A Study and Analysis of Hybrid Intelligent Techniques for Breast Cancer Detection Using Breast Thermograms

Usha Rani Gogoi, Mrinal Kanti Bhowmik, Debotosh Bhattacharjee, Anjan Kumar Ghosh and Gautam Majumdar

Abstract The growing incidence and mortality rate of breast cancer draw the attention of the researchers to develop a technique for improving the survival rate of the cancer patients. Medical infrared thermography (MIT) with sensitivity 90 % has proved itself as a safe and promising method for early breast cancer detection. Moreover, an abnormal breast thermogram can signify breast pathology. The accurate classification and diagnosis of these breast thermograms is one of the major problem in decision making for treatments, which leads to the utilization of hybrid intelligent system in breast thermogram classification. Hybrid intelligent system plays a vital role in survival prediction of a breast cancer patient, and it is highly significant in decision making for treatments and medications. The primary objective of a hybrid intelligent system is to take the advantages of its constituent models and at the same time lessen their limitations. This chapter is an attempt to highlight the reliability of infrared breast thermography and hybrid intelligent system in breast cancer detection and diagnosis. A detailed overview of infrared breast thermography including its principles and role in early breast cancer detection is described here. Several research works are carried out by various researchers

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to identify the breast pathology from breast thermograms by using hybrid intelligent techniques which include extraction and analysis of several statistical features. A study of research works related to feature extraction and classification of breast thermograms using various types of hybrid classifiers is also included in this chapter.

Keywords Breast cancer · Digital infrared imaging · Infrared breast thermography · Breast asymmetry · Breast cancer detection

1 Introduction

The incidence of breast cancer has been increasing globally, and it is the most common among all cancers accounting for more than 1.6 % of deaths. Over the last few decades in India, the average age of developing breast cancer has shifted to 30–40 years [1]. According to the National Cancer Registry Program 2006–2008 (NCRP), breast cancer is the most common cancer in India accounting 25–32 % of all cancers in female [1]. This implies that one-fourth of all female cancer cases is breast cancer [1]. As per the report made by American Society of Clinical Oncology (ASCO) in 2009, the 5-year survival rate of breast cancer has increased from 79 % (in 1984–1986) to 89 % (1996–2004) in United States [1]. Due to the lack of breast cancer awareness and inadequate medical facilities, the survival rate of breast cancer patient is very poor in India comparative to United States. With the growing rate of breast cancer incidence, demand for developing new technologies and improving existing technologies for breast cancer prevention is increasing. Till now, no effective cure is there to prevent breast cancer. The probability of successful treatment and complete recovery of the patient entirely depends on the early detection and diagnosis of the breast cancer. If discovered early, breast cancer is a highly treatable disease, with 97 % chances of survival [2]. Medical imaging like mammography, breast ultrasound, infrared breast thermography, etc. has been considered as an essential tool for early detection, better diagnosis and effective treatment of breast cancer.

Among various breast imaging techniques, mammography is considered as the gold standard for breast cancer detection with a sensitivity of 80 %. However, in case of dense breast tissue in younger women, detection of suspicious lesions is very difficult from mammography. Compare to the older women of age above 50, breast cancers grow very faster in younger women under 40 years. The faster a malignant tumor grows the amount of infrared radiation it generates is also greater that can be recorded using a very sensitive thermal camera. Therefore, particularly for younger women under 40, thermography acts as a safe early risk marker of breast pathology. Moreover, mammography cannot detect a tumor until when it is of a certain size. Keyserlingk et al. [3] state that the minimum size of a cancer tumor to be detected in mammography is 1.68 cm while the average size of the tumor not getting detected in thermography is 1.28 cm which is much smaller. Thus, thermography can also detect those tumors or early changes that cannot be detected and missed by mammography. With the noninvasive, painless, noncontact, radiation-free and low-cost properties, infrared breast thermography is one of the best screening methods available today in medical science for the breast health. Thermography is capable of screening hard to reach areas like axilla and upper chest areas. After having the breast thermogram, sometimes due to the limitations of human perceptibility, the radiologists cannot accurately classify a breast thermogram, which may mislead the treatment options for the patient. In order to improve the survival rate of the breast cancer patient, early detection and decision-making process for initialization of medication and avoidance of aggressive therapies are primary requirements. Hence, accurate classification of the breast thermograms is also a vital component for medical decision-making and proper diagnosis. Compare to the conventional methods, the hybrid intelligent system provides a better classification accuracy which demonstrates that the hybrid intelligent system is proficient enough in undertaking breast thermogram classification.

This chapter provides an overview of breast cancer along with different breast imaging modalities for early detection of breast cancer. A special attention is given to the infrared thermography-based breast disease detection as it is a noninvasive, inexpensive method of breast imaging without using any radiation. This chapter is an attempt to highlight the feasibility and efficiency of hybrid intelligent system in infrared breast thermography-based breast cancer detection and diagnosis. The chapter is structured as follows. A brief outline including types, symptoms, and risk factors of breast cancer is given in Sect. 2. Section 3 illustrates the necessity of detecting breast cancer in early stage. The next section (Sect. 4) describes the importance of imaging modalities in breast cancer detection and diagnosis. Various imaging methods available for breast cancer detection are presented in Sect. 5. This section (Sect. 5) also includes the limitations of each breast imaging method. Section 6 presents the fundamental of digital infrared thermal imaging (DITI). Use of DITI in breast cancer early detection is described in Sect. 7. Section 8 presents all the necessary acquisition protocols for breast thermograms. A review work on image processing and hybrid intelligent system-based breast cancer detection from breast thermograms is presented in Sect. 9. Finally, Sect. 10 concludes this chapter.

2 Breast Cancer

Breast cancer begins in the cells of the breast tissue, either in the lobules that produce milk or in ducts that carry milk to the nipples. The cancerous cells of the breast continue to multiply to form a malignant tumor. A malignant tumor is a grouping of cancer cells that invade into nearby tissues and may invade to other parts of the body such as liver, lung, bone, and brain through the blood stream. Although it is rare, breast cancer can also develop in men. Breast cancer is categorized based on its origin and its level of invading. The entire female breast

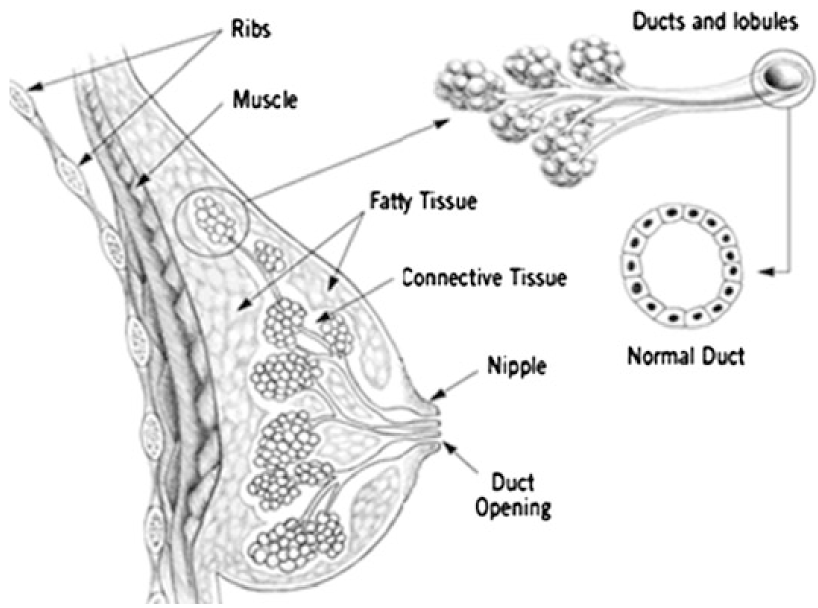

Fig. 1 Anatomy of the female breast [69]

anatomy is shown in Fig. 1. Based on the starting point of breast cancer, it is classified as ductal carcinoma (starts in milk duct) and lobular carcinoma (starts in breast lobule).

It is also classified as invasive and noninvasive (in situ) based on its level of spreading. Carcinoma in situ is a form of cancer where the tumor is confined to the region where it began. Invasive ductal carcinoma (IDC) is the most common breast cancer. It starts in a milk duct of the breast and then it breaks through the wall of the duct and invades into the fatty tissue, lymphatic vessels of the breast. Among all breast cancers, about 80 % is invasive ductal carcinoma. Invasive lobular carcinoma (ILC) is the second most frequent type of breast cancer after invasive ductal carcinoma. Sometimes, people are diagnosed when cancerous cells are totally inside a duct or lobule. It is called carcinoma in situ as no cancer cell has grown out from their original location. Comparative to invasive cancer, carcinoma in situ is easier to treat. The type of breast cancer known as 'Lobular Carcinoma in situ' is not a cancer but its presence indicates a higher risk of developing breast cancer in the future.

In the initial stage of breast cancer, it has no symptom. However, developing a tumor may be associated with the formation of a painless lump that persists after each menstrual cycle. Some other symptoms which may be noticed with the affected breast includes—Any changes in shape, texture, temperature and size of the breast; inflammation in the armpit; pain and tenderness in the breast; nipple discharge (sometimes may contain blood); dimpling of breast skin like orange peel; inverted nipple. When tumor grows larger, the patient may also notice bone pain, nausea, loss of appetite, weight loss, shortness of breath, muscle pain, etc.

2.1 Risk Factors of Breast Cancer

Though the breast cancer is the second deadliest disease after lung cancer, the exact cause of breast cancer is still unknown. The only known thing is that breast cancer is always caused by the damage to the cell's DNA (deoxyribonucleic acid). During the lifetime, the body's cells get reproduced and replaced in a controlled manner. When this control is lost, the cells start to divide more rapidly in an uncontrolled way and continue to form a lump or mass that causes breast cancer. The cells may spread to the lymph nodes or to other parts of the body. Several risk factors are associated with the breast cancer, but having a risk factor does not signify that women will acquire breast cancer while many risk factors increase the chances of having breast cancer. Some risk factors can be avoided or controlled, but some are there that can't be avoided. Some of these risk factors are described below:

- **Gender**: Breast cancer is more prevalent in female. Compared to female, less than 1 % men have breast cancer [4] i.e. the incidence rate is 100 times more common in female than in men.
- **Age**: The breast cancer developing risk increases with the increase of age. Women over 50 have a higher risk of getting breast cancer. Every woman within the age group 50 and 70 should undergo breast cancer screening program in every 3 years. 8 out of 10 women over 50 are diagnosed with breast cancer.
- **Family history**: Women, whose close relatives are suffering from either breast cancer or ovarian cancer before menopause, have a higher risk of developing breast cancer. Most breast cancer cases are not hereditary. However, two genes BRCA1 and BRCA2 (BReast CAncer genes 1 and 2) increases the risk of having breast cancer, and these genes can inherit from parents to the child. Presence of this gene indicates an 80 % likelihood of developing breast cancer. But, not having a close relative with breast cancer does not mean one would not get it.
- **Personal diagnosis of breast cancer**: A woman having breast cancer in one breast has greater chances of developing a new cancer in the other breast or same breast again.
- **Breast density**: The breast is made up of thousands of minute glands (lobules) which produce milk. Compare to the other breast tissue, the glandular cells contain a higher concentration of breast cells to make the breast denser, i.e., dense breast consists of more gland tissue and less fatty tissue. Women having dense breast have a greater chance of getting breast cancer. Also, identification of lump or any abnormal tissue in dense breast mammograms is very difficult. Young women have denser breast than the old women because, the amount of glandular tissue in the breast get decreased with age and replaced with fat.
- **Some benign breast problems**: Women having certain benign (noncancerous) breast problem or changes like developing of noncancerous lump or lobular carcinoma in situ have a greater chance of developing breast cancer.
- **Menstrual periods**: Women, who had periods early or before age of 12 or who entered menopause at a late age or after the age of 55, have a higher risk of

developing breast cancer. The ovaries where the eggs are stored produce oestrogen to regulate the periods. When the periods starts earlier and ends later, it results in over exposing of oestrogen for a longer period. The breast cancer cells are stimulated to grow by the hormone oestrogen.

- **Breast radiation in early life**: Women, who have undergone the radiation treatment to the chest area like X-rays, CT Scans (as treatment of another disease) when they are young have a significantly increased risk of developing breast cancer. The risk is much higher if the radiation is given when the breasts were still developing.
- **Have no child or having them in later life**: Women, having no children or who have the first baby after age 30, have a slightly higher risk of developing cancer. Getting pregnant many times or in younger age cut down the risk of breast cancer as the pregnancy interrupts the exposure to oestrogen. In order to prevent the oestrogen levels, the fat levels of the body must be maintained. Regular exercise or physical activity lowers the oestrogen level and thus reduce the risk of developing cancers.
- **Using oral contraceptives (birth control pills)**: Women who use oral contraceptive pills or any other birth control medication for a long time have higher chances of getting breast cancer. Once the pills are stopped, the risk also gets reduced.
- **Using hormone therapy after menopause**: Women who take hormone replacement therapy especially estrogen and progesterone after menopause, the possibility of developing breast cancer after 5 years of treatment get increased. The risk increases with the intake of hormone replacement therapy, but it becomes normal once the patient stop taking it.
- **Not breastfeeding**: Some research work shows that the breast cancer developing risk reduces with the breastfeeding if it lasts for 1 and half years to 2 years.
- **Alcohol**: The breast cancer developing risk increases with the amount of alcohol intake. Several breast cancers related study shows that one single drink may increase the risk.
- **Being overweight or obesity**: The breast cancer risk highly increases in women who become overweight or obsessed after menopause. It is due to the amount of oestrogen in the body, as obesity causes more oestrogen to produce.
- **Tobacco smoke**: Recent research activity suggests that women who started regularly smoking when they were young are 70 % more expected to develop breast cancer before the age of 50 than the nonsmokers.
- **Being tall**: The risk of having breast cancer is more in women who are taller than average than those who are shorter than average.

2.2 Incidence and Mortality Rate of Breast Cancer

Breast cancer is the second deadliest disease after lung cancer. More than a million women worldwide are identified with breast cancer every year, which accounts 23 % of all cases in female cancer [5]. Moreover, breast cancer is the leading cause of cancer-related death for women in both developed and developing countries. The influence of geographic variation on mortality rate is very less compared to the breast cancer incidence rate [6]. Breast cancer incidence rate is much higher in more developed countries than in the less developed countries, whereas the mortality rate is relatively much higher in less developed countries due to the lack of screening technology and inadequate medical facilities [7]. Being a developing country, the breast cancer incidence and mortality rate in India is increasing with growing migration of the rural population to the cities and due to changes in the lifestyles. According to the survey report made by the International Agency for Research on Cancer (IARC) and the specialized cancer agency of the World Health Organization (WHO), an estimated 70218 women died in India for the year 2012, due to breast cancer which is more than any other country in the world (second: china—47984 deaths and third: US—43909 deaths) though the number of newly diagnosed breast cancer cases was least in India [1]. In the year 2012, for every 5 or 6 women newly diagnosed with breast cancer, 1 woman died in US; for every 4 women newly diagnosed with breast cancer, 1 women died in China and in India for every 2 newly diagnosed cancer women, 1 lady died of it [1].

2.3 Importance of Breast Cancer Awareness for Early Detection of Breast Cancer

Breast cancer awareness is an attempt to make the people familiar with the deadliness of breast cancer through education about the symptoms and treatments. The awareness about the breast cancer symptoms will make the women to realize the importance of getting tested early and to visit a physician when he/she experiences any. This is also associated with a better curing option and long prognosis rate. There are several things like self-breast exam, regular exercise, having healthy diet, etc. that women can do to prevent the occurrence of this disease. Self-breast exam plays a significant role in breast cancer awareness through which a woman can find out the presence of cancer in early stage before moving to the doctor. In order to increase the breast cancer awareness of the people from rural areas, a Breast Cancer Awareness brochure in “BENGALI” language is designed in our Research Laboratory. The booklet provides all the necessary information about breast cancer including its symptoms, the way of performing breast-self-exams, various breast imaging modalities, breast cancer staging, and treatments. This Breast Cancer Awareness brochure will be published very soon in association with Regional

Cancer Centre, Agartala Government Medical College, Agartala, Tripura (West), Government of Tripura, India and Jadavpur University, Kolkata, India.

3 Necessity of Detecting Breast Cancer in Early Stage

With the growing rate of breast cancer incidence, demand for developing new technology and improving existing technology for breast cancer prevention is increasing. The probability of successful treatment and complete recovery of the patient entirely depends on the early detection and diagnosis of the breast cancer [8]. In the modern medical science, there are a large number of newly developed technologies for timely detection of breast cancer to save the lives of many women. The primary goal of screening exams for breast cancer is to detect cancer at a smaller size and at an earlier stage; otherwise, the cancer will extend to other parts of the body. If discovered early, breast cancer is a highly treatable disease, with 97 % chance of survival [2, 9] whereas Lahiri et al. [10], mentioned that early detection of breast cancer leads to 85 % survival chance. Thus, early detection of a breast tumor is the only means to reduce the mortality rate of breast cancer. Since the year 2008, the breast cancer incidence rate has been increased by 20 % while mortality rate has increased by 14 %. About 1.7 million women were newly diagnosed with breast cancer in the year 2012 [6].

4 Medical Imaging Methods for Detection of Breast Cancer

Medical imaging is an imperative diagnostic tool for early detection, better diagnosis, and effective treatment of breast cancer. From medical images, a doctor can evaluate the stage and extent of the cancer. The medical imaging is considered as a critical component of the nation's war on cancer. In Medical Science, there are a lot of medical imaging modalities like mammography, breast ultrasound, breast magnetic resonance imaging, breast-specific gamma imaging, molecular breast imaging, infrared thermography that decrease the mortality rate by playing a significant role in early detection of breast cancer. The incredible power of medical imaging allows researchers and physicians to observe not just within the body, but deep inside the chaos of cancer cells. In this role, imaging is used for:

- Screening, diagnosis, and staging of cancer;
- Guide cancer treatments;
- Finding out whether a treatment is working or not;
- Monitoring recurrence of cancer; and
- Facilitating medical research.

5 Various Medical Imaging Methods

As mentioned above the death rate of breast cancer can only be reduced, if the breast cancer get detected in early stage, i.e., the survival rate, complete recovery, and prognosis rate of breast cancer totally depends on the early detection and proper diagnosis of the breast cancer [8]. In the modern medical science, there are a large number of newly developed imaging modalities and techniques for timely detection of breast cancer to save the lives of many women. Also, the breast cancer mortality rate has been decreased as new imaging technologies have been introduced into today's medical system. Medical images play an important role in knowing the details of the human body for remedial or health science reasons. A succinct overview of the most widely used imaging methods for early breast cancer detection is given below:

1. **Mammography**: Mammography is essentially the only extensively used imaging modality for breast cancer screening. It is a low-dose x-ray of the breast. Breast mammography is of two types: screening mammography and digital mammography. A screening mammogram is suggested for women who have no symptoms of breast cancer. Screening mammography has long been considered as the "Gold standard" for breast cancer screening [11]. A diagnostic mammogram is used for evaluation of new abnormalities of patients having some symptoms of breast cancer. It is an invasive method which involves compression of breasts. Along with the cancerous tumor, breast mammography also identifies cysts, calcifications in the breast. Mammography can find out a cancer tumor in a curable stage. A physician recommends an annual screening mammography for all women over 40 years old since the sensitivity of mammography is very less in younger women with dense breasts [12]. Some samples of mammograms are shown in Fig. 2.

Limitations of Mammography. Although mammography screening is presently considered as the most appropriate method for mass screening in asymptomatic women, it also has several limitations [13]. Some of them are described below:

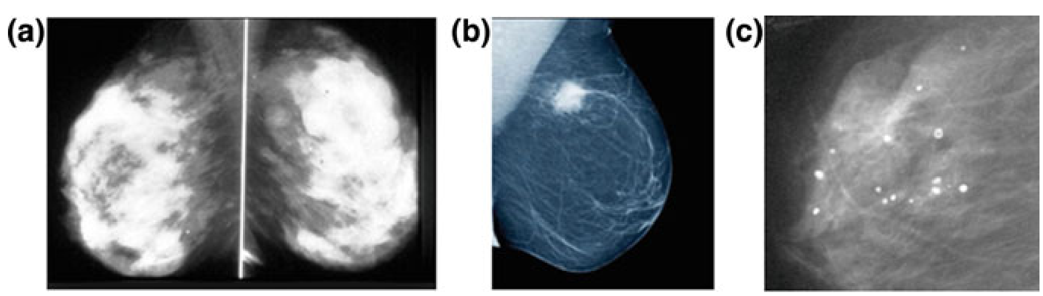

Fig. 2 **a** Dense breast mammogram where both dense breast tissues and tumors appear white while fatty tissue appears black [70]. **b** Mammogram, showing a breast tumor [71]. **c** Micro calcifications in breast mammogram [72]

- **Radiation risk of breast cancer**: Mammography possesses radiation risk of x-ray. Female breast tissue is highly sensitive to radiation, and this electromagnetic radiation triggers the factor that is responsible for cancerous growth. The radiation also raises the possibility of spreading or metastasizing an existing growth [13, 14].
- **False positives and false negatives**: While Mammography can detect breast cancer earlier, it also can generate false positives by detecting some abnormalities. But, the subsequent tests do not reveal the presence of any cancerous tumor [15]. It is called a 'false positive.' This is why women who have done the screening program run the risk of undergoing the tests that would not have been required if they had not been screened.
  The sensitivity of mammograms is about 90 % which indicates there is about a 10 % likelihood that a small tumor is present in the breast, but not detected. It is called a 'false negative' [15]. The screening mammography cannot detect every instance of breast cancer. One major limitation of mammography is that it cannot detect a cancerous tumor in the breast until when it is of certain size.
- **Dense breast**: Breast density differs widely among women. X-rays can easily pass through fat since fat is radiographically translucent whereas connective and epithelial tissue blocks x-rays to a greater extent as they are radiographically dense relative to fat. The detection of tumor is very difficult in mammography since both the tumor and dense breast tissue appear white in mammograms. That is why mammogram is not well suited for women having dense breast and fibrocystic breasts.
- **Risk of fracture**: During the process of mammogram 42 pounds of pressure is given to the breast that makes the compression of breast tissue [14]. This compression may increase the risk of rupture the encapsulation around the cancer tumor.
- **Age**: The accuracy, sensitivity, and specificity of mammography vary with age. Research shows that the mammogram sensitivity is higher for older women (age 60–69) at 85 % compared with younger women (<50 years) at 64 % [16]. It indicates that the mammography is less effective for a patient of younger age.

2. **Breast Magnetic Resonance Imaging (MRI)**: It is noninvasive imaging technique which does not involve any radioactivity and uses powerful *magnetic field of strength 1.5 Tesla* and radio waves to create images of the breast [17]. MRI can show smallest lesions/abnormalities which are not visible through mammography or ultrasound. Breast MRI provides highest quality images of breast anatomy [18]. In Fig. 3, some breast MRI samples are depicted. Breast MRI is not recommended for all breast cancer patients. But, due to higher sensitivity, radiologist recommends a breast MRI along with yearly mammograms. Some situations where another imaging tools like mammography or ultrasound could not find any abnormalities; the MRI is used as an adjunctive tool to provide additional details. One of the problem with MRI is that due to its high sensitivity it gives many false negatives for which it cannot be used alone as a standard tool for breast cancer detection. However, in some cases breast

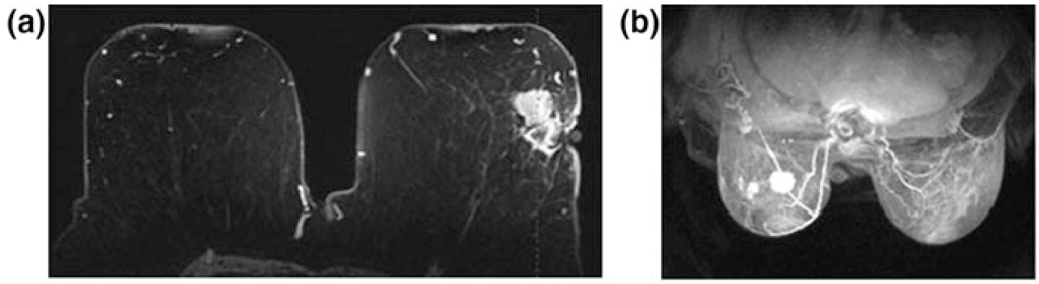

Fig. 3 **a** Breast MRI showing a lesion [73]. **b** Breast MRI of a dense breast [74]

MRI detects a potential and mammographically occult breast cancer threat very early. It is a very costly exam [18].

Limitations of breast MRI. The breast MRI is much more sensitive than the mammography and produces false positive results by detecting breast areas that do not have any cancer, and this leads to unnecessary biopsies [19]. Moreover, the breast MRI cannot detect the micro-calcifications that indicate a suspicious area. It cannot distinguish between cancerous and noncancerous abnormalities [19]. Compare to the other imaging modalities, breast MRI is very expensive exam, and pregnant women are not recommended to have breast MRI since a powerful magnet and a contrast agent is used in breast MRI.

3. **Breast Ultrasound (BUS)**: Breast Ultrasound is an important imaging technique that uses harmless high-frequency sound waves to detect and characterize tumors. The *7.5–12 MHz transducers* are usually used in BUS, which achieves adequate penetration in most of the women [20, 21]. BUS does not utilize ionizing radiation like mammography that makes it a preferred method for pregnant women [22]. It is a painless process as no compression is made on breast during the breast imaging. In ultrasound imaging, echoes reflected from normal, and abnormal tissues are captured by the computer to produce a 2D image called sonogram. BUS produces very sharp and high-contrast images of the breast. Ultrasound can show lumps that are filled with either solid mass or fluid. Radiologists examined these images to determine whether a mass is a solid tumor or just a fluid filled cyst [12, 22]. A cyst and a cancer tumor detected in breast ultrasound are shown in Fig. 4a, b, respectively. Ultrasound is often performed with mammography to identify the area of concern that requires further evaluation. Ultrasound is useful in finding very minute lesions that cannot be felt in a clinical exam, and it is also useful in guiding the needle during the biopsy [22]. Interpreting cancer tumor in mammogram of women with dense breast is difficult, for which breast ultrasound is considered as first diagnostic imaging method for women under the age of 35 [22]. Overall, ultrasound is a quite helpful investigative tool in the diagnosis of various breast cancer symptoms.

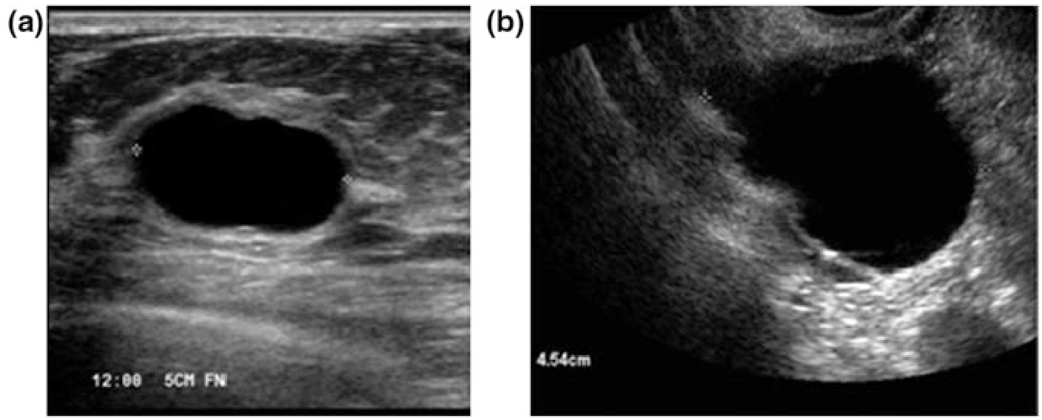

Fig. 4 **a** A simple breast cyst [75]. **b** Breast ultrasound, showing a cancer tumor [76]

Limitations of breast ultrasound. Comparative to the advantages and effectiveness of the breast ultrasound, it has limited drawbacks. One major disadvantage of breast ultrasound is that it cannot replace the mammography of women of age above 40 since like mammography breast ultrasounds are unable to identify calcifications in breasts which is also a sign of breast cancer in very early stage [23, 24]. In addition, ultrasound cannot screen many of cancers ,i.e., many cancer tumors are not visible in ultrasound. Therefore, in most of the cases breast ultrasound is followed by other diagnostic examinations like MRI, mammograms, etc. It cannot be alone used as standard screening tool for breast cancer [24].

4. **Nuclear medicine breast imaging**: It is a promising tool for screening and diagnosis of breast cancer in women with dense breast tissue. It is a noninvasive method of imaging. The FDA (Food and Drug Administration) approved short-term radioactive agent *Tc-99 sestamibi* is injected 5–10 min before the imaging procedure [25]. This radioactive tracer lights up (gamma rays) the cancerous area inside the breast. The breast cell absorbs this radioactive agent. But, the cancerous cells in the breast are found to absorb more of the agents than the normal breast cells, and these cancer cells can be imaged with special semiconductor-based γ-cameras [25]. Nuclear breast imaging covers all the imaging modalities including positron emission mammography to breast-specific gamma imaging. It is the safest diagnostic imaging exams available. Nuclear medicine imaging makes it possible to detect any abnormalities before progression of the disease. Figure 5 shows different types of nuclear medicine breast imaging. Some nuclear breast imaging techniques are:

   - **BSGI (Breast specific gamma imaging) and MBI (Molecular breast imaging)**: BSGI and MBI use a high-resolution gamma camera for imaging of the breast. During the image acquisition, a mild compression is made on breast. It can differentiate between the cancerous tissue and benign tissue of the breast. It is an ideal test to complement the mammography. The sensitivity of MBI is very high for small breast lesions detection. MBI has an

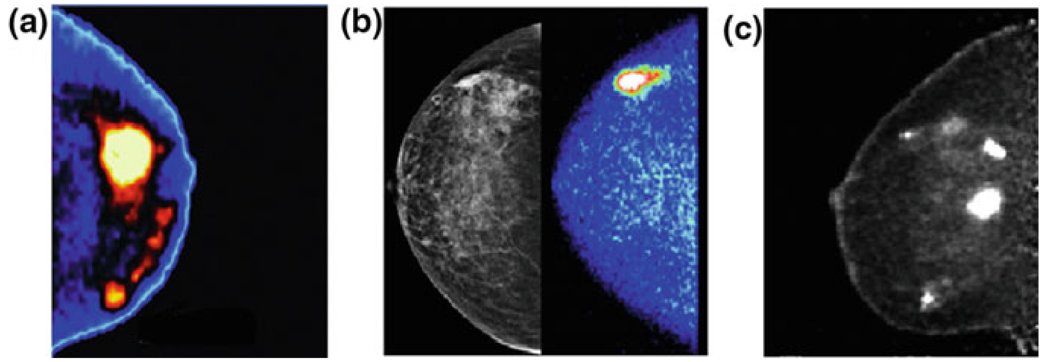

Fig. 5 **a** Detection of cancer tumor in BSGI of a dense breast [77]. **b** Shows the detection of 17 mm cancer tumor in MBI of a breast whose mammogram shows a negative result [78]. **c** Detection of the cancerous tumor in PEM of a breast [79]

overall sensitivity of 90 % in patient with suspected breast cancer. The sensitivity of MBI is 82 % for lesions less than 10 mm in size. Sensitivity is lowest for tumors less than 5 mm in size [25].

- **PEM (Positron Emission Mammography)**: In this imaging technique, a short-lived radioactive sugar-like substance is injected into the body. The substances get accumulated in the cancerous cells of the breast and radiate energy that can be captured using a complicated and advanced imaging camera. PEM can capture the shape; size (equal to pinpoint), and location of the breast tumor [26].

Limitations of Nuclear Medicine Breast Imaging. One of the essential components of nuclear medicine imaging is the use of radiotracer or radioisotopes which has a harmful impact on the health of the patient. Breast is one of the most radiosensitive organs in the body. Due to its radiation, pregnant women are not recommended for nuclear medicine breast imaging. Radioisotopes cause genetic mutation which is also a cause of breast cancer. Excessive use of nuclear medicine may cause the malfunctioning of an enzyme or protein. Also, nuclear medicine is very expensive and requires a huge amount of investment for which several medical institutions cannot afford it.

5. **Infrared Breast Thermography**: Since 1982, FDA (Food and Drug Administration) has approved IR imaging as an adjunct modality to mammography for breast cancer detection [27]. The underlying idea of breast thermography is that the temperature of the skin overlying a malignancy is higher than the skin overlying normal breast tissue which is caused by the increased rate of blood flow and metabolic activity to supplement the tumor's growth [28]. Due to ever increasing need for nutrients, cancerous tumors boost circulations to their cells by opening dormant vessels, and creating new ones. This process results in an increase in regional surface temperature of the breast. Ultra-sensitive medical infrared cameras and complicated computers are used in breast thermography to detect and produce high-resolution images of

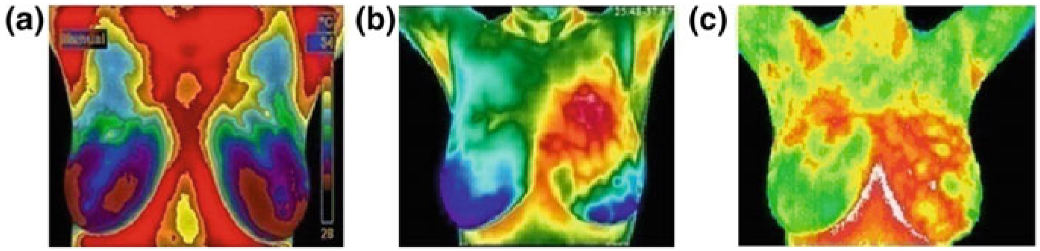

Fig. 6 **a** Healthy breast thermogram: the temperature patterns of two breasts are cool and almost identical [80]. **b** Shows invasive ductal carcinoma in left breast of the patient [81]. **c** Shows fibrocystic changes in the left breast [82]

temperature. Some sample breast thermograms are shown in Fig. 6. Thus, it detects and records the heat pattern of the breast surface. It has the potential to detect breast cancer 10 years earlier than the traditional golden method—mammography [9, 29].

Like the other imaging techniques, the digital infrared imaging does not identify the physical tumor. Instead, it detects the heat pattern produced by increased blood circulations and tumor-related metabolic changes. Identifying the minute variations in normal blood circulation activity, the infrared imaging can find the signs indicating a precancerous state of the breast or the presence of a tumor that is small enough to be detected by physical examination [9, 29]. In order to ensure that the thermographic examination is accurate, it is crucial to follow some simple instructions carefully. With its noninvasive, low-cost, non-radiation, noncontact basis, thermography has distinguished itself as the safe earliest detection technology for breast cancer. In the next section, the procedure for breast thermography is described elaborately.

6 Fundamentals of Digital Infrared Imaging (DII)

Any object whose surface temperature is above absolute 0 K (−273 °C) radiates infrared energy at a wavelength analogous to its surface temperature and its spectral emissivity. Thermographic camera is much sensitive to the radiation emitted by the human body [2, 30, 31]. The relationship between the energy radiated by an object and its temperature is defined by the Stefan–Boltzmann Law. According to the Stefan–Boltzmann Law, the radiation emitted by an object is directly proportional to the object's vicinity, emissivity, and the fourth power of its absolute temperature [31, 32]. Blackbody is considered as the hypothetical object that absorbs all incident radiation. Stefan–Boltzmann Law (Eq. (1)) states that the energy radiation from per unit area of a black body in per unit time is directly proportional to the fourth power of the absolute temperature of a black body. Thus, the total emissive power from a black body can be defined as:

$$E = \sigma T^4 \tag{1}$$

Here, E is the total emissive power (W/m^2), σ is the Stefan–Boltzmann Constant ($\sigma = 5.670373 \times 10^{-8}$ W/m^2 K^4), and T is the absolute temperature (K). According to the Stefan–Boltzmann's law, the emissivity (ε) of a blackbody is unity [10].

A body emits less energy than a black body when it does not absorb all the incident radiation. It is characterized by an emissivity, $\varepsilon < 1$ [10].

Thus, for objects which are not full radiator, the modified Stefan- Boltzmann equation can be defined as:

$$E = \varepsilon \sigma T^4 \tag{2}$$

where, ε is the emissivity of real surfaces or surfaces of non-full radiator. The emissivity of the human skin is more or less constant, and its value is 0.98 ± 0.01 for the wavelength range 2–14 µm [33, 34]. However, application of cosmetics, lotions, may change the emissivity of the human skin [32].

In the electromagnetic spectrum, the Infrared rays are found within the wavelengths of 0.75–1000 µm. The human skin emits infrared radiation in the range 2–20 µm. The entire IR range is subdivided into: near IR (NIR) having the spectral range between 0.75 and 1.4 µm; short-wave IR (SWIR) covers the wavelengths from 3 to 8 µm; long-wave IR (LWIR) covers the wavelength from 8 to 12 µm, and far IR (FIR) which covers all the wavelength beyond 12 µm. For medical IR imaging purposes, LWIR is the most vital IR spectral range. The clinical IR imaging depends upon the spectral transmission and reflection characteristics of tissue and blood. Penetration and reflection are maximum in the red end of the visible spectrum, where the radiation penetrates the superficial layers of skin and tissue up to 2.5 mm depth and is then reflected out again [32]. It is found that almost 90 % of the infrared energy radiated by the human body is in the range of longer wavelengths 6–14 µm [30].

7 Digital Infrared Imaging in Detection of Breast Cancer

The Congressionally Directed Medical Research Program has set some ideal characteristics for early breast cancer detection method which includes: Detection of early lesions, high sensitivity and high specificity, inexpensive, noninvasive, decrease mortality. All these requirements are met by the Infrared imaging [27]. Infrared breast thermography helps in early detection and monitoring of physiologic changes associated with breast pathology. Risk factors for the development of breast cancer can also be established from breast thermography. Digital Infrared imaging of the breast has achieved an average sensitivity and specificity of 90 %. Also, a persistent abnormal thermogram is 10 times more significant than the first-order family history of the disease. The IR image is the highest risk marker for screening the possibility of the presence of an undetected breast cancer or future development of breast cancer [30]. The aggressiveness of breast tumor is directly proportional to the thermo-vascular activity in the breast. Hence, infrared (IR) imaging can also be used as a prognostic indicator [30]. The patient's breast thermogram acts as thermal fingerprints of breast and any changes in this thermal fingerprint may indicate the presence of a breast disease like fibrocystic disease, cancerous tumor, vascular disease, Paget or an infection. Once abnormal heat pattern of the breast gets detected, necessary treatment can be taken to rule out the disease. Since, till now there are not any preventive for breast cancer, the only way to fight back with breast cancer is the early detection.

8 Acquisition of Breast Thermograms

Several factors are there that may modify the human body temperatures and create false findings in the thermogram for which thermograms need to be captured under strict protocols. Several components are there to be considered for characterizing thermal images as a potential tool for detecting breast cancer. It is crucial to follow these simple instructions carefully to ensure that the thermographic examination is accurate. All the requirements for preparing a patient for breast thermograms are described in subsequent sections.

8.1 Instructions Prior to Examinations

The thermographic procedure is performed for assisting the evaluation of the anomalous temperature patterns of the breasts that may or may not indicate the presence of a disease. Circulatory problems, previous injuries, can reduce the body surface temperature. Similarly, regular smoking can also decrease the body surface temperature. Again several activities like physical exertion, consumption of alcohol, and sunburn increase the skin surface temperature [2, 35, 36].

In order to get accurate results from thermal images without contamination of artifacts (anything unnatural that does not belong to normal human physiology), preparation of patients before screening is the utmost importance. The body temperature should be as normal as possible [37]. Hence, before capturing the temperature patterns of the patient body, some protocols are defined that must be followed by the patient to ensure valid test results. Application of cream, lotion, powder on chest, hormone replacement therapy (HRT), pregnancy and menstruation can also affect the breast surface temperature [2, 38]. Rigorous exercise, tight fitting cloth, sun-bathing, underarm shaving, utilization of deodorants, physical therapies, pain medication, smoking, intake of tea, coffee, alcohol, radiation treatment must be avoided prior to the examination [2, 31, 38–41]. Ng et al. [42] and

Acharya [43] considers the patients within the period of the 5th to the 12th day and after the 21st days of the commencement of the menstrual cycle.

8.2 Patient Intake Form

On arrival of the patient, the practitioner should provide a patient data form to the patient for filling up, which includes some necessary information regarding the symptoms and history of the patient for better understanding of the patient background. Some of these information may be the age and weight of the patient; family history of breast cancer; information about previous diagnosis of breast cancer; any treatments like biopsies or surgeries to the patient's breasts; previous breast screening; history of taking hormone treatment; experiencing any symptom of breast cancer etc. [44].

8.3 Patient Acclimation: Pre-imaging Equilibrium

After filling up the intake form, the patient needs to sit in a cool private room and should be informed with the testing procedure. The patients are instructed to undress from the waist up and to remove jewelry [30, 44]. After removing appropriate clothes, the patient is asked to sit and to leave the breasts exposed to air for 10-15 min so that the patient body can acclimate to the room temperature (to equilibrate to the atmosphere of the room) [30, 43, 45, 46]. This will create the "Thermal steady state." During this time of patient preparation, the patient must avoid folding or crossing of arms and legs or placing bare feet on a cold surface [2, 39]. Once acclimated, the patient will be asked to place her hands behind the head for taking the infrared images [39].

8.4 Environment of the Imaging Room

Thermograms are sensitive to environmental changes in temperature, humidity, and air flow for which infrared imaging must be captured under controlled environment [31]. It is essential that the "Infrared Imaging Room" itself is of adequate size to sustain a homogeneous temperature. The size of the examination room should be large enough to allow patients of different sizes to be positioned relatively equidistant from each wall. The room approximately of size 8 feet × 10 feet is sufficient to meet these requirements [47]. The nature of human physiology changes from different external environment as they produce thermal artifacts in the human body. The windows and doors should be adequately sealed to prevent direct airflow on the patient. The room must be free from drafts and sunlight [48]. The temperature of the examination room should be maintained such that the patient's physiology is not altered. The temperature range should be maintained at 18–23 °C [47, 49, 50]. The room temperature changes during the course of the examination must be kept within 1 °C in order to maintain a steady-state physiology. The humidity of the examination room must also be maintained at 60 ± 5 %, such that no air moisture is built upon the skin of the patient that can interact with radiant IR energy [47, 50]. During the time of examination, incandescent lighting should not be used due to the amount of radiation it produces.

8.5 Thermal Camera and Acquisition Systems

For a quality breast thermogram, thermal sensitivity and resolution are the two most important parameters of acquisition system [27]. Thermal sensors with good thermal sensitivity can detect a minute temperature difference. A slight temperature difference in breast thermogram may indicate a suspicious region. The resolution parameter is responsible for the number of colors in the computer display. The temperature transition is very smooth if the resolution of the thermal camera is better. Most of the infrared cameras used for breast imaging have a resolution of 320 × 240 pixels, and it is sufficient enough for informal screening of breast. Thermal camera having resolution of 640 × 480 and good sensitivity can provide more useful thermal and spatial details [27]. Zadeh et al. [51] had used the SDS D-series camera with thermal sensitivity 0.1 °C at 30 °C and resolution 160 × 120 pixels for collecting the breast thermograms of 200 patients at Hakim Sabzevari University in Sabzevar and with the cooperation of Sabzevar University of Medical Science. Arena et al. [52] had asked the patient to sit at a distance of approximately 5 feet away from the infrared camera. They had used an infrared camera having thermal sensitivity of 0.05 °C and resolution 320 × 240 pixels for capturing the breast thermogram of 238 normal patients, 67 newly discovered with cancer patients, and 46 patients who previously had a diagnosis of cancer. Acharya et al. [43] had used NEC-Avio Thermo TVS2000 MKIIST camera system for capturing 50 breast thermogram images, where 25 thermograms were of cancer patients and 25 thermograms were from healthy persons. They had collected their data from the Department of Diagnostic Radiology, Singapore General Hospital. Qi et al. [53] obtained the breast thermograms by using Inframetrics 600 M camera with thermal sensitivity of 0.050 K at Elliott Mastology Centre. Ng et al. [54] had collected the breast thermograms of 90 patients from Singapore General Hospital by using Avio TVS-2000 MkII ST infrared camera. Wishart et al. [55], collected the thermograms of 113 patients using a digital infrared breast scan called Sentinel BreastScan. A DITI system named as Sentinel BreastScan (Infrared Sciences Corp.) having thermal sensitivity 0.08 °C and resolution 320 × 240 pixels was used by Arora et al. [56] for capturing the breast thermograms of 92 patients.

8.6 Capturing Views of Breast Thermograms

All the thermography clinics or hospitals do not use a universal protocol for capturing of breast thermograms that makes it very difficult to follow a certain protocol for capturing. The accuracy of thermogram in detection of the breast abnormality entirely depends on the thermogram image resolution, thermal sensitivity and the number of views of breasts. Most of the FDA registered thermal systems are also not equipped with excellent image resolution and thermal resolution. Bharathi et al. [57] had mentioned that only three views of breast thermograms (Contra-lateral, Medio Lateral Oblique, and Axillary) may result in wrong diagnosis. They used 12 views of breast thermograms capturing at an angular interval of 30°. Campbell [58] suggested for taking the thermograms of the underside of the breast so that the cancer tumor in the lower portion of the breast should not get missed (if any). For capturing the breast underlying area, the patient needs to lie down on her back to cool down underside of the breast. During this process of cooling, the patient should keep her arms away from the breasts. Then the first breast thermogram is captured before capturing any other view of the breast. Figure 7a, shows a thermogram, where some abnormality is seen in the underside of the right breast. However, all the other thermograms of this patient were normal [58], which signifies the necessity of capturing the underside of the breast. This view of breast thermogram is known as supine view.

Kolarić et al. [59] had taken five views of breast thermograms for each patient: including frontal, right semi oblique, right oblique, left-semi oblique, and left oblique view. Five breast thermograms are usually acquired including frontal view, two lateral views and two oblique views in some thermography clinics [60, 61]. Figure 8a–c shows the frontal, right lateral, and left lateral views of breast thermogram.

Moreover, some other views including Bilateral Breast, Right Breast Close Up, Left Breast Close Up and areas of concern are also considered for breast thermography examination [58, 62]. Agostini et al. [63] captured only frontal view

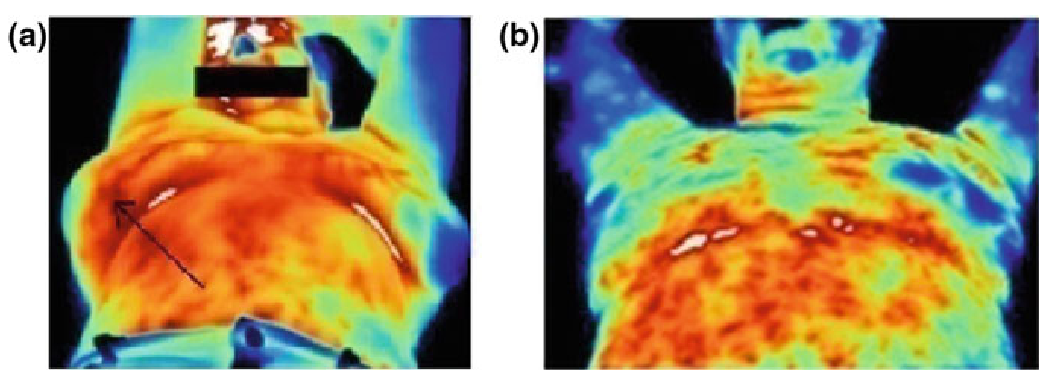

Fig. 7 **a** The arrow shows an abnormality in the underside of the right breast thermogram (supine view) [58]. **b** Normal supine view of breast [58]

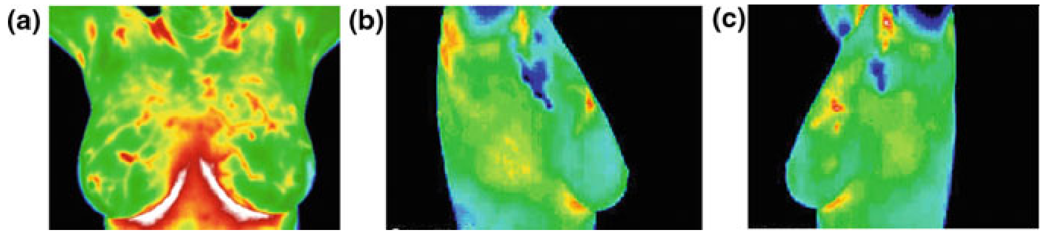

Fig. 8 **a** Anterior view or frontal breast thermogram [37]. **b** Right lateral view breast thermogram [83]. **c** Left lateral view breast thermogram [83]

images of the patient. During capturing, the patient was lying down on an examination table of 40° inclination with their arm up and resting their hands over head [63]. Kennedy et al. [14] asked the patients to stand about 10 feet away in front of the camera with raised arms resting over her head. They acquired three views of breasts including one anterior view and two lateral views of the breast. In breast thermography, capturing of the frontal view of breast thermogram is the utmost importance as it is the only view from which any abnormality or asymmetry between the left breast and right breast can be recognized. Figure 9a, b shows the left and right oblique views of breast thermogram. And Fig. 10 shows close views of left and right breast.

In thermography clinics only frontal breast thermogram is used to create the breast baseline which is the key for getting the benefits of infrared breast thermography in breast cancer detection.

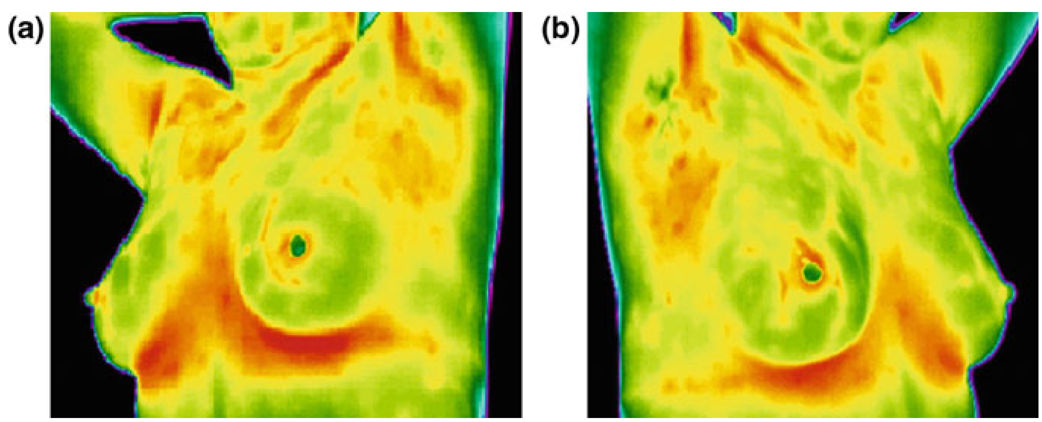

Fig. 9 **a** Left oblique breast thermogram [84]. **b** Right oblique breast thermogram [84]

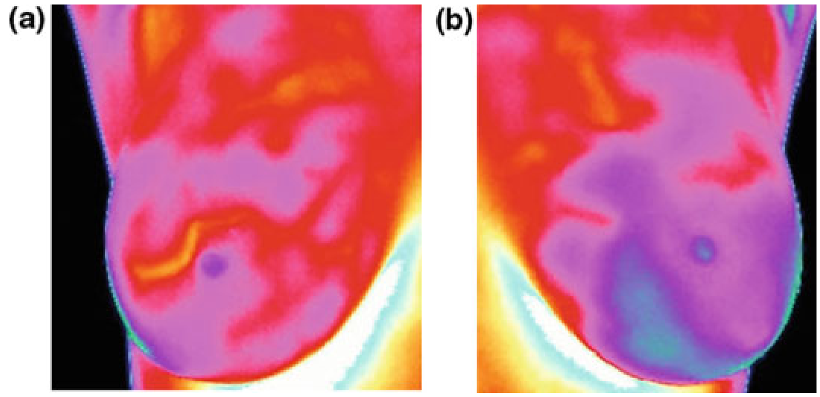

Fig. 10 **a** Close view of right breast; **b** Close view of left breast

9 Analysis of Breast Thermograms Using Hybridized Intelligent System for Abnormality Detection

Breast thermography is a promising technology for early breast cancer detection. Gautherie et al. [64] suggested that an abnormal thermogram is the single most reliable indicator of high risk of breast cancer in its early stage. With the availability of higher sensitive infrared cameras, application of thermography in breast cancer detection has drawn the interest of many researchers toward this domain. In normal breast thermograms, the thermal pattern in both the breasts is almost symmetrical while in case of cancerous breast, temperature asymmetry is observed. Based on this key idea several research work is going on to analyze the breast thermograms. A review on the research works related to the detection of breast cancer by extracting several statistical features from breast thermograms and application of intelligent systems for classification of breast thermograms into normal and abnormal is described in this section. The classification accuracy of hybrid intelligent system on medical data signifies that the hybrid intelligent system is very efficient in the task of detecting an abnormal thermogram. The intelligent and hybrid intelligent system-based computer aided diagnosis (CAD) system works as a promising tool for assisting and providing a "second opinion" to the radiologists or pathologists to produce an accurate and faster diagnosis results. The analysis of breast thermogram is a process of multiple steps including preprocessing of breast thermograms, background removal or extraction of region of interest, extraction of a set of features from each breast thermogram, asymmetry analysis and finally classification of breast thermograms into normal, abnormal, and benign breast. Figure 11 illustrates the general procedure for detecting breast cancer from breast thermograms.

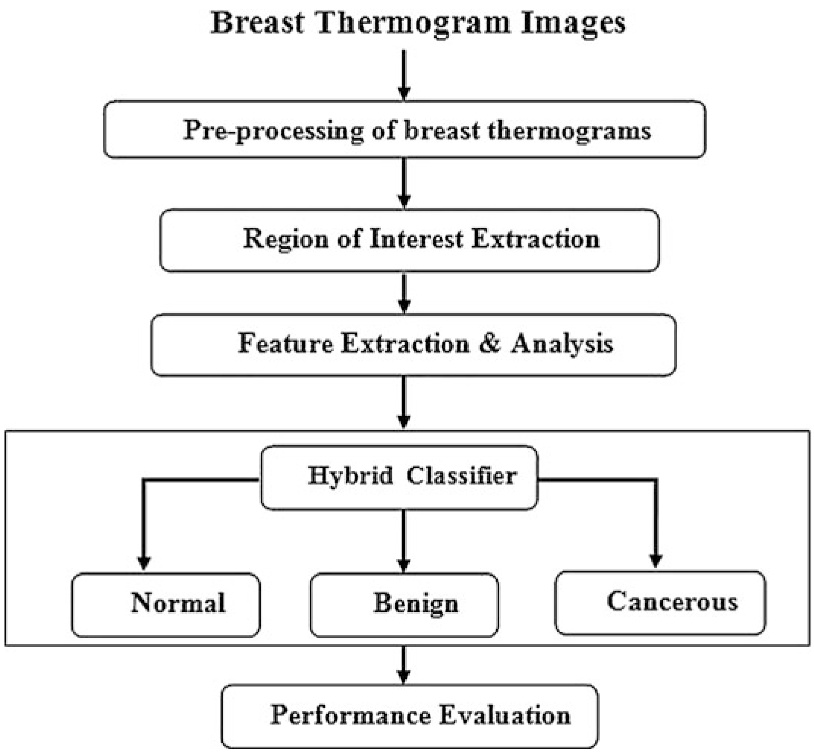

Fig. 11 Overview of the infrared thermography-based breast cancer detection system

9.1 Preprocessing of Breast Thermograms

The most important step in the detection of breast cancer from breast thermogram is the preprocessing of raw data. During capturing, the patients are sitting in a chair or standing, which results in a slight movement of the body. Also, the thermal images commonly exhibit a blurring effect that appears like defocusing. One of the most common techniques for removal of blur in images due to linear motion is the Wiener filter. Moreover, another most common preprocessing operation in breast thermogram is the conversion of the infrared thermal image into a gray scale image. Acharya et al. [43] and Borchartt et al. [11] had converted the breast thermograms into gray scale, after cropping the breast images. Kapoor and Prasad [65], had removed the background of the breast thermograms and resized them to remove the undesired body portion, before processing them.

9.2 Region of Interest Extraction

Along with the necessary information required for breast cancer detection, the breast thermogram also includes some unnecessary details that need to be discarded to improve the accuracy of the cancer detection system.

In the process of breast abnormality detection, identification of the background, and region of interest is a critical need of the system. Schaefer et al. [66] and Borchartt et al. [11] had manually segmented the frontal breast thermograms into left and right breast. In the method proposed by Borchartt, the segmented images are further refined manually to delete all contents not belonging to the breast. In [53, 67], Qi et al. used canny edge detector and Hough transformation to identify four dominant feature curves (left and right body boundaries and two lower boundaries of the breasts) for automatic segmentation of left and right breast.

9.3 Feature Extraction and Asymmetry Analysis

Feature extraction is the process of collecting a set of distinguishable image characteristic, which are most important for feature analysis and classification [42, 67]. It is the most significant part in the analysis of breast thermograms. In feature extraction, a series of statistical features are extracted from the region of interest. Schaefer et al. [66] had extracted total 38 statistical features including basic statistical features, moment features, histogram features, cross co-occurrence features, mutual information, and Fourier descriptors from each breast thermogram which describes the asymmetry between the left and right breasts. Qi et al. [53] had identified the asymmetry between left and right breasts by plotting the thermal histogram of the breast regions (left and right). Another method is there, presented by Qi et al. [67], where the asymmetry between left and right breast thermogram was measured by doing some feature extraction. Some high order statistics like mean, variance, skewness, kurtosis, correlation, entropy, and joint entropy were calculated as the components of the feature vector to quantify the distribution of different intensities in each breast. They suggested that the high order statistics (variance, skewness, and kurtosis) were most useful features to detect asymmetry while low-order statistics mean and entropy could not signify any asymmetry. In [43], Acharya et al. had extracted the statistical features like entropy, contrast and correlation from the gray level co-occurrence matrix (GLCM) to detect the presence of a cancerous tumor. Other features like gray level nonuniformity and run percentage were also calculated from the run-length matrix. After acquisition of breast thermograms, Acharya et al. [50] had converted the 2D thermograms into 1D data by using radon transform. From the transformed data, five higher order spectral features were extracted. The extracted features were—mean magnitude of the spectrum, entropy1, entropy2, entropy3, and phase entropy. For analyzing the asymmetry of the breasts, Zadeh et al. [51] had extracted diagnostic parameters including patient's age, mean, variance, kurtosis, skewness, entropy, difference between the two breasts and thermal pattern of the breasts from breast thermograms. Bharathi et al. [57] had extracted a series of statistical features and Haralick texture features from the breast thermograms. These extracted features before and after the cold stress were analyzed to identify any abnormality. For finding out the abnormal thermograms, Kapoor and Prasad [65] had extracted skewness, kurtosis, entropy, joint entropy, energy, homogeneity and correlation from breast thermograms and analyzed them.

9.4 Classification of Breast Thermograms Using Intelligent Systems

The asymmetry analysis of breast thermograms is followed by the classification of breast thermograms into normal and cancerous breasts. Fuzzy-rule based classifier coupled with significant statistical features plays a vital role in improving the survival rate of breast cancer patients. The life expectancy prediction made by hybrid intelligent system is highly significant in decision making for treatments, medication and therapies. Different classifiers are used in various research works. Schaefer et al. [66] had employed a hybrid fuzzy rule-based classification system for diagnosis where some genetic algorithms were applied to optimize the features and parameters of fuzzy rules. With this classifier, they achieved a correct classification rate of about 80 %. Krawczyk et al. [68] had employed a hybrid multiple classifier system for analyzing breast thermograms. Their multiple classifier system was the hybridization of 3 different intelligence techniques: Neural Network (NN) or Support Vector Machine (SVD) as base classifiers, a neural fuser to unite the individual classifier, and a fuzzy measure. Using of this hybridized classifier for evaluating 150 breast thermograms provided excellent classification accuracy. Qi et al. [53] used unsupervised learning, and each pixel is relabeled to a certain cluster. Finally, pixel distribution of each cluster was analyzed, and abnormalities were determined. In another method proposed by Qi et al. [67], the asymmetry identification was done using two methods: k-means clustering (unsupervised learning) and k-nearest neighborhood (supervised learning) based on feature extraction. They had used 6 normal and 18 cancer patient breast thermograms for evaluating the performance of their method. Acharya et al. [43] employed the Support Vector Machine (SVM) to have automatic classification of breast thermograms as normal and malignant breasts. For automatic classification of breast thermograms, Borchartt et al. [11] had used free LibSVM classifier. The extracted features were fed into the LibSVM software. The LibSVM classified the breast thermograms into two classes: pathology and healthy. In the method proposed by Zadeh et al. [51], a 3 layer Feed-Forward Neural Network with a sigmoidal activation function (logsig) in the middle layer had been used. Acharya et al. [50] had used a feed–forward artificial neural network and SVM for classification of breast thermograms. The extracted features were fed into the input of the feed-forward neural network for classifying the breast thermograms. An Artificial Neural Network had been used in the method proposed by Ng et al. [54] for the analysis of breast thermograms. Kapoor and Prasad [65] had used a multilayer perceptron neural network for classification of breast thermograms. The features extracted from 50 breast thermograms were fed into the neural network to train the system, and remaining 10 breast thermograms were used for testing and validation of the classification system.

Different acquisition systems, used in various research works along with their specifications are listed in Table 1. Summary of different research works in breast cancer detection from breast thermograms is given in Table 2.

Table 1 Summary of acquisition system and number of patients considered in different research works

Authors	Acquisition system	Camera specifications	Number of patients/breast thermograms
Schaefer et al. [66]	Not specified	Not specified	146 Thermograms (29 malignant, 117 benign)
Ng et al. [54]	Avio TVS-2000 MkII ST	Not specified	90 Patients
Qi et al. [53]	Inframetrics 600 M camera	Thermal sensitivity 0.05 K	Not specified
Qi et al. [67]	Inframetrics 600 M camera	Thermal sensitivity 0.05 K	6 Normal, 18 cancerous
Acharya et al. [43]	NEC-avio thermo TVS2000 MKIIST	Not specified	25 Normal, 25 cancerous
Borchartt et al. [11]	Not specified	Resolution 320 × 240	24 Cancerous, 4 normal
Acharya et al. [50]	Thermo TVS2000 MkIIST Avio short wavelength system	Not specified	25 Normal, 25 cancerous
Zadeh et al. [51]	SDS D-series;	Thermal sensitivity 0.1 °C at 30 °C, resolution 160 × 120	200 Patients
Bharathi et al. [57]	MAMRIT (mammary rotational infrared thermographic system)	Not specified	8 Normal, 8 abnormal
Arena et al. [52]	Not specified	Thermal sensitivity 0.05°, resolution 320 × 240	238 Normal, 67 newly discovered and 46 who previously diagnosed with cancer
Wishart et al. [55]	Sentinel breast scan	Not specified	113 Patients
Arora et al. [56]	Sentinel breast scan (infrared sciences corp.)	Thermal sensitivity 0.08 °C, resolution 320 × 240	92 Patients
Kapoor et al. [65]	Infrared thermal imager by irisys	Resolution 320 × 240	60 Patients

Table 2 Summary of statistical features and classifiers used by different researchers

Authors	Feature extracted	Classifier	Accuracy
Schaefer et al. [66]	38 features (basic statistical features, moments, histogram features, cross co-occurrence matrix features, mutual information and Fourier descriptors)	Hybrid fuzzy rule-based classification	Accuracy: 80 %
Qi et al. [53]	No feature extraction	K-means clustering	Not provided
Qi et al. [67]	Mean, variance, skewness, kurtosis, correlation, entropy and joint entropy	K-nearest neighborhood	Not provided
Acharya et al. [43]	First 4 moments, entropy, contrast and correlation, gray level non-uniformity and run percentage	Support vector machine	Accuracy: 88.10 %
			Sensitivity: 90.48 %
			Specificity: 85.71 %
Borchartt et al. [11]	Range of temperature, mean temperature, standard deviation, and quantization of higher tone in eight level posterization	Free LibSVM	Accuracy: 85.71 %
			Sensitivity: 95.83 %
			Specificity: 25.00 %
Acharya et al. [50]	Mean-magnitude of the spectrum, entropy1, entropy2, entropy3, and phase entropy	ANN	Accuracy: 90 %
		SVM	Accuracy: 80 %
Zadeh et al. [51]	Patient's age, mean, variance, kurtosis, skewness, entropy, difference between the two breasts and thermal pattern of the breasts	3 Layer feed-forward neural network	Accuracy: 70 %
			Sensitivity: 50 %
			Specificity: 75 %
Bharathi et al. [57]	Mean, variance, skewness, kurtosis, angular second moment (ASM), contrast, correlation, sum of square, inverse difference moment, sum entropy, sum average, sum variance, entropy, difference variance, information measure of correlation1 and information measure of correlation2, difference entropy	Support vector machine	Not provided
Kapoor et al. [65]	Skewness, kurtosis, entropy, joint-entropy, energy, homogeneity, and correlation	Artificial neural network	Accuracy: 80 %

10 Conclusion

Despite the advances in treatments, the breast cancer remains the second leading cause of the cancer-induced death after lung cancer. There is no diagnostic tool that is capable of significantly reducing the breast cancer mortality. Only possible way of saving lives is the early detection of breast cancer. Most of the breast imaging modalities, although promising but too expensive for routine use. Compare to the other imaging modalities, breast thermography has several advantages that benefits women of all ages. A solid tumor which is small enough to be detected by any of the available diagnostic tool can be detected by infrared thermography due to its higher temperature compared with the surrounding tissue. This facilitates the early detection of the tumor before it invades to the surrounding region. Thermography is a noninvasive, radiation-free, painless, inexpensive imaging modality that can be used as a complementary method to other screening methodologies. Breast mammography alone has a sensitivity of 84 % while used along with thermography its sensitivity has increased to 95 %. Thus, thermography is very adequate for both asymptomatic and symptomatic patients for routine checkups. It also helps the physicians to decide the proper treatment for the symptomatic patients.

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