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# Trends in Breast Cancer Screening Using Thermography: A Review

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***Abstract*— Breast Cancer is one of the deadly cancer types in our life. The early detection and diagnosis of breast cancer increase the chance of successful medical intervention. There is a number of breast cancer screening methods, with each having its own pros and cons. Thermography breast cancer screening is characterized by its painless, non-ionizing, non-invasiveness and non-contact application, which make it a potential target for research and development. Thermography has recently gained an increased interest due to emerged image processing and classification technology. Thus, this paper presents a review of the recent trends or advances in thermography for breast cancer detection.**

***Index Terms*—Breast Cancer screening, Infrared, Review, Thermal imaging, Thermography**

## I. INTRODUCTION

Cancer is the most leading cause of death in a global sense. In a recent report published by the World Health Organization (WHO), cancer accounts for the death of 8.8 million individuals in 2015 alone; and according to the same report, the number of deaths due to breast cancer is exceeding half a million cases [1]. Following the skin cancer, breast cancer is the most frequently reported cancer in women [2], which makes it a potential scientific research target. Breast cancer was reported among the highest causes of death from cancer in Europe in 2012 [3]. In addition, various other statistics and studies are very pessimistic the incidence of breast cancer. According to a recent statistics published by the American Cancer Society in 2017, out of 316,120 recorded breast cancer cases in the US alone, 40,610 individuals were expected to die in 2017 [4]. This figure indicates an approximate 12.85% of the all the recorded cases, which is a very concerning number.

Breast cancer may occur in both males and females; however, its incidence in males is considered very rare. This is due to the nature of cancer occurrence; the frequent appearance is found in the lobules, where the milk is being created, and ducts, where the milk is being carried to the nipple; these are irrelevant to the male's body [5]. Apart from that, breast cancer may occur in lymphatic, connective and fatty tissues on rare occasions. In the initial stages of breast cancer, it is very hard to recognize its existence, as it does not produce any tangible symptoms [6]. In such cases, the created tumor is insignificant, and its treatment is both convenient and efficient. Therefore, breast cancer screening, prior having any symptoms, increases the chance of healing.

In common breast cancer cases, the tumor appears as a lump or swell that causes no pain. However, if it is not screened and treated at its early stage, it would develop and become noticeable. Sensible symptoms seldom happen at early stages of breast cancer. In such rare occasions, some abnormalities can be witnessed in the breast including erosion, burdensomeness, and pain, redness, and swelling, unusual discharges from the nipple, or retraction [4], [7]. These signs and symptoms necessitate a proper check by a physician. In usual circumstances, most of the detected lumps in the breasts do not develop to a cancerous nature; rather they keep their benign nature. Nevertheless, in order to be sure about the nature of the lump or any suspected cancer's availability, a thorough microscopic tissue analysis for the breast must be conducted. With this kind of analysis, it is possible not only acknowledging the availability of cancer, but also its stage [8].

Breast screening examination methods provide a way for early diagnosis of breast cancer prior the tumor develops any noticeable symptoms. There is a number of tools specifically developed for conducting the breast screening examination. In this regard, the most common devised methods are Computerized Tomography (CT), Magnetic Resonance Imaging (MRI), mammography, thermography, and ultrasound. These methods vary in both techniques and expected outcomes. However, it is often found that a combination of more than one method provides more validated results, and considered by some physicians as fundamental [5]. Although mammography is widely accepted by many physicians and specialists, there is an ongoing research for providing more reliable methods. One of the methods that have been gaining a rapid interest in recent years is the thermography [9]. This is due to the potential advantages and low risk of infrared images. In this paper, a review of recent trends in breast cancer screening using thermography is provided. Beyond the introduction, the paper is organized as follows: section II presents a general background on thermography and the needed setup for conducted it, section III provides a thorough investigation of the recent studies in the field, and finally, section IV renders the concluded remarks and possible directions for future research.

## II. BACKGROUND

### A. Thermography concept

Objects naturally emit thermal signals at certain temperatures. The type of emitted or radiated signals and the range of temperature level depend on the object's characteristics [10]. In this regard, the human body, under normal circumstances, radiates Infrared (IR) signals [11]. The radiated IR signals here differ from one part to another based on its heat. This concept is generally applied for medical screenings, especially for the breast cancer. Any cancerous development in the breast is associated with the formation of inflammation and blood vessels, present with higher temperature profile [12]. Thus, the heat map of the breasts and their surrounding environment, captured by a thermographic camera, highlight any unusual developments of breast cancer based on the tissue heat.

Thermography or thermal imaging is used in medicine as a non-invasive method for capturing the heat map of a certain limb. The method is non-contact and nondestructive, and it does not produce any radiation, which makes safer for frequent use. However, thermography for breast cancer is criticized by having a high both false-positive and false-negative rates. False-positive implies requiring the standard mammography while the breasts are fine. On the other hand, false-negative may deviate the proper medical procedure to take place for unhealthy individuals. Apart from these two main issues, technically, thermography is not covered by insurance in most cases [12].

### B. Breast Cancer Thermography

The procedure followed for breast cancer screening using thermography is very straightforward. It starts with a visual inspection of the breasts surface. This allows the physician to correlate any unusual presence to the heat map. Then, the individual is required to remain at room temperature ($18^oC$ to $25^oC$) for 15 minutes for acclimation purpose. At the same time, the individual will have to disrobe the top part of the body, from waist to chin. This procedure is done in a room where both humidity and temperature are controlled. After the body temperature reaches to equilibrium, the individual will be asked to stand in front of the imaging system with hands up right, to image the surfaces of interest; these are upper chest, underarms, and breasts [13]. During the imaging period, the temperature should be maintained $1^oC$. In addition, any source of heat should be eliminated from the room to minimize the external thermal interference. Further, the air-conditioning air flow should be directed away from the individual to avoid any misleading results.

The imaging system is composed of an ultra-sensitive IR camera applicable for medical purposes and a computing unit. The captures images are digitalized and stored on the computing unit for diagnosis. The diagnosis here is made by thermologists with the aid of a computer, where the captured images are mainly categorized based on temperature and vascular analyses [14].

The standard protocol for categorizing is placing the image into one of five Thermological (TH) groups. These groups are:

TH 1: presents a normal uniform non-vascular subject.

TH 2: presents a normal uniform vascular subject.

TH 3: present an equivocal subject.

TH 4: presents an abnormal subject.

TH 5: presents a severely abnormal subject.

Screening result determines the step to be taken next. The Thermologist decides whether mammography or any further test is needed.

### C. Thermography Limitations

Thermography reflects the heat map beneath the skin, which does not exactly locate the tumor for surgical purposes. In addition, a possible confusion may happen when low metabolic tissues with a tumor are imaged. In this case, it will be very challenging to determine the existence of the tumor.

The abovementioned limitations, as well as both false-negative and false-positive rates, made the U.S. Food and Drug Administration (FDA) in 2011 declare that thermography is not a complete substitute of mammography for breast cancer screening [15]. Nevertheless, the recent improvements in thermography for breast cancer screening have made it a potential pre-screening safe method.

## III. RELEVANT WORKS

Although thermography goes back in time for more than five decades, yet the comparative review of this work is restricted to the most recent investigations made in this field. Thus, the prominent research attempts present within the last decade are put forward in this review.

In 2008, Ng and Kee proposed an improved technique for breast cancer thermography. In their study, they integrated Artificial Neural Networks (NN) and biostatistical methods for achieving a high accuracy rate. They specifically used Radial Basis Function Network (RBNF), linear regression, and Receiver Operating Characteristics (ROC) for the analysis purpose. Here, linear regression was used for creating the needful correlation between variables confirmed health status of the subjects, where the correct diagnosis in their study is based on mammography. The determined variables were then fed as inputs to the RBFN, which is trained to determine the final status of the screening. Their choice of RBFN over other ANN was made based on the superiority of the method in terms of speed, classification ability, and decision-making process. For the ultimate evaluation purpose, they considered accuracy, sensitivity, and specificity. For obtaining these measures, ROC was applied to the classified results of RBFN. The evaluation here was based on 90 breast thermography patients' images taken at Singapore General Hospital. Based on these images, the obtained accuracy rate of their study is 80.95%, while the sensitivity and the specificity are 100% and 70.6% respectively [16]. Up to the date of Ng and Kee's study, the obtained results were positive compared to previous relevant studies. However, it is crucial in biomedical image processing studies to test the method on a large-scale dataset in order to ensure its accuracy and applicability. Therefore, considering only 90 patients a testing dataset makes the outcomes questionable.

Tang et al. [17] investigated the possibility of improving breast cancer thermography screening using morphological measurement for Localized Temperature Increases (LTI). They mainly suggested an improved detection of breast cancer is possible if a morphological signal processing technique is used for measuring the LTI caused by the tumor. They applied dataset of 117 patients who are categorized as 47 malignant and 70 benign. Based on their study, they could screen 44 out of 47 cases. The obtained sensitivity is 93.6%. However, the use of a small dataset for breast cancer detection is always criticized. Further, the negative predictive value is 91.2%, which is considered very high. In addition, the recorded false-positive rate is 55.7%, which also indicates a very high false alarm that cannot be tolerated.

One of the important factors in thermography is the edge detection, where the proper identification of breasts reduce the unnecessary areas, thus increases the accuracy and lessens the overhead. Kapoor and Prasad had realized this aspect and suggested edge detection and Hough transform for asymmetric analysis of breast cancer thermography [18]. The authors proposed that applying both image segmentation and asymmetric analysis for breast thermographic images could improve the efficiency of the detection results. In their work, they used edge detection for extracting breasts' boundaries. They further applied Hough transform for extracting the lower boundaries of the breasts. Based on the minimized image areas, which are the areas of interest, the authors classified the segments into pixels. These pixels were then used for breast cancer diagnosis using asymmetric analysis. Even though this study had addressed a very critical issue in breast cancer detection using thermography, it was extremely brief and had no proper actual application. In such scenarios, a suitable judgment for the improvement cannot be done. Yet, the study can be used as a pilot implementation for other studies.

As mentioned in the background section, the interpretation of thermographic breast is generally conducted by thermologists. Here, the interpretation itself can be very tedious, confusing and time-consuming. Thinking about an alternative had sparked the notion of an interpreter, which does this task automatically. The main exact concept was presented in the work of Umadevi et al., where the author developed a possible thermal breast images interpreter for mass screening [19]. The authors had benefited from the work presented in [18] and similar studies, where the interpretation of the thermal images are based on segments' pixels. Using this methodology, the authors developed a thermographic breast screening interpreter called Infrared Thermography Based Image Construction (ITBIC). In this study, a total of 50 females were classified by ITBIC. Their procedure was based on taking the thermal image from in front, right side, and left side. Thus, three sets of images were used for each individual. The study used a sort of boundary detection technique for extracting the Region of Interest (ROI), which was later used for getting needed pixels for classification. The classification process in this work was based on extracting the highest temperature area (color-related analysis). For evaluation purpose, the authors compared the results of their ITBIC assessment with the MRI assessment for the whole dataset. They could obtain 66.7% of sensitivity rate and 97.7% of specificity rate. In addition, the positive and negative predictive values were 80% and 95.6% respectively.

The same authors further developed their own idea for a complete framework for estimating tumor parameters from thermal images [20]. Apart from that, some studies had focused more on the assessment factors of breast cancer screening using thermography. Such a scenario is found in the work of Kontos et al. [21]. The ultimate aim of this study was focused on finding both sensitivity and specificity of Digital Infrared Thermal Imaging (DITI). For this purpose, the authors had deployed a dataset taken from 63 asymptomatic patients. Interestingly, the authors selected patients to compose 58 females and 5 males, which gives their study more confident. Based on their analysis, they could obtain a sensitivity rate of 25% and specificity rate of 85%. Accordingly, they concluded that for the evaluation of asymptomatic patients DITI does not provide an adequate sensitivity to be used as a primary screening method.

Modeling methods for improving the thermal imaging for breast cancer screening have been addressed in the literature. One of the recent examples is the work of Amri et al. [22]. The authors had attempted to create a 3-D model for the breast and base their thermographic cancer detection on it. In their work, they used the Transmission Line Matrix (TLM) to create a 3-D model for the breast with an embedded tumor. This can be then used for analyzing the sensitivity parameters. Such studies are extremely useful, especially for future enhancements of the thermographic system.

One of the reviving reasons of thermographic breast cancer screening is the advances in image processing technologies. Boquete et al. had exactly considered this critical concept while developing their automated breast cancer detection method. The authors here had considered a relatively different technological concept for the analysis of thermographic images, namely the Independent Component Analysis (ICA). The authored used eight cases, six for cancer validation and two for control purpose; the dataset was extracted from an online resource [23]. The study considered the analysis minimum defects, 4 x 4 pixels. It was possible for ICA to detect the cancer existence as independent components of YcrCb. The obtained sensitivity is very promising where a rate of 100% was obtained. Moreover, the obtained specificity is considered very high compared to other studies, where a rate of 94.7% was achieved [24]. The idea of using ICA was further developed later on by Etehadtavakol et al. [25], where the authors used discrete wavelet transform and ICA for classifying breast thermograms.

Similarly, Rajendra Acharya et al. applied texture features and Support Vector Machine (SVM) for breast cancer thermographic automatic screening. Using 50 cases (25 cancerous and 25 normal) the authors could achieve an accuracy of 88.10%, while the sensitivity and specificity were 85.71% and 90.48% respectively [26].

Nicandro et al. preferred to try Naïve Bayesian classifiers for the analysis for thermographic breast cancer screening. In their study, they proposed the use of Naïve Bayesian classifier, Hill-Climber, and Repeated Hill-Climber. They deployed a dataset of 98 cases (77 are cancerous and 21 are healthy). Out of all their experiments, the best accuracy they could achieve is 76.12% obtained by Repeated Hill-Climber. Nevertheless, this accuracy is not adequate for reliable medical applications. Yet, the study itself is a very good reference for comparative investigations [27].

The use of wavelet for the screening of breast cancer using thermography is reported in [28]. In this study, the authors used wavelet-based multifractal analysis for thermographic images analysis. The recruited individuals composed of 33 females that underwent a surgical intervention for removing a breast tumor and 14 females with intact breasts. The authors had also developed an open source tool based on their investigation [29]. This tool can be used as a ready software application for thermographic images analysis.

Gogi et al. conducted a thorough investigation of the use of hybrid intelligent techniques for breast cancer detection using thermograms [30]. The study presents a very rich resource for researchers interested in this particular.

Lashkari et al. had employed the concept of intelligent classification for the screening of breast cancer using thermography. The authors divided their approach into four main steps, namely pre-processing and segmentation, feature extraction, feature selection, and classification. As suggested by a number of previous studies, initially the authors extracted the ROI form the images. Then, right and left breasts were separated using edge detection and thresholding. Further, they considered 23 features based on the segmented images, and they deployed a number of feature selection algorithms for ensuring the best performance. In the classification stage, the authors had used AdaBoost, k-Nearest Neighbors (k-NN), Naïve Bayes (NB), Probability Neural Network (PNN) and SVM for comparative investigation. They applied their method to images captured from 67 patients. According to their findings, the best outcomes are determined by the combination of Genetic Algorithm (GA) and AdaBoost, where 87.42% with images taken with $0^o$ [31].

Zadeh et al. proposed a thorough clustering-based development for automatic breast cancer screening using thermography. In their study, they used artificial intelligence, where the self-organizing neural network is applied for clustering purpose. Next, a multilayer perceptron neural network is used for the final screening. The authors considered double 200 cases and single 50 cases. Bases on the used samples, they could achieve a sensitivity rate of 88% (for the double 200) and 100% (for single 50), while the accuracy was 98.5% for both cases [32]. Similarly, Santana et al. had used the concept of Extreme Learning Machine (EML) for breast cancer diagnosis using thermography. In their study, the authors deployed classifiers built by ANNs, Bayesian, decision trees and Haralick and Zernike attributes. The used sample is categorized into benign, cyst and malignant. According to their findings, ELM and Multilayer Perceptron (MLP) networks had shown the best performance for classification purpose. When the authors set 75% of the dataset (1052 images) for training, they could obtain an accuracy of 73.38%. In addition, the sensitivity and specificity rates were 78% and 88% respectively, while the efficiency of the system was recorded as 83% [33]. The main advantage of this study is a considerable number of used images in the dataset. This increases the credibility of the work and justifies the obtained accuracy drop compared to previously presented methods. In addition, the work presents a thorough comparison between a number of algorithms, which makes it particularly useful for survey studies.

## IV. CONCLUSIONS AND RECOMMENDATIONS

This paper has presented a general review of the concept of breast cancer screening using thermography. The technique itself has a number of advantages make it a potential target for further development. Among these advantages is a convenient and painless procedure, non-invasiveness and non-contact. Even though the method had a lack of interest a few decades ago, the advances in technology and image processing tools have spiked the interest in this method again. This is evident by the number of recent publications relevant to this topic. The brief review of these relevant methods has covered only recent trends restrict to the past decade. Moreover, the review considered the relatively prominent publications in the field. According to the reviewed articles, modern classification and image processing techniques have greatly improved the outcomes of the thermal imaging for breast cancer screening. It is possible with current technology to obtain an accuracy above 90% for big databases with relatively acceptable rates of both specificity and sensitivity. Accordingly, it would be possible with further improvements to enable the thermography to become a standard pre-screening that can be trusted by medical institutes. Further, it is important to highlight that based on the surveyed techniques; it is obvious that the potential methods may lay within ANNs, especially in combination with other methods. Researchers have come to an understanding that techniques, such as ELM and MLP provide a substantial accuracy level, which stimulates the need for further research in this direction.

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