Contrat doctoral – ED Galilée

Titre du sujet : A Multimodal AI Framework for Enhanced Breast Cancer Detection and Diagnosis

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- Discipline : Traitement de l'information.
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- Domaine de recherche : Traitement et analyse d'images, Imagerie médicale.
- Mots clés : Breast Cancer, Detection, Diagnosis, AI, Deep Learning, Classification, Quality, Fusion.

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Breast cancer is the most diagnosed cancer and leading cause of cancer-related deaths among women globally, with the highest incidence in France [1]. Early diagnosis is crucial for improving survival outcomes. Common screening methods include mammography, ultrasound, and MRI. Computer-aided diagnosis (CAD) systems improve efficiency and reduce missed diagnoses. With growing medical data and imaging advancements, AI can significantly enhance breast cancer detection. However, existing AI models face challenges such as reliance on high-quality images, interpretability, and generalizability [2]. Real-world image imperfections can affect accuracy, requiring robust methods that perform well despite variable quality. Moreover, these models often focus on a single imaging modality, neglecting valuable sources like genomics and clinical data, which could improve diagnostic precision. Ensuring generalizability, enhancing interpretability, and validating these models are critical for achieving accurate, bias-free, and effective clinical use.

This study aims to develop a deep learning-based framework for more accurate and efficient breast cancer detection and diagnosis. A key challenge is interpreting heterogeneous data. Mammograms are more sensitive to calcifications than ultrasounds, while MRI excels in soft-tissue contrast for lesion characterization, but neither modality alone captures all diagnostically relevant features. Multimodal AI systems, combining data from mammography, MRI, DBT [3], and data beyond imaging, could revolutionize precision oncology by enabling [2]:
i) Robust image enhancement: employing deep learning-based restoration to address noise, motion artifacts, and low contrast.
ii) Cross-modal feature fusion: Capturing tumor heterogeneity across modalities [4].
iii) Explainable malignancy prediction: Providing stage-specific classifications with interpretable decision pathways, thereby enhancing the transparency and trust in predictions [5].

This thesis develops an end-to-end AI framework integrating three key innovations:

- **Modality-Specific Enhancement Networks:** To improve the diagnostic quality of degraded images.
- **Hierarchical Multimodal Fusion Architectures**: For joint analysis of DBT, MRI, and pathology images.
- **Uncertainty-Aware Classification Models** [6], [7]: To predict malignancy risk, tumor stage (TNM), and molecular subtypes, incorporating uncertainty for better clinical accuracy.

This research project will be supervised by Dr. Marie LUONG (HDR, L2TI) and co-supervised by Dr. John CHAUSSARD (LAGA), in collaboration with Avicenne Hospital (Prof. Laurent ZELEK, in connection with the radiologists at Jean-Verdier Hospital), as well as the Ho Chi Minh City University of Technology – VNU-HCMUT (Prof. Tien Thuong LE).

References

[1] Bray F., Laversanne M., Sung H., Ferlay J., Siegel R. L., Soerjomataram I., & Jemal A. "Global cancer statistics 2022: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries". CA Cancer J Clin. 2024 May-Jun;74(3):229-263.
[2] Luyang Luo, Xi Wang, Yi Lin, Xiaoqi Ma, Andong Tan, Ronald Chan, Varut Vardhanabhuti, Winnie CW Chu, Kwang-Ting Cheng, Hao Chen. " Deep learning in breast cancer imaging: A decade of progress and future directions". IEEE Reviews in Biomedical Engineering. 2025. Vol 18:130-151.
[3] Chong A, Weinstein SP, McDonald ES, Conant EF. "Digital breast tomosynthesis: concepts and clinical practice". Radiology 292.1 (2019): 1-14.
[4] Nakach, Fatima-Zahrae, Ali Idri, and Evgin Goceri. "A comprehensive investigation of multimodal deep learning fusion strategies for breast cancer classification." Artificial Intelligence Review 57.12 (2024): 327.
[5] Gulum, Mehmet A., Christopher M. Trombley, and Mehmed Kantardzic. "A review of explainable deep learning cancer detection models in medical imaging." Applied Sciences 11.10 (2021): 4573.

[6] Kendall, Alex, and Yarin Gal. "What uncertainties do we need in bayesian deep learning for computer vision ?." Advances in neural information processing systems 30 (2017).
[7] T. Zhou, Y. Zhou, G. Li, G. Chen and J. Shen. "Uncertainty-aware hierarchical aggregation network for medical image segmentation". IEEE Transactions on Circuits and Systems for Video Technology, vol. 34, no. 8, pp. 7440-7453, Aug. 2024.