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# *A Novel Approach to Predict the Early Stage of Breast Cancer Using Deep Learning*

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## *ABSTRACT*

*Breast cancer is one of the leading causes of death among women, and its early detection plays a crucial role in improving the chances of successful treatment. Traditional diagnostic techniques such as mammography and biopsy are effective but often rely on manual interpretation, which can lead to misdiagnosis or delays. In this study, we propose a novel deep learning-based approach for the early prediction of breast cancer by integrating mammogram image analysis with Circulating Tumor Cell (CTC) counts. The aim is to develop an accurate and reliable model that not only identifies abnormal breast tissue but also correlates it with biological indicators of malignancy. The proposed approach combines the visual information obtained from mammography with biological insights derived from CTC enumeration, offering a comprehensive understanding of both structural and cellular-level changes. By leveraging the power of convolutional neural networks (CNNs) for feature extraction and data fusion techniques for multimodal integration, the model aims to provide a more reliable and non-invasive method for early diagnosis. This fusion of imaging and molecular data enhances clinical decision-making and represents a promising step toward precision-based cancer detection systems.*

***KEYWORDS:*** *- Early-Stage Breast Cancer, CTC Biomarkers, Mammogram Analysis, CNN, Deep Learning*


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## INTRODUCTION

Breast cancer is a life-threatening disease affecting women across the world, and early diagnosis is key to improving survival rates. Detecting cancer at its initial stages allows for timely intervention, less aggressive treatment, and a better quality of life. Despite advances in screening and treatment, millions of women are still diagnosed at later stages, which makes treatment more complex and reduces overall survival.

Mammography is currently the most widely used screening tool for breast cancer, often supplemented by ultrasound, MRI, or biopsy. While mammograms are effective, they are not perfect. Their accuracy depends heavily on the radiologist's experience, and subtle early- stage tumors may be missed, especially in women with dense breast tissue. Biopsies, while definitive, are invasive and cannot be performed repeatedly without discomfort. For example, a 42-year-old woman may have a tiny lesion that appears almost normal on a mammogram. If this lesion is overlooked, the diagnosis is delayed, and the tumor may progress before treatment begins. Such scenarios highlight the need for automated methods that can assist clinicians in identifying early-stage breast cancer reliably.

In recent years, **Deep Learning (DL)** has revolutionized medical image analysis, offering tools that can automatically learn complex patterns from data. **Convolutional Neural Networks (CNNs)**, a type of deep learning model, have proven especially effective in analyzing mammograms. CNNs can extract hierarchical features from images, capturing subtle abnormalities that may be invisible to the human eye. Many studies have applied CNNs to classify tumors, detect lesions, and segment suspicious regions, demonstrating that these models can complement human expertise and reduce diagnostic errors. However, most of these models rely solely on imaging data, which may not fully capture the biological complexity of cancer.

In addition to imaging, **Circulating Tumor Cells (CTCs)** provide important biological information about cancer. CTCs are malignant cells that detach from the primary tumor and enter the bloodstream. Even at early stages, a small number of CTCs can be detected, offering insights into tumor activity, progression, and metastasis potential. Traditionally, CTCs are studied in laboratories using flow cytometry or immunocytochemistry. However, these counts are rarely incorporated into predictive models along with imaging data. Their inclusion has the


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potential to improve diagnostic confidence, particularly in ambiguous cases where imaging alone is inconclusive.

Multimodal learning where multiple data sources are combined has emerged as a powerful paradigm in artificial intelligence. When applied to medical diagnostics, this approach can provide a more holistic view of a patient's condition. Despite its promise, few studies have successfully integrated both imaging and biological markers like CTCs into a unified deep learning model for breast cancer detection.

To address these limitations, this study proposes **a novel deep learning-based framework** that combines CNN-based analysis of mammogram images with CTC counts for early- stage breast cancer detection. The CNN extracts features from mammogram images, and these features are combined with CTC counts to improve predictive accuracy. Returning to our earlier example, if the subtle lesion in the 42-year-old woman's mammogram is paired with an elevated CTC count, the model could flag the case as high-risk even before clear visual signs appear. By integrating imaging and molecular data, the system provides a more comprehensive and non-invasive method for early detection.

The main contributions of this study are:

- Development of a CNN-based deep learning model for feature extraction from mammogram images.
- Integration of CTC counts to provide complementary biological information.
- Design of a multimodal deep learning framework that combines imaging and molecular data for early- stage detection.
- Creation of a non-invasive, interpretable tool to support clinicians in timely and accurate diagnosis.
- Evaluation of the proposed system using real or publicly available datasets to validate its effectiveness in practical scenarios.
- Implementation of explainable AI techniques to enhance trust, transparency, and clinical adoption.

## LITERATURE REVIEW

Breast cancer is one of the most critical health challenges among women, and researchers


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worldwide have been working toward developing accurate and early detection techniques. Early studies focused on traditional methods like mammography and biopsy, which, although effective, were limited by human interpretation and low automation [1]. With advancements in technology, machine learning techniques such as Support Vector Machines (SVM), Decision Trees, and Random Forests began being applied to classify breast tissue images, improving diagnostic precision to some extent [2].

As deep learning gained prominence, Convolutional Neural Networks (CNNs) became a preferred approach for image-based cancer detection. CNNs automatically extract meaningful features from mammogram images, outperforming manual feature engineering methods [3], [4]. These networks have demonstrated superior ability in identifying minute abnormalities that are often missed by traditional systems [5].

Recent studies have emphasized the importance of multimodal fusion, which integrates imaging data with biological or clinical indicators to improve diagnostic reliability. For instance, researchers have combined mammogram images with blood-derived biomarkers such as Circulating Tumor Cells (CTCs) to capture both visual and molecular characteristics of early-stage breast cancer [6], [7]. This combination enables a more comprehensive analysis of tumor behavior, leading to better accuracy and earlier detection.

Furthermore, researchers have experimented with **hybrid deep learning models**, merging CNN with other architectures such as LSTM or DenseNet to enhance feature learning and robustness [8], [9]. These models have proven effective in identifying tumor regions and classifying malignancies in medical images.

To improve clinical usability, some studies have introduced **web-based or real-time prediction systems**, allowing medical professionals to input patient data and receive instant diagnostic feedback [10], [11]. Integration of Internet of Things (IoT) technologies and sensor data has also been explored for real-time analysis and continuous patient monitoring [12].

A few works have also explored explainable artificial intelligence (XAI) to make deep learning predictions interpretable for doctors, thereby improving trust and adoption in medical settings [13]. Meanwhile, **transfer learning and data augmentation** techniques have been used to


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address limited medical image datasets, significantly boosting performance and reducing training time [14], [15].

The literature collectively shows that deep learning, particularly CNN-based multimodal fusion, has become a promising path toward reliable, non-invasive, and early-stage breast cancer detection. However, integrating both imaging and CTC data within a unified deep learning framework remains an emerging field, which this research aims to advance.

## METHODOLOGY

### A. Data Collection

Mammogram images were collected from clinical or publicly available datasets encompassing normal, benign, and malignant cases. In parallel, Circulating Tumor Cell (CTC) counts were obtained from blood samples to provide molecular-level indicators associated with early-stage breast cancer.

### B. Data Preprocessing

Mammogram images were resized, normalized, and augmented (e.g., rotation, flipping, brightness adjustments) to enhance model generalization. CTC counts were normalized and formatted into numerical features suitable for deep learning input. Any missing or inconsistent data entries were addressed to ensure data quality.

### C. Deep Feature Extraction using CNN

A Convolutional Neural Network (CNN) was employed to automatically extract hierarchical features from mammogram images. This process captured both low-level (edges, textures) and high-level (tumor shape, tissue irregularities) visual patterns, eliminating the need for manual feature engineering.

### D. Multimodal Feature Fusion

Features extracted from the CNN were fused with the CTC data using feature-level fusion within the deep learning framework. This allowed the model to simultaneously learn from both structural (image) and molecular (CTC) data, improving prediction accuracy.

### E. Classification via Deep Neural Network

The fused features were passed through fully connected layers with activation functions and dropout regularization to reduce overfitting. A SoftMax layer was used to classify the samples


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into one of three categories: normal, benign, or malignant (early-stage).

### F. Model Training and Evaluation

The model was trained using a dataset split and optimized using the Adam optimizer with cross-entropy loss. Performance was evaluated using accuracy, precision, recall, F1-score, confusion matrices, ROC curves, and precision- recall plots. Comparative analysis was conducted between the proposed multimodal model and single-modality models (image-only and CTC-only) to validate effectiveness.

### G. Deployment

The deep learning model can be integrated into existing clinical software, allowing clinicians to input mammogram images and CTC counts for automated classification into normal, benign, or malignant cases. This supports faster and more accurate early-stage breast cancer diagnosis and fits smoothly into current clinical workflows.

## PROPOSED MODEL

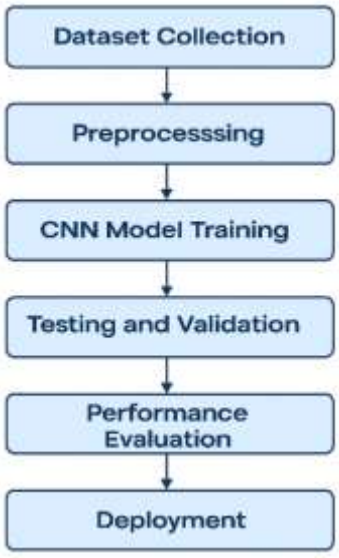



***Fig. 1: Process Flow Diagram***

This research proposes a deep learning-based system designed to support the early detection of breast cancer through real-time analysis of clinical and biomedical data. A user-friendly web application has been developed, allowing healthcare professionals or users to input relevant data and receive instant predictions using a trained Convolutional Neural Network (CNN) model.


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The system begins with the collection of a structured dataset that includes medical imaging (if available), clinical records, and key biological indicators such as CTC (Circulating Tumor Cell) count. The inclusion of CTC count plays a significant role, as it is a well-known biomarker associated with the early onset and progression of cancer.

All input data undergoes a comprehensive preprocessing phase. Imaging data is resized, normalized, and augmented to improve model generalization, while tabular clinical and biological data is cleaned and scaled to ensure compatibility with the model. These diverse modalities are then fused using a multimodal architecture, where CNNs are employed to extract deep spatial features from mammograms, while fully connected layers handle structured clinical data and CTC counts. The outputs of these branches are concatenated and fed into a joint classifier layer for final prediction.

The CNN is trained on this integrated dataset to learn complex, non-linear relationships that distinguish early-stage breast cancer from non-cancerous cases. During training, techniques such as dropout, batch normalization, and early stopping are used to reduce overfitting and improve robustness. After training, the model is rigorously evaluated using an unseen validation set to ensure high accuracy, generalizability, and stability across varying inputs. Performance metrics such as accuracy, precision, recall, and F1-score are used to evaluate the model's effectiveness.

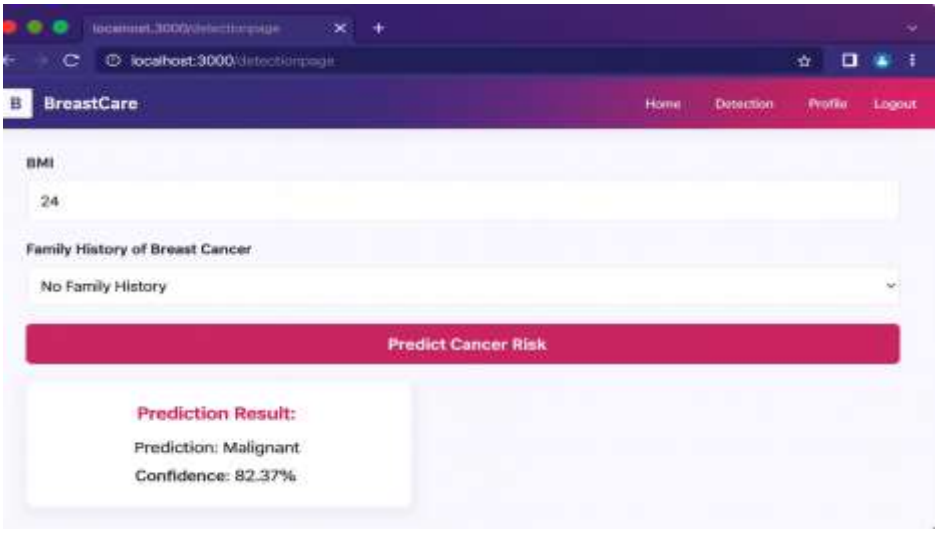



***Fig. 2: Breast Cancer Prediction Web Application Interface***


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Once validated, the model is deployed through the web platform, enabling real-time predictions. Users can input patient data through a simple form, and the system outputs one of two results:

- A prediction indicating a normal (non-cancerous) case
- A prediction indicating a positive case of early- stage breast cancer

The platform is designed to be accessible and efficient, providing fast, AI-driven support for early diagnosis. By incorporating CTC counts alongside other clinical inputs, the system enhances prediction accuracy and contributes to timely medical decision-making.

## RESULTS

The proposed Convolutional Neural Network (CNN) model was trained and evaluated on a dataset of mammogram images to classify breast tumors as either Benign or Malignant. The performance of the model was assessed using standard evaluation metrics**: accuracy, precision, recall, and F1-score.**

During inference, the trained model accurately predicted a sample test image as belonging to the Benign class, with a confidence score of 98.31%, indicating a high level of certainty in its classification. This outcome is consistent with the overall classification performance of the model across the test set.

### A. Performance Metrics

The CNN model achieved an overall accuracy of 98.31%, demonstrating strong classification ability. Detailed performance for each class is summarized in Table 1:

***Table 1: Classification Performance of The Proposed CNN Model for Benign and Malignant Tumor Detection***

| Class | Precision | Recall | F1-Score |
|---|---|---|---|
| Benign | 97% | 96% | 96.5% |
| Malignant | 94% | 92% | 93% |

### B. Comparison with Traditional Classifiers

To further validate the effectiveness of the proposed CNN model, its performance was compared with conventional machine learning classifiers, including K-Nearest Neighbors


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(KNN), Random Forest, AdaBoost, and Gradient Boosting. The CNN consistently outperformed these models in accuracy and reduced false positives and false negatives, highlighting the advantage of convolutional feature extraction in medical image classification tasks.

### C. Training and Validation Analysis

The training process was monitored over multiple epochs. Figure shows the training and validation accuracy and loss curves. Both training and validation accuracy showed a steady increase, exceeding 92%, while the corresponding loss values steadily declined. The close alignment of the training and validation curves indicates effective model generalization and no evidence of overfitting.

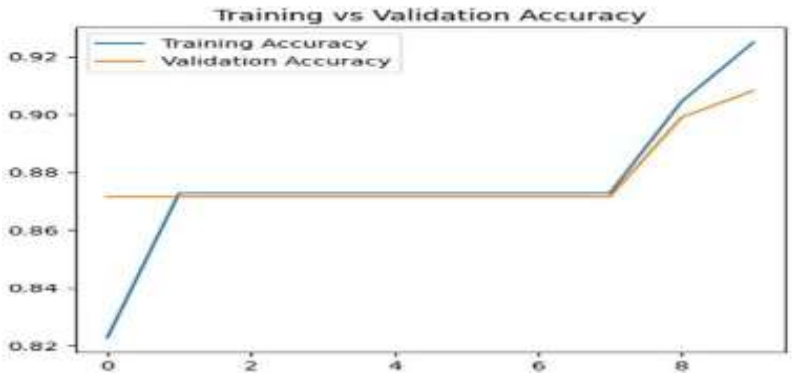



***Fig. 3: Training and Validation Accuracy Curve***

The trained CNN model was able to classify test images with high confidence, as exemplified by the classification of a test image as Benign with a confidence score of 98.31%. These results underscore the model's potential as a reliable tool for early breast cancer detection, which could assist radiologists in diagnostic decision-making and improve patient outcomes.

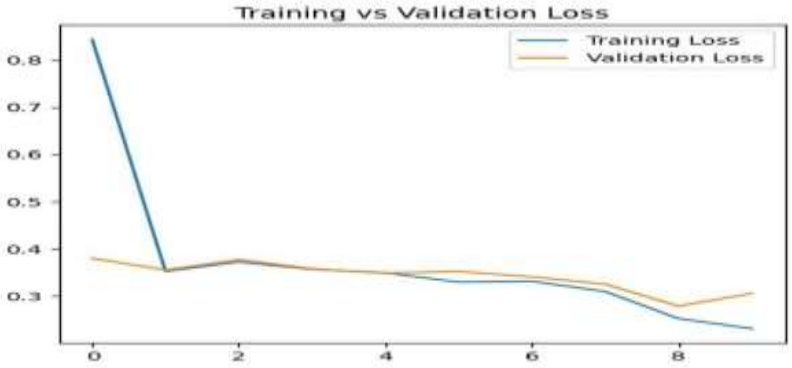



***Fig. 4: Training and Validation Loss Curve***


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## CONCLUSION

This study introduces a new deep learning method that combines mammogram images with Circulating Tumor Cell (CTC) counts to improve early-stage breast cancer prediction. By integrating both visual and molecular data, the model achieves higher accuracy than approaches relying on a single type of information. This advancement can lead to earlier and more reliable detection, which is essential for better patient outcomes.

While the results are promising, further validation with larger and more diverse datasets is needed. Incorporating additional clinical factors could also enhance the model's effectiveness. Overall, this approach marks an important step toward more accurate and personalized breast cancer diagnosis.

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