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Framework for estimating tumour parameters using thermal imaging

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***Background & objectives*: Non-invasive and non-ionizing medical imaging techniques are safe as these can be repeatedly used on as individual and are applicable across all age groups. Breast thermography is a non-invasive and non-ionizing medical imaging that can be potentially used in breast cancer detection and diagnosis. In this study, we used breast thermography to estimate the tumour contour from the breast skin surface temperature.**

***Methods*: We proposed a framework called infrared thermography based image construction (ITBIC) to estimate tumour parameters such as size and depth from cancerous breast skin surface temperature data. Markov Chain Monte Carlo method was used to enhance the accuracy of estimation in order to reflect clearly realistic situation.**

***Results*: We validated our method experimentally using Watermelon and Agar models. For the Watermelon experiment error in estimation of size and depth parameters was 1.5 and 3.8 per cent respectively. For the Agar model it was 0 and 8 per cent respectively. Further, thermal breast screening was done on female volunteers and compared it with the magnetic resonance imaging. The results were positive and encouraging.**

***Interpretation & conclusions*: ITBIC is computationally fast thermal imaging system and is perhaps affordable. Such a system will be useful for doctors or radiologists for breast cancer diagnosis.**

Key words Non-invasive - non-ionizing - thermography - tumour parameters

Breast thermography started during 1956[1], but the results of Breast Cancer Detection and Demonstration Project (BCDDP) done between 1973 and 1981 by American Cancer Society and National Cancer Institute of United States were not promising due to lack of trained professionals and also primitive thermal imaging techniques[2]. Recent advances in sensor technology and awareness of using non-invasive and non-ionizing medical imaging techniques has made breast thermography a choice for breast cancer diagnosis.

Inference of tumour parameters from surface temperature distribution of cancerous skin is an inverse heat transfer problem which is "ill-posed"[3]. Methods have been proposed to find parameters of embedded tumours using surface temperature distribution[4-6]. Thermal texture method[4] finds depth of tumour, but its principle is hard to comprehend[7]. Other methods[5,6] are based on artificial neural network and genetic algorithm. These methods are time consuming and error prone in the presence of the noisy data[8].

More than 1.2 million people are diagnosed with breast cancer each year worldwide and over 500,000 die from this disease[9]. Predictions of breast cancer development for the next 10 years[9] based on cases diagnosed during 2000-2002 world wide has been done[10].

On January 29, 1982 United States Food and Drug Administration (FDA) has approved breast thermography for breast cancer detection and diagnosis[11]. Earlier studies[12-14] on breast thermography showed both positive and negative aspects of the technology.

Intensities of infra red (IR) radiations emitted by human body vary in accordance to the temperature of the body. The process of capturing, converting, and recording IR radiation emissions from human body is referred as thermal imaging or thermography which is used in medicine for vascular disorder detection, chronic pain detection, assessment of skin burn, dentistry, skin cancer detection, breast cancer detection and many others[15-19]. Biologically, metabolic rate of cancerous cells is comparatively higher than normal cells. Hence, tumours act as heat source increasing surface temperatures around the cancerous area which could be seen as a hot spot in a thermal image.

Here we propose the infrared thermography based image construction (ITBIC) framework to find parameters *i.e.* size and depth, of a tumour. We used Markov Chain Monte Carlo (MCMC) numerical method[20] to enhance the accuracy in parameter estimation. Results were obtained experimentally using synthetic tissue models (watermelon and agar) as well as direct clinical trials using volunteer subjects.

Material & Methods

Two different infrared cameras namely Ti40FT from M/s Fluke Corp., USA and Varioscan 3021 ST from Jenoptik Laser, Germany, were used for breast thermal scanning. Specifications of these two infrared cameras are given in Table I. Fifty women of various age groups were screened for breast thermal scanning at Vijaya scans, Chennai, after informed consent was taken from the patients during May 2007 - March 2010. The study protocol was approved by the ethics committee of the Paterson Cancer Center, Chennai. For each breast thermal images were captured of front, left and right side views. The first 27 sets were screened using Ti40FT and second 23 sets were screened using Varioscan 3021 ST. Procedure followed for screening of first and second sets were different. First 27 sets were screened in a room which was air conditioned and with fluorescent bulb on. To normalize, subjects were made to sit in the examination room for 15 min with upper body part undressed. Then the thermal image of the breast part were captured. Second 23 sets were screened in a room which was not air conditioned and with fluorescent bulb off (*i.e.* images were captured in a dark room). For this set of subjects images were obtained immediately (*i.e.* without normalizing) with upper body part undressed. Subject were found to be more comfortable to thermographic procedure when carried out in a dark room.

Table I. Specifications of infrared camera

	Fluke Ti40FT	Varioscan 3021 ST
Spectral range (μm)	8 to 14	8 to 12
Detector type	Focal plane array, Vanadium oxide uncooled microbolometer	Mercury-Cadmium-Telluride (MCT) single element detector Stirling cooling
Thermal sensitivity (mK)	90	30
Image size (pixels)	160 x 120	360 x 240
Spatial resolution (mrad)	2.60	1.5
Field of view	23° horizontal x 17° vertical	(30x20)° to (5x3.3°, with electro optical zoom
Frame rate (Hz)	30	1, 2, 5
Thermal and visible image fusion support	Yes	No
Camera support software	SmartView	Irbis
Manufacturer	M/s Fluke Corp.	Jenoptik Laser

Direct estimation of tumour parameters from breast thermal image is a tedious task. We proposed a framework named ITBIC to estimate tumour parameters from surface temperature data (Fig. 1).

In the initial ITBIC framework[21,22], case of radiative heat transfer model was considered tissue (breast) as cube and tumour as a 2D model *i.e.,* a disc. Subsequently, breast tissue was considered as a 3D hemisphere model and tumour as a sphere model to improve the accuracy of ITBIC framework. Pennes bio-heat transfer equation[23] was used to model heat transfer process within the tissue. Table II gives the values of the tissue and tumour considered by our estimation system for solving Pennes heat transfer equation. COMSOL[24] software was used for solving Pennes heat transfer equation.

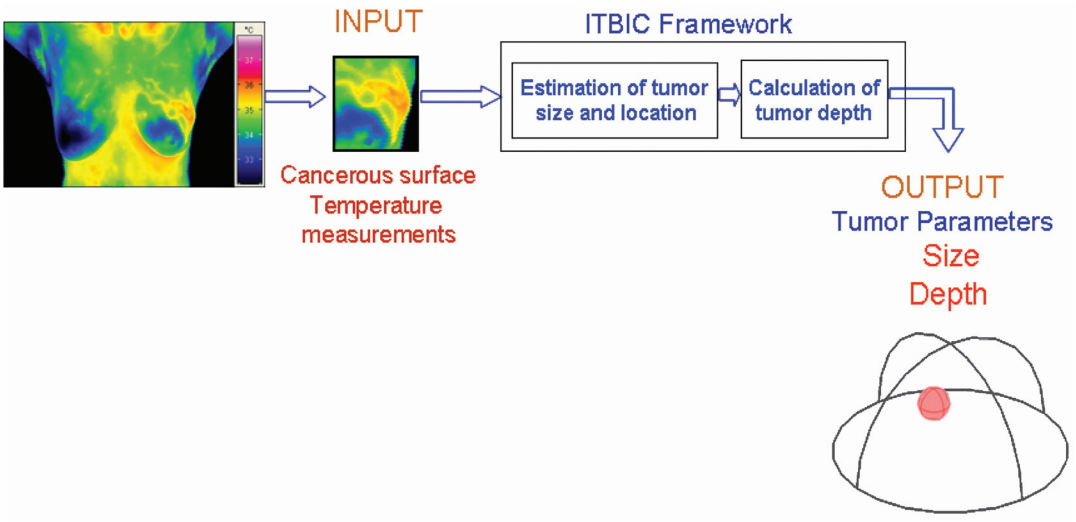

Fig. 1. Framework for tumour parameter estimation.

ITBIC framework works in two stages, first it estimates actual size & location of tumour and second stage calculates depth.

Estimation of size and location: ITBIC frame work is supplied with input of cancerous surface temperature measurements, T_{meas} and then initial assumption for tumor size (r_0) and location (x_0 y_0 z_0) within the hemisphere (breast model). Using COMSOL software, Pennes bio-heat transfer equation is solved to generate surface temperature measurement, T_{gen}, for the initial assumed tumour size (r_0) and location (x_0 y_0 z_0). Then using Metropolis-Hastings algorithm, a MCMC method[20], next estimate of the tumour size (r_i) and location (x_i y_i z_i) is generated depending on the comparison result between T_{meas} and T_{gen}. This procedure is repeated in a loop until a stable estimation for tumor size (r) and location (x y z) is found.

Calculation of depth: Using the estimated values of size (r) and location (x y z) of the tumour inside the breast, depth of the tumour is calculated. Considering the center co-ordinates of the hemisphere as (x_c y_c z_c), estimated location co-ordinates of tumour inside the breast as (x y z) and coordinates on the border surface of the breast as (x_b y_b z_b), value of x_b is equivalent to x and value of y_b is equivalent to y. Depth of the tumor from the top surface of the breast to be calculated is D, which is as follows:

$$R^2 = (x_b - x_c)^2 + (y_b - y_c)^2 + (z_b - z_c)^2$$

$$z_b = \sqrt{R^2 - ((x_b - x_c)^2 + (y_b - y_c)^2)} + z_c$$

$$D = (z_b - z - r)$$

Study with phantom tissue: Framework proposed was validated first with synthetically designed phantom tissue and tumour materials and then clinical studies were carried out to validate. Laboratory experiments were conducted for the study of homogeneous and heterogeneous nature of tissue *i.e*. Agar model experiment to represent homogeneous and Watermelon experiment to represent heterogeneous nature. The experimental apparatus and set up are shown in Fig. 3.

Electric bulb was used with phantom tissues to mimic tumour. Diameter of the electric bulb was 1.28 cm. Phantom tissue with bulb inserted was kept on a thermocol sheet. Electric bulb was connected to power supply unit.

Agar model experiment: Agar powder was boiled in water around 30 min and poured into a plastic jar which contained 4.5 watt electric bulb. The solution was then allowed to cool down to room temperature. At the steady state of room temperature the size of cast model obtained was 10 x 10 x 9 cm (length x width x height), which was shaped like a cube to mimic tissue.

Table II. Pennes bio-heat transfer equation parameters values

Parameter name	Symbol	Tissue	Tumour
Thermal conductivity (W/m)	k	0.42	0.42
Blood perfusion rate (l/s)	ω_b	$18e^{-8}$	$9e^{-6}$
Density (kg/m^3)	ρ_b	920	920
Specific heat of blood (J/kg.K)	c_b	3000	3000
Arterial blood temperature (K)	T_b	310	310
Metabolic heat generation rate (W/m^3)	Q_{met}	450	29000

Table III. ITBIC framework result for Agar model and watermalon experiment

	Tumour size (Radius, cm)		Depth from top (cm)		Depth from side (cm)	
	Actual	Estimated	Actual	Estimated	Actual	Estimated
Agar model: *Agar model*:						
	0.64	0.64	2.00	1.72	5.00	4.89
Watermelon experiment:						
	0.64	0.63	5.00	4.81	5.00	4.81

Table IV. ITBIC framework results for case 1 and 2 breast thermogram

	Tumour size (radius, cm)		Depth from top (cm)	
	Actual	Estimated	Actual	Estimated
Case 1:				
	1.50	1.59	2.50	2.46
Case 2:				
	1.00	1.44	2.00	1.85

Table V. Observed breast temperature variation

Category	Collateral temperature (°C) difference
Normal	< 2
Fibrocystic disease	2 to 3
Malignant + Inflammatory	> 3

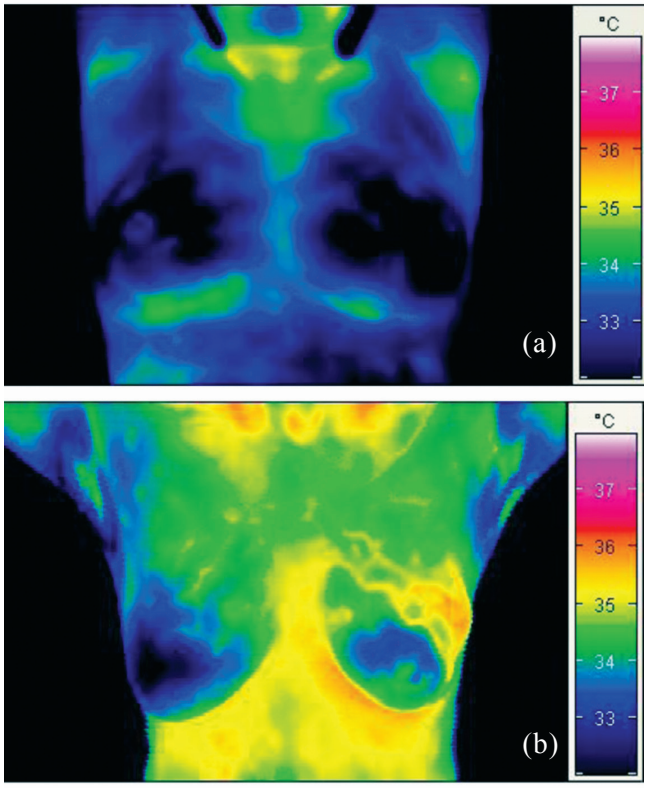

Fig. 2. (a). Normal and **(2b).** abnormal breast thermogram.

Watermelon experiment: Watermelon pulp of size 10 x 10 x 10 cm (length x width x height) was used. Pulp was shaped like a cube to mimic tissue. An electric bulb of 4.5 watts was introduced into the cube to mimic tumour.

Results

Example of an normal and abnormal breast thermal image obtained from women volunteers are shown in Figs 2a and 2b as captured by the Varioscan 3021 ST camera at a temperature range of 32-38°C.

Temperature distribution between left and right parts of the breast was symmetrical for a normal case (45 yr old healthy woman) (Fig. 2a) (as the colour pattern is symmetrical). There will be rise in temperature of the breast skin surface area above the existence of cancerous mass. Thermogram of an abnormal case (female aged 54 yr) (Fig. 2b) showed asymmetrical colour pattern. Her self breast examination showed lump in her left breast part, so she reported to clinic for further examination. MRI scan report of this woman confirmed having cancerous mass in left part of the breast. In the thermal image, left part of the breast showed the increased surface temperature when compared to right part of the breast. Further, biopsy test conducted on this patient also proved lump as malignant neoplasm.

With the experimental set up, the electric bulb was switched on for around 30 min and then thermal images were captured using the camera Fluke Ti40FT for Agar and watermelon experiments (Figs 4, 5).

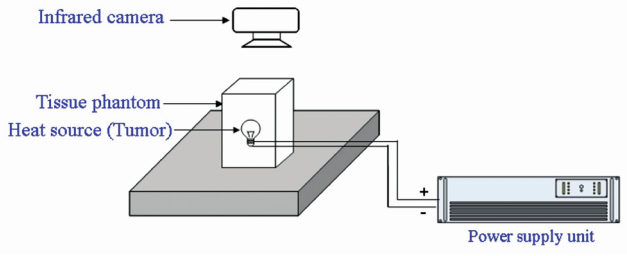

Fig. 3. Laboratory experimental setup with phantom tissue and tumour material.

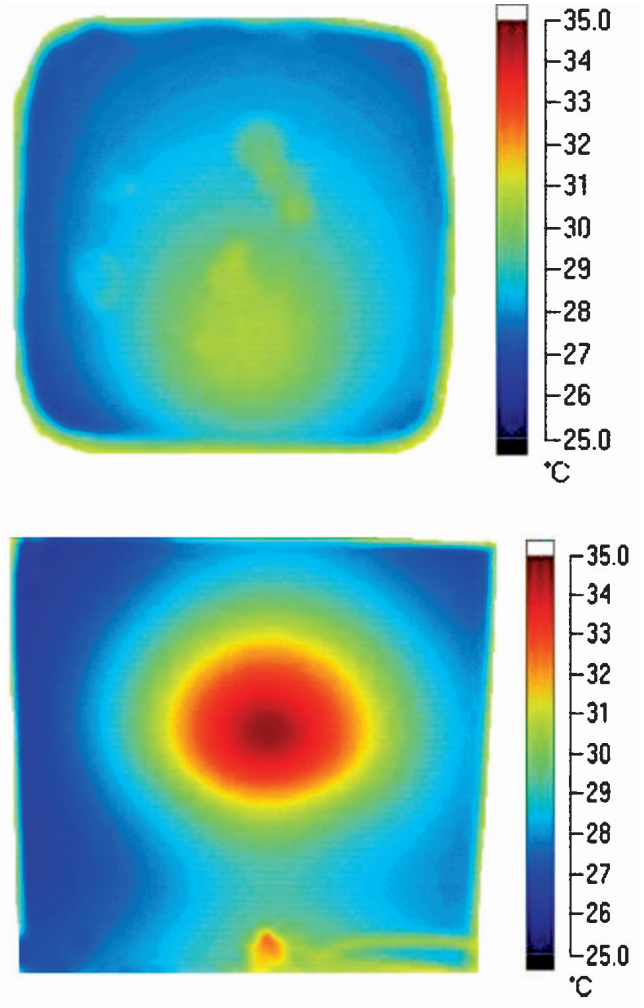

Fig. 4. Infrared images of agar model with surface temperature distribution.

Twenty five surface temperatures, from the top and from a side of agar model were measured. This measurement values were given as an input to ITBIC framework to estimate radius and depth of the tumour. Estimated parameter values against actual values are given in Table III. The estimated values were very close to the actual values.

Among 50 women, two had a focal area of raised temperature in left and right breasts respectively. The same subjects were scanned by MRI and also biopsy was carried out, both tests proved the area to be malignant neoplasm. The temperature difference between normal breast surface and the neoplastic zone was greater than 2°C.

Thermal image and MRI of the first case are shown in Fig. 6a and 6b. She was 54 yr old and had menopause at the age of 44. In the upper part of the left breast (which is marked by a block) tumour was present. Temperature measurements of this skin surface were used as an input to our ITBIC framework to estimate tumour size and depth. Estimated tumour size and depth are given in Table IV. Results of our framework correlated closely with the MRI findings.

Thermal image and MRI of the second case shown in Fig. 7a and 7b. She was around 37 yr old. In the lower part of the right breast (which is marked by a block) the tumour was present. Estimated tumour size and depth are given in Table IV.

Of the 50 female subjects, 44 were normal, two had malignancy, three had fibrocystic disease and one was abscess case. With thermography, temperature difference between left and right parts of the breast in each of these cases were observed (Table V).

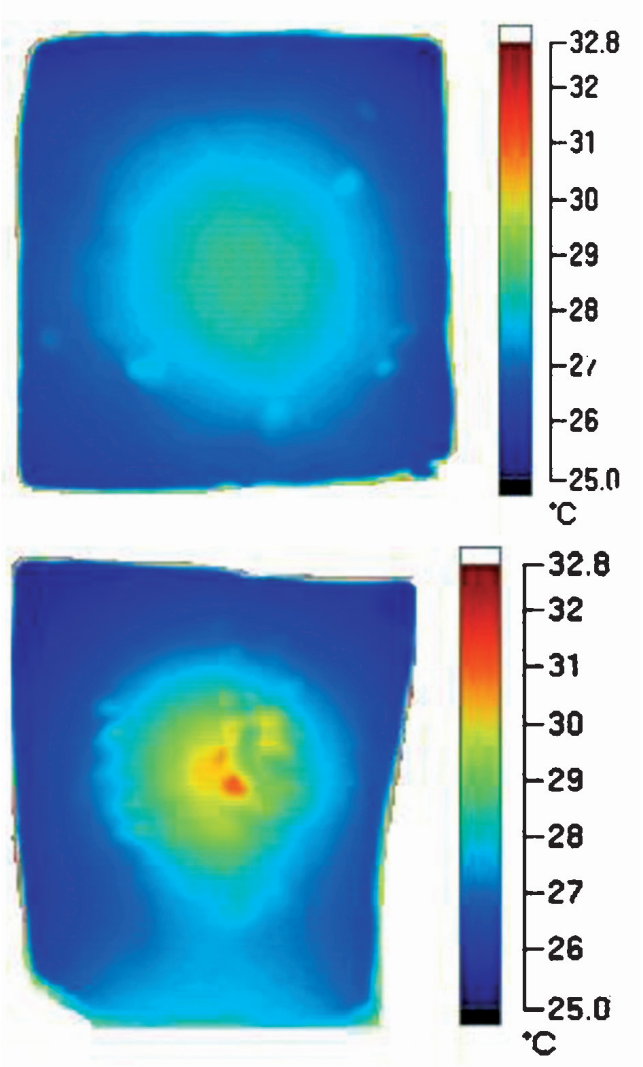

Fig. 5. Watermelon model surface temperature distribution.

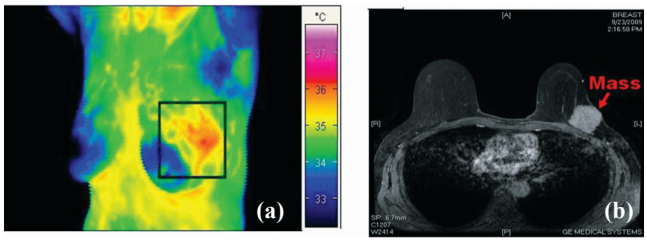

Fig. 6 (a). Breast thermal scan image of *Case 1* showing the abnormality. **(b)** MRI scan image of *Case 1* showing the same abnormality.

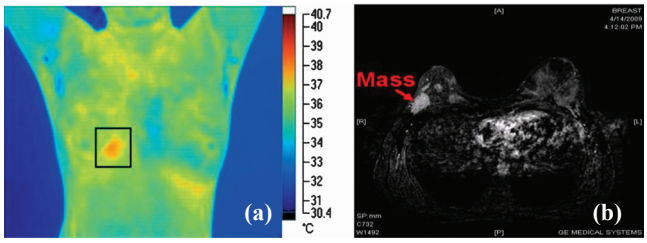

Fig. 7 (a). Breast thermal scan image of *Case 2* showing the abnormality. **(b)** MRI scan image of *Case 2* showing the same abnormality.

Discussion

Presently commonly used medical imaging techniques for breast cancer are mammography, MRI and ultrasound, each having their own advantages and limitations.

Our improved ITBIC framework surpassed all the previous vogue for methods in tumour parameter estimation[5,6,25] in terms of accuracy and simulation time.

The results of ITBIC framework in comparison with conventional method *i.e.* MRI showed a promising relation in estimation of tumour parameters from breast thermograms. Further study of ITBIC framework on large data set need to be done to judge its performance.

In conclusion, a framework was developed to identify parameters of tumour in human female breasts from cancerous skin surface temperature. Information on the size and depth of a tumour may provide critical information to medical professionals for diagnosis. Tumour size and depth parameter values were estimated by ITBIC framework from surface temperature measurements of breast. Estimated values matched with actual values given by MRI scanning method. This shows practicability of using ITBIC framework by medical professionals to diagnose the breast tumour.

Currently, the procedure of breast thermography is not practiced or less in use. Progressively, the use of breast thermography for scanning of subjects may supercede the other scanning methods due to its advantages.

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