body consisting of bones joints like neck, palm, hand and face. Consent statement was signed by each patient. In Non Rheumatoid Arthritis person, the thermogram showed uniform and symmetric temperature variations. In case of abnormality, there was an abrupt variation in the temperature in the abnormal region.

3.3. Image processing by Extraction Maximization Algorithm

The EM algorithm is an iterative method that is cyclic between computing a conditional expectation and solving a maximization problem, hence the name is expectation maximization. The expectation maximization (EM) algorithm calculates maximum likelihood estimates of unknown parameters in probabilistic models involving latent variables.

The steps of EM algorithm are as follows.

1. Set K= and initialize $\theta_0$such that $L_{\theta k}$ (Y) is finite.

2. Expectation E step: Compute

$Q(\theta, \theta_k) = E_{\theta k}$ {log P_θ (Z, Y) |Y) = ∫log P_θ (Z, Y)

$P_{\theta k}$ (Z | Y) dz.

3. Maximization (M) step: Compute

$\theta_{k+1} = arg_\theta$ max Q (θ, θ_k)

4. If not converged update k = k + 1 and return to step 2.

3.4. Image processing by Fuzzy C Mean Algorithm

The Fuzzy C-Means (FCM) clustering algorithm was first introduced by Dunn [14] and later was extended by Robert L [15]. The algorithm has an iterative clustering methodology that produces an optimal c partition by minimizing the weighted within group sum of squared error objective function J_{FCM} [15].

$$J_{FCM}=\sum_{k=1}^{n}\sum_{i=1}^{c}\left(\left(u_{ik}{}^{q}\right)d^2(x_k, v_i)\right) \quad (1)$$

A solution of the object function J_{FCM} can be obtained via an iterative process, which is carried out as follows.

1. Set values for c, q and $\acute{\varepsilon}$.
2. Initialize the fuzzy partition matrix U=$[u_{ik}]$
3. Set the loop counter b = 0.
4. Calculate the c cluster centers ${v_i}^{(b)}$ with $u^{(b)}$

$${v_i}^{(b)} = \frac{\sum_{k=1}^{n} ({u_{ik}}^{b})^{q} xk}{\sum_{k=1}^{n} ({u_{ik}}^{b})^{q}} \quad (2)$$

5. Calculate the membership $u^{(b+1)}$. for k=1 to n, calculate the following. $I_k = \{i | 1 \le i \le c, d_{ik} =$ *xk− vi=0 //;* For the kth column of the matrix, compute new membership values.

(a) If $I_k = \varphi$, then ${u_{ik}}^{b+1} = \frac{1}{\sum_{j=1}^{c} \left(\frac{d_{ik}}{d_{jk}}\right)^{\frac{2}{(q-1)}}}$ (3)

(b) Else ${u_{ik}}^{(b+1)}$=0 for all i∉ I and $\sum_{i \notin \mathrm{Ik}} {u_{ik}}^{b+1}$=1; next k.

6. If$\left|\left|u^{b} - u^{b+1}\right|\right| < \in$, stop; otherwise set b=b+1 and go to step 4.

Thermal image of Rheumatoid and Non Rheumatoid subject were taken and images were converted to HSV then Fuzzy C means algorithm applied the segmented image is then superimposed with original image.

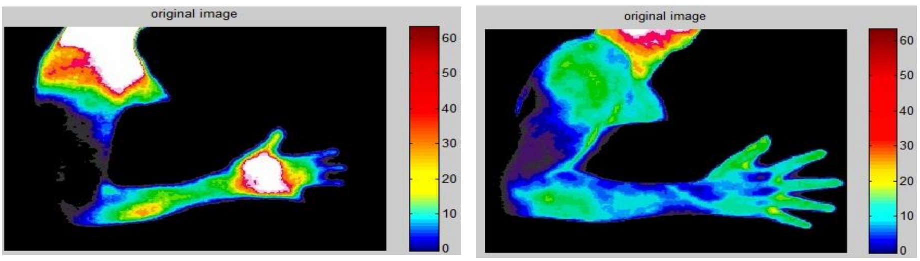
4. EXPERIMENTAL RESULTS

4.1. Skin Temperature Measurement and Image Segmentation

It has been observed that the heat distribution in RA subject is much more than that of the healthy subject. In case of abnormality, abnormal condition the regions show abrupt variations in temperature distribution. This variation of temperature is analyzed for prediction of Rheumatoid Arthritis. The fuzzy c means algorithm and extraction maximization algorithm were used for segmenting the images.

4.2. Results for Hand Thermal Image

Thermal image of rheumatoid arthritis patients showing skin temperature higher in abnormal regions than the normal regions is as shown in Figure 2(a). And also indicates the region with high skin temperature in the abnormal areas. The thermal image of the skin temperature distribution of a normal patient in without Rheumatoid Arthritis is as shown in Figure 2(b).



(a) *(b)*

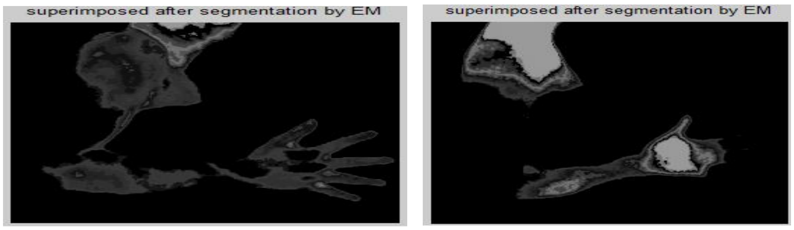
Fig2(a). *Hand Thermal image of Rheumatoid Arthritis subject* **(b)** *Hand thermal image of Non Rheumatoid Arthritis subject*

These images were captured by thermal camera and were used as an input to image segmentation process the images were first converted to HSV image. The HSV image was obtained and the EM algorithm was applied by initializing θ to a random value. The value of Z was computed iterative steps were performed until it gets converged as shown in the EM algorithm. The superimposed image was obtained from the final output of Non Rheumatoid subject which is as shown in the Figure 2(c). The output image of EM algorithm superimposed after segmentation for Non Rheumatoid subject is as shown in Figure 2(d).

The Fuzzy C-Means algorithm is used for segmenting the images which resulted in better output compared to that of EM algorithm. The output images after segmentation are superimposed by the original image. The superimposed image after segmentation by Fuzzy-C Means algorithm for Non Rheumatoid Arthritis subject is as shown in Figure 2(e).

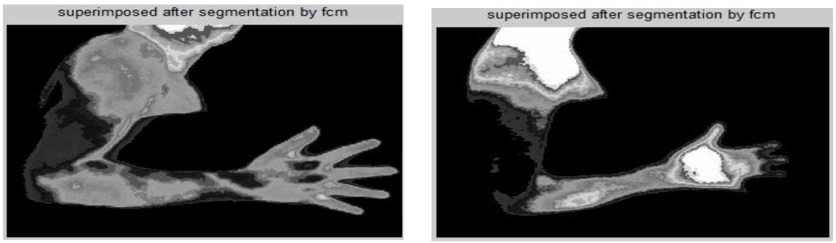
The Rheumatoid Arthritis patient image of hand was analyzed with Fuzzy C-Means algorithm the output after segmentation of the image by FCM algorithm is superimposed with original image as shown in the Figure 2(f).

Fuzzy C-Mean output superimposed with original image is used for plotting the heat distribution index from the values of HDI the comparison graph was plotted. The comparison graph shows the difference in temperature levels of normal and abnormal subject as shown in Figure 2(g). The subject suffering from the Rheumatoid Arthritis disease was having certain increase in temperature compared to that of normal Non Rheumatoid Arthritis Subject.



(c) *(d)*

Fig2(c). *Superimposed after segmentation by EM algorithm for Non RA subject* **(d)** *Superimposed after segmentation by EM algorithm for RA subject*



(e) *(f)*

Fig2(e). *Super imposed after segmentation by FCM algorithm for Non RA subject* **(f)** *Super imposed after segmentation by FCM algorithm for RA subject*

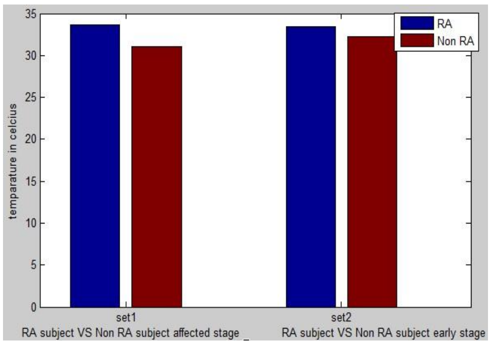
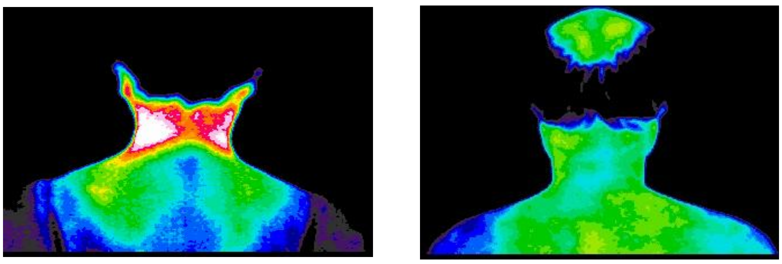


Fig2(g). *Temperature comparison graph for hand images of RA and Non RA subject*

4.3. Results for Neck Thermal Image

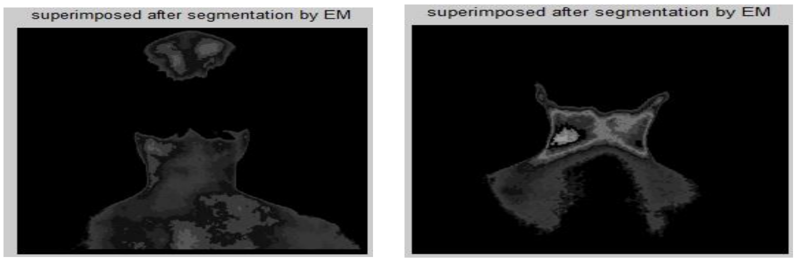


(a) *(b)*

Fig3(a). *Neck thermal image of Rheumatoid Arthritis subject* **(b)** *Neck thermal image of Non-Rheumatoid Arthritis subject*

Neck image was analyzed as there are joints involved in the neck area which resulted in the rise in temperature. The thermal images of neck area of Rheumatoid and Non-Rheumatoid subject were captured. The image captured for a Rheumatoid Arthritis patient the patient had mentioned pain in this area so we considered this area in the analysis as shown in Figure 3(a). The Non Rheumatoid subject is as shown in the Figure 3(b).

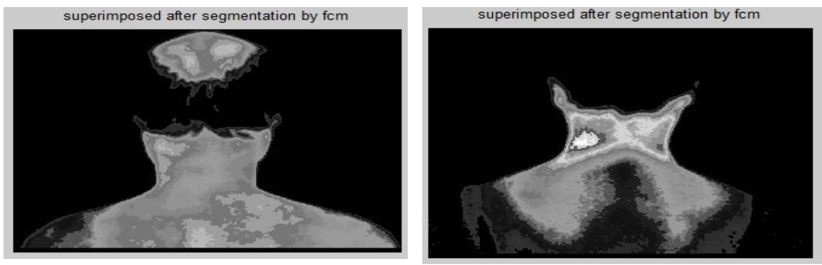
These images were used as input image both the images had shown difference in temperature distribution the Non-Rheumatoid Arthritis subject had uniform temperature distribution over the image. The Rheumatoid Arthritis patient the neck area had specially shown the significant increase in temperature compared to that of the normal subject. The EM algorithm was applied on these images considering the healthy subject the EM output of superimposed image by EM is as shown in Figure 3(c). The images of unhealthy subject after superimposed after segmentation by EM algorithm is as shown in Figure 3(d).



(c) *(d)*

Fig3(c) *Superimposed after segmentation by EM algorithm for Non RA subject (d) Rheumatoid arthritis subject neck part image by EM algorithm for RA subject*

EM algorithm for the neck ouput does not show the better segmentation result so by applying the Fuzzy C-Means algorithm the better segmentation is obtained. The algorithm has an iterative clustering methodology that produces an optimal c partition by minimizing the weight within group sum of squared error objective function. The images were processed for Fuzzy algorithm. The output of the superimposed image after segmentation by Fuzzy C-Means algorithm for healthy subject is as shown in Figure 3(e). The unhealthy subject with neck pain is as shown in Figure 3(f). The Fuzzy C-Means algorithm shows good extraction performance.



(e) *(f)*

Fig3(e). *Super imposed after segmentation by FCM algorithm for Non RA subject* **(f)** *Rheumatoid arthritis subject neck part image by FCM algorithm for RA subject*

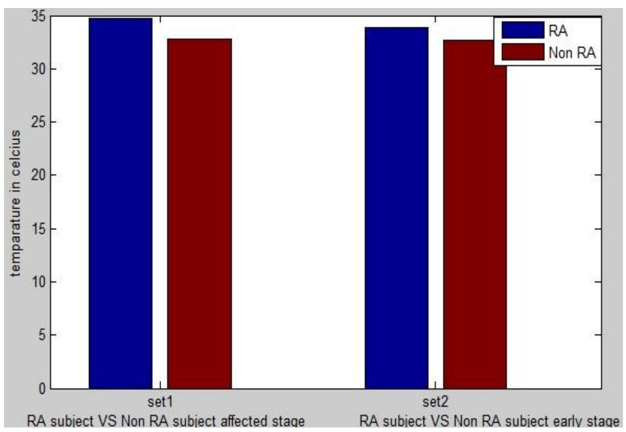
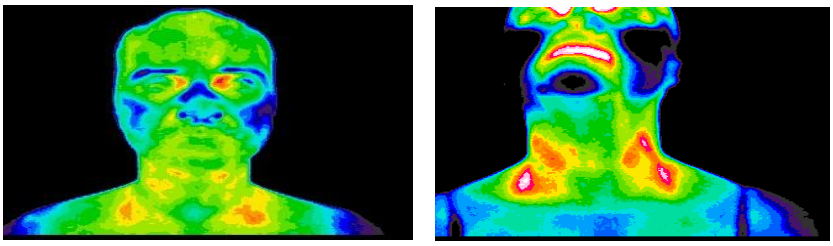


Fig3(g). *Temperature comparison graph for neck images of RA and Non RA subject*

We analyzed the heat distribution in the neck region of healthy and unhealthy subjects and evaluated the temperature differences between Rheumatoid and Non Rheumatoid subjects which showed the temperature difference of 1-1.6°C.

Fuzzy C-Mean output superimposed with original image is used for plotting the heat distribution index from the values of HDI the comparison graph was plotted. The comparison graph shows the difference in temperature levels of normal and abnormal subject is as shown in Figure 3(g).

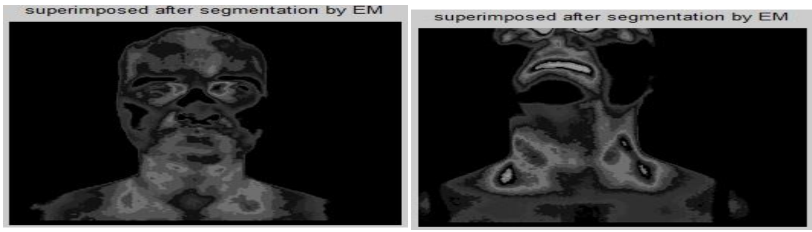
4.4. Results for Face Thermal Image



(a) *(b)*

Fig4(a). *Face thermal image of Non Rheumatoid Arthritis subject* **(b)** *Face thermal image of Rheumatoid Arthritis subject*

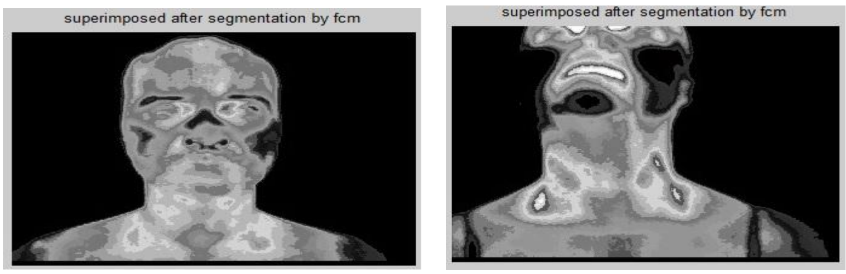
Face is a major part consisting of jaw bone and the skull. Here as the mouth is involved in continuous opening and closing this joint need to be considered for thermal imaging for detection of RA. The Face thermal image of Non Rheumatoid Arthritis subject is as shown in Figure 4(a). While the Face thermal image of Rheumatoid Arthritis subject is as shown in Figure 4(b). Thermal images of subject with Rheumatoid Arthritis and Non Rheumatoid Arthritis are taken the images had shown variation in temperature. EM and Fuzzy C- Means algorithm was applied on these images



(c) *(d)*

Fig4(c). *Superimposed after segmentation by EM algorithm for Non RA subject* **(d)** *Rheumatoid arthritis subject neck part image by EM algorithm*

The image Superimposed after segmentation by EM algorithm for Non RA subject is as shown in Figure 4(c). While Rheumatoid arthritis subject neck part by EM algorithm is as shown in Figure 4(d). For the facial image captured the EM algorithm is applied on both the images healthy and unhealthy subjects. The expectation maximization (EM) algorithm computes maximum likelihood approximation of unknown parameters in probabilistic models involving the latent variables. The healthy subject image of face after segmentation my EM is shown.



(e) *(f)*

Fig4(e) *Super imposed after segmentation by FCM algorithm for Non RA subject* **(f)** *Rheumatoid arthritis subject neck part image by FCM algorithm*

Fuzzy C-Means algorithm shows faster convergence compared to that of the EM algorithm. The healthy subject image Superimposed after segmentation by FCM algorithm for Non RA subject shown in Figure 4(e). While Rheumatoid arthritis subject neck part image by FCM algorithm is as shown in Figure 4(f). Fuzzy C-Mean output superimposed with original image is used for plotting the heat distribution index from the values of HDI the comparison graph was plotted. The comparison graph shows the difference in temperature levels of normal and abnormal subject as shown in Figure 4(g). The variation in the measured skin temperature for Rheumatoid Arthritis patient compared to normal participant was 1-1.5°C.

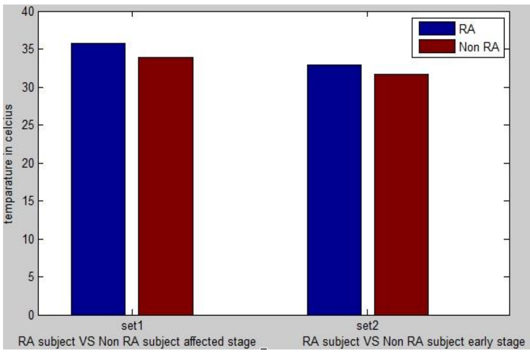


Fig4(g). *Temperature comparison graph for face images of RA and Non RA subject*

5. Conclusion

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. The heat distribution curve showed that the increase in temperature distribution in the arthritis affected region of the palm. 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. EM algorithm is an iteration algorithm of first order 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 variation in the measured skin temperature for Rheumatoid Arthritis patient compared to normal participant was 1-1.5°C. The Rheumatoid Arthritis patient can easily differed from normal subject for diagnosis of Rheumatoid Arthritis disease. This technology can be 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.

Acknowledgment

We are thankful to Dr. Aniruddha G. Tembe Rheumatologist at Aditya Birla Memorial Hospital, Chinchwad, Pune for his valuable discussion on causes of RA disease Dr. Aniruddha G. Tembe has provided us the overview of recent detection techniques used in hospitals for RA detection and help us in preparation of RA patients databank. We are also thankful to the Senior Manager Mr. Sudhir Neurgaonkar of The Centre for Bio-field Sciences MIT Pune for providing thermal imaging facilities.

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AUTHORS' BIOGRAPHY

Nizami Mohiyuddin has received Bachelor's in Electronics and Telecommunication Engineering from M.G.M's College of Engineering, Nanded. He is currently pursuing Master's in VLSI and Embedded system from MIT college of Engneering, Pune.

Pradeepkumar Dhage is working as an Asst.Professor in department of E&TC, MIT College of engineering. He has 5 years of experience. His research interests are in the area of Biomedical and Embedded system. He has been invited as key note speaker to ARAI (Automotive Research Association of India) research lab for their Industry PIP programs. He has published six papers in reputed journals.

Krishna K. Warhade received the Bachelor in Engineering in Electronics in 1995 and Master of Engineering in Instrumentation in 1999 both from Shri Guru Govind Singhji Institute of Engineering and Technology, Nanded, and Ph.D. in November 2010 from the Department of Electrical Engineering, Indian Institute of Technology Bombay, India. He has 20 years of experience in teaching and research. He is currently working as a Professor in the Department of Electronics and Telecommunication Engineering, MIT College of Engineering, Pune, India. His research interests are in the area of signal processing, image processing, video segmentation, video retrieval, wavelets, precision agriculture and biomedical.