Original Article

Smart Breast Cancer Screening: AI-Powered Thermal Imaging for Rural Healthcare

Sangeeta Parshionikar[1,2], Vijaya Babu Burra[1], Debnath Bhattacharyya[3]

[1]*Department of Computer Science and Engineering, Koneru Lakshmaiah Education Foundation, KLEF, Vaddeswaram, Guntur, Andhra Pradesh, India.*
[2]*Department of Computer Engineering, Fr. Conceicao Rodrigues College of Engineering, Mumbai, India.*
[3]*Department of Information Technology, Aditya Institute of Technology and Management, Tekkali, Srikakulam, Andhra Pradesh, India.*

[1]*Corresponding Author : sangeeta@frcrce.ac.in*

Abstract - Breast Cancer is the most predominant among all types of cancers and the leading cause of death not only in India but worldwide also. The scenario is worse in rural areas. This is due to the fact that women in rural areas are not aware of breast cancer symptoms, its adverse effects, and its causes. This results in the detection of breast cancer at an advanced stage. Also, the medical facility is not easily accessible to them. Subsequently, this results in an increase in mortality rate. Hence, there is an urgent need to have a cost-effective and efficient smart healthcare system for the detection and monitoring of Breast cancer in rural women. In this research work, a smart breast cancer detection system, especially useful to remotely located people, is proposed. The proposed system makes use of infrared thermal images for the detection of breast cancer. The system can be deployed in the primary health center of every village to provide the facility to remotely located people. With the AI technology, data from the primary health center is uploaded to the cloud for classification. An enhanced multi-scale deep convolutional capsule neural network classifies and detects the presence or absence of a cancer tumor, and sends information back to the health center, along with the treatment procedure and the availability of the nearest cancer center. A full-stack web application is developed to evaluate its practical application. This application aims to bring AI-driven breast cancer detection to remote villages, enhancing healthcare accessibility in underserved areas. The system uses Node.js for the backend, MongoDB for data management, and React with the ShadCN UI library for the frontend, providing a seamless user experience.

Keywords - Artificial Intelligence, Breast Cancer, Deep learning model, Healthcare system, Infrared Images, Remote monitoring.

1. Introduction

Detection of Breast Cancer (BC) in early stages is still an issue in the healthcare sector. The breast cancer care delivery system needs a lot of improvement to reduce the burden on medical experts and pathologists. Breast Cancer is the leading cause of high mortality rate not only in India but worldwide also [1].

Traditional diagnosis methods have issues of radiation exposure, are painful, expensive, and not easily accessible to people in remote locations. Hence, an inexpensive, convenient, and accessible all-in-one breast cancer diagnosis technique is urgently needed. India has low survival rates in Breast Cancer patients compared with other Western countries. This is mainly due to delayed diagnosis at the advanced stage and inadequate treatment facilities. Also, in rural areas, the main cause of the high mortality rate is unawareness about the disease. In actuality, around 70% of the population lives in rural regions, while 95% of cancer care delivery centers are available in urban regions. Almost 40% of medical centers are not provisioned with advanced cancer care equipment [2]. Timely radiotherapy is not easily available to most BC patients. In India, the entire healthcare sector is facing many challenges, such as a shortage of healthcare personnel, medical resources, patient consultation, funding for treatment, and remote monitoring [3].

These challenges are more pronounced in the developing countries, where Artificial Intelligence (AI) is becoming the key in transforming traditional healthcare to smart healthcare. AI has the capability to support medical experts in making diagnoses, predicting the spread of diseases, and designing treatment paths [4]. In the rural part of India, women are not aware of this kind of disease, its symptoms, or its adverse effects. They are not even aware of precautionary measures, such as a timely check-up. This results in the detection of BC in the advanced stage. This is the main cause of the high mortality rate due to BC in India.

1.1. Research Gaps

1.1.1. Lack of Affordable and Non-Invasive Screening Solutions for Early Breast Cancer in Rural Areas

Available methods of detecting breast cancer are costly, radiological, and mostly inconvenient to the rural community. The development of affordable, painless, and easily deployable early screening modalities can be a much-needed and missing stopgap solution to resource-restricted and remote areas.

1.1.2. Minimal Implementation of AI-based Breast Cancer Detection in Remotely Operated Healthcare Systems in the Clouds

In spite of the fact that deep learning models, especially CNNs, have proven to be highly accurate when it comes to breast cancer image classification, the practical implementation of their application to the cloud-based remote monitoring frameworks of rural healthcare delivery is not well studied.

1.1.3. High False Negative Rates and Poor Optimization of the Current AI Models

Most of the available breast cancer detection models fail to deal with the problem of false negative cases, which is crucial in life-threatening diseases. The research gap is the integration of more sophisticated feature extraction, segmentation, and optimization algorithms to enhance diagnostic accuracy, especially in the detection of early-stage cancer.

1.1.4. Neglected Remote Patient Monitoring Role in Diagnostic Delays Reduction

Despite the acknowledged usefulness of remote patient monitoring, this screening tool in relation to breast cancer in developing nations has not been studied in detail before. It is necessary to conduct research to determine the ability of cloud-enabled AI systems to minimize diagnostic waiting time, overload on experts, and healthcare disparities across the urban and rural populations.

1.2. Problem Statement

The high mortality due to breast cancer is still a problem in developing nations such as India because of late diagnosis, limited access to affordable screening services in rural regions, and application of prohibitively expensive or radiation-based diagnostic services in urban regions. Despite the potential of AI-based deep learning models in the detection of breast cancer, their application in remote healthcare systems with cloud-enabled systems in rural areas is insufficient, and most of the models currently existing are characterized by high false negative rates, which is a setback to making the diagnosis at the early stage. Therefore, there is an urgent requirement for an affordable, non-invasive, and cloud-based remote breast cancer screening system with optimized AI models to facilitate the early diagnosis of breast cancer, minimize false negatives, and enhance accessibility

and healthcare outcomes to women in resource-constrained rural areas. Remote patient monitoring is found to be a boon for remotely located patients where a medical facility is not easily accessible. Deep learning models have the capability to correctly classify the images as normal or malignant. Research papers reveal that Convolutional Neural Networks (CNNs) work well in the classification of breast images. By using novel feature extraction methods, segmentation techniques, and good optimization techniques, it is possible to recognize cancerous and non-cancerous images with fewer false negative cases. By inculcating cloud based remote BC monitoring system in primary health centers of villages or remote areas, women in rural areas can benefit a lot. Also, the burden on medical professionals can be lowered to a great extent. In this research paper, cloud based remote BC monitoring technique is proposed.

The main contribution of this research is

- Enhance healthcare accessibility in underserved areas/ remote villages by building a full-stack web application for breast cancer detection using Node.js for the backend, MongoDB for data management, and React with the ShadCN UI library for the frontend.
- Ensure that patients receive a diagnosis pathway from the most proximate medical expert within the specified geographic regions via geospatial queries.
- Develop a complete, cost-effective, and efficient system to monitor Breast Cancer patients remotely.

The remaining part of the manuscript is organized in the following way: Section 2 is a literature survey. Section 3 expounds the proposed methodology. The results and discussions are emphasized in Section 4. The conclusion of the manuscript is presented in Section 5.

2. Literature Survey

A comprehensive survey on existing studies of detection approaches for breast cancer, covering traditional and modern methodologies, and recent advancements, is provided in this chapter. This literature survey aims to review previous studies, find out gaps in research, and set the base for the current research at hand. In paper [5], the author discussed the challenges in the detection of BC using digital mammography and digital breast tomosynthesis faced by AI. The paper further aimed to discuss upcoming technologies used and developments in artificial intelligence for the automatic detection of BC. The subset of AI, Deep learning, has shown significant improvement in classification and reduced false positives and false negatives, which is an important factor in the diagnosis of BC. To inculcate these AI developments in clinical practices requires further research, validation, and ethical guidelines to improve transparency. The author Mashekova et al. [6] proposed an approach of thermography, which is safe, non-invasive, and can be easily adapted. This non-contact technology is capable of detecting breast cancer

at an early stage. This method has been proven to be very convenient to the patient, and it is cheaper compared to other available methods. Researchers [7] built a new tool for detecting breast cancer using thermal imaging, CNN, and cloud computing. They have developed a smart app for smartphones for early detection of breast cancer, which would be useful, especially for remote areas and elderly people. A graphical user interface is designed by the authors to link it with the AirDroid application for sending images from a mobile phone to the cloud and then back to the mobile phone for retrieving diagnostic results from the cloud. The proposed tool proved that different distances and different image acquisition systems do not affect the functioning or operation of the app. To verify the detection accuracy, the authors have applied four effects on thermal images, such as flipping, tilting, and blurring. The number of experiments showed high accuracy performance for the classification of breast cancer. Authors have recorded the response time as six seconds for successfully receiving the result on the mobile app via the AirDroid application and transferring images to the cloud. The reason cloud computing is used in their research work is the size of the mobile app and GUI due to the large database. Also, deep CNNs require a high-speed GUI for image processing, which is not possible on a mobile phone.

This research work is carried out on the thermal images along with the clinical data that includes the age of the patient, symptoms like redness, rashes, or swelling on the breast, any other medical issues, and family history [8, 9]. Authors have considered five different angles of thermal images of the breast, including front view, 45° left and right, and 90 ° left and right. The authors built a separate CNN model for each of the above-mentioned view angles of the breast. Results of all five models are combined to train the final neural network. They have compared the performance of single-input and multi-input CNN models and concluded that the multi-view CNN outperforms the single-input CNN. Data augmentation techniques are also used here to boost the result of the multi-view CNN. The major finding of this research is that the addition of patients' clinical data proved beneficial in increasing the performance of the CNN model. These five-view images, along with clinical data, provide improved accuracy for a convolutional neural network.

Md. Taimur Ahad presented the comparative study of the performance of six CNN techniques, including a transfer learning and an ensemble model [10]. Experiments were carried out on both original and augmented histopathology image datasets. It has been observed that an ensemble method performed better compared to all other methods, providing higher accuracy and classification. The author has also suggested developing a mobile-based app for breast cancer detection as a future scope. Kandlikar et al. pointed out how advanced infrared cameras can be utilized in the detection of BC in their research paper [11]. A high-sensitivity camera captures hot spots in breast images with more precision. A

paper [12] described a method that would be useful for breast self-exam mass screening. Authors have integrated the transfer learning technique with a Bayesian network to experiment on breast thermograms. Four pre-trained models, namely VGG16, Xception, Resnet 50, and MobileNet (trained on the Imagenet database), were explored in their work. The combination of CNN and BN improved the accuracy to 90.85% with a limited database size.

Gaber T. et al. [13] demonstrated how the U-Net network is used to highlight features of thermal images, and a two-class DL approach is used to classify normal and abnormal breasts. In a research paper [14], the author developed a comfortable wearable system for continuous breast monitoring. The system was based on detecting differences in the electrical properties of breast tissues in the microwave band using flexible antennas as a sensor. Yong Zhao et al. [6] proposed a novel BC diagnosis system comprising a CNN and Bayesian Networks with Thermal images. They reported a significantly higher accuracy even with a small set of breast images. One of the prominent outcomes of the research is that the feature extracted from the image leads to accurate diagnosis, and a medical expert can easily recognize which feature is helpful in the detection of BC. Since the feature reported here is the temperature value, which is directly related to the existence of a tumor, explainability is inherent in the research. A study by Samir Yadav [15] related thermography with ancient time therapy to recognize the deceased part of the body with its higher temperature compared to the rest of the body. On a similar basis, thermography can be used to identify a cancerous body part. Thermal images are then given to a trained machine learning model to classify healthy and malignant images. The author concluded that this is a better alternative to identify breast cancer without touch or radiation. This easier and effective approach needs to be implemented in clinics and hospitals to reduce the increasing mortality rate due to BC.

Authors [7, 16] addressed here the big challenge of handling vast data that emerged from the health monitoring system. Fog computing is implemented to overcome the problem of massive data. By having capabilities such as real-time processing and scalability, Fog computing simplifies patient monitoring using wearable devices. A novel technique for computation offloading is proposed to reduce latency, improve security, and resource use in healthcare monitoring systems. The study [17] highlighted the underutilization of Multidisciplinary Care (MDC) in early-stage breast cancer patients, with less than 75% receiving comprehensive specialist evaluation. Socioeconomic status, age, comorbidities, and geographic location significantly influenced MDC access. Importantly, MDC was associated with better adherence to national quality care metrics. Considering the limitations of the traditional softmax activation function, which lacks discriminative power, the author [18] proposed four softmax loss functions with angular

margins. All four methods have shown excellent results in extracting discriminative features and making decisions into classes.

Authors of a research paper [20] concluded that convolutional Neural Networks with thermography show better results in BC diagnosis. 100% accuracy in BC detection is possible with Advanced CNN models, Resnet 101, and DenseNet 201, so it is suggested that CNN with thermography would be the future of medical clinical practice. A study by Dharani et al. [21] proposed an enhanced DL technique with Fuzzy C-means clustering to improve accuracy in the detection of BC. The region of interest is extracted to isolate the malignant part from the rest of the body. The heat maps are generated from 2D thermal images. The hot spots are the indications of a cancerous region. This method could be a good approach in the diagnosis of BC and can be considered for practical implementation.

A paper [22] clearly outlines a structured approach to early breast cancer detection using advanced imaging and deep learning techniques such as SqueezeNet. It effectively highlights each stage of the process, from pre-processing to classification, while introducing a novel optimization algorithm (FSSFO) to enhance model performance. A review

paper [23] is on Thermography as a screening methodology for early detection of breast cancer. Since most of BC deep learning detection techniques generate lots of features, processing of these features requires lots of memory. Also, the time required for processing these features is longer. The author [24] proposed a hybrid technique involving Genetic Algorithm and Grey Wolf Optimizer to reduce the size of the feature vector, which further reduces computation time. This literature review investigated various BC detection techniques, ranging from conventional diagnostic methods to modern AI-assisted approaches for early breast cancer detection. The research approach, including the top-level block diagram, dataset selection, preprocessing methods, model architecture, evaluation metrics, and full-stack web application implemented in this study, is covered in detail in the next chapter.

3. Proposed Methodology

The proposed remote breast cancer patients monitoring system architecture is shown in Figure 1. It mainly comprises three entities: the village's local primary health centre, a cloud-based AI model, and an available cancer specialist for consultation. The Primary Health Center (PHC) is equipped with a high-sensitivity thermal infrared camera and communication technologies.
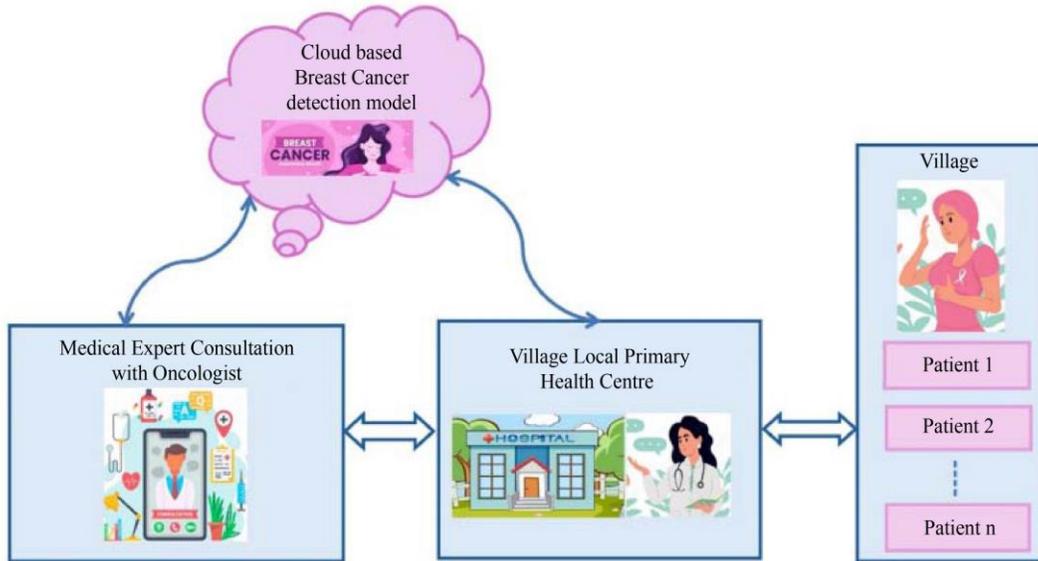

Fig. 1 Smart healthcare system architecture for remote breast monitoring

The patients from remote areas can easily approach the local PHC. The medical officer at PHC captures the breast images with the help of an Infrared camera. The IR images, along with physical examination parameters such as body temperature, change in shape or size of breast, redness, and inflammation, are given to a deep learning model. A Deep Learning (DL) model classifies the images as normal or malignant. The classification result from the uploaded data shows that the patient is normal, and no abnormality was

found; then the same information is directly seen at the primary health center's dashboard. On the other side, if the classification result shows abnormality and the case is found malignant, then an alert goes to the concerned experts. Figure 2 demonstrates the end-to-end workflow of the proposed framework as shown below. The workflow diagram of the proposed method clearly depicts three major entities, namely Local PHC, Deep Learning model, and Medical expert/ Oncologist.

3.1. Local Primary Health Center

Primary Health Centres (PHCs) in India are fundamental to the rural health care system and form the community-based part of the healthcare system, delivering accessible and affordable medical care. The centers are small clinics with a physician, where minor surgeries can be performed, and they are part of the government-funded public health infrastructure. Many Sub-Centers and Primary Health Centers are being converted into Health and Wellness Centers as part of the Ayushman Bharat initiative for the delivery of comprehensive primary healthcare. Therefore, Breast cancer detection and awareness services should be incorporated in the current setup of Primary Health Centres (PHCs) in India in order to meet the requirements of rural women. This includes diagnosing and treating conditions earlier and faster to achieve better outcomes. With this scenario, this research paper proposed a novel setup at PHC equipped with an Infrared camera and a communication setup [18, 28].
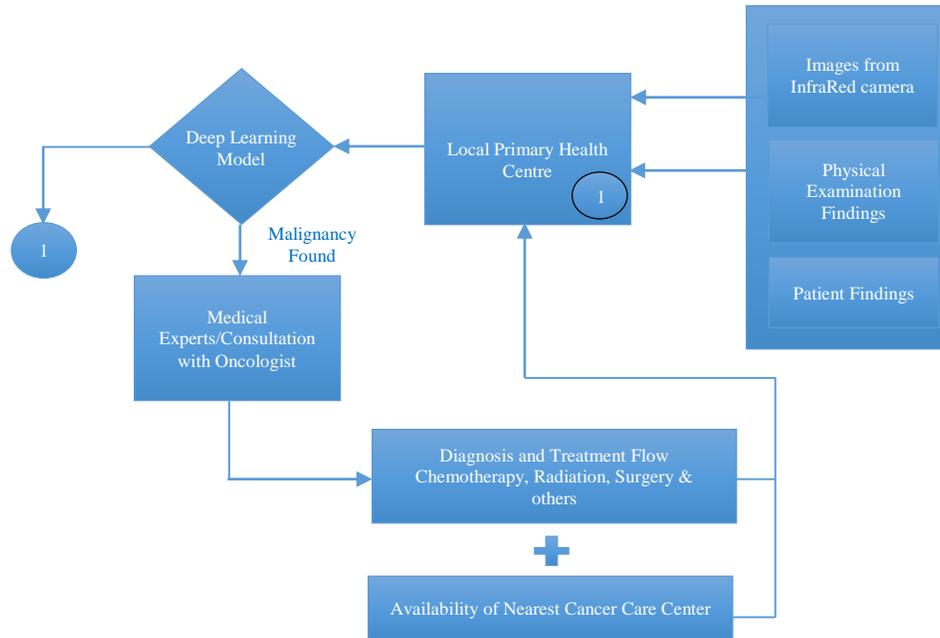

Fig. 2 The end-to-end workflow of the proposed framework

Along with Infrared images of the breast, physical examination finding parameters such as structural change in size or shape of the breast, swelling, and body temperature are uploaded. A trained deep learning model detects whether the patient is normal or has any malignancy. The registered medical expert receives a notification via email if the case is malignant. The doctor recommends a line of treatment by studying the report and going through the examination details.

3.2. Deep Learning Model

The DL model used here is an Enhanced Multi-scale Deep Convolutional Capsule Neural Network. The model is optimized with Orchard Optimization Algorithm (EMDCC-OOA). The complete implementation of the EMDCC-OOA model is described in the previous research paper. The AI model employed in this study is adopted from previously published work and is used without modification for the deployment and evaluation of the proposed web application. The four main steps involved in the above architecture are preprocessing, feature extraction, segmentation, and classification. The DMR-IR dataset is used here for thermal breast images. It consists of a total of 1340 breast images. Out of which 860 images are of the malignant category, while 480 are normal cases. These images are captured using a FLIR SC620 thermal camera and have a resolution of 640 × 480 pixels. To preprocess the input image, the Anisotropic Gaussian side windows guided filtering technique is used.

This technique is used to reduce the noise and to preserve the edges. After preprocessing, feature extraction is performed with the Dual Sparse Graph-based Regularized Deep Nonnegative Matrix Factorization technique, especially to include important features, complex structures, and underlying patterns of the data. Once the features are extracted, segmentation is performed to obtain an accurate region of interest using the Hierarchical Cascaded DeeplabV3+method. Deep CNN layers are employed in the EMDCC to extract features, and multi-scale information is included in the architecture to boost classification performance. The multi-scale information records temperature variations in detail at various levels, whereas the CapNet architecture offers a more comprehensive understanding of the thermal patterns in the IR images. The EMDCC model is optimized with the orchard optimization algorithm and has shown outstanding performance in classification.

3.3. Consultation with Oncologist

The breast cancer detection system leverages postal codes (pincodes) instead of direct reverse geocoding to ensure independence from third-party APIs while minimizing computational and storage requirements.

By utilizing pincodes, the system can efficiently correlate addresses between relevant parties, i.e., PHC and the medical experts, enabling seamless geospatial queries without the need for extensive processing power or external data sources. This approach enhances the system's reliability, reduces operational costs, and ensures privacy by eliminating dependencies on external geolocation services. Ultimately, this method provides a computationally and economically efficient solution for integrating geospatial analysis into the detection process.

The registered doctor gets alerted in case of malignancy. Based on geospatial queries, the nearest doctor receives an alert along with the patient's report from the proposed web app. On thoroughly studying the case, the doctor recommended the line of treatment. The recommended treatment information is visible to the resident doctor at PHC through the dashboard. The same can be easily conveyed to the concerned patient and guide them on how to proceed further. This application has the provision to suggest the nearest cancer care center that is easily reachable from the remote place, along with the treatment procedure.

Thus, based on the location of the PHC, patients are directed to the nearest charitable cancer institute for treatment. These charitable cancer hospitals provide free anticancer drugs, medicine, chemotherapies, and clinical tests to poor people, especially those who come from rural areas. A remote breast cancer patient monitoring system can provide a significant benefit to women located in geographically remote areas, where they can easily access these services.

4. Results and Discussion

In this research, the integration of the model into a full-stack web application, SWASTHYA, developed as a proof of concept to evaluate its practical application, is demonstrated. The application is designed to support key stakeholders, including local primary health center administrators, patients, and doctors, by facilitating a streamlined workflow. This application aims to bring AI-driven breast cancer detection to remote villages, enhancing healthcare accessibility in underserved areas. The system uses Node.js for the backend, MongoDB for data management, and React with the ShadCN UI library for the frontend, providing a seamless user experience. The AI model, originally based on EMDCCN, has been converted to ONNX format for better compatibility and performance. The project features a modular design for effective management and scalability. The backend architecture includes models, controllers, routes, services, and utilities, catering to three primary user roles: local admins, doctors, and patients. The home page of the web application can be seen in Figure 3. The home page provides the list of PHCs under the primary health care center tab, as well as registered oncologists under the healthcare provider tab.

Fig. 3 Home page of the web application swathya mainly demonstrates the PHC admin login and the doctor login

4.1. Primary Health Center Local Admin

The SWASTHYA website has two main aspects: Local Admin login and Doctor login. A resident doctor or local administrator at the primary health center first logs in with their PHC center name. Admin logs into the system using the pincode of their area, as shown in Figure 4.
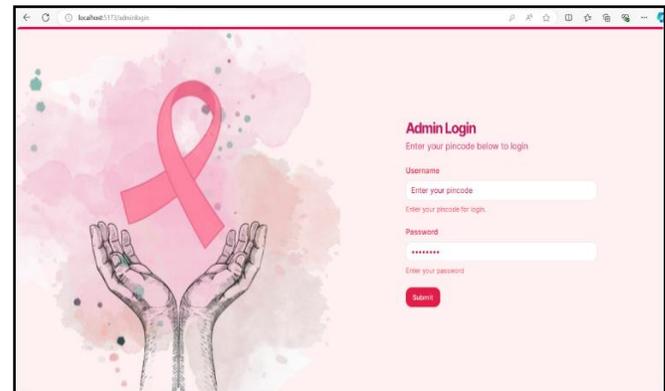

Fig. 4 Admin login page with user name as local pincode. This is required to implement geospatial queries.

The local administrator at the primary health center is responsible for creating and overseeing patient records. Once login is done successfully, the details of patients such as name, gender, age, aadhar number, and locality are filled up by the admin. The infrared camera (FLIR SC series camera) is used to take images of the breast.

These images are then uploaded while filling in the details of the patient. Physical examination is also done to check for any abnormalities such as swelling, redness, numbness, or structural changes in the shape of the breast. etc. The same is recorded in the patient's form as shown in Figure 5, along with an IR image of the breast. Details of the patient can be

downloaded as a PDF file for future reference. A sample of a PDF file is illustrated in Figure 6(a). The model, which is already trained with thermal images taken from the Kaggle repository, starts working on new images.

Immediately, it classifies the images as normal or malignant one. During this process, the model analyzes test results. In cases where test results are positive, the system automatically assigns a doctor to the patient and transmits the result via email to the designated doctor. The email notification to the nearest doctor is seen in Figure 6(b). In cases where test results are negative, the same is conveyed to the patient instantly by the local admin.
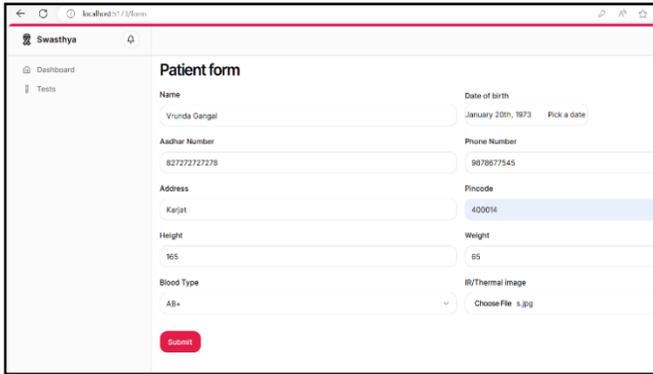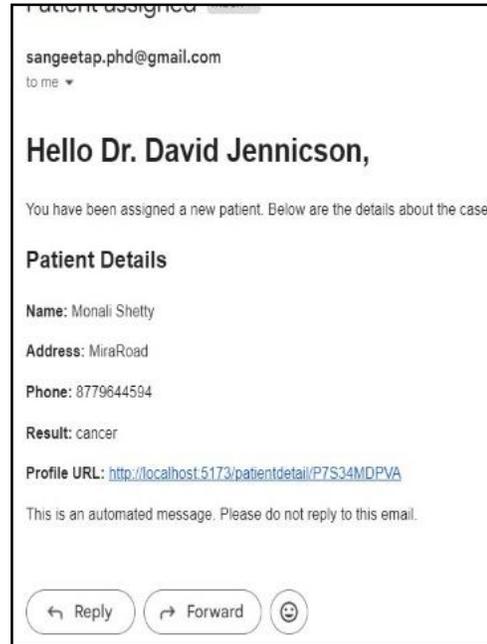

Fig. 5 Patient form includes details of the patient such as name, aadhar number, blood group, pincode, and breast thermal image

Local admin can see the history of all patients. All cancer cases are highlighted in red and are assigned to the doctor, while normal cases are marked pink and no doctor is assigned to them. The same is displayed in Figure 7.
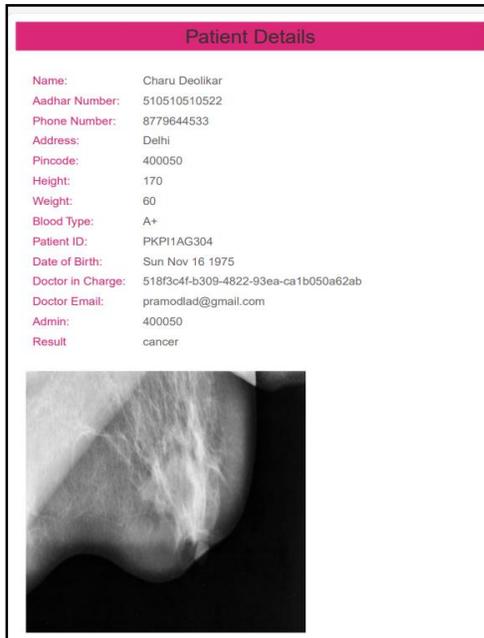
(a)

(b)

Fig. 6(a) Downloadable PDF sample containing the details of the patient. Admin login has all patients' details saved in PDF format, and (b) An email notification to the nearest doctor. Email is sent to the doctor only when cases are found Positive.
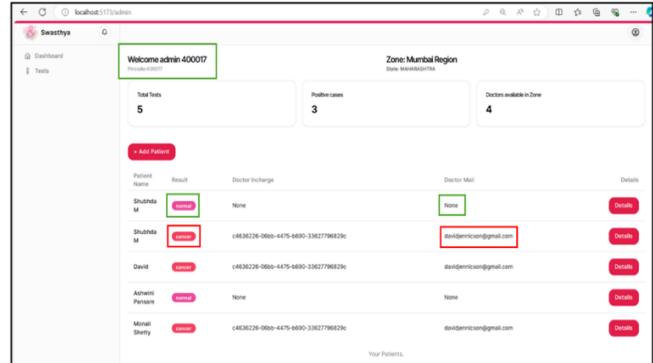

Fig. 7 Local PHC admin page showing details of all patients with green color highlighting normal cases, while red color highlights malignant cases with assigned doctor

4.2. Doctor Login

The doctor begins the registration process by submitting essential details, such as state medical board credentials and registration numbers. Their accounts undergo verification through an email-based OTP system. The doctor's signup page and OTP verification page can be seen in Figure 8. Once verified, these accounts become accessible to local administrators, who play a crucial role in managing patient data. The assignment of doctors is determined through geospatial queries, which match patients with the nearest available doctor based on their address. The system currently focuses on Indian regions, which are further divided into states and zones, to enhance the accuracy of these assignments. This method ensures that patients receive care from the most

proximate healthcare provider within the specified geographic regions. Then the doctor can study the case. An expert doctor has to log in to the website to get access to the images and results from the AI module. After a thorough case study, the expert doctor suggests the mode of treatment, whether the patient needs to go for radiation, chemotherapy, hormone therapy, or surgery. An expert doctor uploads the prescription mentioning the required medicines and suggested therapy. Once assigned, doctors can review patient data and generate prescriptions. The doctor's prescription section is shown in Figure 9. These prescriptions are subsequently available for local administrators to review, ensuring effective management and oversight.

(a)
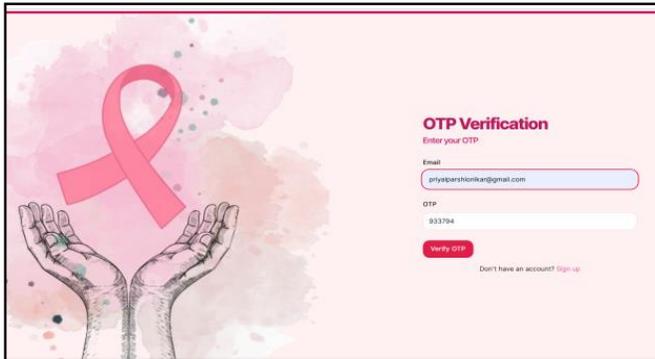
(b)

Fig. 8 (a) The Doctors' signup page requires registration number, State medical board, phone, and email ID, and (b) Once the doctor's account is signed up and undergoes verification through an email-based OTP system.
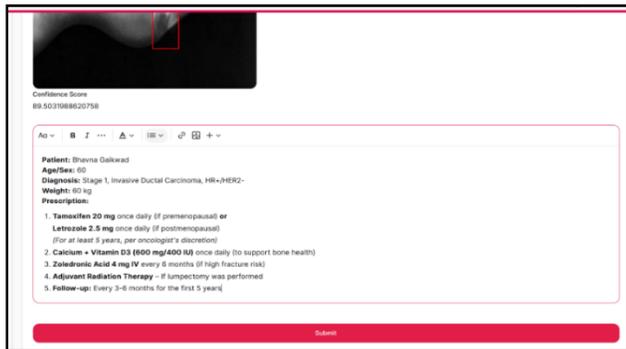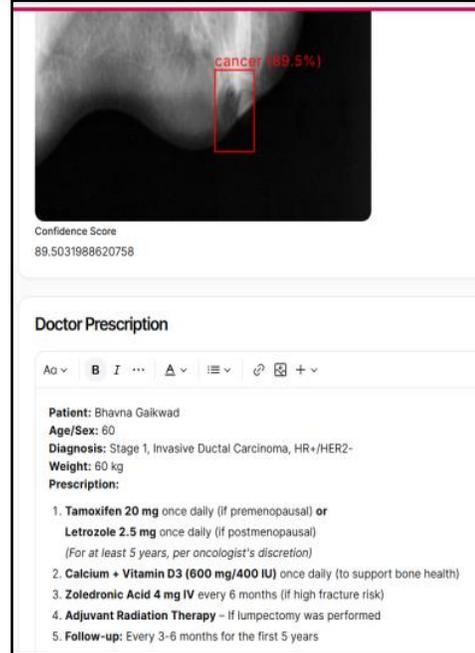

Fig. 9 Prescription sample given by the doctor

Fig. 10 Prescription is visible to PHC admin

5. Conclusion

The proposed smart breast cancer detection system harnesses the power of cutting-edge AI and deep learning techniques, creating a technical solution to a major healthcare shortcoming in rural areas, specifically for remote patients. In addition, by implementing infrared thermal imaging and developing a full-stack web application, the proposed system is an economical and efficient means for early breast cancer detection. This scheme also increases access to healthcare in geographically challenged areas of the country.

Timely detection of disease and treatment options becomes accessible. This solution within primary health centers can significantly reduce mortality by identifying cancer in its early stages and referring patients to the cancer institute. This paper underscores the revolutionary power of AI to enhance and elevate rural healthcare, laying the foundation for scalable interventions in underserved areas.

Developing edge computing for real-time data analysis reduces the latency but enhances system reliability. Future studies can be directed towards maintaining multilingual support with local dialects in voice & guidance instructions, which can ensure usability and accessibility for the rural population who are less literate.

Using more advanced architectures such as GANs would further tune the precision and correctness of the distributed tumor across the image. Partnering with the government and non-government organizations can help set the policy and technology directions to deploy the system in different rural regions for social impact at scale. The ultimate challenge for

this feature is its implementation in practical scenarios, so large-scale clinical trials to validate the system's performance across diverse individuals, while ensuring compliance with industrial healthcare standards, are a must for widespread adoption. These future directions are intended to expand upon the existing system and enhance its capability, scalability, and impact in addressing the healthcare needs of rural communities. Also, the strong data privacy and security protocols are required to be included to ensure data is secured during transmission and storage, which can further be explored in future research.

Author Contribution Statement

SP and VB conceived and designed the research. SP and VB wrote the manuscript. SP built a webapp and conducted experiments. VB and DB analyzed the result and conducted verification. All authors read and approved the manuscript.

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