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Review Article

Modern Artificial Intelligence Enhanced Breast Thermography: Better Cameras, Better Algorithms have led to Acceptable Clinical Performance

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Abstract: Infrared thermal imaging technology has been used in medicine since the 1960s (1) but fell out of favour with the introduction of more sophisticated imaging technologies. Recently, there has been a global resurgence in the utilisation of thermal imaging in many regions of the body (2) (Figure 1A). This has been possible due to improvements in camera capability along with development of advanced computational techniques to assist in reading of images. This report will review the important innovations that have renewed the utilisation of breast thermography to detect breast abnormalities.

Key words: Thermography, Breast Diseases, Software, Algorithms, Computers.

INTRODUCTION

Infrared thermal imaging (TI) technology has been used in medicine since the 1960s [1] but fell out of favour with the introduction of more sophisticated imaging technologies. Recently, there has been a global resurgence in the utilisation of TI in many regions of the body [2] (Figure 1A). This has been possible due to improvements in camera capability along with development of advanced computational techniques to assist in reading of images. This report will review the important innovations that have renewed the utilisation of breast thermography to detect breast abnormalities [3]. This technique has special relevance in low and middle income countries (Figure 2) such as India where there are just 55 mammography machines at Government district hospitals to cater to 763 districts [4, 5].

Technical Details

Advances in Camera Technology

Early thermal cameras were large with limited discriminating capability and used single-element detectors and required cooling with liquid nitrogen. The next generation cameras had two detectors, used time delay integration algorithms for image enhancement and electronic cooling systems that improved performance. The current generation of cameras use microelectromechanical systems and microbolometers with on-chip image processing [6]. Their thermal sensitivity is about 0.01 to 0.05 °C with spatial resolution less than 2 mm (Figure 1B) and is compact, portable, light weight and is inexpensive in comparison to the previous versions [7]. The US-FDA had approved thermography as an adjunct to mammography in 1982; since then, the thermal sensitivity of cameras has increased considerable and currently a temperature difference of 0.02 C can be discriminated between points less than 2 mm apart (Figure 3).

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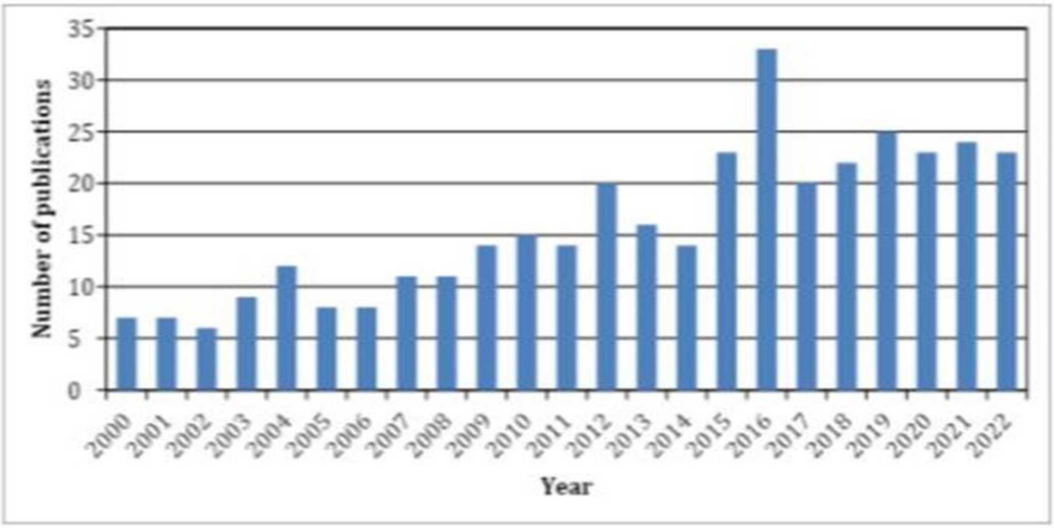


Figure 1A: Increasing number of publications on breast thermography in recent years

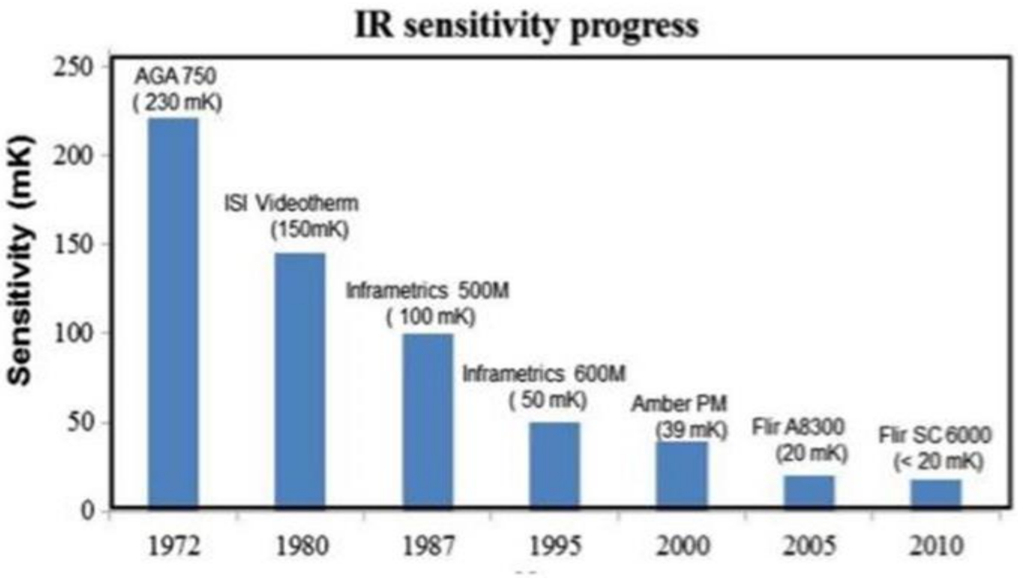


Figure 1B: Shows the improvements in infrared camera sensitivity and performance in recent years

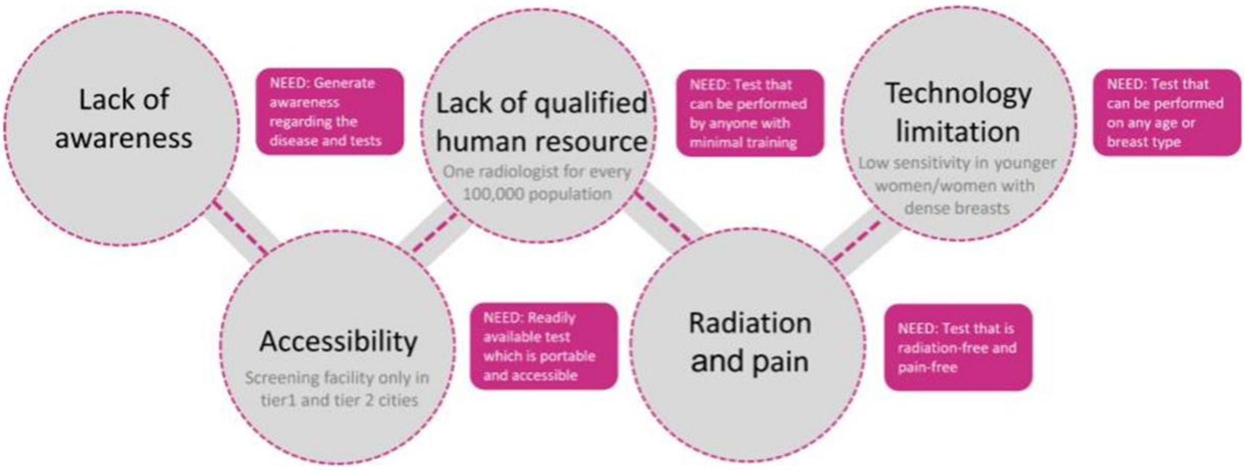


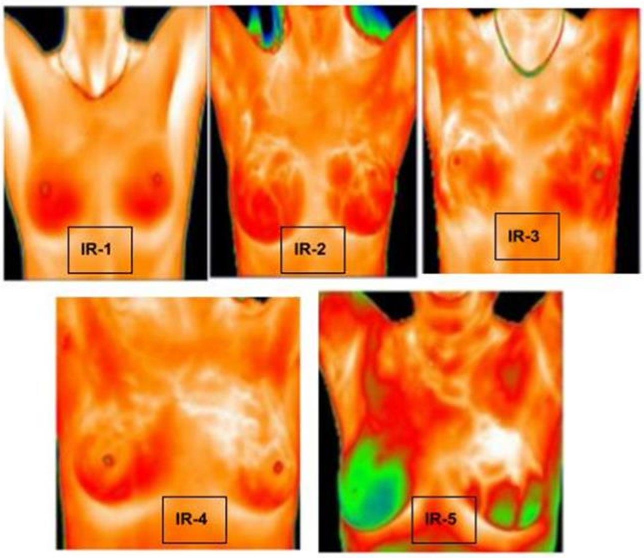
Figure 2: Hurdles in detecting breast cancer in low and middle income countries

Feature	AGA Thermovision 680 (year 1980)	FLIR e76 (year 2020)
Technology	Photovoltaic Indium Antimonide with nitrogen coolant	Uncooled bolometer, focal array detector
Resolution	High definition type, medium persistence phoshor	76.800 pixels per picture (320 X 240).
Spectral Range	8 to 13 mm	8 µm to 14 µm
Thermal Sensitivity	0.2° C	0.02°C

Figure 3: Upper image is AGA 680, lower image is Flir e76, the table compares the technology and performance of these 2 generations of thermal cameras to highlight the excellent thermal sensitivity of modern cameras

Advances in Computational Technology

Previous usage of thermography to detect breast disease was hampered by lower resolution of thermal cameras where images were represented using false color palettes. The evaluation of the breast thermal image was qualitative and not quantitative and led to unacceptably low sensitivity and specificity. Figure 4 demonstrates the difficulty in detecting anomalies by manual interpretation of images.



Visual criteria (Ville-Marie scale) for classification of lesions by manual thermography.	
IR-1	absence of any vascular pattern
IR-2	significant but symmetrical vascular pattern
IR 3	one abnormal sign
IR 4	two abnormal signs
IR 5	three or more abnormal signs

Figure 4: Visual scale used previously to interpret breast thermograms. The difficulty in identifying the lesion using standard colour schemes is well illustrated here

Modern high-resolution thermal cameras can detect minute temperature differences and also rearrange these values into an "image", creating a heat map of the breast's region of interest, where each "pixel" express an equivalent temperature value and when combined with computer algorithms enable quantitative interpretation [8]. There are five steps in the process: preprocessing, segmentation, feature extraction, selection, and classification. Firstly, the software performs quality check to ascertain if the uploaded thermal images are focused correctly [9]. Preprocessing is then done with contrast enhancement of breast area by selecting the maximum and minimum temperature limits for the color palette such that more than 70% of body pixels are above green in the Rainbow color palette (Figure 5A). The region of interest is identified and segmented and suspicious features are extracted.

Thermal radiomics deals with the features that quantify breast thermal patterns and their associations with cancerous metabolism [10]. Hotspot radiomics are features extracted from regions of high thermal activity using a fusion of multiple histogram-based thresholds. From these hotspots, 34 features are extracted to characterize the shape, size, symmetry, and temperature of these thermal activities (Figure 5B). Areolar radiomics involves feature extraction from hotspots overlapping the areola and 16 features such as symmetry, coverage, shape, and boundary of hotspots are extracted. Vascular radiomics [11] are extracted in a different way. Unlike hotspot and areolar segmentation where there are distinct boundaries, thermal signatures of breast vessels are diffuse, representing transmitted heat from vessels beneath the skin surface. This results in spurious results when traditional vessel detection techniques are applied directly. To overcome this, three level gaussian enhancements of vessel structures is performed followed by passage through shape and temperature filters to segment the vessel structures (Figure 5C). From the detected vessel structures, 17 features including number of vessels, branches, caliber, symmetry, relative temperatures are extracted.

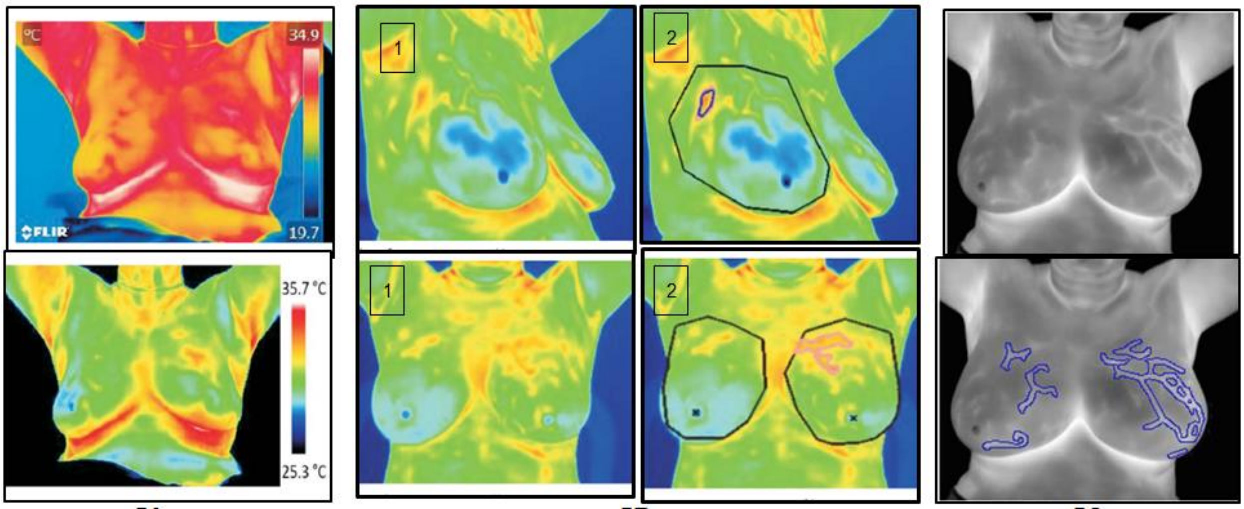


Figure 5A: Upper Image is generated by thermal camera with default upper and lower temperature limits for the colour bar. Lower image is the contrast enhanced image generated by the software with auto-selected upper and lower temperature limits. Figure 5B: Upper: Software enhanced image (1) without annotation (2) with Hotspot marking (blue border). Lower: Software enhanced Image (1) without annotation (2) Image with Warmspot marking (pink border) Figure 5C. Upper: Sample, unmarked thermal image of a woman Lower: Vessel-like structures marked in blue boundary

For classification of these extracted features, an algorithm was trained using an anonymized dataset of 265 subjects provided by Manipal University and Central Diagnostic Research Foundation (10-12). Models using both support vector machines and random forests (RF) were compared and it was found that the RF performed better than SVM [11]. 3 random forest classifiers configured for 200 decision trees over independent sets of vascular, thermal and areolar features are used to obtain three scores, vascular, thermobiological and areolar scores. The three scores are combined to get an ensemble score. Additionally if a lump is present, equal weight is given to both the hotspot and vascular scores and an additional risk score of 0.25 is added. In other cases 4:1 ratio of hotspot score to vascular score is given. If any of these scores is greater than a threshold (such as 0.5), it calls for the clinician’s attention so that subsequent diagnostic tests can be prescribed. The early results of this technology have been encouraging (Table 1).

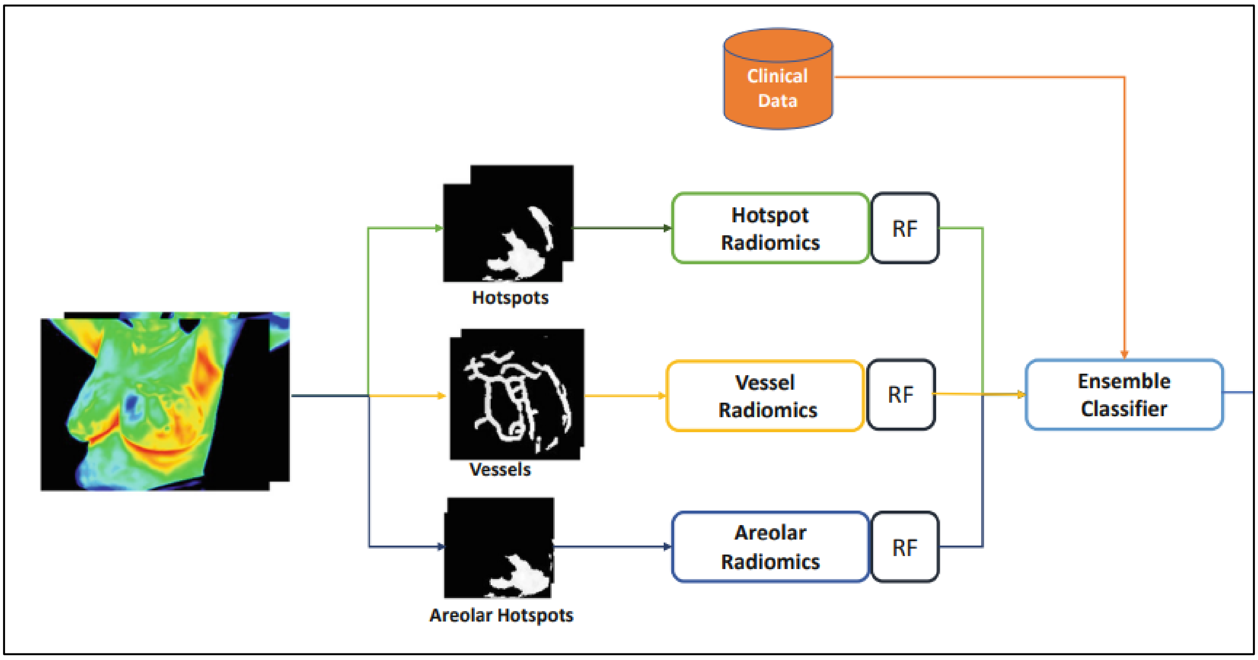


Figure 6: Block diagram showing different analysis modules

Table 1: Summary of results of the clinical studies using the technique

Title	Type of Study	Salient Findings	Journal
Observational Study to Evaluate the Clinical Efficacy of Thermalytix for Detecting Breast Cancer in Symptomatic and Asymptomatic Women	Multisite observational study included 470 symptomatic/asymptomatic women who presented for a breast health checkup in two centers.	Sensitivity of 91.02%, specificity of 82.39% in detection of breast malignancy. Overall area under the curve (AUC) of 0.90	JCO Global Oncology 2020 (13)
Multicentric study to evaluate the effectiveness of Thermalytix as compared with standard screening modalities in subjects who show possible symptoms of suspected breast cancer	A prospective two centre cohort study was conducted at cancer care centres, located in Bangalore, South India and 258 symptomatic women were included	Sensitivity of 82.5%, specificity 80.5% as compared with diagnostic mammogram, which had sensitivity of 92% and specificity of 45.9%. The overall area under the curve (AUC) was 0.845	BMJ Open 2021 (14)
Acceptance of artificial intelligence (AI)-based screening for breast health in urban slums of central Karnataka, India – SWOC analysis	The study during 2019–21 among women in urban slums of central Karnataka to understand the acceptance of an artificial intelligence-based imaging solution for screening breast health	768 women underwent thermalytix most of whom were age group 31–40 years (35%), belonging to the Muslim religion (68.5%) with a mean monthly family income of Rs. 11,950.67/-. SWOC analysis identified reduced cost for the screening services and involvement of female self-help groups (SHGs) as strengths.	Journal of Family Medicine and Primary Care 2022 (15)
A prospective evaluation of breast thermography enhanced by a novel machine learning technique for screening breast abnormalities in a general population of women presenting to a secondary care hospital	A prospective, comparative study evaluated the performance of Thermalytix in 459 women at Max Hospital Delhi and had Thermalytix followed by 2-D mammography.	Overall sensitivity of Thermalytix was 95.24% and specificity 88.58%. In women with dense breasts the sensitivity was 100% and specificity was 81.65%	Front. Artif. Intel 2023 (16)

CONCLUSION

The combination of modern cameras and advanced algorithms is the basis for the renewed interest in thermography to detect breast cancer.

Author Contribution

The entire manuscript was conceived and written by SC.

Conflict of Interest: None.

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