

Periodic Dynamic Thermography for Breast Cancer Assessment

Majid Shokoufi¹, Parvind K Grewal², Calum MacAulay³ and Farid Golnaraghi^{1*}

¹Mechatronic Systems Engineering, School of Engineering Science, Simon Fraser University, 250-13450 102 Avenue, Canada

²BC Cancer Agency Abbotsford Cancer Centre, Sumas Wing, Level 3, 32900 Marshall Rd, Abbotsford, Canada

³British Columbia Cancer Research Centre, 675 West 10th Avenue, Vancouver, BC, V5Z 1L3, Canada

*Corresponding author: Farid Golnaraghi, Mechatronic Systems Engineering, School of Engineering Science, Simon Fraser University, 250-13450 102 Avenue, Surrey, BC V3T0A3, Canada, Tel: 778-782-8577; E-mail: mfgolnar@sfu.ca

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Abstract

In this paper we propose Periodic Dynamic Thermography (PDT), in conjunction with Image processing and Analysis, to be an easy to use procedure involving capturing thermal images of the breast. The authors present a proof of concept study for subjects to image their own breasts periodically, starting from early ages of adolescence, where mammography is not recommended. Utilizing the proposed procedure, it is envisaged that each subject will establish historical thermal images of their own breasts where they can later be analyzed, by a physician, to assess the causes of thermal changes identified on the surface of the breast. Towards this end we have utilized phantoms, solved the heat transfer equations for the phantom shape boundary conditions with COMSOL, and confirmed the resulting thermal distribution with the observed temperature distribution for the phantoms. Based on this model's promising results we propose the development of a system to capture thermographic images of the subject from their early years in life, periodically (monthly or bi-weekly), with image analysis application software to be used as an assessment tool to alert the subject of any abnormal thermal changes.

Keywords: Thermography; Far infrared; Image Analysis; Image segmentation; Breast cancer

Introduction

Breast cancer is the uncontrolled growth of breast cells and is the second leading cause of cancer related death in women [1-3]. Therefore, breast cancer screening, diagnosis, prognosis and monitoring are a critical issue to women's health. Clinical breast exam (CBE), mammography and ultrasound are common breast screening tools. The US Preventive Services (USPSTF) recommends screening mammography every 1 to 2 years for women aged 40 or older. Similarly, in Canada, Canadian Breast Cancer Foundation (CBCF) recommends mammography for women aged 50 and older, every two years with consideration for annual mammography given in circumstances of increased risk [4]. Though, X-ray mammography is a primary screening method around the world, but it uses ionizing radiation which can cause cancer development. Also it is not advised for women with dense breast due to a high false negative detection ratio [5]. Therefore, routine mammographic screening is not suggested for women under age 40, and screening mammography is recommended for women ages 40 to 49 at the discretion of the woman and her physician [4]. So, in this paper, the authors introduce PDT in conjunction with imaging technique in order to help physician in the early detection of breast cancer. Breast thermography is a non-invasive and non-contact imaging techniques used in the medical imaging area and it can be used as an adjunct imaging tool in the early detection of breast cancer (screening), diagnosis and monitoring [4]. Since, pre-cancerous and cancerous masses are highly metabolic tissue, they need an abundant supply of nutrients to maintain their growth and this can increase the surface temperature of the breast 1 to 3°Celsius [4,6]. U.S. Food and Drug Administration (FDA) has approved thermography as an additional diagnostic tool for breast cancer screening and diagnosis

when used in combination with mammography and it is not a stand-alone method for breast cancer screening and diagnosis due to the non-standardization of thermographic imaging procedure and the high false negative and false positive rate [7-9]. Though, thermography has high sensitivity and negative predictive value [7] of 90% and does not require ionizing radiation, compression, contact or intravenous injection, but it is not accepted as a stand-alone screening technology for breast cancer [10-12].

During past two decades, great progress has occurred in electronic devices and software programming. In parallel with these developments, infrared image sensors, in association with optoelectronic devices, have been evolving very rapidly such that currently thermal image sensors are available at a reasonable cost with high performance. New image processing techniques and algorithms have been employed to further increase the accuracy, sensitivity and specificity of thermography. Usually these techniques have been applied to a single thermography image attempting to identify higher temperature areas in a set of images captured over duration of two to ten minutes [8].

Whereas routine mammographic screening for women under age 40 is not recommended [4], the authors' objective in this paper is to introduce and demonstrate the concept of PDT that can be performed periodically (monthly or bi-weekly) to aid in the early detection of abnormal thermal changes associated with cancer development in younger women whom the current imaging technique is not recommended for. PDT is the procedure of capturing thermal images of an area of interest, periodically, over a long duration that may extend from years to the subjects' lifetime. The intent is that such a procedure would be a self-applied test that would be an adjunct for breast self-exams for women in younger age or with dense breasts where mammography is not suggested and as such the goal would be to improve the poor performance of the present approaches applied to

the general at risk population. The authors in this paper have analyzed PDT through a prototype proof of concept set up, concluding that PDT could be a useful adjunct screening procedure for early breast cancer detection.

Thermography Technology and Sensors

Infrared radiation is electromagnetic radiation emitted by all objects with a temperature greater than absolute zero. Infrared radiation can be used to remotely determine the temperature of objects. Infrared radiation extends from the red edge of the visible spectrum at .74 μm to .1mm. According to the Wien's displacement law [13]:

$$\lambda_{\max} T = b \quad (1)$$

Where λmax is the wavelength of the peak of the emission from a black body, T is the temperature and b is the Wien's displacement constant given by $2.8977685(51) \times 10^{-3}$ m·K. For a normal human body temperature of 37°C, the corresponding wavelength using Wien's displacement law is around 9.3 μm. Therefore, Long-Wavelength InfraRed (LWIR) range is the "thermal imaging region" in which sensors obtain a passive picture of the surface without the requirement of any external light or thermal source[13].

There are three different contactless thermography sensors: Pyroelectric (PE), Microbolometer (MB) and Thermopile. For high spatial resolution the best available technology is the Microbolometer and is available with resolutions between 30×30 pixels to 1200×800 pixel sensors. Table 1 depicts spatial resolution of an area of 25×25 cm² for different thermal image sensors.

Sensor Model	Heimann PE array	ULIS Uncooled Mb	ULIS Uncooled Mb	ULIS Uncooled Mb
Sensor (Pixels)	64×62	80×80	160×120	240×240
Spatial resolution	3.9×4(mm ²)	3.12×3.12(mm ²)	1.56×2.08(mm ²)	1.04×1.04(mm ²)

Table 1: Spatial resolution of thermal image sensors for 25×25cm².

Area of interest, as per the application, is ~25 cm×25 cm (normal breast area). In order to have acceptable spatial resolution (1.04×1.04mm²) for the thermographic images, a thermographic camera (FLIR i7) with 240×240 pixels has been used in this experiment.

Thermal Image Processing

Most of the present breast cancer thermography systems use just a single thermographic image, and analyze it to find thermal profile variation on the surface of the breast [11,14]. Further, software algorithms have been applied for post processing of the captured thermograms and estimating temperature variability and conclude probability of the presence or absence of lesion.

In the proposed method, we propose that a person starts to capture thermogram images from 30 years of age, bi-weekly (or monthly) results in 24 (12) images in a year. The developed post processing software algorithm will process each image individually and then as a sequential set comparing each image with all the prior images, to monitor the relative temperature changes in the breast thermograms over specific time ranges. Then, various image processing algorithms have been applied for post processing and decision making; such as

segmentation, edge detection, contrast stretching and Multi classifier image processing. The thermographic images and the extracted data (statistical data and image processing analyses results from images) are used by the application software and interpreted by investigation specialist, to conclude whether there are any abnormal temperature changes over specific time spans and area. In the image processing algorithm the absolute temperature of different region of interest is not important but the software does consider any changes in relative temperature [9,15,16].

Experimental Set up (Feasibility study)

In order to assess feasibility of the approach, the authors first tested it on a phantom with FLIR i7 camera. A cylindrical shaped phantom 10cm in diameter and 3cm in height with a 100Ω resistor inserted at a depth of 2 cm in the center was used (Figure 1A). The aim of having a resistor inside the phantom is to have a controllable heat source inside the phantom to simulate growth of an abnormal lesion or a benign thermal source [17].

The phantom used in this study is a water based phantom that mimics tissue static thermal properties at room temperature [17]. The specific heat capacity c of phantom at room temperature is 3.07 Jg⁻¹K⁻¹, the density, ρ, is 1.10 g/cm³; these values are quite close to that of breast tissue at 37-43°C. As the phantom is water based, it absorbs 75% of the IR radiation similar to breast tissue and isogram pattern on the breast skin are caused by convection from the internal heat source [13].

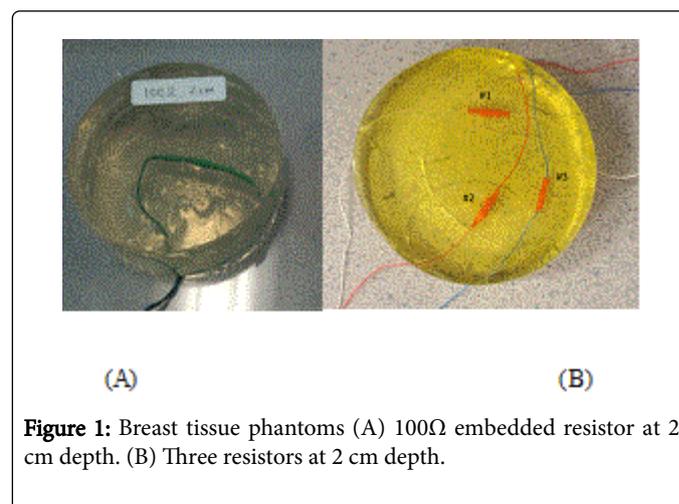


Figure 1: Breast tissue phantoms (A) 100Ω embedded resistor at 2 cm depth. (B) Three resistors at 2 cm depth.

In order to mimic other heat sources in the tissue, like benign tissue and vessels, a phantom with three resistances at a depth of 2 cm was also developed (Figure 1B). Abnormal lesions have higher biological activity compared to normal tissue therefore temperature of abnormal tissue is higher than normal tissue. Cancerous tissue has a 1-3°C temperature difference between normal tissues on the skin surface immediately above the cancerous tissue. If we apply 5Volts to the resistor, the temperature difference on the phantoms surface will be 2°C (also verified through simulation in COMSOL). We measured this difference with two methods, one using a thermography camera and the other using a single element IR temperature sensor from Melexis.

Experimental Procedure

The experimental procedure consists of leaving the phantom for 4 hours in the lab to allow it to settle into the ambient temperature (the

phantom is kept frozen during storage); this is followed by applying different levels of voltage to the resistors, starting with zero volts while increasing it by 0.25 volts every 15 minutes. In the first experiment the set up consisted of a power supply source attached to the phantom to control the input voltage to the resistor to mimic a growing tumor. Increasing the voltage of the resistor increases the temperature of the resistor similar to the increase in temperature of a growing tumor due to increased metabolic activity and vasculature [18].

In the first experiment, to mimic a growing tumor (first phantom), a voltage step of 0.25volts is used with 12 steps going from 0.25 Volts to approximately three volts. A time gap of 15 minutes is given between each voltage step and measurement time, to allow the temperature to stabilize, and reach to a steady state before taking the measurement.

In the second experiment, we have conducted the test on the second phantom in a manner identical to the first experimental procedure. In this case, two constant voltages (mimicking normal vascular activity in the tissue) and a varying voltage (mimicking abnormal lesion development in the tissue) were applied to the resistors, as shown in Table 2.

	Resistance #1	Resistance #2	Resistance #3
Test #1	2.93V	0V	varying
Test #2	2.9V	varying	2.14V
Test #3	2.14V	2.9V	varying

Table 2: Numbers of tests have been done on phantom#2 with different applied voltages.

The resistors which a constant voltage has been applied are acting as the normal biological activity inside the tissue like vascular patterns.

Results

The images from the first experiment (phantom #1 – images 1 to 12), show the development of a growing tumor captured using a LWIR camera (Figure 2A). For each image, temperatures at three points were taken over the phantom: the ambient room temperature, overall surface temperature of the phantom and the surface temperature of the phantom immediately above the resistor position. Figure 2A depicts the color scale level for the thermographic images during the experiment. The maximum temperature difference across the phantom was 1°C when 2.8 volt applied to the resistor. It is almost half of the temperature difference on the surface of the tissue where there is an abnormal tissue underneath.

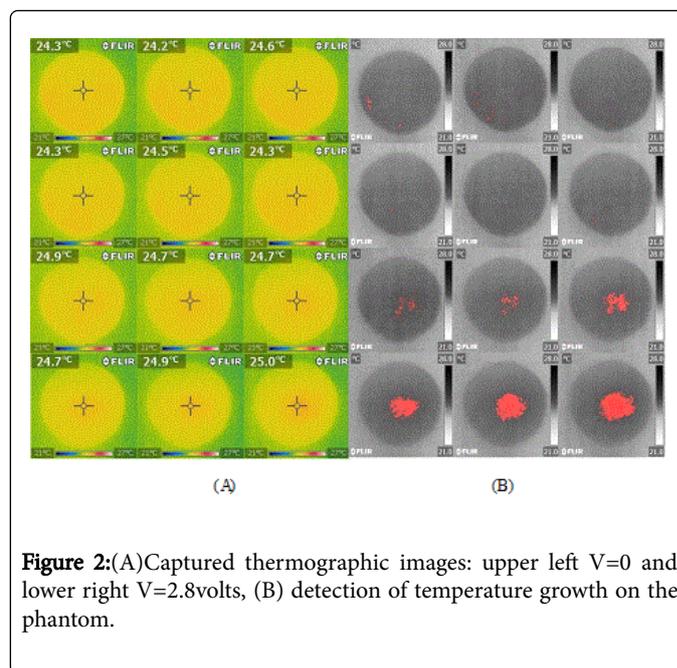


Figure 2:(A)Captured thermographic images: upper left V=0 and lower right V=2.8volts, (B) detection of temperature growth on the phantom.

For better visualization and understanding of the concept, FLIR Research ID image processing software has been used to increase the sharpness and contrast of the images by applying a contrast stretching algorithm. Figure 3A is a processed image that shows the temperature distribution across the phantom. Contrast stretching and Robert's operator have further been applied using Matlab® [19], to mark any temperature changes among the thermographic images. Further, an edge detection algorithm is applied to register the position of all the phantoms' thermographic images [20]. This helps to monitor the temperature distribution across the altered area. Figure 3B shows one of the thermographic images after applying an edge detection algorithm. All processed thermographic images were scaled between 21°C (white color) and 28°C (black color). These minimum and maximum temperatures were determined as a function of ambient temperature. In this experiment, thermographic images have been taken almost under identical conditions so there were no distance changes. Thus, we did not face magnification issues; but these effects should be considered in future work.

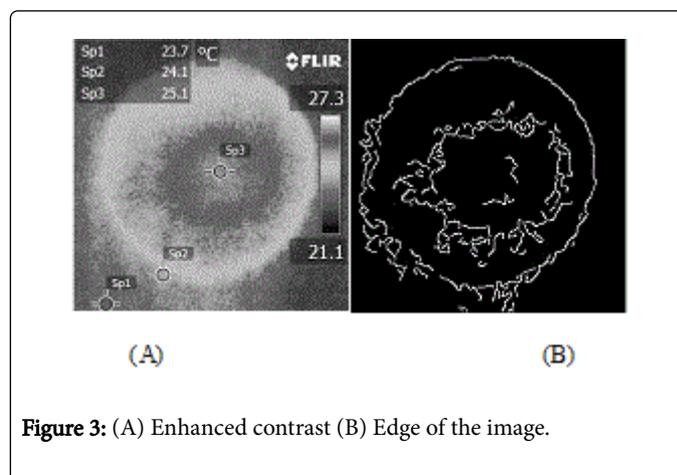


Figure 3: (A) Enhanced contrast (B) Edge of the image.

One of the main parameters, which had to be defined very cautiously, was the temperature threshold. It needs to be defined for each individual image. Four parameters have been used to define the threshold temperature: mean and standard deviation of ambient temperature and suspect area. Figure 2B depicts the result of the above mentioned algorithm applied to each image. The processed thermographic images shows that with this approach a suspected temperature rise on the surface can be found during a large span of time by comparing the present image with its history images. Also these images help us to calculate the speed of the mimicked abnormal lesion growth generated by the heat source underneath of the suspect area.

To assist in arriving at a conclusion, the suspected area (red part in Figure 2B) is an area which temperature increase over the time. The mean and standard deviation of the suspect area are calculated and depicted in Figure 4A. The bar graph and standard deviation shows that there is a detectable temperature growth on the surface of the phantom but this temperature growth could also be noise. In order to avoid false temperature increase detection and for improved detection, the interquartile range (IQR) of the detected area has been calculated. Figure 4B illustrates IQR for all images where, X-axis and Y-axis are thermographic image number and normalized temperature on the phantom, respectively. Horizontal lines within the center of boxes are the median and the whiskers show the range for all the data in each thermographic image. This figure shows that if there is any temperature increase, the size of the box (central 50 percentile) will increase. In this experiment, reflection was a problem. If there was any other object near to the phantom with a higher temperature, the radiation from these objects could be reflected from surface of the phantom and the thermographic camera can capture it as higher temperature on the phantom (first, second and third pictures in Figures 2 and 4). In the first three pictures in Figures 2, there are temperature rises on the surface of the phantom, as demonstrated in Figures 5A and 5B. However, this temperature growth is due to the reflected heat radiation of a person who was standing near the phantom while the thermographic images have been captured. Figure 4b shows, when there is reflected heat radiation, the range of the interquartile box is very small; but if there is heat conduction, because of a heat source in the tissue, the interquartile box size will be larger.

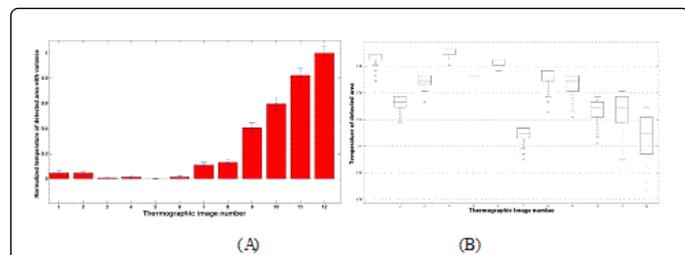


Figure 4: A) Mean and standard deviation of detected area, B) Box plot of thermographic images shown in Figure 4.

The experiments were repeated with phantom # 2 with two constant voltages and one varying voltage as shown in Table 2. Two different voltages of 2.9 v and 2.1 v were applied to resistors #1 (R#1) and #3 (R#3) inside the phantom, increasing the temperature of surface by about 1°C and 0.7°C, respectively. Like the first experiment, 0.25 v voltage step was applied to resistor #2 with 12 steps going from 0.25 v to approximately three volts. Again, a time gap of 15 minutes was

applied between each voltage step and measurement point, to allow the stabilization of the temperature before the measurement. Figures 5A and 5B depict two processed thermographic images for test #2, for which 0.5 v and 2.7 v were applied to the resistor #2.

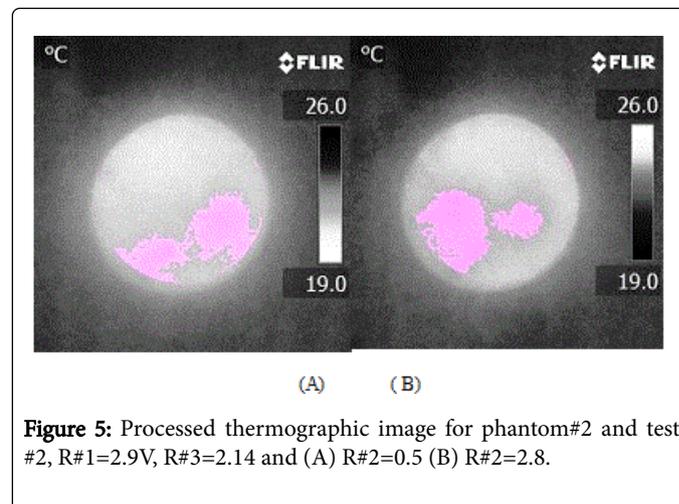


Figure 5: Processed thermographic image for phantom#2 and test #2, R#1=2.9V, R#3=2.14 and (A) R#2=0.5 (B) R#2=2.8.

As Figure 5A shows that the heat in the lower right side of the phantom is generated by 2.7 v power supply (maximum temperature in this area was 1°C higher than its surroundings) and the heat in the lower left side of the phantom is generated by 2.14 v power supply (maximum temperature in this area is 0.7°C higher than the surrounding area). These heat sources mimic normal biological activity. Near to the heat source #3 (left upper side) where, there is an increasing heat source over time that mimics abnormal tissue. Figure 5B depicts the thermographic images in step 11 (2.8 v has been applied to resistor #3 at this stage). As it has been shown in Figure 5, just with using single shot thermographic image, without having the temperature distribution history, cannot distinguish between the normal and abnormal biological activity inside the tissue. So, our proposed procedure may increase the sensitivity, specificity and accuracy of the thermography.

Discussion

We proposed a LWIR dynamic thermography system that is reliable and cost effective for routine breast health screening and monitoring where other imaging modality are not recommended. For breast screening the thermograms could be captured biweekly or monthly, and for monitoring, during therapy, thermograms can be captured daily or weekly. Young women could start using this device at a relatively young age (30 years), after few years each subject will have a substantial individual historical database of the temperature distribution of their breasts. Further, imaging analysis application software will process these data. These images and data may help a physician or specialist identify any abnormal temperature fluctuations in the breasts and calculate the probability of abnormal tissue occurring in vivo. This could help improve accuracy, high false negative and false positive rate of thermography arising from complexities of vascular patterns. For the overall success of the implementation of this technology, more work needs to be done considering non homogeneous phantoms, depicting the thermal profiles of a human breast which the authors are looking forward to work on in future. The standardization of the technique as well as a

behavioral study of how well this methodology would be accepted is also envisioned.

This procedure and algorithm may also have application in monitoring (any kind of therapy such as chemotherapy and radiotherapy). During therapy, the physician needs to know the effect of the therapy on the cancerous tissue and how well the therapy is working on specific cancer cells. Accordingly, the physician can adjust the amount of chemotherapy dose depending upon the present size and activity of cancerous tissue. Also in post cancer treatment follow-up, patients need to have regular medical checkups, including a review of patients' medical history. In this instance the proposed method could play a role as an adjunct technique in detecting any growing heat source in the previously treated area.

Conclusion

Based on the findings in other studies [4,6,18,21], there is a 1°C - 3°C temperature variation between the skin surface above abnormal tissue and the surrounded healthy tissue. In this study sequential image processing techniques were used to monitor temperature fluctuations in phantoms to verify the above concept. As a diagnostic tool, we propose to utilize thermography, acquired periodically, in young women on a bi-weekly or monthly basis to detect temperature increases early.

The experimental results from this study have shown that Periodic Dynamic Thermography in conjunction with image analysis has the potential possibly to be used as an adjunct breast tumor screening technique as well as monitoring modality.

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