Qualitative and Quantitative Evaluation of Breast Images-Comparative Study of Mammogram and Thermogram

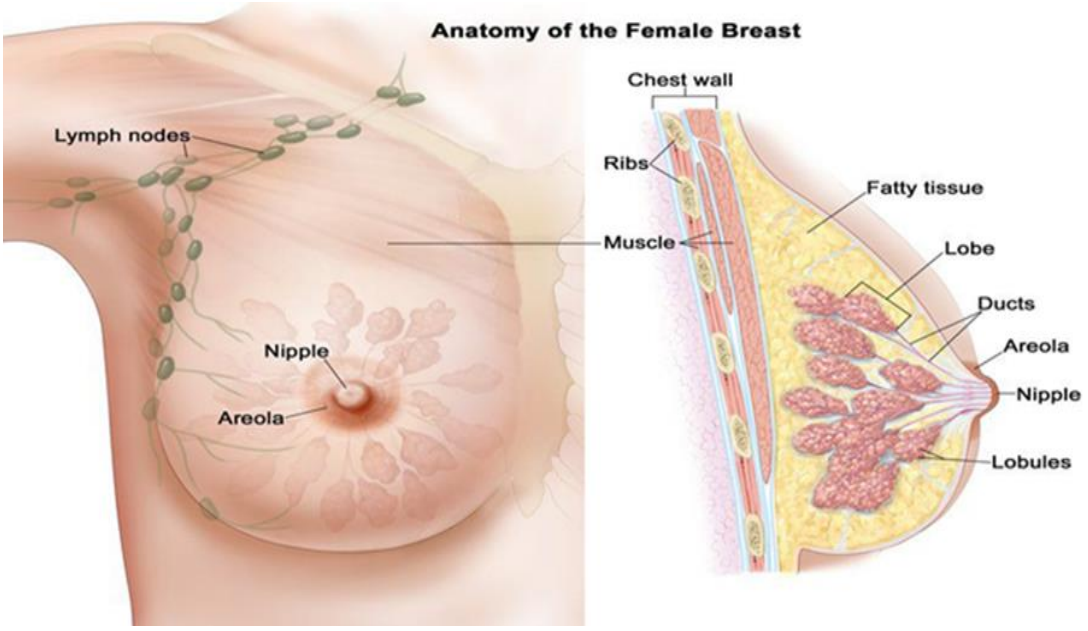
N Sriraam[1*], Praneethi K[2], Kavya N[3], Usha N[4], Sharath D[5], Prabha Ravi[6], Bharathi Hiremath[7], B Venkatraman[8], M. Menaka[9]
[1,3,4,5,6]Centre for Imaging Technologies, RIT, Bangalore,560054, India
[2]Department of Radiodiagnosis, RMH, Bangalore, 560054, India
7 Department of Surgery, RMCH, Bangalore, 560054, India
[8,9]Health, Safety and Environmental Group, IGCAR, Kalpakkam, 603102, India
sriraam@msrit.edu*

Abstract: The early detection of breast cancer can lower the risk of mortality among women. Mammography has been considered as standard tool for screening breast cancer today. Despite its ability in detecting breast condition, mammography has some drawbacks. Mammography technique is less effective for younger patients and it is not suitable for women with dense breasts. Thermography is being proposed as adjunct screening tool for breast cancer detection. Breast infrared thermography is a noninvasive procedure suitable for all age groups and does not involve any exposure of radiation. Hence the proposed study focused on feature extraction in breast thermograms for detecting breast cancer and compared with mammogram results to show that even breast thermography gives a significant difference between normal and abnormal patterns of breast images. The thermography can be used as a complimentary tool together with mammography to enhance its efficiency in detecting breast cancer, but it cannot substitute mammography completely. The texture features such asskewness, kurtosis, cluster prominence, entropy and coarsenesswere extracted from thermogram and mammogram images and analysis were done. The aim of the present study was to compare the results of normal and malignant subjects using mammogram and thermogram modalities. The obtained results show the significant difference among the features extracted to classify normal and abnormal images.

I. INTRODUCTION

Breast cancer is one of the major issue in women's health today. Breast cancer affects mental, physical and social aspects of women life. It creates major problems such as stress, depression, pain, problems in marital relations, family consequences and complications of treatment affects the quality of patient's life. Hence the primary aim of medical care is to improve the patient's life quality by providing support which is important and multi-dimensional prerequisite that should be provided to patients [1].

Breast cancer develops from the breast tissue due touncontrolled grown of cells. Different parts of the breast can be affected by cancer. The lobules, ducts, and connective tissue are the three main parts of the breast. The cancer is said to be metastasized when it spreads to other body parts. There are some caution signs or symptoms of breast cancer. They are lump in the breast, breast thickening or swelling, skin irritation, redness, pain and pulling in of the nipple, change in breast size, shape and nipple discharge. There are many factors which increase the risk of breast cancer in women like age, personal history of breast cancer, high estrogen levels, high dose radiation to breast, consumption of alcohol, late menopause, never breastfed a child, obesity and genetic mutation in DNA of cancer cells[2].If cancer cells have extended to one or more lymph nodes, there is a high possibility that they could have spread to other parts in the body. Generally, a surgical biopsy is required to take away one or more lymph nodes and decide whether cancer is present.There are different breast cancer modalities for breast cancer detection today and out of them, mammography is the gold standard imaging technique. However mammography has some limitations such as exposure to x-ray radiation, painful and it is less effective for women less than 50 years age. On other hand, Thermography is harmless, effective in all age groups and it is non-ionizing technique. Hence today, many research works are carrying out to find whether thermography can be used as adjunct tool with mammogram to overcome the above limitations in detecting breast cancer. Image



Courtesy: National Breast cancer foundation

Fig.1. Anatomy of female breast

CLINICAL PERSPECTIVE OF MAMMOGRAM

There are many techniques for breast cancer screening. Among them, mammography is the standard tool for screening breast cancer which uses low energy x-rays to diagnose and screening of the breast. Fig. 2(a), shows breast mammogram image. Mammogram includes two or more x ray films of each breast.

There are two types of mammogram:

- **Screening mammogram***:* A screening mammogram is an x-ray of the breast used to find the changes in the breast before any symptoms of breast cancer in women. It usually includes two x-ray pictures of each breast, bilateral craniocaudal (CC) and mediolateral oblique (MLO) views. Using a screening mammogram, it is possible to find a lump that cannot be felt[3].
- **Diagnostic mammogram***:* A diagnostic mammogram is an X-ray of the breast used to diagnose unusual changes in the breast i.e., after a lump has been found. A diagnostic mammogram is also used to evaluate the noticed abnormalities using screening mammogram [4].A diagnostic mammogram may include full CC, MLO, and/or supplemental views to evaluate an area of clinical or imaging concern.

Apart from cancer, there are some other conditions occur in the breast that can be detected on a mammogram.

- Cyst: A cyst is benign mass with collection of fluid. Cysts appear due to the changes of hormones during mensuration and hormone replacement. They are harmless and appear alone or in groups.
- Calcifications: Micro and macro calcifications appear as white spots in mammogram images. They are the cluster of calcium deposits occurs due to reabsorbed blood and inflammatory reactions.
- Fibroadenoma (FA): It is a non-cancerous solid tissue. It is round in shape and moves under the skin easily. It can be tender, painful or sometimes painless.
- Carcinoma in situ: In situ meanscancer which do not spread from the region it begins. Ductal carcinoma in situ (DCIS) is the most common of non-invasive breast cancer.

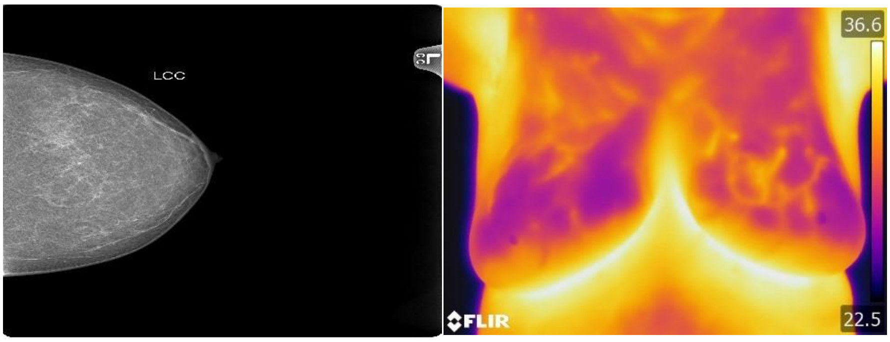
The mammogram results are categorized using number system of 0 to 6 as shown in Table 1. Breast Imaging Reporting and Data System or BIRADS is the standard system to determine the mammogram findings. This makes the follow-up easier.

Table 1: BIRADS categories to determine mammogram findings[5]

BIRADS Category	Definition	Meaning
0	Comparing to prior mammograms	Possible abnormalities may have observed by radiologists hence comparison of new mammogram with older one of same patient is needed to find the changes over time
1	Negative	No abnormalities were found
2	Benign (Non-cancerous)	There is no cancer sign but radiologists describe a finding as benign
3	Probably benign (Short time follow up is suggested)	High chance of being benign (not cancer). Regular follow up helps to avoid unnecessary biopsies
4	Suspicious abnormality	Findings could be cancer. Biopsy should be considered. 4A- Low suspicion of being cancer 4B- Intermediate suspicion of being cancer 4C- Moderate suspicion of being cancer
5	Highly suggestive of malignancy	Findings seem to be cancer and have great chance of being cancer (95% at least). Biopsy is must
6	Proven malignancy	Proven malignancy by known biopsy

CLINICAL PERSPECTIVE OF THERMOGRAM

Thermal imaging involves mapping of surface temperature of an object by detecting infrared radiation emitted by it using a thermal camera. Fig. 2(b), shows breast thermogram image.Thermal imaging is used to measure the skin temperature on the breast's surface. It does not involve any radiations and it is non-invasive test. Blood flow and metabolism are higher in cancerous region due to fast multiplication of cancer cells. This makes the skin temperature to increase which helps to detect and monitor the early signs of breast cancer [25]. Thermography is more helpful for patients under the age of 50 because mammography can be less effective for this group. One need to understand that thermography is not a substitute for mammography. Thermal imaging is based on the principle that the metabolism and vascular circulation is always higher in pre-cancerous tissue when compared to normal. Hence the need for nutrients increases and creates new blood vessels that is necessary to sustain the tumor growth. This process is called neo-angiogenesis and results in an increased breast's surface temperature. These temperature differences are detected and analyzed using medical infrared cameras and produces high resolution images.



(a) (b)

Fig.2.(a) Breast mammogramimage (b) Breast thermogram image

Other than angiogenesis, there are number of factors for these thermal changes such as inflammation, nitric oxide and estrogen. Nitric oxide causes vasodilation in the body. Nitric oxide is produced by cells of immune system. Even cancer cells also produce nitric oxide and enrich the nutrient supply and oxygen delivery to cancer cells which results in increasing regional temperature. Cancer cells leads to vasodilation in case of inflammation. Imbalance in estrogen could cause the vasodilation which leads to local temperature changes [6].

SALIENT FEATURES OF BREAST THERMOGRAPHY

- Digital infrared imaging may be the initial signal for detecting the possibility of developing breast cancer which finds the temperature variations early.
- Thermography examination can be used on people of any age. This provide a baseline study which can be compared with future tests to find if there are any abnormalities that develop.
- Depending upon certain factors, re-examinations are performed to monitor the

breasts which helps the women to detect cancer at its earliest stage and prevents invasive tumor growth.

- Thermography can be used together with mammographic screening.

Table 2: Ville Marie Infrared Grading Scale

ABNORMAL SIGNS: 1. Significant vascular asymmetry 2. Vascular anarchy with infrequent tortuous that form abnormal patterns. 3. 1^0C focal increase in temperature comparative to the contralateral site and when associated with clinical abnormal area 4. 2^0C focal temperature change versus the contralateral breast site 5. 3^0C focal temperature versus rest of the ipsilateral breast when not present on the contralateral site 6. Global change in the breast temperature of 1.5^0C versus contralateral breast
INFRARED SCALE: IR1= Absence of any vascular pattern to mild vascular symmetry IR2= Significant but symmetrical vascular pattern to moderate vascular asymmetry, particularly if stable IR3= One abnormal sign IR4= Two abnormal signs IR5=Three abnormal signs

The Ville-Marie IR grading scale [7] is a technique used to evaluate the thermograms shown in Table 2.

RELATED BACKGROUND

Digital infrared thermal imaging plays an important role in differentiating various breast abnormalities in patients [8]. The breast thermography measures the breast surface temperature using infrared camera. The thermal features such as asymmetry, high temperature, hyper thermic vascularity and complex vascular patterns are the indicative of breast cancer [9]. In addition, malignant cells increase the nitric oxide levels which results in local vasodilation and it leads to the emission of heat [10]. In medical field, continuous monitoring of data is very important. CPS helps in integrating the network and provides the flexibility and data optimization [11]. Computer aided diagnosis (CAD) is an artificial intelligence technique that utilizes pattern recognition to highlight suspicious features on imaging and marks them for the radiologist to interpret [12]. CAD supports the technicians in analysis of outcomes by executing medical exams using particular protocols [13]. There are many techniques to segment the abnormal breast mass region from thermogram. K means clustering partition the image into k clusters and Euclidian distance is calculated from the data point to each cluster [14]. The ROI segmentation using level set algorithm helps to select the boundary of contour and segments the breast region [15]. The breast boundary segmentation using pixel clustering and skin air boundary estimation is suitable for most calcification shapes and sizes [16]. The dragonfly algorithm is used to obtain the best thresholds which segments the image based on spatial information of the image pixel [17]. The estimation of background noise helps in automatic breast tissue segmentation by discarding the pixels below five standard deviation of noise level [18].

The high-level information of the image is extracted using different features from segmented breasts such as

The vascular patterns of thermal images give significant information in abnormality grading of breast cancer at the early stages.

statistical, morphological, frequency domain, histogram and other texture features [19]. Markov random field model is used to extract features which is a statistical model and useful in several areas of image processing. Defining cliques, determining potential function and defining energy changes are the three steps involved in MRF model [20]. Clustering is another method used to extract local information and helps in identifying abnormalities. The list of features differs based on the given medical images. The optimization techniques were used to reduce the data and to obtain more meaningful outcomes. This helps in easy interpretation of results. Discretization on training data are performed and concept hierarchy is developed which reduce the data by replacing low level with high level concepts [22].

The texture feature extraction gives the changes between normal and abnormal images and its accuracy depends on proper segmentation and classification techniques [23].It can be seen that previous works used different methods to find the breast cancer and finding breast asymmetry. Representation learning and texture analysis techniques were proposed for modeling the temperature changes in breasts [28]. Another method explores the difference of thermal patterns seen in patient's skin. The temperature arrays are computed and different features were extracted for automatic detection of tumors [29]. Analyzing the breast thermal images using intelligent computer based system is an efficient tool which supports the radiologists [30]. The present work concentrates on clinical aspects of mammogram and thermogram and analysis was done to show that thermal imaging can be used as adjunct tool with mammogram.

II. MATERIALS AND METHODS

STUDY DATABASE

The thermal imaging was conducted in Ramaiah Memorial Hospital, Bangalore using FLIR T650sc thermal camera. Inclusion criteria consist of age group of 30 and above and exclusion criteria involves patients operated for breast lesions previously, conservative breasts and people under mensuration cycle. The total patients attended for thermal screening were 140. Out of 140 patients, 54 patients were operated and 86 patients were non-operated. Some patients rejected to take the test due to less knowledge and misconception on thermal imaging.

Table 3. Factors considered for thermal data collection

Family history	Positive
	Negative
Menopausal status	Premenopausal
	Postmenopausal
Symptoms	Symptomatic
	Non-symptomatic
Condition	Normal
	Benign
	Malignant
Age	All age groups
Surgical Factors	Operative cases
	Non operative cases

Table 3 shows the factors considered during collecting the data. In the above factors, the patient under mensural cycle and patients with operated breasts were excluded. All age groups were considered for the study. The mammogram images corresponding patient's thermal images and reports were collected from the Ramaiah Memorial hospital. MLO and CC views were collected and all images were of dimension 4728×5928.

STUDY DESIGN

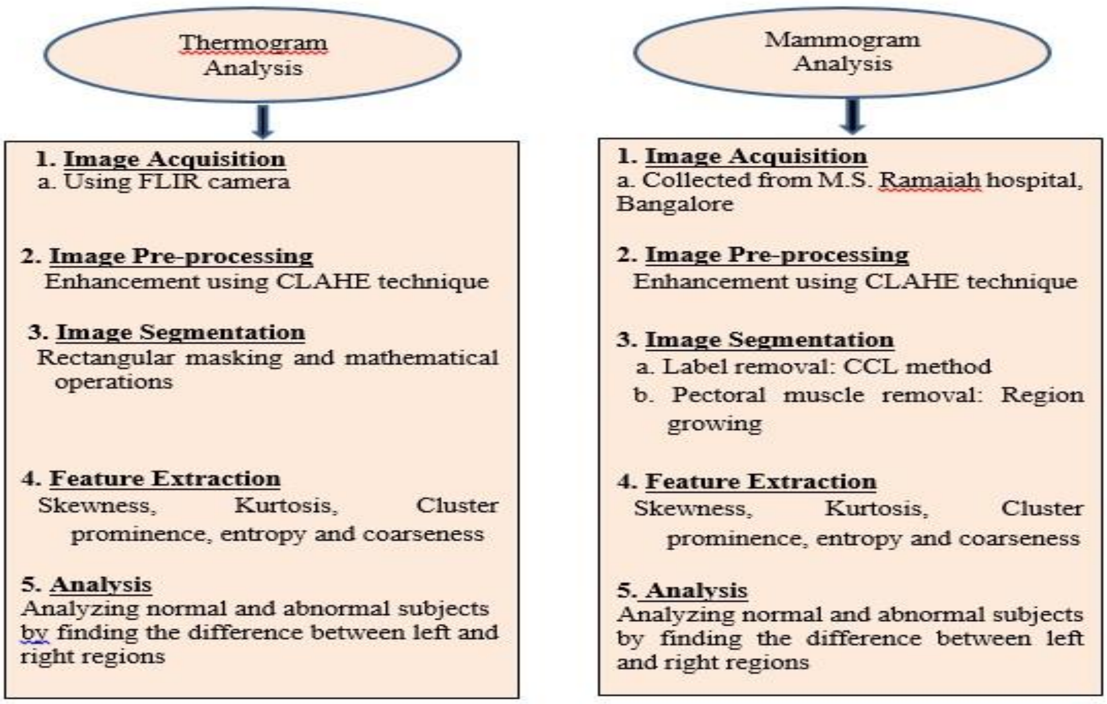


Fig.3. Study design of proposed technique

Some protocols have been followed to collect the thermal images:

- The patients were instructed not to apply any lotions, deodorants, antiperspirants and cosmetics before the exam.
- The imaging room must be temperature controlled and maintained approximately at 23°C.
- The patients were asked to complete the breast history and consent form.

- Then patients were requested to disrobe from the waist up and to sit in the temperature-controlled room for about 15 minutes.
- After that, patients were made to sit in front of the imaging system. The protocol includes different imaging views such as frontal (0^0), oblique (+/- 30^0) and lateral views (+/- 90^0).

PREPROCESSING TECHNIQUE

The thermal images were converted into grayscale images and resized to 600x600. The enhancement was done using contrast limited adaptive histogram equalization technique. It helps in improving the image contrast and to avoid the noise amplification problem.CLAHE technique divides the images into sub-regions and calculates the equalization of each region. This makes the hidden features more evident due to flattening the gray level distribution. The steps involved in CLAHE technique are as follows:

- Dividing the input image into related regions of equal size and calculating the intensity histogram of each regions.
- The histograms are clipped by setting the clip limits. It is a threshold parameter for altering the image contrast. It must be fixed to minimum optimal value.
- Transformation function is used to modify each histogram in such a way that height of the histogram should not exceed the fixed clip limit. Bilinear interpolation technique is used to combine the neighboring tiles.

The mathematical expression for CLAHE technique with uniform distribution is given as

$$\boldsymbol{g = [g_{max} - g_{min}] * P(f) + g_{min}}$$

Where, $g_{max}$and $g_{min}$are maximum and minimum pixel values respectively, g is the pixel value computed and P(f) is cumulative probability distribution.

The pre-processing of raw images is very important which improves the image quality. The mammogram images were resized to 600x600 to increase the computational speed. Contrast adjustment technique was used to improve the image quality.

SEGMENTATION TECHNIQUES

The labels on the thermal images were removed using FLIR software. The parameters of rectangular mask were defined and created the logical mask to obtain the region of interest and removing unnecessary body portions. The left and right breasts were separated using mathematical operations. The Connected Component Labelling (CCL) technique was used to find and eliminate the connected pixels in the mammogram images. Pectoral muscles are situated on both side of MLO views. The pixel intensity in region of interest and pectoral muscle is almost same. The thresholding technique was used to remove the pectoral muscle.

FEATURE EXTRACTION

In this work, the frontal view of thermal images was considered. The CC or MLO views were considered in mammogram images which have maximum information. The texture features such as skewness, kurtosis, cluster prominence, entropy and coarseness were considered and the equations were given below,1-5 [25,26, 27]. For an image I, p(i,j) is one element in an image, N will be the number of gray levels.

I. Skewness= $\boldsymbol{\sigma^{-3}\left[\sum_{i=0}^{G-1}(i-\mu)^3 P(i)\right]}$ (1)

II. Kurtosis= $\boldsymbol{\sigma^{-4}\left[\sum_{i=0}^{G-1}(i-\mu)^4 P(i)\right]}$ (2)

III. Cluster Prominence =$\boldsymbol{\sum_{i=1}^{N}\sum_{j=1}^{N}(i+j-2\mu)^3 p(i,j)}$ (3)

IV. Coarseness= $\boldsymbol{A_l(x,y) = \frac{1}{2^{2l}}\sum_{i=x-2^{l-1}}^{x+2^{l-1}-1}\left(\sum_{j=y-2^{l-1}}^{y+2^{l-1}-1} f(i,j)\right)}$ (4)

V. Entropy= $\boldsymbol{-\sum_{i=1}^{N}\sum_{j=1}^{N} p(i,j) log p(i,j)}$ (5)

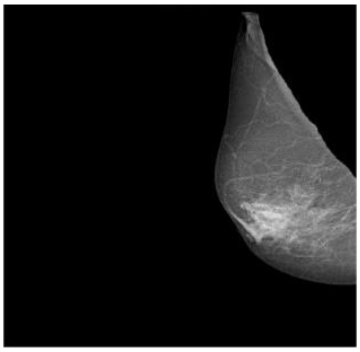
where, μ is mean and P(i) will be the probability of occurrence of each gray level i.

III. RESULTS AND ANALYSIS

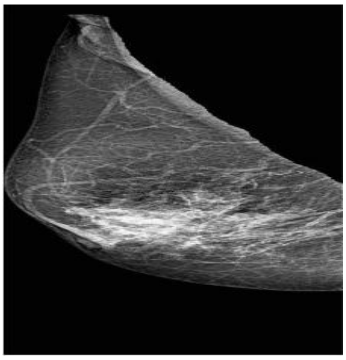
The computer aided diagnosis techniques have been used and analysis was done and results were computed. The texture features were extracted from mammogram and corresponding thermal images. The difference among normal and abnormal images was obtained in both modalities.

(a) Original image

(b) Pectoral muscle removed image



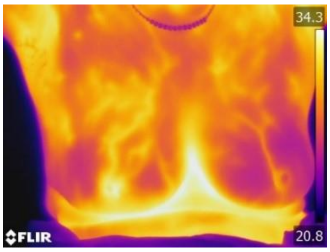
(c) Label removed image



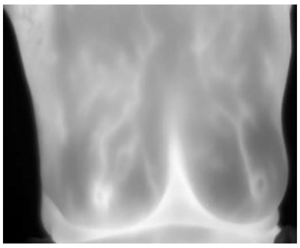
(d) Enhanced image

Fig. 4: Examples of proposed method (a) Original image (b) pectoral muscle removal (c) label removed image (d) enhanced image

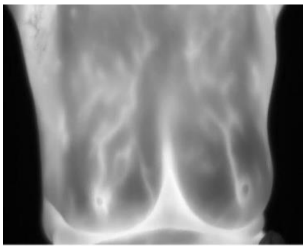
Fig. 4, shows the preprocessing and segmentation of mammogram image using proposed techniques. The pectoral muscles were removed efficiently using thresholding technique. The labels were removed using CCL method. The normal image does not contain lump in it. Hence, the complete image is considered as region of interest in the proposed work.



(a)



(b)

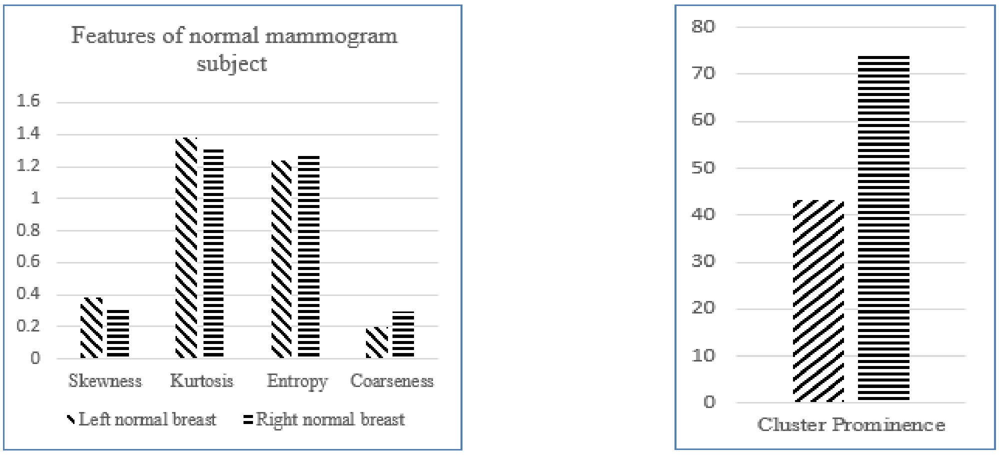


(c)

(d) (e)

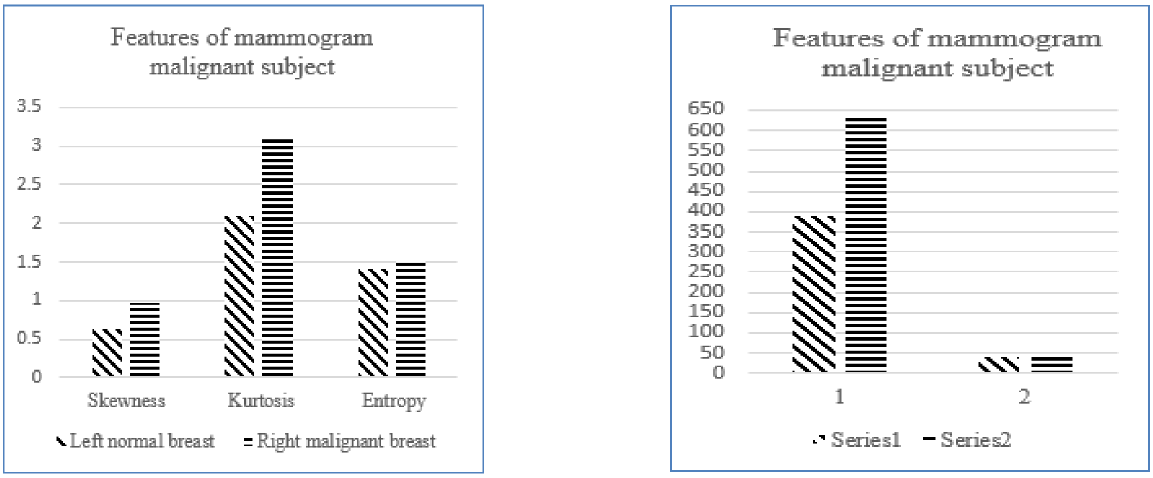
Fig.5 (a) Original image (b) Gray scale image (c) Enhanced image(d) Right breast (e) Left breast

Fig. 5, shows the segmentation results of thermal image. The image is converted into grayscale and segmented the left and right breasts. The xmin, xmax, ymin and ymax values were computed and the images were divided equally by considering center value. The under breast region is removed manually.



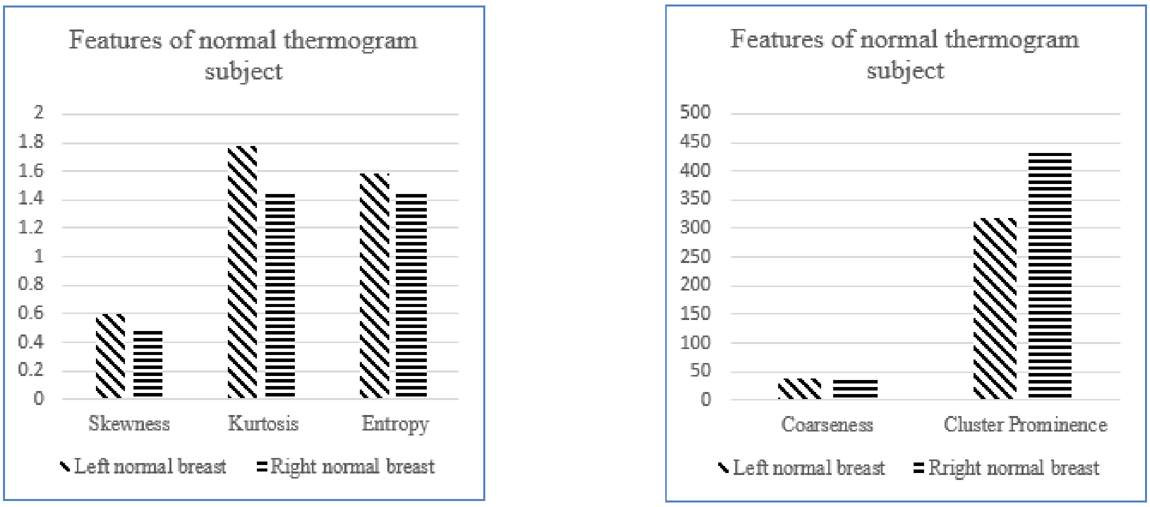
(a) (b)

Fig.6.Texture features of left and right breast regions using mammogram of normal subject



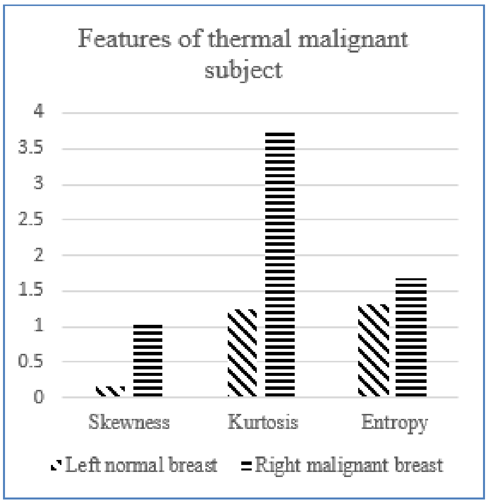
(a) (b)

Fig. 7. Texture features of left and right breast regions using mammogram of malignant subject

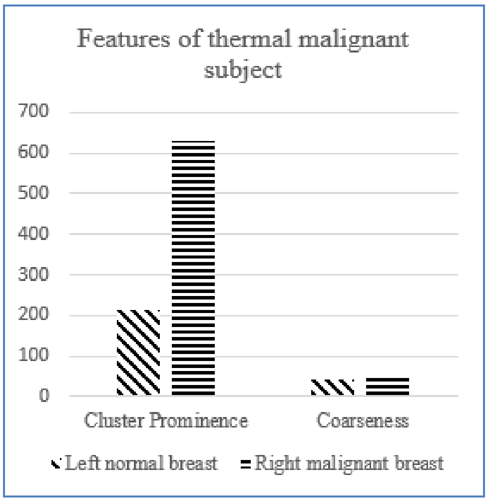


(a) (b)

Fig.8.Texture features of left and right breast regions using thermogram of normal subject



(a)



(b)

Fig. 9. Texture features of left and right breast regions using thermogram of malignant subject

The values of texture features obtained from normal and abnormal images of mammogram imagewere plotted in Fig.6, and Fig.7.Similarly, the values of texture features obtained from normal and abnormal images of thermogram image were plotted in Fig. 8 and Fig. 9. The features considered areskewness, kurtosis, cluster prominence, entropy and coarseness. The skewness, kurtosis and cluster prominence are the measure of asymmetry. Coarseness provides the information about texture element size. It gives the difference between coarse and fine textures.Entropy measures the randomness which characterizes the image textures. The featuresare high for abnormal images compared to normal due to high asymmetry and due to the presence of lump whose pixel intensity is high compared to surrounding pixels. This difference in the thermal images helps in detecting the presence of abnormality.

Table 4. Finding difference between right and left regions in mammogram and thermogram subjects

	Difference between right and left regions			
Features	Normal mammogram subject	Malignant mammogram subject	Normal thermal subject	Malignant thermal subject
Skewness	0.08	0.33	0.09	0.92
kurtosis	0.06	1.02	0.32	2.50
Cluster Prominence	31.34	239.02	115.06	416.64
Entropy	0.05	0.1	0.14	0.35
Coarseness	0.1	0.89	1.34	4.39

Table 4 shows the values of difference between right and left regions in mammogram and thermogram subjects considering both normal and malignant cases. In the normal subject both breats were normal and in the abnormal subject, left breast is normal and right breast is malignant. The difference values were high in the abnormal subject compared to normal in both mammogram and thermogram modalities. This indicates the high asymmetricity in abnormal subject comparatively. This helps in the early detection of breast abnormalities and analysis of breast regions.

DISCUSSION

Today many researchers are discussing on the benefits and harms involved in mammography screening. This influenced us to work on thermography in detecting breast cancer. In 2009, a comparative review of thermography was done for breast cancer screening which inferred that thermography does not give any information about morphological features of the breast but it provides the information on the functional characteristics on thermal and vascular condition of tissue. The literature also discussed that according to villemarie study, the sensitivity in detecting breast cancer is high when the thermography is combined with mammography instead of using thermography alone [6].

In 2010, the comparative study of standard mammography with digital mammography and digital infrared thermal imaging was done for screening of breast cancer. In their study, authors concluded that digital infrared thermal imaging can be used for detecting breast cancer but currently the obtained evidence is not sufficient to support the use of any of these new technologies in population screening but would assist the further evaluation [24].

In 2016, another comparative study was carried out in which 132 patients were included. The sensitivity, specificity, PPV, NPV and accuracy were calculated for mammography and thermography techniques and the study confirmed that at the present time, thermography cannot substitute for mammography for early diagnosis of breast cancer [10]. Another research article in 2018 [14] has concluded that k means clustering of color thermogram helps in locating the abnormal mass region.

Studies conducted in the past shows mixed opinion about the usage of thermography in detecting breast cancer. The proposed analysis was done on texture features to show that as mammogram, the thermogram also capable of giving significant difference among the features extracted from normal and abnormal images but thermogram cannot substitute mammogram. Currently, thermogram modality can only be used as an adjunct tool with mammography for detection of breast cancer. The current study has some limitations such as less sample size and unwanted under breast hot region. As a future direction, the mass screening will be carried out to increase the sample size for this study and automated computer aided technique will be applied to obtain the region of interest.

IV. CONCLUSION

The increased rate of metabolism and neo-angiogenesis causes the temperature changes in the affected area which can be identified using thermal imaging. It is simple and comfortable technique and also effective for dense breasts. Thermography provides information on thermal and vascular changes in tissue physiology. These conditions occur before the occurrence of structural changes happens due to cancer. IR imaging may be an indicator which signifies less aggressive lesions associated with breast images. Hence thermography has a potential in detecting breast abnormalities in early stage. The thermal imaging can be performed as a complementary tool for diagnosing breast cancer. It is not a substitute for mammography at the present time. Proper usage of breast physical and self-examinations, digital infrared imaging and mammography collectively can provide the early detection. If treated early, cure rates greater than 95% are possible.

REFERENCES

[1] R Ataollahi, M & Sharifi, J & R Paknahad, M &Paknahad, A. Breast cancer and associated factors: a review. Journal of medicine and life.(2015) 8. 6-11.

[2] American Cancer Society. Breast Cancer Facts & Figures 2017-2018. Atlanta: American Cancer Society, Inc. 2017.

[3] Information on World Health Organization (WHO), Early diagnosis and screening, Breast cancer, www.who.int/cancer/prevention/diagnosis-screening/breast-cancer/en/

[4] Information on https://www.hopkinsmedicine.org/health/treatment-tests-and-therapies/mammogram-procedure

[5] Information onhttps://www.cancer.org/cancer/breast-cancer/screening-tests-and-early-detection/mammograms/understanding-your-mammogram-report.html

[6] Kennedy, D. A., Lee, T., & Seely, D. A Comparative Review of Thermography as a Breast Cancer Screening Technique. Integrative Cancer Therapies, 8(1), (2009) 9–16.

[7] Nicholas A. Diakides, Joseph D. Bronzino," Medical Infrared Imaging", 1st Edition, CRC Press Published July 23, Reference - 448 Pages (2007).

[8] Sarigoz, T., Ertan, T., Topuz, O., Sevim, Y., &Cihan, Y. Role of digital infrared thermal imaging in the diagnosis of breast mass: A pilot study. Infrared Physics & Technology, 91, (2018) 214–219.

[9] Gonzalez-Hernandez, J.-L., Recinella, A. N., Kandlikar, S. G., Dabydeen, D., Medeiros, L., &Phatak, P. Technology, application and potential of dynamic breast thermography for the detection of breast cancer. International Journal of Heat and Mass Transfer, 131, (2019) 558–573.

[10] Omranipour R, Kazemian A, Alipour S, Najafi M, Alidoosti M, Navid M, Alikhassi A, Ahmadinejad N, Bagheri K, Izadi S: Comparison of the Accuracy of Thermography and Mammography in the Detection of Breast Cancer. Breast Care (2016), 11:260-264.

[11] N. Kavya, N. Usha, N. Sriraam, D. Sharath and P. Ravi, "Breast Cancer Detection using Non Invasive Imaging and Cyber Physical System," 2018 3rd International Conference on Circuits, Control, Communication and Computing (I4C), Bangalore, India, (2018) , pp. 1-4.

[12] Janine Katzen and Katerina Dodelzon, A review of computer aided detection in mammography, Elsevier, Clinical Imaging, (2018), pp. 305-309.

[13] Abdel-Nasser, M., Saleh, A., Moreno, A., & Puig, D, Automatic nipple detection in breast thermograms. Expert Systems with Applications, (2016), 64, 365–374.

[14] Kirubha, A.S.P., et al., Comparison of PET–CT and thermography with breast biopsy in evaluation of breast cancer:A case study. Infrared Physics & Technology, (2015), 73: p. 115-125.

[15] J. Josephine Selle, A. Shenbagavalli, N. Sriraam, B. Venkatraman, M. Jayashree & M. Menaka, Automated recognition of ROIs for breast thermograms of lateral view-a pilot study, Quantitative InfraRed Thermography Journal, 15:2, . (2018),194-213.

[16] Shi P, Zhong J, Rampun A, Wang H. A hierarchical pipeline for breast boundary segmentation and calcification detection in mammograms. Comput Biol Med. (2018), 96:178–8

[17] Cortés MAD, Ortega-Sánchez N, Hinojosa S, Oliva D, Cuevas E, Rojas R, Demin A ,A Multi-Level Thresholding Method for Breast Thermograms Analysis using Dragonfly Algorithm. Infrared Physics & Technology, (2018).

[18] Celaya-Padilla, J. M., Guzmán-Valdivia, C. H., Galván-Tejada, C. E., Galván-Tejada, J. I., Gamboa-Rosales, H., Garza-Veloz, I., Nandal, A. Contralateral asymmetry for breast cancer detection: A CADx approach. Biocybernetics and Biomedical Engineering, 38(1), (2018). 115–125.

[19] Lashkari, A., Pak, F., &Firouzmand, M. Breast thermal images classification using optimal feature selectors and classifiers. The Journal of Engineering, 2016(7), (2016) 237–248.

[20] Rastghalam, R., &Pourghassem, H. Breast cancer detection using MRF-based probable texture feature and decision-level fusion-based classification using HMM on thermography images. Pattern Recognition, 51, (2016), 176–186.

[21] Sathees, P., & Manoharan, S. C. Proposal of index to estimate breast similarities in thermograms using fuzzy C means and anisotropic diffusion filter based fuzzy C means clustering. Infrared Physics & Technology, 93, (2018), 316–325.

[22] GoudarziM,MaghooliK.Extraction of fuzzy rules at different concept levels related to image features of mammography for diagnosis of breastcancer.Biocybern Biomed Eng(2018),3(4):1004–14

[23] Kavya, N., & Padmaja, K. V. Glaucoma detection using texture features extraction, 51st Asilomar Conference on Signals, Systems, and Computers,(2017).

[24] Kosus, N., Kosus, A., Duran, M., Simavli, S., &Turhan, N. Comparison of standard mammography with digital mammography and digital infrared thermal imaging for breast cancer screening. Journal of the Turkish German Gynecological Association, 11(3), (2010), 152–157.

[25] Usha N, N. Sriraam, Kavya N, Sharath D, Prabha Ravi, Bharathi Hiremath, B Venkataraman and M. Menaka, Feature Selection and Classification for Analysis of Breast Thermograms at 2nd IEEE International Conference on Signal Processing and Communication (ICSPC'19), (2019), 276-280.

[26] Brynolfsson, P., Nilsson, D., Torheim, T., Asklund, T., Karlsson, C. T., Trygg, J.,Garpebring, A, Haralick texture features from apparent diffusion coefficient (ADC) MRI images depend on imaging and pre-processing parameters. Scientific Reports, 7(1), (2017).

[27] [27] Majtner, T., & Svoboda, D, Extension of Tamura Texture Features for 3D Fluorescence Microscopy, Second International Conference on 3D Imaging, Modeling, Processing, Visualization & Transmission, (2012).

[28] Abdel-Nasser, Mohamed &Moreno, Antonio & Puig, Domenec, Breast Cancer Detection in Thermal Infrared Images Using Representation Learning and Texture Analysis Methods. Electronics,(2019).

[29] Silva, T. A. E. da, Silva, L. F. da, Muchaluat-Saade, D. C., &Conci, A, A Computational Method to Assist the Diagnosis of Breast Disease Using Dynamic Thermography. Sensors, 20(14), (2020).

[30] Singh, D., & Singh, A. K, Role of image thermography in early breast cancer detection- Past, present and future. Computer Methods and Programs in Biomedicine, 183, 105074,(2020).