Standardization of Infrared Breast Thermogram Acquisition Protocols and Abnormality Analysis of Breast Thermograms

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ABSTRACT

The non-invasive, painless, radiation-free and cost-effective infrared breast thermography (IBT) makes a significant contribution to improving the survival rate of breast cancer patients by early detecting the disease. This paper presents a set of standard breast thermogram acquisition protocols to improve the potentiality and accuracy of infrared breast thermograms in early breast cancer detection. By maintaining all these protocols, an infrared breast thermogram acquisition setup has been established at the Regional Cancer Centre (RCC) of Government Medical College (AGMC), Tripura, India. The acquisition of breast thermogram is followed by the breast thermogram interpretation, for identifying the presence of any abnormality. However, due to the presence of complex vascular patterns, accurate interpretation of breast thermogram is a very challenging task. The bilateral symmetry of the thermal patterns in each breast thermogram is quantitatively computed by statistical feature analysis. A series of statistical features are extracted from a set of 20 thermograms of both healthy and unhealthy subjects. Finally, the extracted features are analyzed for breast abnormality detection. The key contributions made by this paper can be highlighted as – a) the designing of a standard protocol suite for accurate acquisition of breast thermograms, b) creation of a new breast thermogram dataset by maintaining the protocol suite, and c) statistical analysis of the thermograms for abnormality detection. By doing so, this proposed work can minimize the rate of false findings in breast thermograms and thus, it will increase the utilization potentiality of breast thermograms in early breast cancer detection.

Keywords: Breast Cancer, Infrared Breast thermography, Breast thermography acquisition protocol, Bilateral Symmetry, Asymmetry analysis

1. INTRODUCTION

More than a million women worldwide are identified with breast cancer every year, which accounts 23% of all cases of female cancer [1]. Besides, the rate of incidence, the breast cancer death rate is also very high. According to the International Agency for Research on Cancer [2], since 2008, the incidence rate of breast cancer has been increased by more than 20% while the mortality rate has been increased by 14%. There is no certain way to prevent breast cancer. However, the probability of successful treatment and the complete recovery of the breast cancer patient entirely depend on the early detection and diagnosis of breast cancer. E.Y.K. Ng [3] stated that breast cancer is a highly treatable disease with 97% chances of survival if discovered early. In this respect, infrared breast thermography has distinguished itself as the earliest breast cancer detection methodology. It has the potential to detect breast cancer 10 years earlier than the traditional gold standard method- mammography [5], [6]. Compare to the other breast imaging modalities, breast thermography is cheaper and easier to use, for which it can be used for routine checkup [7], [9]. Keyserlingk et al. [8] said that thermography can detect those tumors that cannot be detected or missed by mammography. Thus, use of thermography for detecting breast cancer holds a great promise in detecting the cancer tumor in its early stage. The painless and radiation-free nature of thermography makes the breast thermography more reliable and feasible in breast cancer detection since women breast is very sensitive to radiation, and this can trigger the factors for cancerous growth [10]. The breast thermography can identify the presence of a breast tumor from the raised temperature associated with

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the increased metabolic activity, for which an abnormal breast thermogram is considered as the significant biological risk marker for the existence of a tumor [3]. In [6], Keyserlingk et al. reported that when in their study, suspicious mammograms were combined with abnormal breast thermograms, a sensitivity of 95% was obtained. This 95% sensitivity improved to 98% when the clinical examination was also included. They concluded that the combination of one imaging modality with others may nullify the deficiencies of each other. Thus, if breast thermography is used as an adjunctive tool to mammography, it will increase the accuracy of the breast screening. Therefore, it should be emphasized that the breast thermography is mainly to improve the breast screening sensitivity, but not to replace the other existing methods.

However, the breast thermography is very much sensitive to the environmental changes, which may reduce the potentiality of breast thermography in early breast cancer detection. This leads to the standardization of the breast thermography procedure. Standardization of breast thermography specifies that the breast thermograms should be captured under some strict protocols. The absence of standard protocols leads to false findings and wrong interpretation of the breast thermograms [9], [11]. There are several national & international associations and authors, who have proposed and published various standard protocols to perform a valid and accurate infrared breast thermography. In 1986, the American Academy of Thermology published some guidelines for conducting thermographic examinations [12]. K. Ammer et al. [13] had also provided some standard procedure for infrared imaging. Undergoing some simple steps before thermography will make the breast thermography as a popular tool for early breast cancer detection. In a study carried out by E. Y. K. Ng et al. [7], the patients were instructed to abstain from alcohol, cigarettes and any form of drugs that could affect the body's biological system. Application of powder or ointment in the patient's breast surface was also prohibited. They also considered the period of the menstrual cycle of the patients. During the time of acquisition, the room temperature and humidity was maintained at 20^oC - 22^oC and 60 ± 5% respectively [7]. Similarly, H. Q. Yang et al. [40] had maintained a thermal equilibrium condition in the examination room and performed patient acclimation of 15 minutes before taking the thermograms. In 2002, J. Keyserlingk [4] and his associates had performed a research work on infrared breast thermography based breast cancer detection, in which the acquisition was taken place in a draft free thermally controlled dark room maintained at 18^oC - 20^oC. Prior to the examination, the patient was also asked to refrain from alcohol, coffee, smoking, exercise, deodorant, and lotion for three hours prior to testing. The patient acclimation period was kept as 5 minutes in which patient was instructed to sit with her hands locked over her head. Thus, there is not a single universal protocol suite, and different authors had maintained different parameters for acquisition of breast thermograms. Therefore, the primary intention of this paper is to achieve a higher level of consistency in the use of breast thermography by considering some imperative parameters and measures of breast thermography.

Undergoing a number of research works, a new standard breast thermogram acquisition setup with some standard protocols has been proposed here. The breast thermogram acquisition setup is established at the Regional Cancer Centre (RCC), Agartala Government Medical College (AGMC), Government of Tripura, India. The thermal imaging system used in our research work is FLIR T650sc thermal camera with the thermal sensitivity of 20 mK at 30^o C. Acquisition of breast thermograms is followed by the computerized analysis of the thermograms for breast abnormality detection. The paper emphasizes on developing a statistical feature based infrared breast thermogram processing technique that can signify the presence of thermal asymmetry in a thermogram. The developed method involves the extraction of twelve statistical features including both the first order and second order features. The analysis was carried out on a dataset of 20 thermograms that includes the thermograms of 10 healthy persons and 10 unhealthy patients. From the analysis, it is found that among the first order statistical features - mean, skewness, kurtosis, and entropy show better discriminating ability than the remaining features. Similarly, among the second order statistics, three features namely contrast, entropy and correlation can differentiate the normal thermograms from the abnormal thermograms.

This paper is organized as follows. In Section 2, a brief description of the infrared breast thermography has been provided. Section 3 elaborately describes the designing of the protocol suite for the acquisition of breast thermograms. The detailed description of the breast thermogram dataset is provided in Section 4. Section 5 presents the bilateral asymmetry analysis of the breast thermograms which is followed by the performance evaluation in Section 6. Finally, Section 7 concludes the paper. The workflow of the paper is shown in Figure 1.

2. INFRARED BREAST THERMOGRAPHY

All objects with a temperature above absolute zero (-273K) in the universe emit infrared energy as a function of their body temperature. The relation between the body temperature and radiated energy is defined by the Stefan-Boltzmann

Law, which states that the total radiation emitted by an object is directly proportional to the object's area, its emissivity and the fourth power of its absolute body temperature [30]. Thus, the intensity of the infrared radiation depends on the body temperature of the object, i.e., a hotter object radiates more intense infrared radiation at a shorter wavelength. In the electromagnetic spectrum, infrared radiation covers the range from 0.75 µm to 1,000 µm. But, the infrared radiation emitted by the human body occupies a narrow band of 8 µm to 12 µm, [31] which is usually used by the medical system for disease diagnosis purpose. Humans are homeotherms and capable of maintaining a constant temperature that is different from that of the surroundings. A few degree changes in temperature may be the indication of physical dysfunction, i.e., "In whatever part of the body, excess of heat or cold is felt, the disease is there to be discovered" [32].

Infrared thermography is a functional or physiological imaging modality that can be used to detect the physiological changes that are associated with regional vasodilation, hyperthermia, hypermetabolism and hypervascularization [31]. Formation of a malignant breast tumor is associated with Angiogenesis and higher metabolic rate, for which the cancerous cells are at a higher temperature than the normal cells around [34]. Moreover, the cancerous cells have an imbalanced metabolic activity that leads to the utilization of high amount of blood glucose. This high metabolic activity causes an increase in local temperature in comparisons to the normal cells. And this phenomenon has enabled the Infrared thermography as a reliable and efficient technique for envisioning the abnormality [28]. Besides the formation of a tumor, there are some breast diseases where no tumor formation takes place. In such cases, the presence of high vascularization asymmetry is found in breasts which can be detected by Infrared thermography [27]. In a screening program of 10,000 women, Gautherie found that the application of infrared thermography to asymptomatic patients played a very crucial role in assessing the risk of developing cancer and thus, to divide the patients into low-risk and high-risk categories [26]. By following a patient group of 1416 patients, Spitalier concluded that a persistently abnormal breast thermogram is associated with high risk of developing cancer [33].

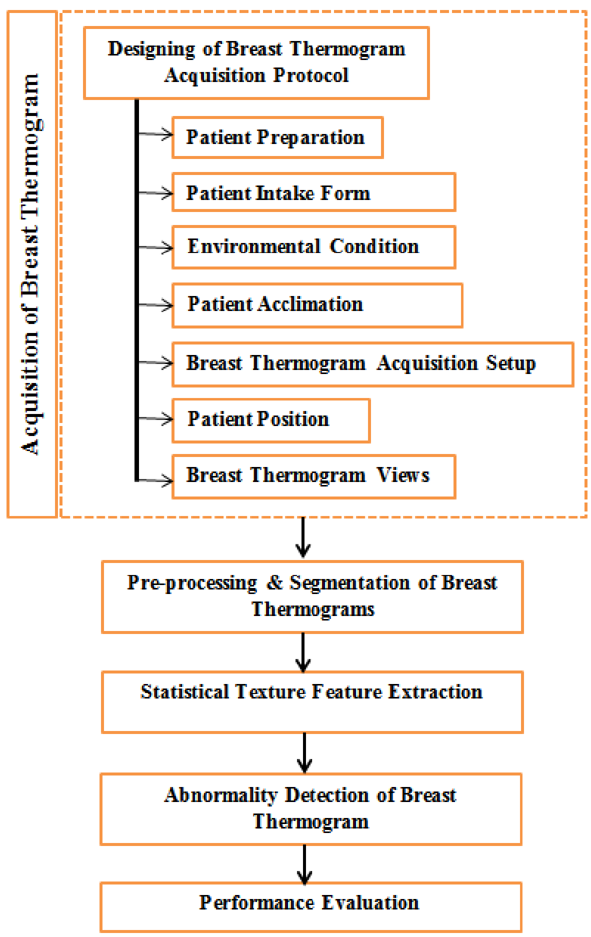


Figure 1. Workflow of Predicting Abnormality from Infrared Breast Thermograms

3. PROTOCOL SELECTION FOR ACQUISITION OF INFRARED BREAST THERMOGRAMS

Although infrared thermography with 90% of sensitivity has proved itself as a potential tool for early detection of any breast abnormality, its accuracy relies on several factors. Ignoring these factors may degrade the efficacy and sensitivity of the breast thermography. Hence, a standard protocol suite is desired to be followed during the acquisition of breast thermograms so that the thermogram can provide accurate temperature values. However, there is no standard protocol for acquisition and interpretation of abnormal thermal images and to fix the size and location of an embedded tumor. In [3], E.Y.K. Ng discussed the performance and environmental requirements in characterizing thermography to be used for breast tumor screening. Based on the information from the existing breast thermography acquisition protocols, a new protocol suite for the acquisition of breast thermogram has been designed. The proposed protocol suite consists of aspects such as patient preparation, the environmental condition of the examination room, patient's intake form, patient acclimation, patient positioning, thermal imager system and capturing views. Each of these components has their individual influence on Infrared thermography. By maintaining all these protocols, an infrared breast thermogram acquisition setup has been established at the Regional Cancer Centre (RCC) of Agartala Government Medical College (AGMC), Govt. of Tripura, India. This section elaborately describes the set of protocols used for patient preparation, patient acclimation, breast thermogram acquisition, etc. in this research work.

3.1 Patient Preparation

Preparing and managing a patient prior and during the breast thermography examination may reduce the chances of appearing thermal artifacts and thus, improves the precision of breast thermograms. Several human body related issues like the symmetry of body temperature, previous injuries, circulatory problems, etc. are associated with the accuracy of breast thermography [3, 5]. Factors like regular smoking and alcohol intake also reduce the surface temperature of the body [3], [14]. A study carried out by D. Carlo suggested that smoking causes an increase in blood pressure while a decrease in skin temperature [15]. Moreover, application of cosmetics and ointments has a significant influence on the infrared readings. It is because, the evaporation of water and alcohol from the ointment or lotion causes real cooling of the skin surface, which affects the microcirculation skin regulators [16]. In [17], K. L. Ewing et al. concluded that intaking of alcohol and smoking before the thermographic examination, change the regular thermal pattern to a greater extent that makes it impossible to interpret the thermograms. Considering all these factors, a set of instructions has been designed for the pre-exam preparation of the patients. The set of instructions used in our research work is listed below-

- The patient should avoid prolonged sun exposure for a week.
- The patient should avoid the application of lotion or ointment or talcum powder on the breasts.
- The patient should avoid physical activity or exercise on the day of breast thermography.
- The patient should avoid pain medication (if any) on the day of examination.
- The patient should avoid tight fitting clothes.
- The patient should avoid smoking or consumption of alcohol before the breast thermography.
- The patient should not intake coffee, tea, soda or any other beverages containing caffeine.
- The patient should avoid heavy meal on the day of breast thermography.
- The patient should be in her 5^{th} -12^{th} day and 21^{st} day of the menstrual cycle.

3.2 Patient Intake Form

For a better understanding of patient's family background in our research work, an INTAKE FORM has been designed. The patient intake form is a kind of form, in which a patient gives his/her all personal information including name, age, sex, height, weight, etc. and disease related information like symptoms (if any), duration, etc.. The patient also provides his/her family history of breast cancer or any other cancer, previous medical tests, diagnoses, surgeries, physical therapies (if any), etc.. The written consent is also used to take from the patients on the intake form for using their breast thermograms for the research purpose.

3.3 Environment of the Breast Thermography Room

For maintaining the quality of the breast thermograms, the environmental conditions of the examination room should be controlled. In our research work, the size of the room is adequate to maintain a consistent temperature. Also, sufficient space is there inside the examination room so that patients of any size can feel comfortable and get enough space to make their movements. The examination room is free from ventilators and windows. For maintaining the temperature of the room in the range of 20-24^{o} C, an air conditioner is placed in the room. For accurately monitoring the ambient temperature and the humidity of the examination room, a Thermo-Hygrometer has also been utilized in our research work. In the examination room, instead of incandescent light, fluorescent lighting are used since incandescent lighting produces a high amount of infrared radiation that may interfere the process of breast thermography.

3.4 Patient Acclimation

The acclimation of a patient before breast thermography is an essential task as external factors may modify the human body temperature. Hence prior to the breast imaging, it is must to give time to the patient's body to equilibrate with the ambient temperature of the examination room [19]. After taking the consent, the patient is brought to a private place inside the examination room. Then, the patient is instructed to disrobe from her waist up and to remove jewelry like neckpieces, chain, etc. (if any). Then the patient is asked to lie down on a bed cum table (specially designed for our research work) for 15 minutes, and this will allow the patient's body to equilibrate with the ambient temperature of the examination room. During the period of equilibrium, the patient is instructed to keep his/her hands over head and also to avoid crossing of arms. Moreover, during the time of patient acclimation, the examination room is kept dark.

3.5 A Cubicle with Black Background

In the process of infrared thermography, consideration of the background is very much essential. The thermal reflections are the bane of infrared thermography that is more prevalent in objects having less emissivity. These factors lead to incorrect analysis and wrong diagnosis of the breast thermograms. Hence, controlling the background in infrared breast thermography is one of the most necessary tasks to make more accurate temperature measurements. In this work, a cubicle with black background has been designed for having a homogeneous background while capturing the breast thermograms. This cubicle with the black background is also used for providing privacy to the patients during acclimation time. Figure 2 shows the structure of the black cubicle.

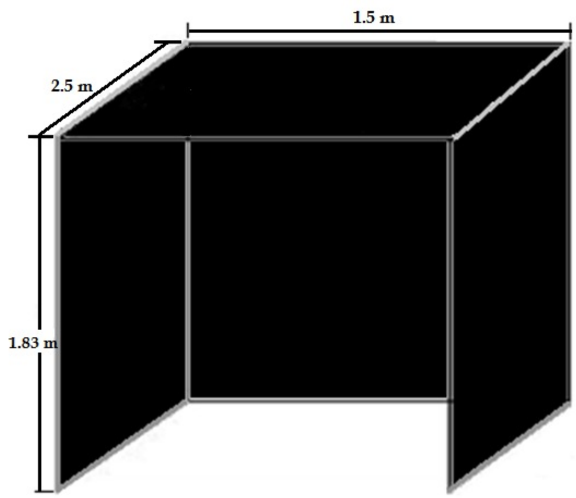


Figure 2. Structure of the Black Cubicle

3.6 Thermal Imaging Camera System

The entire procedure of breast thermography mainly depends on the infrared camera specifications such as the dynamic range, image resolution and thermal sensitivity of the infrared camera. The dynamic range of the infrared camera should be sufficient enough so that it can preserve the fine details in breast thermograms [18]. Like dynamic range, a thermal camera with good thermal sensitivity can detect a minute temperature variation by discriminating the thermal radiation more precisely. Here, in our research work, the FLIR T650sc thermal camera with thermal sensitivity of < 20 mK @ 30^{o}C, spectral range of 7.5 -14.0 μm and image resolution of 640 x 480 pixels has been used for acquisition of breast thermograms. For mounting the thermal camera, a vertical height adjustable tripod stand with a heavy base is used. The

FLIR Thermography cameras were licensed by FDA in the year 2004 to use as an adjunctive tool to other clinical diagnostic measures for the diagnosis and screening of the changes in skin surface temperature [20].

3.7 Patient Positioning

The positioning of the patient and the thermal camera during capturing is one of the critical components for accurate imaging. An alignment of about 90^o is maintained in between the camera lens, and breast area of each patient. To improve the precision of the temperature readings and the interpretation accuracy of the thermograms, a distance of 1 meter is kept between the thermal camera and the patient body as shown in Figure 3. In most of the cases, 1 meter distance is sufficient to fill the viewable image area, but in some instances due to the larger body structure of the patients, this distance is not adequate to produce accurate thermograms. Hence in those cases, a distance in which the breast area is best fitted to the thermal camera is considered. In such cases, a measuring tape is used to record the distance of the patient from the camera.

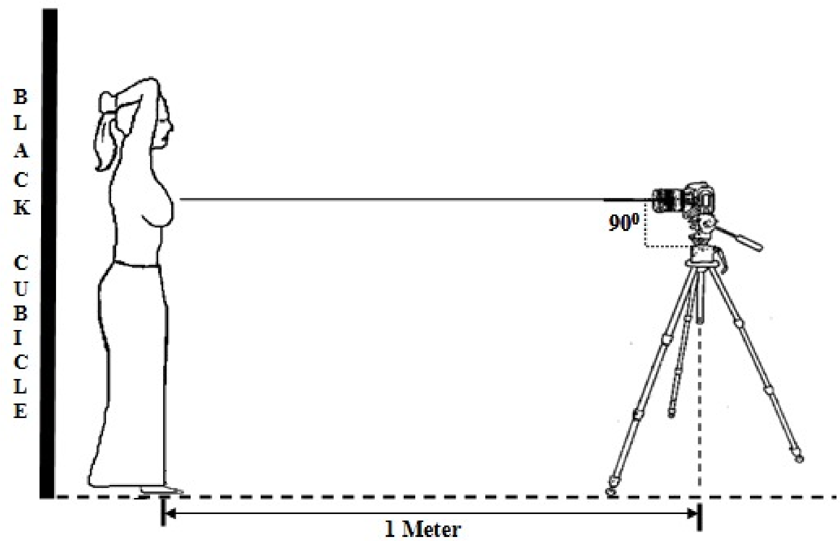


Figure 3. The position of a patient in front of the Thermal Imager.

3.8 Breast Thermogram Views

Along with the other parameters of breast thermography, the direction in which a breast thermogram should be captured is also considered in our research work. G. Bharathi et al. [21] suggested that breast imaging in a limited number of views reduces the accuracy of abnormality detection for which they had performed complete imaging of each breast. Moreover, the formation of a breast tumor is not confined to a fixed region, which makes it necessary to take the breast images from all possible directions. In our research work, the capturing starts with the supine view of the breast which is followed by the capturing of frontal view, left lateral view, right lateral view, left oblique view, right oblique view, and close up views of each breast.

4. DETAILS OF THE BREAST THERMOGRAM DATASET

The breast thermogram dataset used in this research work comprises of the thermograms of 10 healthy subjects and 10 unhealthy subjects. Subjects with previous breast surgery or with loss of one or both breasts are not considered in this work. The age of the subjects varies in between 28 to 80 years. While doing thermography, for each of these subjects the mammography report is also collected for verification of the result of breast thermography. In some cases, the Fine Needle Aspiration Cytology (FNAC) report is also available and these reports are also used for evaluation of the breast thermography result. The subjects whose mammograms are found to be healthy or normal are considered as healthy persons while subjects whose mammograms or FNAC shows the presence of any malignant and benign tumor are considered as unhealthy patients. The details of the breast thermograms of each healthy or unhealthy patient are depicted in Table 1, where the corresponding mammography result is also provided. From Table 1, it is clear that in case of the healthy persons with normal mammography report, the thermal pattern of the bilateral breasts, i.e., the left and right breast is symmetrical, while in case of the patients with malignant or benign tumor in any breast shows either asymmetric bilateral thermal pattern or the presence of any hotspot in one or both breasts.

Table 1. Details of samples in the dataset including age, the temperature pattern of the bilateral breast and clinical observation based on the mammography report.

Healthy Person				**Unhealthy Person**			
Sl. No.	**Age (Yrs)**	**Bilateral Thermal Pattern**	**Clinical Observation (Mammography Report)**	**Sl. No.**	**Age (Yrs)**	**Bilateral Thermal Pattern**	**Clinical Observation (Mammography Report)**
1	45	Symmetrical	Normal Study	1	38	Hotspot (Right)	Malignant Tumor (Right)
2	50	Slightly Asymmetric	Normal Study	2	55	Hotspot (Left)	Malignant Tumor (Left)
3	29	Symmetrical	Normal Study	3	62	Hotspot (Left)	Malignant Tumor (Left)
4	46	Symmetrical	Normal Study	4	46	Hotspot (Left)	Malignant Tumor (Left)
5	39	Symmetrical	Normal Study	5	58	Asymmetrical	Malignant Tumor (Left)
6	43	Symmetrical	Normal Study	6	39	Hotspot (Left)	Malignant Tumor (Left)
7	46	Symmetrical	Normal Study	7	35	Hotspot (Left)	Malignant Tumor (Left)
8	40	Slightly Asymmetric	Dense Breast	8	28	Asymmetrical	Benign Mass (Right)
9	28	Slightly Asymmetric	Dense Breast	9	60	Asymmetrical	Malignant Mass (Left)
10	80	Symmetric	Normal Study	10	40	Asymmetrical	Malignant mass (Right)

5. BILATERAL ASYMMETRY ANALYSIS OF BREAST THERMOGRAMS

The distribution of skin temperature of a healthy body exhibits a bilateral symmetry, i.e., the human body is thermally symmetrical. Based on this idea, presence of any bilateral asymmetry or asymmetric thermal patterns in a breast thermogram may be the indication of a pathological condition. As mentioned above, the human body temperature depends on the metabolic activity, blood flow, and the surrounding temperature, etc.. The formation of a cancerous breast tumor is associated with a high metabolic activity that causes an increase in local temperature in comparisons to the normal cells. In the dataset of normal breast thermograms, it has been noticed that the thermal patterns are almost symmetrical in both breasts while, in case of the abnormal breast thermograms, the presence of a hot spot and thermal asymmetry is observed. Samples of a normal and an abnormal breast thermogram is shown in Figure 4. Since breast thermography is a functional imaging modality, it does not give any structure based information (tumor size, architectural distortion, and micro-calcifications, etc.). It is just a mapping of the skin temperature or infrared energy em-

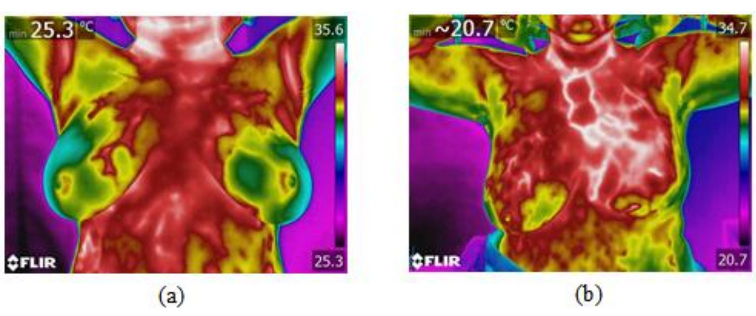


Figure 4. The sample of (a) A Normal Breast Thermogram with almost symmetrical thermal patterns in left and right breast, and (b) An Abnormal Breast Thermogram with some hot region in the left breast.

-itted by the human body parts. Hence, one popular method for breast abnormality detection is to make a comparison between the thermal patterns of the left and right breast. Here in this paper, the identification of the asymmetry is done by doing the statistical feature extraction and analysis. The process of abnormality detection comprises of the following steps-

5.1 Pre-processing & Segmentation of Breast Thermograms

The primary objective of segmenting a breast thermogram is to discard all those portions that are not belonging to the breast region. Thermal images are poor in contrast for which it lacks clear edges, and it is amorphous in nature [22]. Hence, segmentation of breast thermogram is a very tedious task. However, the precision of interpretation of a breast thermogram entirely relies on the accurate segmentation of breast thermogram. Segmentation of breast thermogram can either be manual or automatic. Here in this work, extraction of breast region is performed manually by generating a breast mask from an edge image. The pre-processing and segmentation procedure of a breast thermogram is shown in Figure 5. The segmentation of breast thermogram results in the extraction of left and right breast of a thermogram. Moreover, the dimensions of all the segmented images are kept fixed of size 200 x 200 for ease of computation. The pre-processing & segmentation procedure comprises of:

(1) Conversion of the breast thermograms from RGB to grayscale images;

(2) Removal of the unnecessary portions of the grayscale thermograms manually;

(3) Use of the canny edge detector: The canny edge detector with a threshold value is used to detect only the significant edges of breasts while neglecting the weak edges;

(4) Designing of a unique breast mask: With the help of the edge image generated from the above step, a unique breast mask for each breast thermogram has been designed manually;

(5) Multiplying the individual beast mask on the corresponding grayscale image in step 2 to remove the unnecessary regions of the thermogram;

(6) Segmentation of breast region from each breast thermogram; and

(7) Finally, separation of left and right breast segments of each breast thermogram.

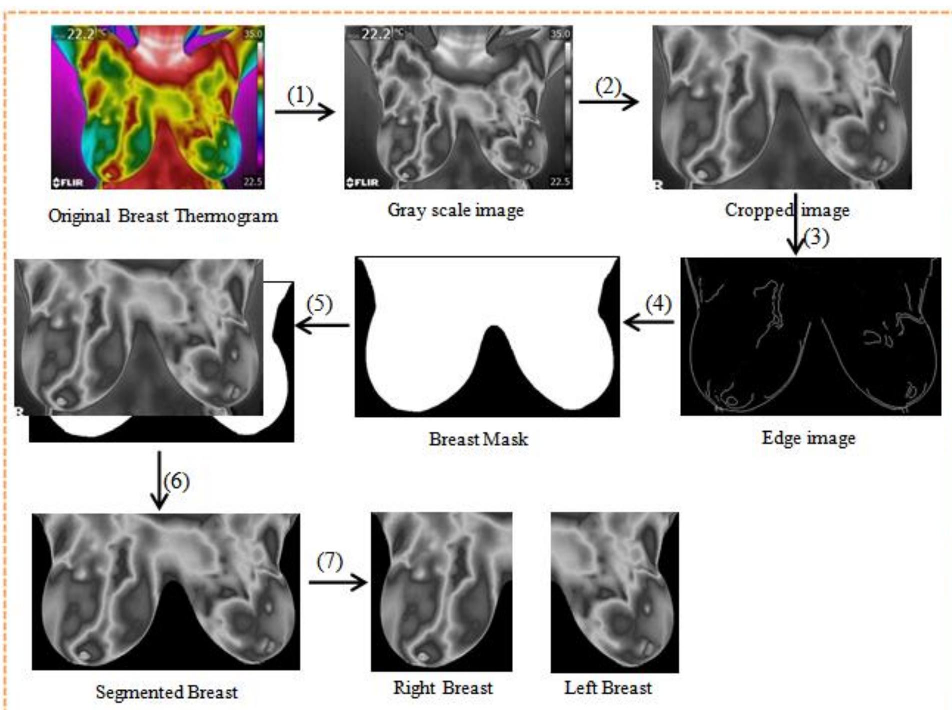


Figure 5. Segmentation Procedure of an Infrared Breast Thermogram

5.2 Extraction of Features from Breast Thermograms

Feature extraction is the process of defining a set of features where each feature represents the most significant information of an image. Thus, by doing feature extraction, an image to be analyzed is represented by a reduced set of features known as texture features. Texture feature describes the textural properties of an image, such as orientation, roughness, smoothness, contrast, regularity and spatial structure, etc. [23]. Here in our approach, extraction of first and second order statistical features is performed, which provides information about the texture or spatial distribution of the gray values in a thermogram. The first order statistical features compute the properties of individual pixel value while the second order statistical features estimate the properties of two pixels of a particular location [24]. In first order statistical feature extraction, information of image texture is extracted from the histogram of image intensity. However, the computation of second order statistical texture features is based on the probability of finding a gray-level pair at a random distances and orientations over the whole image, which is also known as Gray-level Co-occurrence Matrix (GLCM) [25]. The first order and second order statistical features computed in this work are illustrated below-

5.2.1 First Order Statistical Features

The first order statistical features are also known as the Gray Level Histogram Based Texture Features as they can directly be computed from the image histogram or pixel occurrence probability. They do not consider the relationship between the neighboring pixels for which it cannot provide the texture information of an image. The histogram of an image describes the probability of occurrence of each intensity value in an image and thus, histogram reflects the periodicity and density of image texture element structures. The histogram of an image is described as follows-

Let, $h(r_k)$ is a discrete function of an image f(x,y) with G gray scales and x=0,1,2,……G – 1, y=0,1,2,…….G – 1. Then, $h(r_k)$ can be denoted as-

$$h(r_k) = n_k$$

Where, r_k is the k^{th} gray level and n_k is the number of pixels with r_k gray level. Then, the probability of occurrence of gray level r_k is $P(r_k)$ and can be defined as-

$$P(r_k) = \frac{n_k}{n}$$, n = Total number of pixels in an image.

The first order statistical features that are computed from the intensity histogram are-

1) Mean, $f_1 = \sum_{i=0}^{G-1} i.P(i)$ (1)

2) Variance, $f_2 = \sum_{i=0}^{G-1} (i-\mu)^2.P(i)$ (2)

3) Standard Deviation, $f_3 = \sqrt{\sum_{i=0}^{G-1} (i-\mu)^2.P(i)}$ (3)

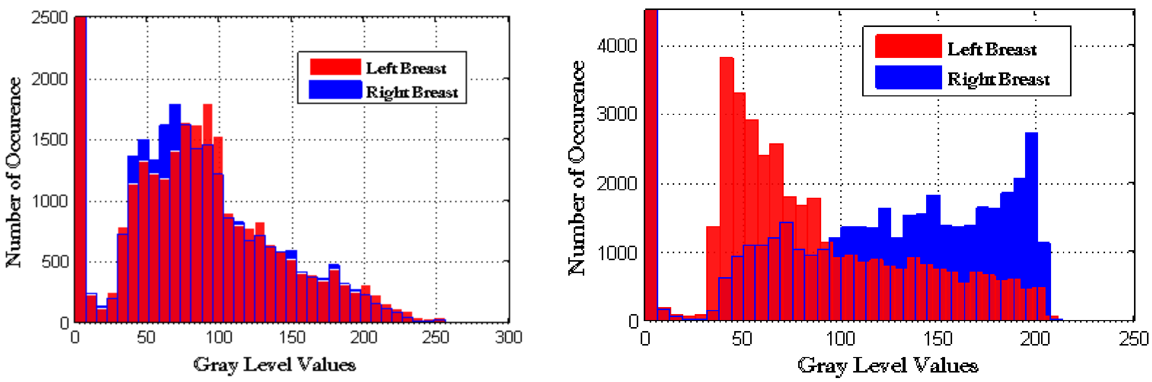
4) Skewness, $f_4 = \sigma^{-3}[\sum_{i=0}^{G-1} (i-\mu)^3.P(i)]$ (4)

5) Kurtosis, $f_5 = \sigma^{-4}[\sum_{i=0}^{G-1} (i-\mu)^4.P(i)]$ (5)

6) Entropy, $f_6 = -[\sum_{i=0}^{G-1} P(i).\log_2[P(i)]$ (6)

In this work, the histograms of left and right breasts of each breast thermogram of the normal and abnormal group have been analyzed. Samples of histograms obtained from a normal and an abnormal breast thermogram are shown in Figure

6(a) and 6(b) respectively. In an intensity histogram, the X-axis illustrates the gray level values of the image and the Y-axis illustrates the number of occurrences of each intensity value. As shown in Figure 6(a), the left and right breast histograms of each normal breast thermogram with bilateral symmetry illustrate that the intensity distribution of the left breast is closely symmetrical to the intensity distribution of the right breast which in turn describes the presence of the thermal symmetry between the two breasts. On the other hand, from the histograms of the left and right breast of an abnormal thermogram as shown in Figure 6(b), it is clear that the intensity distribution of left breast is not symmetrical to the intensity distribution of the right breast. Also, there is a large difference in the intensity distributions of both breasts.



(a) (b)

Figure 6. Histogram of the left and right breast of (a) A Normal Breast Thermogram and (b) An Abnormal Breast Thermogram

5.2.2 Second Order Statistical Features

The second order statistical features deal with the relative positions of the gray levels within an image. The Gray Level Co-occurrence Matrix (GLCM) is a well-known method for extracting second order statistical texture features. The GLCM is a presentation of how often different combinations of pixel gray levels could occur in an image. However, several variables play a role in the computation of co-occurrence matrices like the interpixel distance and orientation, the spatial resolution of an image. A GLCM is a square matrix where the number of rows and columns is equal to the number of gray levels G in the image f(x,y). If P(i, j, d, θ) is the GLCM matrix, then each entry of P(i , j, d, θ) defines the frequency of occurrence of a pixel i at the position (x,y) with a certain pixel j at the position (x + dx, y + dy) with a distance d and direction θ. Thus, each entry of P(i, j, d, θ) gives the frequency of occurrence of a pixel pair and its mathematical expression is,

$$P(i, j, d, \theta) = \{ (x, y), (x + dx, y + dy) \mid f(x, y) = i, f(x + dx, y + dy) = j \} \quad (7)$$

Where, dx, dy are the position offsets (d) and θ is the direction which can take four directions: Horizontal (0^o), Diagonal (45^o), Vertical (90^o), and Anti-diagonal (135^o) [24]. Here, in this work, the interpixel distance d is kept constant to 1 and four main orientations were averaged. The Co-occurrence matrix based features [29], used in this work are provided below.

7) Energy, $f_7 = \sum_{i=0}^{G-1}\sum_{j=0}^{G-1}\{P(i, j)\}^2$ (8)

8) Contrast, $f_8 = \sum_{i=0}^{G-1} k^2 \{\sum_{i=1}^{G}\sum_{j=1}^{G} P(i, j)\}, \qquad |i - j| = k$ (9)

9) Entropy, $f_9 = -\sum_{i=0}^{G-1}\sum_{j=0}^{G-1} P(i, j).\log\{P(i, j)\}$ (10)

10) Dissimilarity, $f_{10} = \sum_{i=0}^{G-1}\sum_{j=0}^{G-1} |i - j| .P(i, j)$ (11)

11) Correlation, $f_{11} = \frac{\sum_{i=0}^{G-1}\sum_{j=0}^{G-1}(i.j).P(i,j) - \mu_x\mu_y}{\sigma_x\sigma_y}$ (12)

Where, μ_x, μ_y, σ_x and σ_y are the means and standard deviations of P_x and P_y respectively. $P_x(i)$ is the i^{th} entry obtained by summing the rows of P(i, j). P_x and P_y are also called Marginal Probability Matrices.

12) Inverse Difference Moment, $f_{12} = \sum_{i=0}^{G-1}\sum_{j=0}^{G-1}\frac{1}{1+(i-j)^2}P(i,j)$ (13)

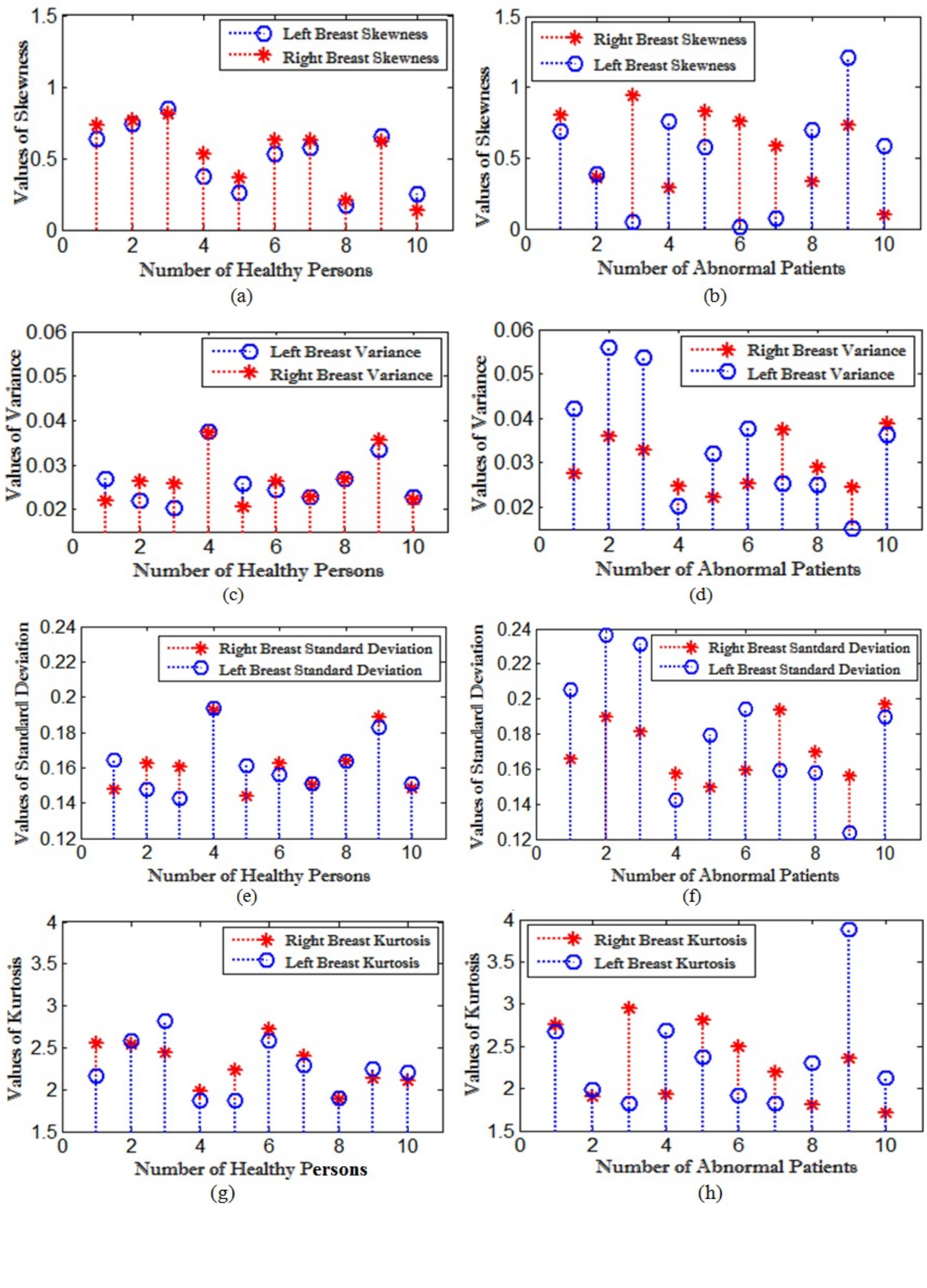
5.3 Statistical Feature Analysis

After extracting these twelve feature values from both left and right breast segment of each normal and abnormal breast thermogram, an analysis of the feature values are done to find out any abnormal characteristics. A sample of feature values obtained from the left and right breast of a normal and an abnormal breast thermogram are tabulated in Table 2. The first order statistical feature values obtained from each thermogram of the normal and the abnormal groups are plotted in Figure 7(a-l). The X-axis of the Figure 7 represents the number of healthy or abnormal patients and the Y-axis shows the feature values of each individual subject. From the Figure 7(b, d, f, h, j, l), it is found that in most of the abnormal cases, the feature difference is significantly large between the left and right breast. On the other hand, the same feature values of left and right breasts of each normal thermogram are closely symmetrical producing a very negligible difference as shown in Figure 7(a, c, e, g, i, k). Among all these features, the mean shows a better discrimination power.

Table 2. First and Second order feature values extracted from the left and right breast of a normal and an abnormal breast thermogram.

	Features	**Normal Thermogram**		**Abnormal Thermogram**	
		Left Breast	**Right Breast**	**Left Breast**	**Right Breast**
First Order Features	Mean	99.9851	100.9988	139.7084	95.0738
	Variance	0.0219	0.0264	0.0536	0.033
	Standard Deviation	0.1478	0.1625	0.2315	0.1816
	Skewness	0.7441	0.7654	0.0482	0.9392
	Kurtosis	2.5835	2.5422	1.8251	2.9474
	Entropy	7.0085	7.0785	7.7085	7.194
Second Order Features	Energy	0.1798	0.1808	0.1289	0.1747
	Contrast	0.2236	0.2258	0.1957	0.1829
	Entropy	2.1259	2.1259	2.4210	2.1390
	Dissimilarity	0.1688	0.1632	0.1511	0.1371
	Correlation	0.9441	0.9547	0.9797	0.9645
	Inverse Difference Moment	0.9967	0.9967	0.9971	0.9973

As shown in Figure 7(l), it is clear that there is a large difference between the mean intensity values of the left and right breast of all abnormal breast thermograms. Now, to find out other discriminating features, a comparison of all remaining five features has been made. Considering the feature values extracted from all normal breast thermograms, feature vectors for each first order feature have been created for both left & right breast like “left_skewness”, “right_skewness”, "left_kurtosis", "right_kurtosis" etc.. In order to find out the best discriminative features among all first order features, absolute maximum of both left and right feature vector of each feature has been computed and plotted in the same plane as shown in Figure 8(a). Similarly, the feature vectors of each feature are also generated for the left and right breasts of all thermograms of the abnormal group, and the corresponding absolute maximum values plot is shown in Figure 8(b).



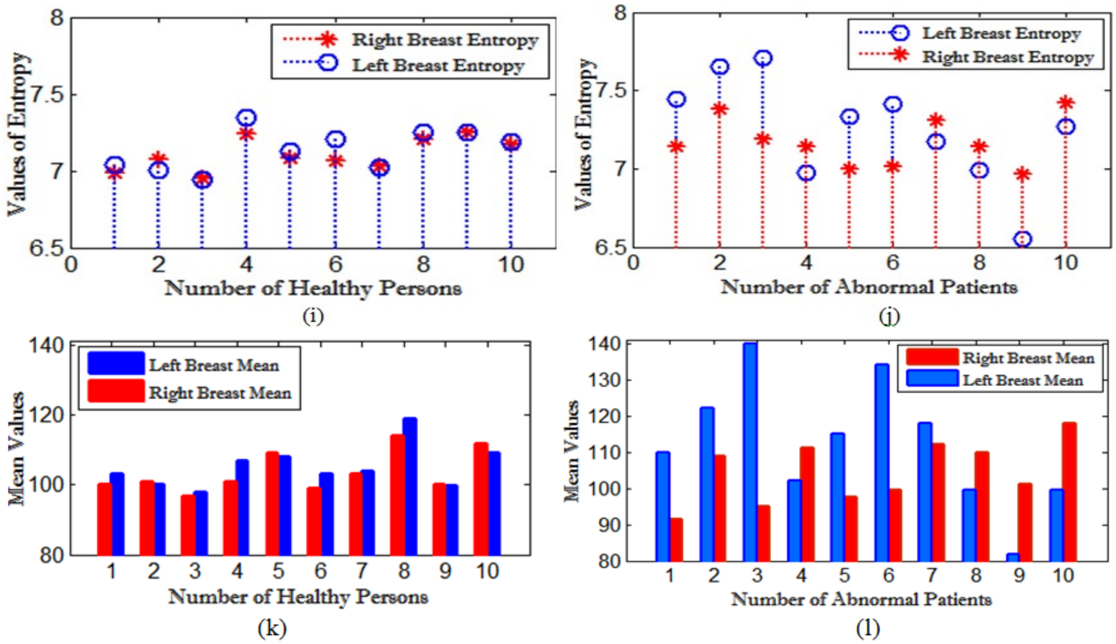


Figure 7. First order feature values- (a,b) Skewness (c,d) Variance (e,f) Standard Deviation (g,h) Kurtosis (i,j) Entropy and (k,l) Mean values of the left and right breast of all thermograms of the Normal and Abnormal group respectively.

In a breast thermogram, each intensity value represents a temperature and hence, a small difference in the feature values of the left and right breast indicates an abnormality. Figure 8(a) reveals that the absolute maximum values of each left and right feature vectors of each feature in the normal group are almost similar. But, in the abnormal group, the maximum feature values of the left and right feature vectors of each feature are quite different from each other as shown in Figure 8(b). However, the amount of difference is different for each feature. The features that show a greater extent of difference between the maximum values of left and right feature vectors are considered as most discriminative features. Here, from Figure 8(b), it is observed that the features: skewness, kurtosis, and entropy show a better degree of difference between the left and right breast of abnormal thermograms. Thus, among all the first order features, four features namely mean, skewness, kurtosis, and entropy play a significant role in differentiating the normal thermograms from the abnormal thermograms.

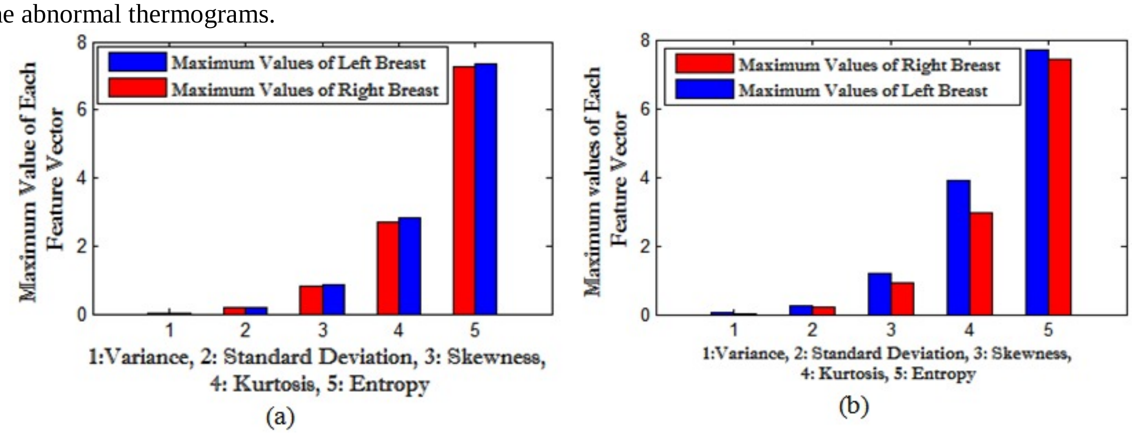
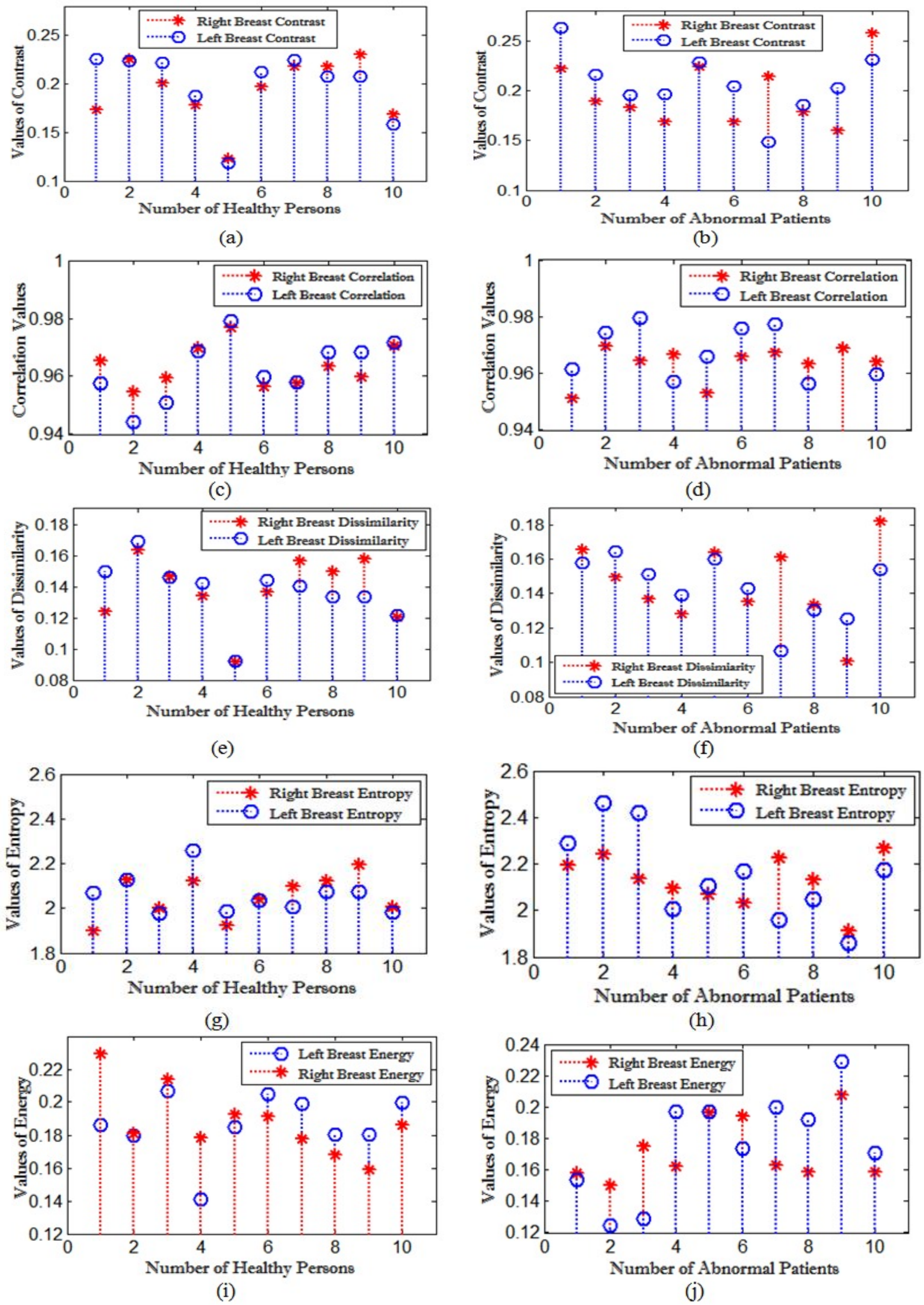
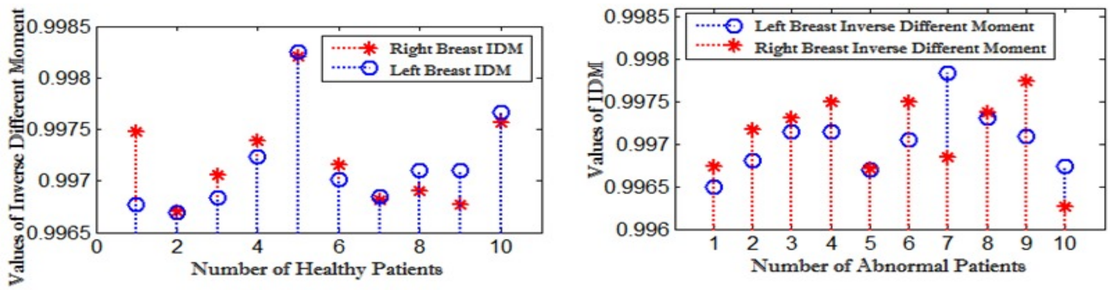


Figure 8. The maximum values of feature vectors of all first order features for the (a) Normal Breast Thermogram Group and (b) Abnormal Breast Thermogram Group.

After analyzing the first order feature values, the second-order features are also extracted and analyzed from each normal and abnormal breast thermogram. Like the first order feature values, the second-order feature values obtained from all the normal and abnormal breast thermogram are plotted in Figure 9 (a-l). As seen in Figure 9, like the first order features, the second order features are not much effective in identifying the presence of breast abnormality in abnormal breast thermograms. Although, there is a difference between the left and right breast of the abnormal thermograms, but these differences are not decisive. However among all these second order features, contrast, correlation and entropy show better discrimination ability between the normal and abnormal thermograms by showing a significant difference or asymmetry between the left and right breasts of abnormal thermograms. And this asymmetry between two breasts of a thermogram signifies the presence of an abnormality.





(k) (l)

Figure 9. Second Order Feature Values- (a,b) Contrast (c,d) Correlation (e,f) Dissimilarity (g,h) Entropy (i,j) Energy and (j,k) Inverse Different Moment values of the left and right breast of all thermograms of Normal and Abnormal Group respectively.

Thus, from the statistical feature based asymmetry analysis of the breast thermograms, the following observations can be made:

1. Intensity based histogram plays a crucial role in abnormality detection of breast thermograms by plotting the intensity variations in the breast thermograms.

2. Among all the first order statistical features computed here, features like mean, skewness, kurtosis, and entropy illustrates a noticeable difference between the left and right breast of an abnormal breast thermogram while these differences are very small in case of the left and right breast of a normal breast thermogram.

3. Similarly, among all the computed second order statistical features, mainly three features: contrast, entropy, and correlation show significant differences between the left and right breast of an abnormal breast thermogram.

6. PERFORMANCE EVALUATION

In order to evaluate the performance of the proposed system, the result of the statistical analysis of the breast thermograms are compared with the result of the X-ray mammography and FNAC (if available). Thermograms of the patients with benign breast diseases or malignant breast tumors (verified by X-ray mammography or FNAC) are considered as abnormal thermograms and thermograms of healthy patients are considered as normal thermograms. In literature, various performance measures are there to evaluate the performance of a system. In this work, a very popular performance measure technique: 1) Sensitivity, 2) Specificity and 3) Accuracy have been used for evaluating the performance of the system. The term sensitivity is the ratio of the actual positives which are predicted as positive and specificity is the ratio of actual negatives that are predicted as negative. Accuracy is the probability of correctly identifying the true positives and true negatives. Mathematically, the sensitivity, specificity, and accuracy can be defined as-

$$\text{Sensitivity} = \frac{TP}{TP+FN}, \qquad \text{Specificity} = \frac{TN}{TN+FP}, \qquad \text{Accuracy} = \frac{TP+TN}{TP+TN+FP+FN}$$

Where, TP = Abnormal cases identified as Abnormal
TN = Normal cases identified as Normal
FP = Normal cases identified as Abnormal, and
FN = Abnormal cases identified as normal

For performance evaluation, a dataset of 20 breast thermograms has been used. The results of the asymmetry analysis are compared with the mammography or FNAC report of each individual patient to compute the values of TP, TN, FP and FN and their corresponding values are depicted in Figure 10. Considering the values of these four parameters, the Sensitivity, Specificity and Accuracy of the asymmetry analysis based abnormality detection system are found to be 90% each. The accuracy of the system illustrates the necessity of the standardization of the breast thermogram acquisition in breast abnormality detection by identifying the presence of the asymmetric thermal patterns present in abnormal breast thermograms.

	Abnormal (Predicated)	Normal (Predicted)
Abnormal (Actual (10))	9 TP	1 FN
Normal (Actual (10))	1 FP	9 TN

Figure 10: Shows the values of TP, TN, FP, and FN

7. CONCLUSION

Due to the increasing incidence and mortality rate of breast cancer, the early detection of breast cancer is a challenge for today's medical system and biomedical engineering. In this scenario, infrared breast thermography with 90% sensitivity has proved itself as an efficient tool for early breast cancer detection. Moreover, designing of a computerized system for analysis of the breast thermograms plays a crucial role in early breast cancer detection. This research work has provided a standard breast thermogram acquisition protocol to improve the potentiality of breast thermograms and also developed a breast thermogram database. Statistical feature based analysis of the breast thermograms allows us to differentiate the normal thermograms from the abnormal thermograms even when the degree of dissimilarity present between the left and right breast of each thermogram is subtle. Thus, it helps to find out the presence of any breast abnormality that may be developed to breast cancer in future. While comparing the result of the breast thermogram analysis system with the result of mammography / FNAC report, a detection accuracy of 90% is obtained, which in turn shows the effectiveness of the thermograms of our dataset to detect the breast abnormality.

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