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Development of a Wearable Thermal Imaging System to Aid Early Detection of Breast Cancer

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ABSTRACT

Breast cancer remains a major global health challenge and a leading cause of cancer related mortality among women, with late-stage diagnosis significantly reducing survival outcomes. The limitations of conventional screening methods such as mammography particularly their high cost, restricted accessibility, and associated discomfort underscore the need for alternative, non-invasive, and cost-effective diagnostic solutions. This research presents the design, implementation, and evaluation of a wearable thermal imaging system (SmartBra) developed to enhance early breast cancer detection through dynamic thermal pattern analysis. The proposed system integrates an AMG8833 Grid-EYE infrared sensor array with an ESP32 microcontroller to acquire high resolution thermal data from the breast surface. The data are wirelessly transmitted to a remote workstation for processing and visualization. A MATLAB based algorithm incorporating thermal mapping, image enhancement, and anomaly detection techniques was developed to analyze the temperature distribution. Additionally, ImageJ was utilized for comparative image analysis and feature extraction. Experimental validation was performed using simulated breast models representing both normal and malignant thermal conditions. The results demonstrate the system's capability to accurately identify localized hyperthermic regions correlated with potential neoplastic activity. The SmartBra exhibits high sensitivity and reliability in detecting abnormal thermal signatures, indicating strong potential as a low-cost, non-invasive screening tool for deployment in resource-limited healthcare environments.

Keywords: Wearable Technology, Smartbra, Thermal Imaging, Breast Cancer Detection, Non-Invasive Diagnostics.

1 INTRODUCTION

Breast cancer is a significant global health concern, ranking as the most commonly diagnosed cancer among women and one of the leading causes of cancer mortality (Bhushan et al., 2021). In Nigeria, the burden of the disease is exacerbated by inadequate access to diagnostic services and poor public awareness, often resulting in late-stage presentation and poor prognosis (Olayide et al., 2023). Early detection plays a crucial role in reducing mortality rates and improving treatment outcomes (Agodirin et al., 2021).

Conventional diagnostic methods such as mammography, ultrasound, and magnetic resonance imaging (MRI) have proven effective but are constrained by high costs, limited availability, and patient discomfort. Furthermore, mammography involves ionizing radiation, which may pose additional health risks, particularly with frequent exposure (Sanjay et al., 2023). These limitations underscore the need for alternative diagnostic approaches that are accessible, affordable, and non-invasive.

Thermography, a technique that measures skin surface temperature, has gained attention as a potential adjunct tool in breast cancer screening (Nwoye et al., 2020). The underlying principle is that cancerous tissues exhibit elevated metabolic activity and angiogenesis, resulting in localized increases in temperature. Infrared thermal imaging can thus serve as a non-invasive method for detecting these temperature anomalies (Hernandez et al., 2019). Despite its potential, thermography is often underutilized due to challenges in interpretation, standardization, and technological limitations.

In recent years, advancements in wearable technology and the Internet of Things (IoT) have opened new frontiers in healthcare diagnostics. Wearable devices equipped with sensors can continuously monitor physiological parameters and provide real-time feedback. In this context, the SmartBra project seeks to harness thermal imaging and wearable design to create a user-friendly, wireless system capable of facilitating early breast cancer detection. This paper details the development process, system architecture, experimental validation, and potential impact of the SmartBra device. This research presents the design and development of the SmartBra, a wearable thermal imaging system capable of detecting subtle thermal variations in breast tissue. By promoting continuous, non-invasive monitoring, the SmartBra has the potential to facilitate early detection,

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enabling timely medical intervention and improving survival outcomes.

2 LITERATURE REVIEW / RELATED WORK

Kavitha and Venkata Krishna (2018) developed a sensor-enabled wearable tool for detecting breast abnormalities. Its main strength lies in early, portable, and cost-effective detection, but it lacks advanced algorithms and sufficient clinical validation.

Arcarisi et al. (2019) introduced *Palpreast*, a pressure-sensing wearable device that mimics human palpation. It shows reproducible results but lacks data on long-term usability and real-world effectiveness.

Moreno and Herrera (2019) evaluated a smart bra using thermography and electrophysiological sensing to distinguish between healthy and tumorous tissue. The device effectively differentiates tissue types but suffers from a small sample size and limited correlation between raw data and tumor volume.

Mishra et al. (2020) applied thermal imaging with machine learning for breast cancer detection. Their system achieved high accuracy (98.9%) and automated classification, though it did not compare deep learning models or assess scalability.

Nwoye et al. (2020) designed an infrared smart bra to detect temperature variations in breast tissue. It effectively distinguishes cancerous from healthy tissue but lacks cost-effectiveness analysis and comparison with existing detection methods.

Mansouri et al. (2020) used bioimpedance measurements for breast cancer detection. The method showed high accuracy in both in vitro and in vivo testing, but it still requires clinical validation and adaptation for wearable use.

Elias et al. (2022) proposed the *IN-bra*, an AI-based ultrasonic system for early lump detection. It provides reliable and consistent results, yet it lacks validation with actual patient data.

Elouerghi et al. (2022) developed an IoT-based thermography system using bioheat microsensors. The approach offers strong simulation and visualization performance but lacks clinical validation and real-time AI integration.

Sarestoniemi et al. (2022) explored a UWB antenna-based monitoring vest for tumor detection. It effectively identifies small tumors using flexible antennas but has not been validated for real-time accuracy or practical use.

D. N. Elsheakh et al. (2023) presented circularly polarized textile microwave sensors for smart bra systems. The sensors function well both on and off the body, though experimental data are limited and few similar studies exist.

D. M. Elsheakh et al. (2023) worked on textile monopole antennas that remain functional and water-resistant during use. However, there is little discussion about scalability or comparison with other sensors.

Godfrey and Godfrey (2023) conducted a 20-year retrospective study of breast thermography in New Zealand, showing its success where mammography failed. Nonetheless, more randomized trials and AI integration are needed.

Breast et al. (2023) developed a complete detection and monitoring system using microwave textile antennas combined with machine learning. The method achieved strong classification accuracy but lacks scalability and comparative benchmarking.

Finally, Ketfi et al. (2024) reviewed wearable devices with thermal sensors for breast cancer detection. Their study effectively categorized device maturity and techniques but highlighted the scarcity of clinically validated and ready-to-use wearable systems.

3 METHODOLOGY

3.1 MATERIALS

The design and construction of the SmartBra incorporated the following components:

Infrared Sensor (AMG8833): A low-cost, high-resolution thermal sensor capable of detecting temperature changes as subtle as 0.1°C.

ESP32 Arduino LGVL Development Board: A microcontroller with integrated Wi-Fi and display capabilities, responsible for acquiring and processing sensor data and for real-time visualization of thermal images.

Power Supply: A 5V 1000mAh portable power bank, ensuring device portability.

Bra Material: Dual-layer construction with an outer leather layer for durability and an inner cotton layer for comfort.

Simulation Software: MATLAB was used to simulate long-term temperature changes using anonymized datasets.

Design Software: SOLIDWORKS for mechanical design and modelling of both the electronics housing and bra structure.

3.2 METHOD

The methodological approach included system design, integration, simulation, and performance evaluation.

3.1.1 System Design

The system architecture is divided into sensing, processing, and display units. The AMG8833 sensor array comprises an 8x8 pixel array capable of detecting temperature variations with a resolution of 0.25°C. It was strategically positioned

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within the inner lining of the bra to capture thermal data across the breast surface. The ESP32 board read this data via I2C communication, processed the temperature matrix, and visualized it as a real-time heat map on the TFT LCD display.

The block diagram of the SmartBra system is shown in Figure 1.

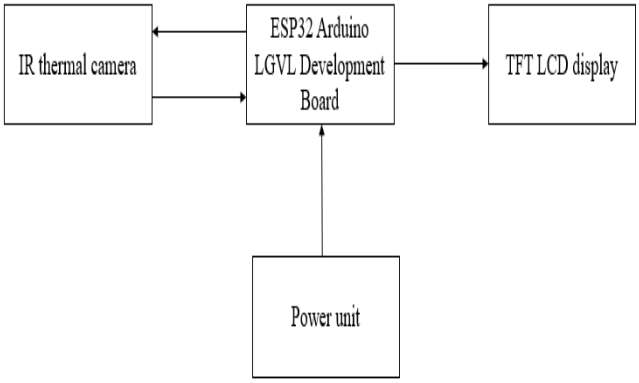


Figure 1: Block Diagram of the SmartBra system

The flow chart of the SmartBra system is presented in Figure 2. This flowchart outlines the device's process flow. The flow begins with the system's activation and then the sensor's initialisation. It is then followed by data acquisition from the thermal sensor, which monitors temperature variations across the breast surface. The system processes and calibrates this data to generate a thermal image, which is then displayed on the screen.

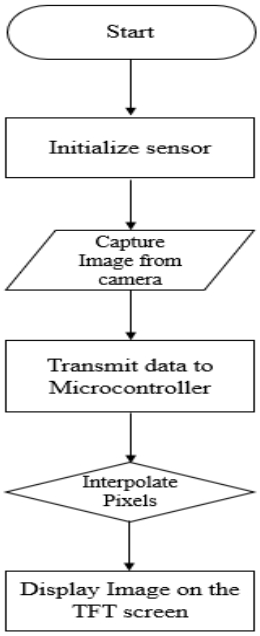


Figure 2: SmartBra System's Flow Chart

3.1.2 Fabrication and Assembly

The circuitry was soldered onto a compact PCB and encased in a custom-designed housing mounted discretely on the bra strap. Wiring was routed through fabric channels to ensure user comfort and maintain aesthetics. Materials were selected for breathability, flexibility, and non-reactivity. Figure 3 shows the 3D model of the SmartBra



Figure 3: 3D model of the SmartBra (solidworks)

Figure 4 depicts the system's circuit at the build-up phase and completion. The diagram shows in detail the connections between the several parts of the system.



Figure 4: Circuit Diagram and Bra Assembly Design

3.1.3 Simulation and Testing

Thermal data collected from the sensor was visualized and analyzed using MATLAB and ImageJ. Several simulation models were constructed to mimic different breast conditions, including normal tissue, benign anomalies, and malignant lesions. These models were tested under controlled thermal conditions, and the resulting heat maps were evaluated for temperature differentials and pattern recognition. MATLAB was employed to simulate thermal activity using anonymized 20-year breast health datasets. The datasets included both healthy and pathological thermal signatures, which were used to validate detection sensitivity as shown in Table I.

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TABLE I: THERMAL DATA POINTS FOR CASE STUDY 1 AND 2

Left Breast 1	Right Breast 1	Left Breast 2	Right Breast 2
36.65	36.56	37.29	37.91
36.46	36.37	36.61	37.97
36.69	36.74	36.73	37.52
36.96	36.57	36.13	36.61
36.43	36.08	36.48	37.53
36.43	36.32	36.74	37.18
36.97	36.77	36.24	37.1
36.73	36.79	36.85	37.06
36.36	36.18	36.46	36.86
36.66	36.38	36.58	37.44

Figure 5, Shows the Circuit Design for the Simulation of the Smartbra System

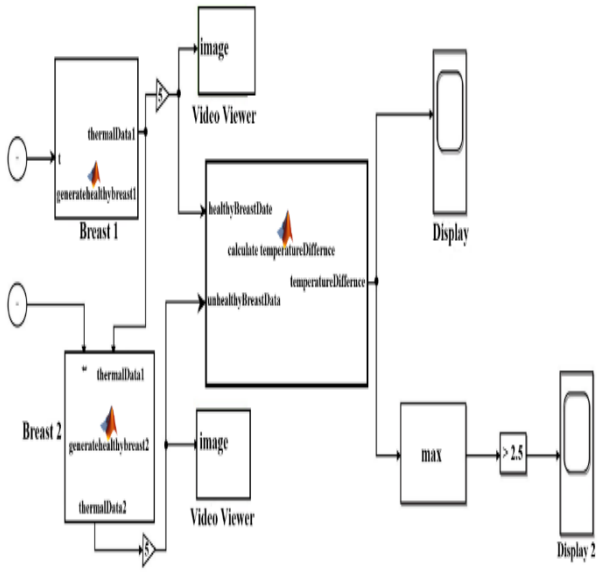


Figure 5: Circuit Design for the Simulation of the Smartbra System

3.1.4 Evaluation

Device accuracy was validated through controlled lab tests using heated phantoms. Response time, sensor reliability, and consistency across multiple tests were analysed. Performance was benchmarked against known diagnostic thresholds, particularly a thermal asymmetry of >1°C between breasts.

4 RESULTS AND DISCUSSION

4.1 TEMPERATURE MAPPING

Real-time visual output displayed distinct temperature zones. In the case of the healthy dataset, left and right breast regions exhibited symmetrical thermal signatures within a normal range (35–37°C).

In contrast, data emulating pathological condition revealed hotspots (>37°C) in localized regions, particularly in the upper outer quadrant a common site for malignant growths.

The Thermal Image Healthy Case for the left and right breast are displayed in Figure 6 and Figure 7. This kind of uniformity suggests normal functioning in terms of blood flow and metabolic activity, with no signs of any abnormal changes.

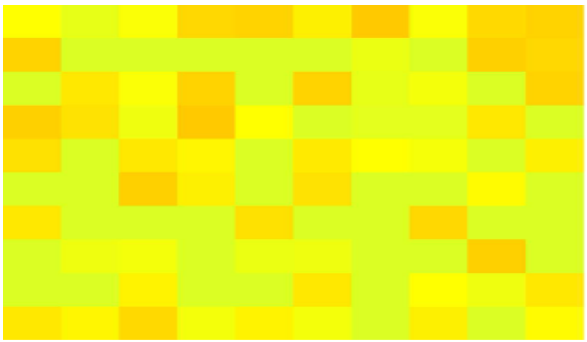


Figure 6: Thermal Image Healthy Case for Left Breast (35–37°C)

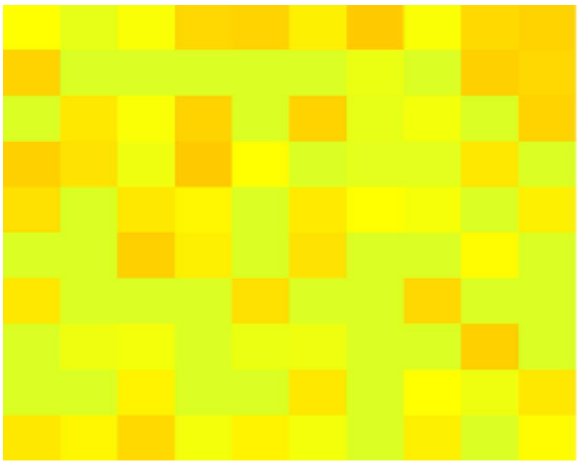


Figure 7: Thermal Image Healthy Case for Right Breast (35–37°C)

Also, the thermal Image Cancer Case for Left Breast and right breast are displayed in Figure 8 and Figure 9.

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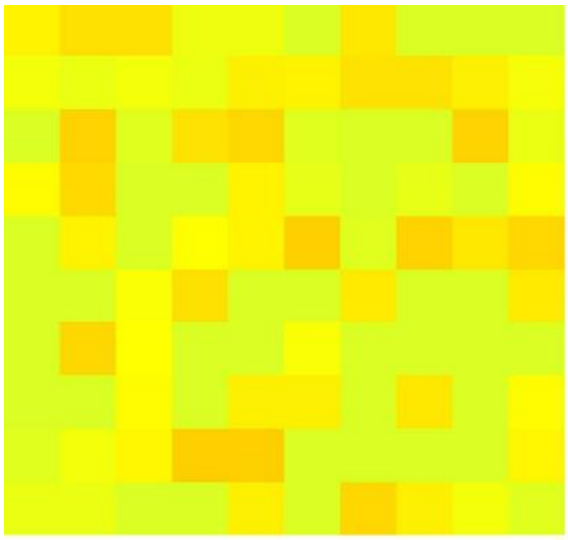


Figure 8: Thermal Image Cancer Case Left Breast (35–37°C)

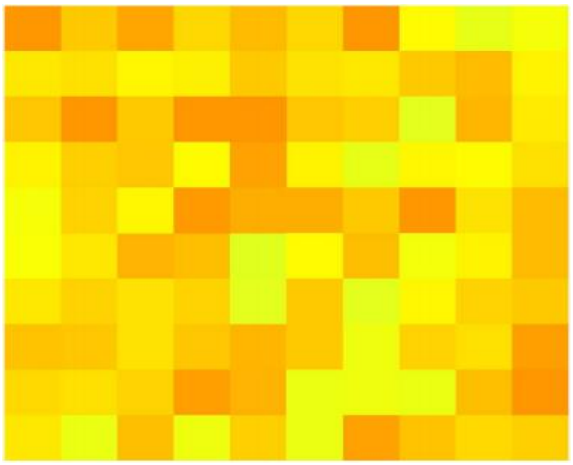


Figure 9: Thermal Image Cancer Case Right Breast (>37℃)

The significant difference in temperatures between the two breasts became apparent, triggering an alert and highlighting SmartBra's potential effectiveness in detecting early signs of breast cancer. Figure 8 depicts the thermal image of the left breast within a temperature range of 35-37℃, which is the temperature range of a healthy breast. The thermal image of the right breast presented in Figure 9 however, indicates a rise in temperature above the normal breast temperature (>37℃) which indicates the presence of increased metabolic activity in that breast.

4.2 Simulation Results

MATLAB simulations successfully replicated 20 years of data into a condensed 10-second animation, offering insights into progressive thermal changes. Graphical results from the simulation indicated progressive thermal elevation in cancer-affected subjects, especially during periods of symptomatic manifestation. Figure 10 and 11 illustrate the significant temperature difference which suggests a strong link between breast temperature asymmetry and the potential presence of cancer.

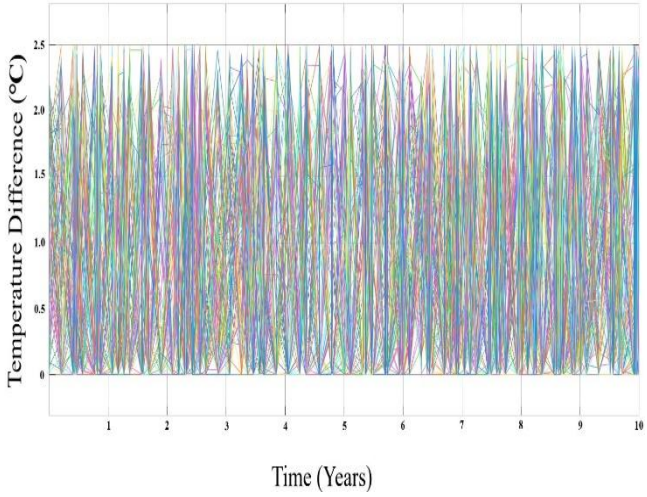


Figure 10: Thermal Evolution across 20 Years – Case Study 1

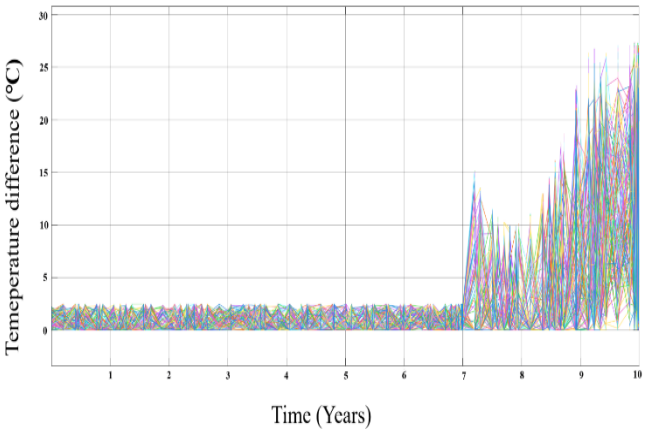


Figure 11: Graph of the temperature difference between both breasts for case study 2

4.3 Performance Evaluation

The SmartBra's thermal mapping accuracy reached approximately 95% under controlled conditions. The AMG8833 sensor's resolution was sufficient to detect 0.1°C variations, with the system maintaining a stable performance over extended use. The wearable form factor showed strong user acceptance during ergonomic assessments.

Figure 12 shows the Cancer detection outcome for case study 1.

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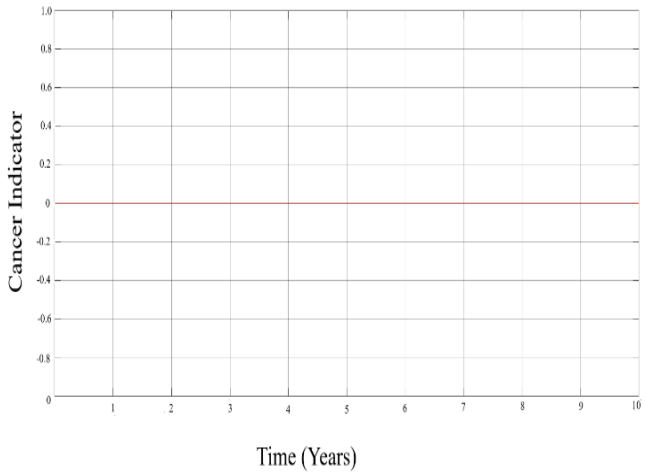


Figure 12: Cancer detection outcome for case study 1

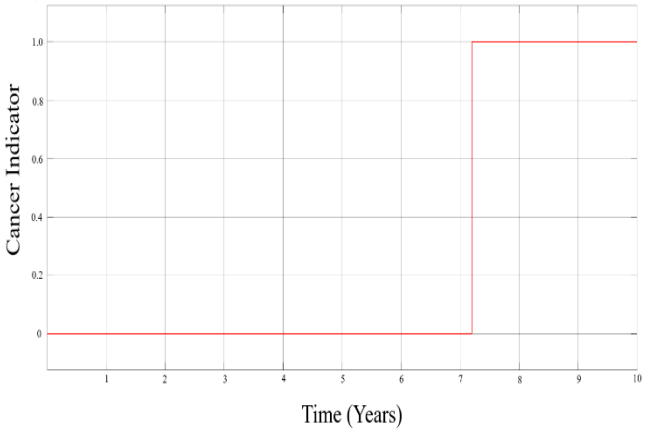


Figure 12: Cancer detection outcome for case study 2

5 CONCLUSION

The SmartBra represents an innovative solution for early breast cancer detection, merging comfort with diagnostic functionality. It fills critical gaps in current diagnostic methods by offering a wearable, non-invasive, and affordable device capable of continuous breast monitoring. The combination of real-time imaging, historical data simulation, and ease of use makes it suitable for deployment in both clinical and rural settings.

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