

A Review on Inflammatory Pain Detection in Human Body through Infrared Image Analysis

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Abstract— Temperature difference in the skin surface reflects the abnormality present in the human body. Considering the phenomenon, detection and forecasting the change of temperature is the principal objective of using Medical Infrared Thermography (MIT) as a diagnostic tool for inflammatory pain diseases. Medical Infrared Thermography (MIT) is a non-invasive, non-contact and fast imaging technique that record and monitor the flow of body temperature by receiving the infrared emitted from the skin surface. Based on the standardization of thermogram acquisition and processing techniques and by the adoption of advanced infrared cameras, presently it is feasible to detect the minor temperature difference of the skin surface in the high-resolution infrared images. Recently, the research on inflammatory pain detection using medical infrared thermography concentrated on the area of temperature and statistical analysis based automated detection of abnormality from the thermograms. The paper introduces a significant review focusing on the area of different inflammatory pain detection using infrared thermography along with the environmental condition, protocol selection, and acquisition system specification in summarized tabular format. Based on the rigorous study of the publications in the area of inflammatory pain thermography, the paper also explores the area of thermogram processing and analysis of pain in a review work format.

Keywords—*Thermography; infrared; pain; inflammation*

I. INTRODUCTION

Human body distribution of temperature is widely affected by pathological abnormalities. Hence the recording of inflammation of the skin surface related with the core temperature distribution can provide essential information regarding the underlying physiological activities. The dissipation of inflammation from the skin surface is radiating in nature and lies in the infrared spectrum of light [1]. The spectrum range of inflammation makes the infrared detector suitable for recording and analysis of the thermoregulatory distribution of the skin. Medical Infrared Thermography is a non-invasive imaging technique that can detect abnormality by allocating and quantifying the inflammatory changes in the skin surface related to the temperature distribution. Since 1987, it has been accepted as a diagnostic imaging technique by the American Medical Association Council and also recently approved by American Academy of Medical Infrared

Imaging for medical imaging [2]. The detection method of the Medical Infrared Thermography is primarily based on the evaluation of temperature distribution among contralateral parts of the body. In case of healthy subjects the difference in temperature distribution is not higher than 0.5-degree Celsius [3]. Starting from the last eighties, detection of pain using thermal imaging was examined in many past investigations. Most of the investigations provide statistical quantification techniques for the abnormality analysis. Based on the study of the most relevant works published in the past, the paper represents a review work on pain detection using Medical Infrared Thermography along with the survey of acquisition conditions.

In the rest of the paper, the section II describes some inflammatory pains that can be detected using Medical Infrared thermography. Section III contains the methodological review work related to the pain thermography. The section IV and V represent the review work related to protocol selection for thermogram acquisition, thermal camera specification and disease related thermogram description in descriptive and tabular format. Finally the conclusion along with future work is made in section VI followed by the acknowledgement and the reference part.

II. MEDICAL INFRARED THERMOGRAPHY IN INFLAMMATORY PAIN DETECTION

Temperature distribution analysis and early detection of abnormality due to inflammatory pain are recognizable by Medical Infrared Thermography. Thermographic detections are compared with the clinical observations and tests for possible confirmations. Although the technique heavily depends on the surrounding and background environment, there are a number of reasons for accepting the technique for diagnosis of inflammatory pain. In general, inflammation is related to pain diseases like arthritis, frozen shoulder, Prolapse Intervertebral Disc (PIVD), spondylosis, etc. which are not defence system begins attacking the healthy tissues instead of detected by clinical observations. In case of arthritis, the immune system of the body become affected and the body foreign substances, and it causes inflammation, pain and joint damage. The presence of additional inflammation due to arthritis can be detected using medical infrared thermography.

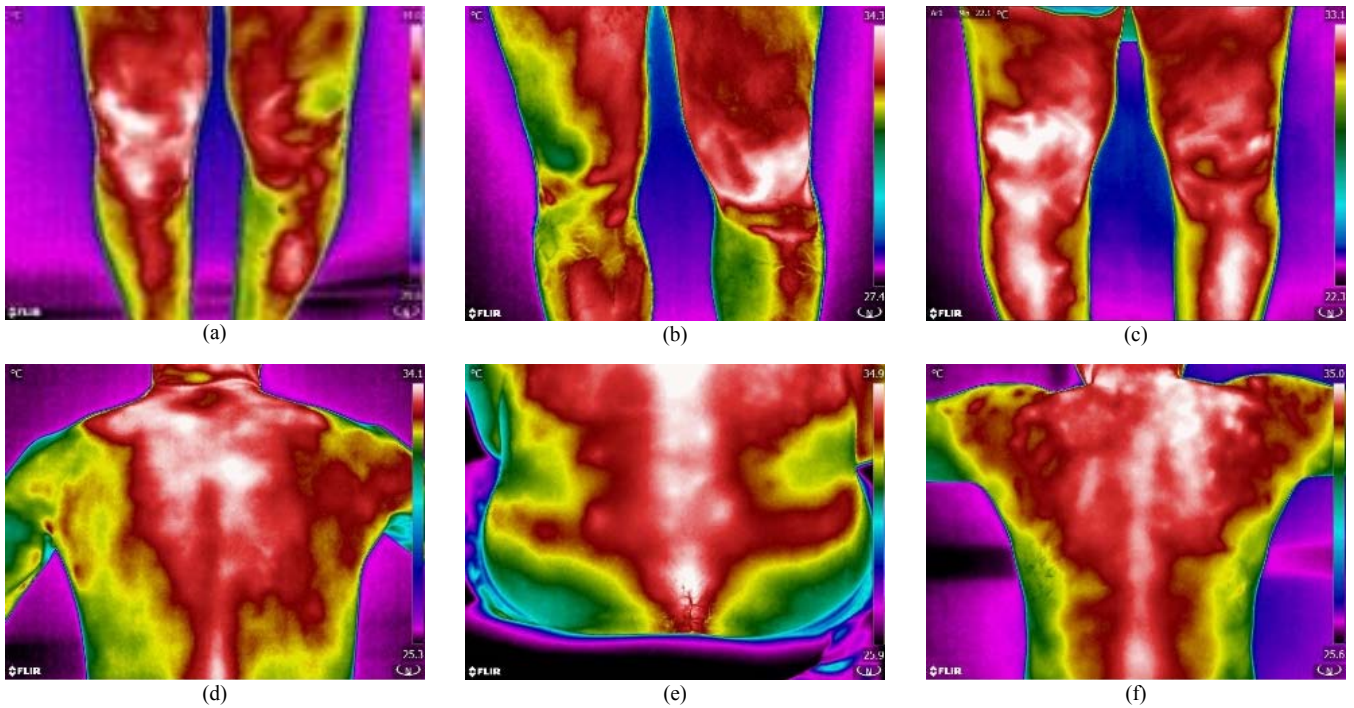


Fig. 1. Inflammatory pain thermogram of patient suffering from (a)Osteoarthritis (b)Gouty arthritis (c)Reactive arthritis (d)Frozen shoulder (e)PIVD pain (f)Cervical spondylosis.

In frozen shoulder also, pain and restriction of movement arises due to inflammation. The capsule in the shoulder area has ligament and holds the bones of the shoulder with each other. The inflammation in capsule area restricts the movement of joints and generates pain that can be early detected by the thermal imaging. The inflammation due to Prolapse Inter Vertebral Disc (PIVD) pain can generate neuronal activity along with swelling in compression of a nerve in the intervertebral region. Detection and treatment of inflammation using thermography in the initial stage can avoid the nerve compression stage in the human body.

The Fig.1 shows some of the examples of medical infrared thermography based detection of inflammation due to pain. The thermograms are captured using FLIR T650SC acquisition system in Physical Medicine and Rehabilitation (PMR) Department, Agartala Government Medical College (AGMC) of Govind Ballav Pant (GBP) Hospital, Agartala, Tripura (W) under the supervision of Dr. Satyabrata Nath, Assistant Professor, PMR Department, Agartala Government Medical College (AGMC), Govind Ballav Pant (GBP) Hospital, Govt. of Tripura.

III. METHODOLOGICAL REVIEW OF PAIN THERMOGRAM ANALYSIS

The skin of the human body contributes an important part in thermoregulation by preserving or dissipating heat. The infrared thermal imaging or the clinical thermography reports the distribution of temperature in human skin by receiving infrared radiation from the surface of the human body [4], [5].

In the past years, authors had detected the abnormality in a human body based on the analysis of temperature distribution and correlated intensity distribution of thermograms.

In 1995, Kim et al. [6] analyzed the thermal difference to detect the lumbar disc herniation. For this purpose, the severity of pain was measured by Visual Analog Scale (VAS) and Graphic Rating Scale (GRS) and compared with the thermal difference to differentiate and detect acute and chronic disc herniation and its level. The thermal difference that they measured for acute and chronic disc herniation was based on the degree of pain, duration of clinical symptom, comparison with clinical signs, types of herniation according to radiological study and based on level of herniation like mild, moderate and severity of pain and compare with the radiological studies like CT Scan, MRI etc.

In the year 1997, Hooshmand, H [7] also detected abnormality in the whole body related to pain using the temperature analysis method. The analysis had been performed on the control volunteers group and neuropathic pain patients. The method was based on the concept that unmyelinated perivascular sympathetic small c-fibers are the origin of neuropathic pain. As because the c-fibers are too small so that they are best evaluated with infrared thermal imaging compared with EMG/NCV or MRI or CT. After analysis, the rate of true positive was 78% and false positive detected 14%.

To analyze pain in the human body using thermal images, Herry et al. [4] suggested a computer aided decision support technique and summarized the result of the analysis in the year

2002. This technique was the combination of image processing and temperature analysis method. In this technique, in the first step, to remove noise from thermal images, they had followed Poisson distribution and removed noise using Wavelet-based removal technique proposed by Nowak and Baraniuk[8]. Then edge detection and morphological operations were adopted for classification of a body part from the image. In the next step, analysis of abnormal high or low-temperature areas was performed by statistical analysis and comparison of intensity distributions of symmetrical or comparable regions of interest and the result is summarized in a computer aided decision support scheme.

Again in the year 2003, Frize et al. [9] reported a technique based on thermal pattern analysis to detect physiological disorder caused by pain in the human body. The technique was focused on the thermal pattern analysis of normal subjects and

abnormal subjects related to pain. For denoising, the thermal images they again followed wavelet-based noise removal technique. To improve the efficiency of images, they removed the undesirable portion of the image. Then to detect the region of interest, classical grid of polygon and isothermal representation of images were used. In the output of image processing steps, the statistical analysis was performed to detect an abnormality.

Subsequently to detect Rheumatoid Arthritis (RA) Frize et al. [5] proposed a temperature measurement based statistical analysis method in the year 2011. This analysis was performed on a normal group of persons with no rheumatoid arthritis and a group of patients suffering from rheumatoid arthritis. In the first step of the analysis, the difference between the average temperature of joints in the control group and the patient group was determined. In the next step, the identification of

TABLE I. SURVEY TABLE OF PAIN THERMOGRAM ANALYSIS

Year	Author	Method Used	Purpose	Software/ Image Processing toolbox used
1995	Kim et al. [6]	Temperature analysis	Detection of disc herniation based on thermal difference and correlation of the thermal difference with severity of pain.	Not mentioned.
1997	Hooshmand, H [7]	Temperature analysis	Detection of abnormality related to pain in human body based on temperature analysis.	Not mentioned.
2002	Herry et al. [4]	Image processing, temperature analysis and statistical analysis.	Analysis of thermal images related to the area of pain in human body and based on computer aided decision support system summarization of the result of analysis.	MATLAB
2003	Frize et al. [9]	Image processing and statistical analysis	Detection of physiological disorder caused by pain in human body based on thermal pattern analysis.	MATLAB
2007	Park et al. [10]	Statistical analysis of temperature distribution	Detection of shoulder impingement using temperature based statistical analysis by comparison between healthy group and patient group.	SPSS 13.0
2008	Lee, Junghoon et al. [11]	Image processing and temperature analysis based on SOFES algorithm.	Automated detection of suspicious pain regions.	MTIS (Medical Thermal Imaging Software)
2010	Tkacova, M., et al [13]	Histogram analysis of temperature.	Asymmetry factor based computer assisted diagnosis of carpal tunnel pain syndrome.	Smart View software
2011	Zivcak, J., et al[15]	Statistical analysis of temperature.	Detection of the influence of carpal tunnel syndrome in temperature distribution in contra lateral region of hand dorsal region.	SmartView 2.1, FLUKE, USA
2011	Frize et al. [5]	Temperature measurement based statistical analysis.	Rheumatoid arthritis detection based on temperature measurement and analysis in healthy group of people and patients group.	MATLAB
2011	Borojevic, N., et al[16].	Basic statistical analysis of temperature distribution.	Temperature distribution based asymmetry analysis of hand region due to Rheumatoid arthritis and Osteoarthritis.	Statistica7.0, ThermoWEB system, ThermoMED proprietary software
2012	Snehalatha, U., et al[17]	Heat distribution index based temperature analysis and segmentation of region of interest using fuzzy c means algorithm and Expectation Maximization (EM) algorithm.	Heat distribution index based evaluation of rheumatoid arthritis and thermogram processing based automatic segmentation of abnormal region of interest.	FLIR software version 1.2, Matlab version 7.1, SPSS 10.0

joints was performed which gives the best confirmation of the presence of Rheumatoid Arthritis based on the temperature difference. In the last step, statistical analysis was performed to find out the significant statistical difference of temperature of joints in the control group and the patient group. The statistical features used for the analysis was skewness, kurtosis, variance, mode/max, median/max, min/max, max-min, $(\text{mode}-\text{mean})^2$, mode/min, median/min and mean/min.

For shoulder impingement analysis, Park et al. [10] also used statistical analysis method to analyze the temperature distribution of related thermograms. The thermography screening was applied to the region of interest of both the control group and patient group. The statistical analysis of thermogram was performed by SPSS 13.0 using the independent t-test for comparison of each Region Of Interest of patient group and control group. The clinical symptoms, physical examination findings and the thermographic findings are compared by 1- way analysis of variance with a Bonferroni post hoc test on numeric data and Pearson χ^2 analysis for the binomial data. Pearson linear correlation was performed to find the correlation between the clinical and thermographic data. Clinical abnormality was determined based on the finding of asymmetrical distribution of temperature in between the contralateral body parts..

In 2008, Lee, Junghoon, et al. [11] proposed a technique for automatic detection of suspicious pain regions on digital infrared thermal images based on SOFES (Survival of the Fitness kind of the Evolution Strategy) algorithm. The suspicious pain region can be detected by using multimodal function optimization algorithm, such as SOFES algorithm [12] based on the concept that the painful region represents a low temperature or high temperature compared with its neighbor regions on one's skin in thermography. The preprocessing steps that were required before applying SOFES algorithm are Region of Interest (ROI) detection, FPA sensor's output signal extraction and applying Gaussian to blur the

image.

In 2010, Tkacova, M., et al.[13] performed infrared thermography analysis in a group of patients suffering from carpal tunnel syndrome. The analysis was based on the asymmetry factor calculation using the histogram of the temperature distribution of contralateral hand parts. To determine the asymmetry factor, the authors used the method explained by Huygen et al.[14] in the year 1998. The authors Zivcak, J., et al [15.]extended their work in the year 2011 by applying statistical features in the large no. of thermogram to calculate the asymmetry of temperature distribution. The temperature analysis was performed in 5 points of the dorsal side of the hand. The analysis indicates that the temperature distribution of the median nerve in the dorsal hand side was significantly different between the control group and carpal tunnel syndrome group. The analysis shows 0,714 sensitivity with 0,714±0, 1207 confidence interval and 0,852 specificity with 0,852±0,095 of confidence interval.

In 2011, Borojevic, N., et al. [16.] also analyzed the thermogram of rheumatoid arthritis and osteoarthritis in human hand. The basic statistical analysis of temperature was performed. The asymmetry of temperature distribution was measured using 4 ways ANOVA test in between the ventral and dorsal side of hand of healthy and arthritis subjects. The mean value showed the best significant difference between the two subjects (healthy and arthritis subjects)

The heat distribution related to rheumatoid arthritis was again evaluated by Snehalatha, U., et al.[17] in 2012 depending on the heat distribution index. The authors also segment the region of interest using fuzzy c means and Expectation Maximization algorithm. From the analysis, they predicted an abrupt temperature variation in the affected due to rheumatoid arthritis. All the analysis of temperature variation performed by different authors related to inflammatory pain presented in the section are summarized in Table I.

TABLE II. SURVEY TABLE OF PAIN THERMOGRAPHY ACQUISITION PROTOCOL

Author	Thermogram Acquisition Condition of Patient		Room Temperature	Special Recommendation at the Time of Capturing
	<i>Clothing in the area of capturing</i>	<i>Stabilization before capturing</i>		
Frize et al. [5]	Short sleeved T-shirts and shorts. No shoes and socks.	15 minutes	20°C.	No application of lotion, talcum powder or deodorant and putting off rings, bracelets or neck-lace.
Park et al.[10]	No	15 minutes	19°C to 21°C	Not mentioned.
Lee, Jung-hoon et al. [11]	No	20 minutes	Not mentioned	No application of lotion or ointments and putting off rings, watches or neck-lace.
Tkacova, M., et al [13]	No	20 minutes	20°C	Not mentioned
Zivcak, J., et al[15]	No	20 minutes	20°C	Not mentioned
Borojevic, N., et al[16]	Not mentioned	Not mentioned	Not mentioned	Approximately constant temperature and humidity of the capturing room required.
Snehalatha, U., et al[17]	No	10 minutes	20°C	Not mentioned

IV. SURVEY ON IMAGE ACQUISITION PROTOCOLS

For thermal imaging related to pain, there is no protocol that is universally accepted as acquisition standard at present. For this reason, each clinic or university or research group follows their own protocol as per their needs. But there is a similarity found in the acquisition condition of patients, room temperature, and other different factors. Frize et al. [5] recommended the thermography at 20°C room temperature. They instructed their patients, not to apply talcum powder, lotion or deodorant on skin on the day of examination. Some controllable factors such as hot drinks, alcohol, physical exercise, etc. could potentially produce effect on the skin. For this purpose, they recommended not to take hot drinks one hour prior to the imaging, not to smoke two hours prior to the examination and to avoid prolonged sun exposure for a week before imaging. Also they suggested avoidance of alcohol twelve hours prior to the imaging and also avoidance of acupuncture, hot or cold presses, physiotherapy, TENS (Transcutaneous Electrical Nerve Stimulation) and physical exercise twenty-four hours prior of the session. According to Park et al.[10] room temperature needs to be set on 19 to 20°C and patients need to be in upper body disrobed condition 15 minutes before the screening to get a stabilized condition. Lee, Junghoon, et al.[11] recommended their patients not to apply any lotion or ointments and also to put off rings, necklaces, and watches. They also recommended that patients should quit physical therapies. According to their preparation for thermography, in order to be stabilized, patients should keep themselves undressed for more than 20 minutes before imaging. Tkacova, M., et al[13] and Zivcak, J., et al [15] also suggested to keep the region of interest for thermography in

undressed condition for 20 minutes before capturing of thermogram at 20°C . The room for thermography was retracted blind from solar radiation. Borojevic, N., et al.[16] performed their acquisition in a stable condition of temperature and humidity. Snehalatha, U., et al[17] also recommended to perform the capturing in a stable temperature of 20°C with 20 minutes stabilization of patients in disrobed condition at the area of imaging. Table II summarizes the details of the acquisition protocols described above.

V. SURVEY ON THERMAL CAMERA AND THERMOGRAMS

Kim et al. [6] analyzed thermography related to lumbar disc herniation of 147 patients and grouped them into acute and chronic based on severity of pain which was measured by Visual Analog Scale (VAS) and Graphic Rating Scale(GRS). The number of cases related to acute disc herniation was 78 and 69 were present in chronic disc herniation. The thermography camera used by the author was Digital Infrared Thermographic Imaging (D.I.T.I. DOREX Inc) for evaluation of pain based on thermograms. Hooshmand, H [7] studied the thermography related to neuropathic pain in the human body using Agema Cameras with Bales Scientific Thermal Processor. For this purpose, 682 thermograms of neuropathic pain patients and 100 thermograms of control volunteers had been taken for the study. Herry et al. [4] considers 100 patients from the Pain Clinic of the Moncton Hospital, New Brunswick, Canada in between the year 1981 and 1984 by using a thermal camera of 128x128 pixels with 256 gray intensities level named as AGA Thermovision 680 medical

TABLE III. SUMMARY OF THE THERMAL CAMERA SPECIFICATION AND THERMOGRAM DESCRIPTION

Author	Method Used	Resolution	Total No of Thermograms	Disease Detected
Kim et al. [6]	D.I.T.I. system (DOREX Inc.)	Not mentioned	147	Lumbar disc herniation
Hooshmand, H [7]	Agema Cameras with Bales Scientific Thermal Processor	Not mentioned	Patient group: 682 Control group: 100	Neuropathic pain
Herry et al. [4]	AGA Thermovision 680 medical and AGA OSCAR	128x128	100	Pain patients
Frize et al. [9]	AGA Thermovision 680 medical and AGA OSCAR	128x128	First set :100 Second set :24 Total :124	Back and leg pain
Park et al. [10]	IRIS 5000	Not mentioned	Patient group:70 Control group :30	Shoulder impingement
Lee, Junghoon et al. [11]	ThermalVision of MESH Co., Inc	320x240	Not mentioned	Glycosuria, Degenerative arthritis,Varicose vein
Tkacova, M., et al [13]	ThermaCam Fluke Ti55/20	320×240	Patient group:7 Control group :7	Carpal tunnel syndrome
Zivcak, J., et al. [15]	ThermaCam Fluke Ti55/20	320×240	268	Carpal tunnel syndrome
Frize et al. [5]	Not mentioned	320x240	Patient group: 13 Control group: 18	Rheumatoid arthritis (RA)
Borojevic, N., et al. [16].	Thermo Tracer TH7102WL	Not mentioned	Patient group: 15 Control group: 6	Rheumatoid arthritis (RA) and osteoarthritis (OA).
Snehalatha, U., et al. [17]	ThermaCAMT400	Not mentioned	Patient group: 10 Control group: 10	Rheumatoid arthritis (RA)

ans AGA OSCAR. Frize et al. [9] captured the first set of 100 thermograms related to pain in the human body from Pain Clinic of the Moncton Hospital, New Brunswick, Canada, between 1981 and 1984. The second set of 24 thermograms related to normal healthy volunteers had been taken in the year June 2002 for comparison and analysis with thermograms related to pain. All the thermograms were of the back and legs of the human body. Frize et al. [5] used a thermal camera of 320x240 pixels to analyze the thermograms of patients suffering from Rheumatoid Arthritis. They had taken thermograms of 13 patients and 18 normal subjects, and those images were collected from knees, wrists, palms and from joints of hand. Among those 13 patients, 9 were female, and 4 were male and out of 18 normal subjects 8 were female and 10 were male. The wavelength of the thermal camera was from 7.5 to 13 μm , and Field of View (FOV) was 24°x18° with 1.3 mrad spatial resolution and 0.05°C at 30°C thermal resolution. The minimum focus distance was 30 cm, and the imaging speed was 30 frame/sec. Park et al. [10] present a research related to the thermographic imaging in patients with shoulder impingement syndrome. This was performed by using the IRIS5000 (Medicore, Seoul, Korea) and consisted of a computer, an infrared camera and a liquid crystal display monitor. Thermograms of upper body of 100 selected patients in 4 views were taken from shoulder and elbow joints at the clinic in the Department of Orthopaedic Surgery. The four views were posterior, anterior, left and right lateral views and, among those 100 patients, 55 were men, and 45 were women. They had also taken 30 thermograms of the same four views from normal persons without any pain or problem to study the thermography related to shoulder impingement. Lee, Junghoon et al. [11] collected thermograms of patients suffering from glycosuria, degenerative arthritis and varicose vein using a Thermal Vision of MESH Co., Inc. in Republic of Korea. The images were of size 320x240 pixels, and the thermal sensitivity of the camera was less than 50 mk. For analysis, Tkacova, M., et al [13] collected 7 thermograms related with carpal tunnel syndrome patients and also collected 7 symmetrical thermograms of healthy persons using ThermoCam Fluke Ti55/20 acquisition system. with thermal sensitivity 0.05°C at 30°C and resolution 320x240 pixels. The spectral range of the camera was 8 to 14 μm . The dorsal view of the hand was taken parallel at the distance of 0.55 meter and in extended analysis, Zivcak, J., et al [15] had taken total 268 thermograms of dorsal hand side of both the healthy patients and pathological hands containing Carpal Tunnel Syndrome with 0.98 thermal camera emissivity. Borojevic, N., et al [16] captured ventral and dorsal side of hand using Thermo Tracer TH7102WL system. Their analysis was performed on the thermograms of 6 healthy volunteers, 8 patients containing rheumatoid arthritis and 7 patients of osteoarthritis. Snehalatha, U., et al. [17] also captured thermogram of anterior and posterior view of hand for rheumatoid arthritis using ThermoCAMT400 camera from 1-meter distance of the region of interest. The thermograms was taken from 10 patients with rheumatoid arthritis and for analysis thermogram of 10 normal persons are also taken and

analyzed. The Table III represents summary of camera specification and details of thermogram and disease in tabular form.

VI. CONCLUSION AND FUTURE WORK

With the advent of high sensitivity infrared cameras, Medical Infrared Thermography is becoming an alternative diagnostic tool for inflammatory pain detection. In addition to high sensitivity, thermogram resolution and accuracy, infrared thermography is a non-invasive methodology with harmless imaging technology. The thermograms are stored digitally for further analysis using various software packages and image processing based analysis to obtain the pattern of temperature distribution. In this paper, the methodological review briefly describes the analytical methods of pain thermograms. Studies so far indicate that, the statistical analysis of temperature distribution of thermogram is common and widely accepted method for abnormality analysis related to inflammatory pain. The review based study also shows that, the control environmental condition and proper protocol selection for minimum interference are effective parts of the accurate thermogram acquisition. But there is no protocol that is universally accepted for inflammatory pain analysis a present. In the future phase, the work will be extended by creation and analysis of database related to inflammatory pain in the human body by following required standardized protocols of thermogram acquisition.

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