Chapter 5

Advances in Breast Thermography

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Additional information is available at the end of the chapter

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Abstract

Thermography-based breast cancer screening has several advantages as it is non-contact, non-invasive and safe. Many clinical trials have shown its effectiveness to detect cancer earlier than any other modality. Historically, thermography has only been used as an adjunct modality due to the high expertise required for manual interpretation of the thermal images and high false-positive rates otherwise found in general use. Recent developments in thermal sensors, image capture protocols and computer-aided software diagnostics are showing great promise in making this modality a mainstream cancer screening method. This chapter describes some of these advances in breast thermography and computer-aided diagnostics that are poised to improve the quality of cancer care.

Keywords: breast cancer, thermography, analytics, machine learning, artificial intelligence, medical imaging, breast thermography, computer-aided diagnostics

1. Introduction

Breast cancer is the leading cause of cancer deaths in women today. According to WHO, 1 in every 12 women have the risk of a breast abnormality in her lifetime. It is well established that early diagnosis is very critical to increase survival rates. For example, a study sponsored by Australian Government found that the breast cancer survival is strongly associated with tumor size at detection. In Australia in 1997, five-year relative survival was 98, 95, 93, 88 and 73% for women with tumors of size 0–10, 11–15, 16–19, 20–29 and 30 mm or greater, respectively [1]. Unfortunately, 70% of the breast cancer cases are detected when the tumor size is over 30 mm [2]. Therefore, there is a critical need for a method that can detect early-stage breast cancer.

Thermography is a method of cancer screening that has been known to detect early-stage cancer [3]. However, there is a lot of variation in the results of clinical studies based on thermography and many show low specificity. A medical scientist and deep expert in thermography, Dr. Gautherie, observed that the lack of technical skill and expertise to interpret thermal images leads to this low diagnostic accuracy [3]. Recent developments on high-resolution thermal cameras and computer algorithms for thermal analysis are making the interpretation process more factual. With increased computation power, automated diagnostics is also able to decrease the false-positive rates. Hence, thermal imaging along with computer-aided diagnostics is showing a promise of upgrading breast thermography to main stream usage. In this chapter, we study these recent trends in advanced thermal imaging as well as the advances in imaging algorithms.

2. Introduction to thermography

Infrared thermography is the recording of temperature distribution of a body using the infrared radiation emitted by the surface of that body at wavelengths between 7 and 14 μm. With this information, it is possible to create a visual map or thermogram of the distribution of temperatures on the surface of the object imaged. The sensitivity of modern infrared cameras is such that temperature differences to 0.025°C can be detected.

Thermography can be used for breast cancer screening based on the fact that the temperature of the tumor is about 2°C higher than the neighboring tissues and blood vessel activity surrounding a developing cancer is almost always higher than in normal breast tissue. Since breast tissue is part of the skin, vascular alterations due to cancer result in temperature changes on the surface of the breast which can be captured with infrared thermography. Thermal abnormalities identified with thermal imaging are among the earliest signs of a precancerous or cancerous lesion of the breast.

Thermal imaging is a noncontact, noninvasive and extremely privacy aware. Since thermal cameras are small, they are very portable and can be used for screening in rural camps.

There are many certified thermographers and thermologists who continue to practice using thermal analysis for breast cancer diagnosis [4].

3. Comparison with mammography

Most common methods used for cancer screening today is clinical examination, mammography and ultrasound. Among them, mammography is considered as a gold standard for breast cancer screening. It uses X-rays to screen the breast region and digitizes the density difference in image format. Typically, cancerous tumor has high density compared to surrounding region and can be easily distinguished from other regions. Studies [5–7] show that it gives a sensitivity of 68% to 88% (or as low as 48% for extremely dense breasts) and specificities ranging from 82% to 98%. In addition, it has the following disadvantages:

1. *Low sensitivity toward younger women:* In order to clearly detect tumors using X-rays, the density of the lump should be higher than the surrounding tissue density. Breast tissue density in younger women is high and decreases with age and exposure to hormonal changes [8]. This makes mammography mainly applicable for women with age greater than 45 years.
2. *Risk of radiation:* X-rays can cause genetic change in the tissues, and these mutations increase with increased dosage of radiation and duration of exposure. A study presented at an annual meeting of Radiology Society of North America (RSNA) observed that high-risk women exposed before age 20 or with five or more exposures were 2.5 times more likely to develop breast cancer than high-risk women not exposed to low-dose radiation [9]. This limits the mammography as a frequent screening modality.
3. *Fear and pain:* To get proper mammograms, breast region should be compressed. An approximate of 15–20 pounds of pressure is applied on the breast region to image. Due to high compression involved, sometimes it might also lead to rupture of tumor. Many surveys described this as painful screening method that subjects would like to avoid [10].
4. *Privacy:* Apart from pain and fear of radiation, it is reported in Ref. [11] that nearly 38% among women from different ethnic groups and with more than 60% among South Asian countries like India and Pakistan do not go for screening due to embarrassment of disrobing.

Thermography overcomes the above issues and enables more people to go for screening. It can work on women of all age groups. It is a non-contact, non-invasive modality with passive infrared measurement, which does not involve any radiation, hence a safe screening method. Since the thermal images can essentially be captured from a laptop connected to the thermal camera, it is also extremely privacy aware.

Among other modalities, clinical breast exam can detect tumors only once they are large enough to be palpable and result in many false positives. Effective use of sono-mammography (ultrasound) for cancer detection requires location of the lump. Hence, ultrasound is best used as a correlation modality. Once a lump is detected either through mammography or thermography or clinical breast examination, ultrasound will be very useful to reconfirm malignancy or not.

4. Biological explanation

Cancer cells release nitric oxide [12, 13] into the blood and lead to alteration in microcirculation. This nitric oxide coupled with aggressiveness of cancer to grow increases the blood circulation by dilating the vessels and leads to creation of new blood vessels (neo-angiogenesis) and dormant vessel recruiting. Experimentally, Folkman [14, 15] observed this dependency of tumor growth with angiogenesis by implanting tumour cells in mice. Large volume of blood flow in these vessels connected to tumor makes them hotter when compared to normal blood vessels. This large flow distorts the vessel structure, and vessels become dilated as well as elongated, causing the increase in the dimension of vessel caliber and length [16, 17]. This elongation combined with the large flow deviates the vessel structure from normal vessels by

making them more tortuous due to formation of bends [18–20]. In fact, it is experimentally evident that this high tortuosity is observed much before angiogenesis [18].

In addition, it has been empirically observed that tumor temperature is higher than the neighboring temperatures with the help of contact temperature measurements. In Ref. [21], Gautherie claimed that this high heat is due to high metabolic activity at tumor location. Hence, this region appears brighter and hotter in thermographic images when compared to surroundings. It is also observed that tumor temperature is warmer compared to the blood vessels feeding the tumor region [21]. Aggressiveness of cancer cells makes the boundary of tumor irregular as they break the boundary formed by basal laminas to invade the neighboring tissues [19, 20]. This is not seen in case of benign tumors whose cells behave similar to normal cells. This makes the benign tumor boundaries regular.

The size of tumor indicates the stage of cancer and largely affects the survival rate. A survey conducted by Narod [2] observed drastic decrease in survival rate with increase in tumor size. Early detection of cancer increases the chances of survival. Thermography outperforms other modalities when it comes to early detection. Changes such as vasodilation, neo-angiogenesis and high tortuosity of blood vessels which are found in initial stages of cancer result in thermal impressions and hence can be detected in thermography [15–19]. These might not be observed in other modalities which depend upon detecting architectural distortions that appear only when tumor is sufficiently grown. A study by Gautherie and Gros [3] over 58,000 patients for 12 years showed that thermography detected breast cancer five years earlier in around 400 patients than mammography and ultrasonography.

Abnormality in thermogram is not the sole criterion for malignancy. Increase in heat pattern might even be observed due to hormonal response, lactation and presence of benign tumors such as fibrocystic and fibroadenoma. However, these non-malignant conditions have different projections in the thermographic image when compared to malignant tumors. Unlike in malignant breasts where there is asymmetrical heat map, heat response is mostly symmetrical across the two breasts with high hormonal response. Estrogen released during hormonal activity produces nitric oxide that causes increase in heat and vessel dilation [12]. Similar activity happens in the case of lactating mothers except that a little asymmetry in heat map is seen due to uneven lactation in both breasts. There is an increase in heat signature even in benign cases such as fibrocystic and fibroadenoma [21, 22]. In contrast to malignant tumors, these cells are not aggressive and behave similar to normal cells [19, 23]. Other than these cases, abnormal heat pattern leading to vasodilation and angiogenesis can also occur during inflammation caused by infection or wound healing [12, 14]. Though these abnormalities are formed, they have distinct features compared to malignancy that can be distinguished.

Some recent explorations have shown that thermography can even help in prognosis. Since the increase of temperature in malignant tumors is primarily due to the release of nitric oxide, which is caused due to hormonal activity, the temperature distribution on the breasts also provides signals on the hormonal receptor status of malignant tumors. Zore et al. [9] have studied the effect of hormone receptor status of malignant tumors on thermograph through a quantitative analysis of average or maximum temperatures of the tumor, the mirror tumor site and

the breasts. While no statistically significant difference was found in the overall temperature distribution in breasts with hormone receptors being positive or negative, they report a significant difference in average and maximum tumor temperature measurements. Another computer-aided study [24] reported an accuracy of more than 80% for automated estimation of hormonal receptor status of malignant tumors. This shows the potential of a non-invasive way of predicting the hormone receptor status of malignancies through thermal imaging, before going through Immuno-Histo-Chemistry (IHC) analysis on the tumor samples after surgery.

5. Protocols for capturing thermal images

A standard imaging protocol has to be followed for any modality to make it a repeatable and operator agnostic procedure that can reduce subjectivity and errors in image capture. Likewise, a set of instructions has to be followed in thermography as well [25, 26].

Most importantly, before capturing the images, patient must be cooled for minimum period of 10–15 min in a room maintained at a temperature of 16-22 °C. This helps in attaining thermal equilibrium with the surrounding environment [25]. Cooling is mandatory as it helps in removal of extraneous heat caused due to external reasons such as tight clothing, apparel and friction from a hand bag or outside temperature. Cooling also helps in enhancing the temperature pattern of tumorous regions compared to non-tumourous regions [27–30]. It is observed that normal tissue reacts quickly to external cooling, whereas malignant reacts slowly, making it appear hotter compared to rest of the breast region. For quick cooling of images, cold challenge can be used where patient hands are immersed in cold water causing the regulation of body temperature with sympathetic stimulus [30].

When it comes to capturing the actual thermal images, imaging protocols can be categorized into discrete and continuous imaging protocols.

Discrete imaging protocols: These protocols are interested in specific set of static fixed views. The basic views which are observed in most discrete protocols include frontal view (0°), oblique views (±30°) and lateral views (±90°). Some variations of different protocols in the way of the mentioned views are captured, such as (a) seated position, (b) supine position, (c) standing position and (d) combinations of {a,b,c}. Subset of mentioned views/changing the angle of views/ adding more view angles are also being used in some studies.

A tumor has less effect with cooling compared to normal tissues whose heat signatures decrease drastically [28, 30]. To study the nature of cancer cells further, some protocols include the above combinations of different views after cooling the breasts. Some protocols consider only fully cooled breasts, while some capture the breast image before and after cooling and analyze the thermal patterns of the cooled breast and uncooled breasts [31].

Continuous imaging protocols: Continuous imaging protocols capture videos of the breast as they are cooled, instead of static images. These protocols are not as popular as discrete due to the large processing time needed to analyze. However, much larger information can be captured in a video. For example, tumorous regions do not cool as fast as rest of the tissues.

6. Advances in thermal cameras

Medical thermography is also benefiting from the rapid advancement in the quality of thermal imaging too. Temperature capture has evolved from a complicated probe-based method to a camera-based registration.

Over the years, improvements in silicon technology have made a huge impact on the technology used in IR detectors. Many use cases of thermal imaging are evolving in biomedical, transport, energy and environmental applications, and they have been the key business driver for this growth, as well. **Figure 1** depicts the history of development of infrared sensors, which is very well described in Ref. [32]. The real breakthroughs were focal plane arrays and bi-dimensional arrays improving spatial resolution and thermal sensitivity.

Broadly, infrared cameras can be divided into cooled and uncooled detectors. Cooled thermal cameras have infrared detectors integrated with cryocoolers and enable measurement of very low temperatures as well as very high resolution and improved sensitivity as thermally-induced noise is reduced. However, cooled cameras are expensive and may be needed only for applications that require very high resolution and high sensitivity.

Microbolometer focal plane arrays (FPAs) have tremendously modified the way of image capture by allowing an array of sensors at the focal plane of lens to detect the LWIR wavelengths [32, 33]. This integration has led to the development of uncooled infrared detectors that are typically small, handheld and also restricted the need for expensive cooling techniques. The current uncooled cameras work on the principle of change in resistance or voltage or current due to the emitted infrared radiation. The resolution is direct function of number of pixels in the microbolometer array per unit area. With the advances in silicon technology, these digital infrared uncooled cameras have massively transformed from a low resolution to high resolution of 640 × 480 pixels to 1024 × 768 pixels or more. The current cameras also have improved the sensors to obtain a thermal sensitivity and accuracy error of at most 20 mK and 1°C respectively. To detect the infrared radiation, vanadium oxide (VOx) and amorphous silicon are common materials in microbolometer [32].

The lens is costly compared to lens found in normal video-shoot cameras, since normal glass cannot be used to make the lens due to its property of blocking LWIR radiation and reflecting the LWIR incident on the lens. Hence, Germanium (Ge), Chalcogenide glass, Zinc Selenide (ZnSe) and Zinc Sulfide (ZnS) that are LWIR-transmissive are used for the lens preparation.

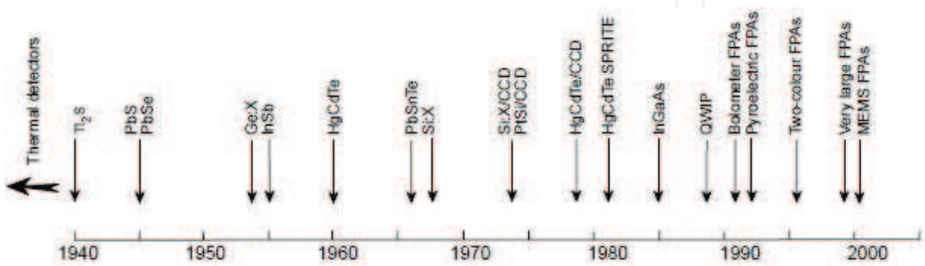

Figure 1. Advances in thermal sensor technology (reproduced from Ref. [32]).

These uncooled cameras have also reduced the cost and heavy maintenance that would be needed for the cooled detectors. Some popular camera models used for medical purposes are shown in **Figure 2**. Today, FLIR, Fluke and Meditherm are thermal camera vendors preferred by thermographers for medical thermography as many of these camera models are already FDA-certified for tele-thermology.

6.1. Visual interpretation of thermal images

There are different protocols followed by thermographers for analyzing and interpreting thermal images, especially for breast cancer screening. Most of this work in creating the protocols have taken place in the 1970s and 1980s, such as the Marseille protocol [13–15], Hobbins protocol [30], Gautherie protocol [21], Hoekstra protocol [34] and, more recently, with newer thermal cameras, the Villa Marie protocol [12]. An attempt to obtain an agreement of different experienced thermographers was also made in 1975 to provide a consistent set of observations to be noted [17].

All of these protocols give different thermographic category ratings of four to five levels, starting from normal to highly suspicious of malignancy. Multiple criteria are noted, using both vascular and non-vascular observations. These criteria are generally qualitative rather than quantitative. The visual interpretation necessitates heuristic rules to combine these observations to determine a thermographic category. Some protocols assign numbers to each observation and combine them using a mathematical function for categorization. This also shows the need for experience and proper training for thermographic interpretation.

Regardless of the variations across protocols, these criteria can be broadly classified into vascular and non-vascular criteria, with some generality in these criteria, as follows:

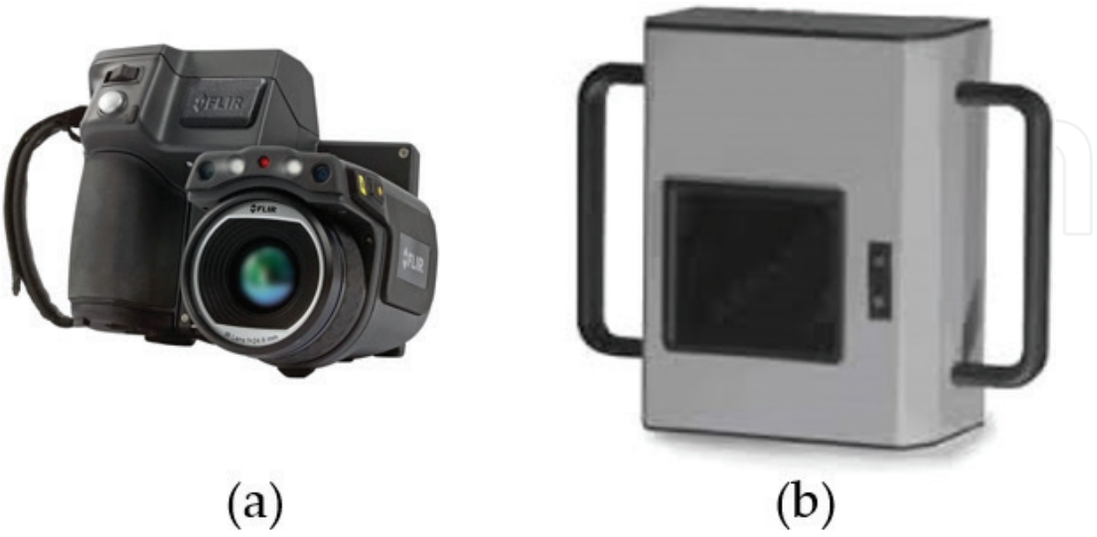

Figure 2. Two thermal camera models from different vendors (a) FLIR T650SC (b) Meditherm IRIS 2000.

Non-vascular criteria:

1. Focal increase in temperature by a fixed interval, e.g., 1, 2, 3°C
2. Global increase in temperature compared to the contralateral breast by, say, 1.5°C
3. Regional increase in temperature, including specific quadrants
4. Differences in temperature between contralateral regions or between different quadrants/regions in the same side
5. Abnormal location of focal increase including areolar regions or along edges/bulges
6. Abnormal physical observations: bulging/size variation, retraction

Vascular criteria:

1. Vascular asymmetry
2. Vascular anarchy, including tortuous or serpentine or loops or clusters or bifurcations
3. Increased vascular density
4. Abnormal directions of clusters of vessels, such as vertical, horizontal
5. Number of vessels
6. Caliber of vessels
7. Abnormal location of vascularity and avascularity

The general interpretation from these protocols is that with few and mild abnormal findings, the categorization is toward normal and likely benign. With increased abnormality, the observations tend toward increased suspicion of malignancy. Another important point to note is that benign diseases also exhibit some abnormal thermal vascular/non-vascular criteria [30]. The diagnosis for benign conditions is made by follow-up of thermography over a few months, by which time the abnormal thermal findings change or reduce or disappear.

Due to these multiple diverse metrics used by practitioners and no standardized way of interpretation across different expert thermographers, the thermological interpretation becomes very subjective and many times results in high false positives. Many efforts are therefore underway to remove subjectivity using computer-aided diagnostic methods—some of which are described later in this chapter.

7. Clinical validations

Thermography is not a new technique for breast cancer screening. Its presence has been there since 1960 [26]. There have been many longitudinal and clinical trials performed to show its efficacy. In 1982, FDA approved thermography as an adjunct modality for breast cancer

screening. **Table 1** lists out the studies that has been done to show the potential of thermography. This technique is undervalued due to the difficulty in interpreting the thermograms with naked eye. The interpretation varies from observer to observer and needs high expertise to correctly validate the diagnosis result, limiting to few thermographers. With advent of technology, in both hardware and software, automated analysis of thermograms is emerging to obtain high sensitivity and specificity.

Studies	Subjects	Follow-up	Results	Comments
Gershon–Cohen [41], 1967	1924	No follow-up	Sensitivity—91.6% Specificity—92.4%	
Stark and Way [42], 1974	4621	No follow-up	Sensitivity—98.3% Specificity—93.5%	–
Spitalier [43, 44], 1982	61,000	10-Year period	Sensitivity—89% Specificity—89%	They reported that thermography was the first alarm in 60% cancer cases and stated that abnormal thermogram represents
Haberman [45], 1980	39,802	3-Year period	Sensitivity—85% Specificity—70%	30% of cancers showed their initial signs in thermography compared with traditional screening
Gros and Gautherie [3, 21, 46, 47], 1980	85,000	5-Year period for 58,000 patients	Sensitivity—90% Specificity—88%	Out of 1245 women that showed − ve signs with traditional screening in their first visit, more than 33% have got cancer in this 5-year period
Jones [48], 1983	70,000	No follow-up	Sensitivity—87% Specificity—85%	
Parisky [37], 2003	769	No follow-up	Sensitivity—97%	
Rassiwala [49], 2014	1008	No follow-up	Sensitivity—97.6% Specificity—99.2%	

Table 1. List of large-scale studies.

8. Advances in software technology

As seen in the clinical validation, the sensitivity observed with visual analysis is acceptable, but specificity is lower than desired with visual interpretation. Further, visual observations and heuristic categorization are subject to human error and variation through subjective interpretation. To solve these problems, there are automated and semiautomated approaches for diagnostics [35]. We review some of the software tools available from companies who are intending to provide a replicable method of interpreting thermal images.

We review the technology used in three such software tools from Niramai health, Total vision and Mammo vision. All these approaches use static images obtained after cooling the subject with discrete imaging protocols.

8.1. Visualization tools for thermal interpretation

Given that a thermologist has to look at five colored images, where the temperature differences between neighboring regions need to be identified by minute color variations, interpretation of thermal breast images is a huge cognitive overload and very error prone. So, software tools that aid in visualization and capturing of the observations about thermal patterns are becoming available.

Total vision software from Med-hot.com gives an excellent visualization of the thermal images and additional support for a thermographer to systematically look for specific abnormal thermal pattern alongside a rule-based decision-making support to simplify the interpretation process. However, it does not have any automation of the diagnosis.

Mammo vision [31] is a semi-automated tool that tries to identify the non-vascular abnormal thermal patterns during dynamic thermography with cold challenge. It considers 10 images in total, 5 images before cooling and 5 images after cooling, for the analysis. An elliptical grid is used to approximate breast region, and it automatically extracts the lateral symmetry, isothermia in each quadrant, areolar temperature, nipple temperature, temperature decrease with cooling and hotspot parameter. Additionally, the clinician can manually identify the vascularity in the breast by looking at grayscale thermal image, which is then used by the tool to categorize the subjects into five groups. The tool defines assessment criteria called Breast Infrared Assessment System (BIRAS) with which they categorize the images into five groups with BIRAS 1 being low risk and BIRAS 5 being high risk.

8.2. Use of sophisticated computer-aided diagnostics

Use of sophisticated artificial intelligence algorithms for enabling automatic diagnosis or clinical interpretation guidance is most needed to reduce subjectivity in interpretation [37]. Niramai Thermalytix software is one such advanced software tool with a technology that enables end-to-end fully automated approach for the diagnosis [38–40]. The Niramai tool uses complex computer algorithms for the following five key aspects of automated diagnostics.

1. Autotagging

Since one single view may not be sufficient to capture tumor region in different parts of the breast region, multiple views are taken. Typically, there are five thermal images in multiple views that are captured; one of the common mistakes done by clinicians is to name the image wrongly. It is observed that many a times humans are confused with classification of right and left sides of breast in the image correctly and resulting in improper tagging of lateral and oblique views. Hence, Niramai software provides an automated tagging support. This reduces the error in naming or false tagging, which in turn would have resulted in other errors such as segmentation error and misclassification of subjects. Their software automatically tags the views based on the body border curvature and body area.

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2. Detecting the region of interest

The thermal image is captured with the patient sitting about three feet from the camera. This captures the thermal signature of the top part of body of the subject starting from neck region. A tool like Niramai that does automatic analysis of breast cancer has to accurately crop the region of interest (ROI), namely the breast tissue region. For this, Niramai tool removes inframammary fold, axilla, sternum and thyroid regions that are usually warm regions and might unnecessarily cause false positives. Additional heuristic based on the shape of body gives accurate segmentation of the ROI as shown in **Figure 3**. There is considerable research in the detection of ROI for single view [35], and tools that provide manual support through freehand segmentation and adjustable and draggable ellipse that the clinician can use mark the region of interest. Niramai software automatically detects the breast region using a polygon approximation of region that makes it easier for a clinician to edit, if needed.

3. Tumor localization

Once the region of interest for analysis is determined, next technical challenge is to accurately identify the exact location of an abnormality or a lesion. This usually means detecting regions having warm and hot temperature pixels in the image and analyzing the heat pattern around the same. The heat patterns found in the thermal images are then analyzed for specific tumor properties. Tumor-specific patterns include multiple important thermal patterns or features that typically help in discriminating malignancy versus benign conditions [38].

Symmetry plays a significant role in detecting whether a hot patch is abnormal. So, a subset of the ROI showing a significant increase in temperature as compared to the neighboring areas and contralateral sides is identified. In NIRAMAI, two varieties of abnormal regions

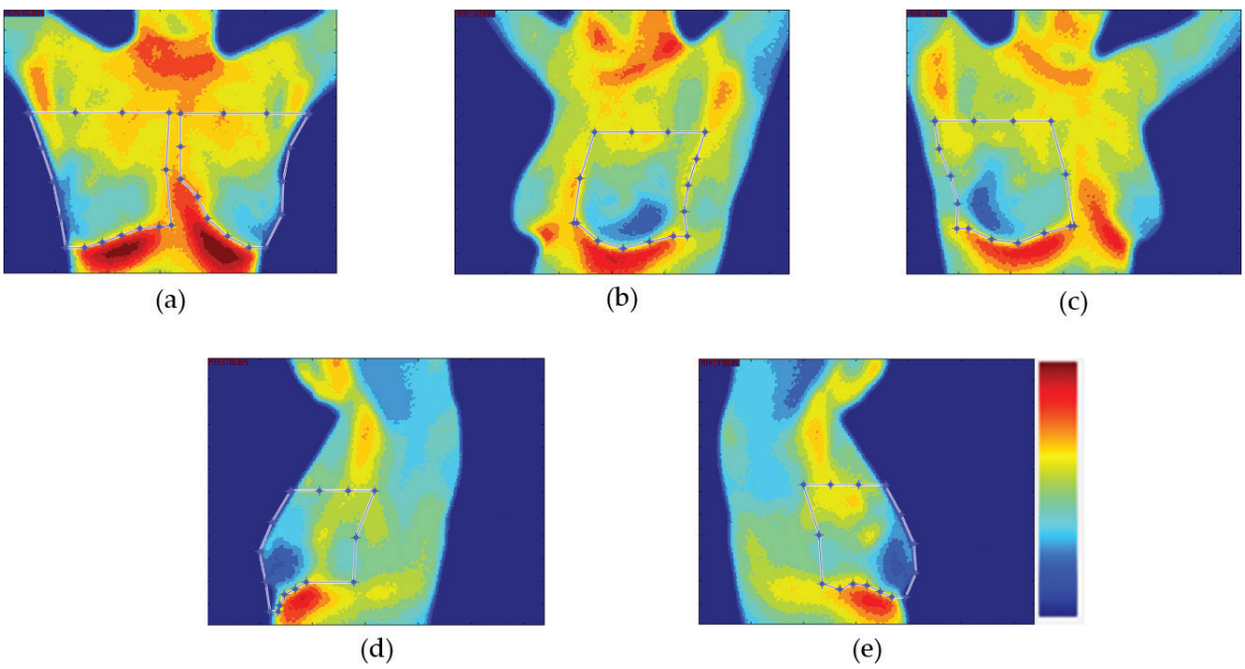

Figure 3. Results of automated segmentation in different views. (a) Frontal (b) Left Oblique (c) Right Oblique (d) Left Lateral (e) Right Lateral.

are extracted, hot-spots and warm-spots, based on the degree of their thermal response. This categorization helps to increase sensitivity with low thermal response tumors without increasing the false positives. Hot-spots correspond to high-temperature regions segmented using a combination of temperature-based thresholds. Warm-spots correspond to slightly lower temperature regions as compared to hot-spots with a change in parameters. One way of categorizing the same is using the modes and maximum temperature values, as shown in Eqs. (1) and (2).

$$T_a = T_{overallmax} - \mathrm{T} \tag{1}$$

$$T_b = \Gamma + \mathrm{P}(T_{overallmax} - \Gamma) \tag{2}$$

In above equations, Γ refers to the mean of the modes of the ROI temperature histograms in all views, and $T_{\text{overallmax}}$ represents the overall maximum temperature in all views. (P, T) are parameters chosen depending on the dataset.

Niramai tool detects hot-spots and warm-spots in each view of the subject. The best views of hot-spots and warm-spots are defined as the view in which the normalized size of the detected abnormal regions with respect to the ROI is maximum. **Figure 4** shows some sample subject images with their corresponding hotspots identified by NIRAMAI tool. From the detected hot-spots in multiple views, the hot-spots and warm spots corresponding to the best view are usually used to extract core features. Since symmetry places an important role, features are also extracted using the best view and its contralateral side view.

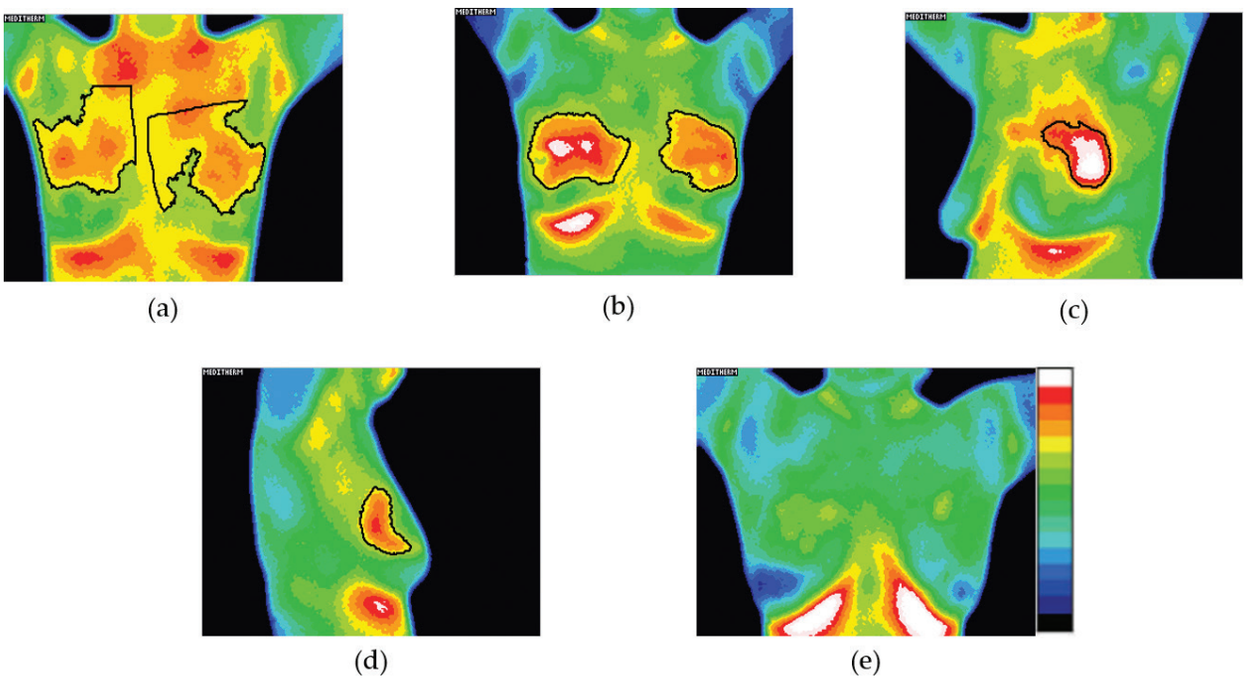

Figure 4. Sample subject images for (a) hormone-sensitive tissues showing warm-spots, (b) lactating case showing warm-spots, (c) malignant case showing hot-spots, (d) benign case showing warm-spots and (e) normal case.

4. Feature extraction

Once the hot- and warm-spots showing potential lesion is detected, three high-level properties of the lesion are extracted. These are boundary features, thermal symmetry and temperature distribution.

Malignant tumor cells are aggressive in nature, which makes them to invade surrounding tissues by rupturing through the boundary formed by basal laminas [19]. This makes the boundary irregular for malignant cases compared to non-malignant and benign cases which behave similar to normal cells.

In the case of malignant tumors, benign tumors, inflammation or wound-healing cases, an increase in temperature in the abnormal regions is observed. This leads to a difference in thermal heat patterns compared to the contralateral breasts. However, similarity in thermal heat patterns is seen for normal, hormonal, lactating conditions [12, 22, 36] due to the presence of similar hormone-sensitive tissues in both the breasts. This property is captured by including symmetrical features.

Finally, the mean temperature difference between the detected abnormal region and the remaining region of interest is calculated to get the relative increase in temperature compared to the neighboring region. In addition, many other temperature parameters of the abnormal region can be used for analysis.

5. Automated classification

Computer algorithms based on artificial intelligence and machine learning are making huge inroads in automated diagnostics [38]. Many methods of supervised classification are being developed where a small group of patient data is used to train a probabilistic model that represents the decision criteria based on the extracted features. A simple such classifier is a random forest that is able to identify the significant discriminatory features and learns a combination of the features and feature groups that helps decide on malignancy subjects. Other classifiers include support vector machines, Kmeans classifiers and deep learning.

9. Conclusions

In the recent years, use of Information Technology in healthcare diagnostics is proving to be very effective in improving efficiency and quality of care. Thermography is highly suited for breast cancer screening owing to its ability to detect cancer much earlier than any other modality, patient safety and privacy. The complexity and subjectivity in interpretation of thermal imaging has been a major deterrent in wide acceptance of the usage of thermography. Use of computer-aided diagnostics for automated thermography interpretation is just round the corner. With software support, thermal analysis and interpretation can be more efficient, effective and non-subjective. This chapter described some of the recent developments in both the hardware and the software of a thermographic solution that shows great promise that breast thermography will be a mainstream cancer screening modality very soon.

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References

[1] Nickson C, Kavanagh AM. Tumor size at detection according to different measures of mammographic breast density. Journal of Medical Screening. 2009;**16**(3):140-146. DOI: 10.1258/jms.2009.009054

[2] Narod SA. Tumor size predicts long-term survival among women with lymph node-positive breast cancer. Current Oncology. 2012;**19**(5):249-253

[3] Gautherie M, Gros CM. Breast thermography and cancer risk prediction. Cancer. 1980;**45**(1):51-56. DOI: 10.1002/cncr.2820450110

[4] American College of Clinical Thermology. ACCT Approved Thermography Clinics [Internet]. Available from: http://www.thermologyonline.org/Breast/breast_thermography_clinics.htm [Accessed: March 25, 2017]

[5] Kolb TM, Lichy J, Newhouse JH. Comparison of the performance of screening mammography, physical examination, and breast US and evaluation of factors that influence them: An analysis of 27 825 patient evaluations. Radiology. 2002;**25**(1). DOI: 10.1148/radiol.2251011667

[6] Skaane P. Studies comparing screen-film mammography and full-field digital mammography in breast cancer screening: Updated review. Acta Radiology. 2009;**50**(1):3-14. DOI: 10.1080/02841850802563269

[7] Svahn TM, Chakraborty DP, Ikeda D, Zackrisson S, Do Y, Mattsson S, Andersson I. Breast tomosynthesis and digital mammography: A comparison of diagnostic accuracy. The British Journal of Radiology. 2017;**85**(1019):e1074–e1082. DOI: 10.1259/bjr/53282892

[8] Ginsburg OM, Martin LJ, Boyd NF. Mammographic density, lobular involution, and risk of breast cancer. British Journal of Cancer. 2008;**99**(9):1369-1374. DOI: 10.1038/sj.bjc.6604635

[9] Zore Z, Boras I, Stanec M, Orešić T, Zore IF. Influence of hormonal status on thermography findings in breast cancer. Acta Clinica Croatica. 2013;**52**(1):35-42

[10] Collins K, Winslow M, Reed MW, Walters SJ, Robinson T, Madan J, Green T, Cocker H, Wyld L. The views of older women towards mammographic screening: A qualitative and quantitative study. British Journal of Cancer. 2010;**102**(10):1461-1467

[11] Forbes LJL, Atkins L, Thurnham A, Layburn J, Haste F, Ramirez AJ. Breast cancer awareness and barriers to symptomatic presentation among women from different ethnic groups in East London. British Journal of Cancer. 2011;**105**(10):1474-1479. DOI: 10.1038/bjc.2011.406

[12] Kennedy DA, Lee T, Seely D. A comparative review of thermography as a breast cancer screening technique. Integrative Cancer Therapies. 2009;**8**(1):9-16. DOI: 10.1177/1534735408326171

[13] Thomsen LL, Miles DW, Happerfield L, Bobrow LG, Knowles RG, Moncada S. Nitric oxide synthase activity in human breast cancer. British Journal of Cancer. 1995;**72**(1):41

[14] Folkman J. What is the evidence that tumors are angiogenesis dependent? Cancer Spectrum Knowledge Environment. 1990;**82**(1):4-6

[15] Folkman J. Tumor angiogenesis: Therapeutic implications. New England Journal of Medicine. 1971;**285**(21):1182-1186

[16] Konerding MA, Malkusch W, Klapthor B, van Ackern C, Fait E, Hill SA, Parkins C, Chaplin DJ, Presta M, Denekamp J. Evidence for characteristic vascular patterns in solid tumors: Quantitative studies using corrosion casts. British Journal of Cancer. 1999;**80**(5-6):724

[17] Goel S, Duda DG, Xu L, Munn LL, Boucher Y, Fukumura D, Jain RK. Normalization of the vasculature for treatment of cancer and other diseases. Physiological Reviews. 2011;**91**(3):1071-1121

[18] Li C-Y, Shan S, Huang Q, Braun RD, Lanzen J, Hu K, Lin P, Dewhirst MW. Initial stages of tumor cell-induced angiogenesis: Evaluation via skin window chambers in rodent models. Journal of the National Cancer Institute. 2000;**92**(2):143-147

[19] Baish JW, Jain RK. Fractals and cancer. Cancer Research. 2000;**60**(14):3683-3688

[20] Bullitt E, Zeng D, Gerig G, Aylward S, Joshi S, Smith JK, Lin W, Ewend MG. Vessel tortuosity and brain tumor malignancy: A blinded study. Academic Radiology. 2005;**12**(10):1232-1240

[21] Gautherie M. Thermobiological assessment of benign and malignant breast diseases. American Journal of Obstetrics and Gynecology. 1983;**147**(8):861-869

[22] Keyserlingk JR, Ahlgren PD, Yu E, Belliveau N, Yassa M. Functional infrared imaging of the breast. IEEE Engineering in Medicine and Biology Magazine. 2000;**19**(3):30-41

[23] Harvey L, et al. Cancer. In: Harvey L, editor. Molecular Cell Biology. 7th ed. New York: W.H. Freeman and Co.; 2013. pp. 1113-1148

[24] Kakileti S, Venkataramani K, Madhu H. Automatic determination of hormone receptor status in breast cancer using thermography. In: 19th International Conference on Medical Image Computing and Computer-Assisted Intervention—MICCAI. Vol. 9900. Springer; 2016. DOI: 10.1007/978-3-319-46720-7_74

[25] Ring EFJ, Ammer K. The technique of infrared imaging in medicine. Thermology International. 2000;**10**(1):7-14

[26] Amalu WC, Hobbins WB, Head JF, Elliot RL. Infrared imaging of the breast. In: Diakides M, Bronzino JD, Peterson DR, editors. Medical Infrared Imaging: Principles and Practices. CRC Press; Taylor & Francis Group, Boca Raton, Florida. 2012. pp. 10.1-10.22. DOI: 10.1201/b12938-11

[27] Gautherie M. Thermopathology of breast cancer: Measurement and analysis of in vivo temperature and blood flow. Annals of the New York Academy of Sciences. 1980; **335**(1):383-415

[28] Laaperi E, Laaperi AL, Strakowska M, Wiecek B, Przymusiala P. Cold provocation improves breast cancer detection with IR thermography: A pilot study. Thermology International. 2012;**22**(4):152-156

[29] Ohashi Y, Uchida I. Applying dynamic thermography in the diagnosis of breast cancer. IEEE Engineering in Medicine and Biology Magazine. 2000;**19**(3):42-51

[30] Hobbins WB. Thermography of the breast—A skin organ. In: Thermal Assessment of Breast Health. proceedings of an international conference held in Washington, DC, USA, July 20-24, 1983. pp. 40-48

[31] Berz R, Schulte-Uebbing C. MammoVision (infrared breast thermography) compared to X-ray mammography and ultrasonography. In: Diakides M, Bronzino JD, Peterson DR, editors. Medical Infrared Imaging: Principles and Practices. CRC Press; 2012. pp. 12.1-12.12. DOI: 10.1201/b12938-13

[32] Rogalski A. Infrared detectors: Status and trends. Progress in Quantum Electronics. 2003;**27**(2):59-210

[33] Corsi C. Infrared: A key technology for security systems. Advances in Optical Technologies. 2012;**2012**. DOI: 10.1155/2012/838752

[34] Carmeliet P, Jain RK. Angiogenesis in cancer and other diseases. Nature. 2000;**407** (6801):249-257

[35] Borchartt TB, Conci A, Lima RCF, Resmini R, Sanchez A. Breast thermography from an image processing viewpoint: A survey. Signal Processing. 2010;**93**(10):2785-2803

[36] Gautherie M. Improved system for the objective evaluation of breast thermograms. Progress in Clinical and Biological Research. 1982;**107**:897

[37] Parisky YR, Sardi A, Hamm R, Hughes K, Esserman L, Rust S, Callahan K. Efficacy of computerized infrared imaging analysis to evaluate mammographically suspicious lesions. American Journal of Roentgenology. 2003;**180**(1):263-269. DOI: 10.2214/ajr.180.1.1800263

[38] Madhu H, Kakileti ST, Venkataramani K, Jabbireddy S. Extraction of medically interpretable features for classification of malignancy in breast thermography. In: 2016 IEEE 38th Annual International Conference of the Engineering in Medicine and Biology

Society (EMBC); August; Orlando, Florida. IEEE; 2016. pp. 1062-1065. DOI: 10.1109/EMBC.2016.7590886

[39] Kakileti ST, Venkataramani K. Automated blood vessel extraction in two-dimensional breast thermography. In: 2016 IEEE International Conference on Image Processing (ICIP); September; Phoenix, Arizona. IEEE; 2016. pp. 380-384. DOI: 10.1109/ICIP.2016.7532383

[40] Venkataramani K, Mestha LK, Ramachandra L, Prasad SS, Kumar V, Raja PJ. Semi-automated breast cancer tumor detection with thermographic video imaging. In: 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC). IEEE; 2015. pp. 2022-2025

[41] Gershon-Cohen J, Haberman-Brueschke JA, Brueschke EE. Medical thermography: A summary of current status. Radiologic clinics of North America. 1965;**3**(3):403

[42] Stark, Agnes M, Way S. The screening of well women for the early detection of breast cancer using clinical examination with thermography and mammography. Cancer. 1974;**33**(6):1671-1679. DOI: 10.1002/1097-0142(197406)33:6<1671::AID-CNCR2820330630>3.0.CO;2-4

[43] Spitalier H, Giraud D, et al. Does infrared thermography truly have a role in present day breast cancer management?. In: Liss AR, editor. Biomedical Thermology. New York: 1982. pp. 269-278.

[44] Amalric R, Giraud D, Altschuler C, Amalric F, Spitalier JM, Brandone H, Ayme Y, Gardiol AA. Does infrared thermography truly have a role in present-day breast cancer management?. Progress in Clinical and Biological Research. 1981;**107**:269-278

[45] Haberman, JoAnn D, Love, Francis TJ, John E. Screening a rural population for breast cancer using thermography and physical examination techniques: Methods and results-A preliminary report. Annals of the New York Academy of Sciences. 1980;**335**(1):492-500. DOI: 10.1111/j.1749-6632.1980.tb50774.x

[46] Sciarra J. Breast cancer: Strategies for early detection. In: Thermal Assessment of Breast Health (Proceedings of the International Conference on Thermal Assessment of Breast Health); MTP Press LTD; 1983. pp. 117-129

[47] Louis K, Walter J, Gautherie M. Long-term assessment of breast cancer risk by thermal imaging. In: Liss AR, editor. Biomedical Thermology; New York: 1982. pp. 279-301

[48] Jones CH. Thermography of the female breast. Diagnosis of Breast Disease. Baltimore: University Park Press; 1983. pp. 214-234

[49] Rassiwala M, Mathur P, Mathur R, Farid K, Shukla S, Gupta PK, Jain B. Evaluation of digital infra-red thermal imaging as an adjunctive screening method for breast carcinoma: A pilot study. International Journal of Surgery. 2014;**12**(12):1439-1443. DOI: http://dx.doi.org/10.1016/j.ijsu.2014.10.010

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