HybridCN-NAS: Precision Acute Leukemia Diagnosis Using Multi-Head Self-Attention Framework

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Abstract

Acute lymphoblastic leukemia classification poses a significant diagnostic challenge, requiring accurate differentiation between benign hematogones and malignant lymphoblast subtypes. This study presents a novel four-phase deep learning framework for automated peripheral blood smear image analysis. It integrates Reinhard stain normalization, CLAHE contrast enhancement, Attention U-Net segmentation, and a HybridCN-NAS feature extractor combining ConvNeXt and NASNet Large architectures. Multi-head self-attention classification was applied to 3,256 images from 89 patients across four cellular classes. Additional components include multiscale enhancement, watershed segmentation, z-score normalization, and mRMR feature selection. The model achieved 99.92% accuracy, 99.64% AUC, and 99.79% MCC. A web-based diagnostic system provides real-time, interpretable, confidence-weighted predictions.

Introduction

Cancer remains one of the most formidable medical challenges globally, with leukemia accounting for 487,294 incident cases and 305,405 annual deaths, according to the International Agency for Research on Cancer [1]. This hematologic malignancy arises from abnormal white blood cell proliferation and is classified by progression rate (acute/chronic) and cellular lineage (lymphocytic/myelogenous), complicating pathological diagnosis [2]. While deep learning techniques have advanced leukemia detection, most current models rely on single-cell datasets that fail to capture the complexity of real-world multi-cell peripheral blood smear environments. Addressing this limitation, we propose a deep learning framework that integrates attention-based segmentation, hybrid feature extraction, and multi-head self-attention mechanisms, specifically designed to manage the diagnostic challenges of multi-cell microscopic image analysis in leukemia classification.

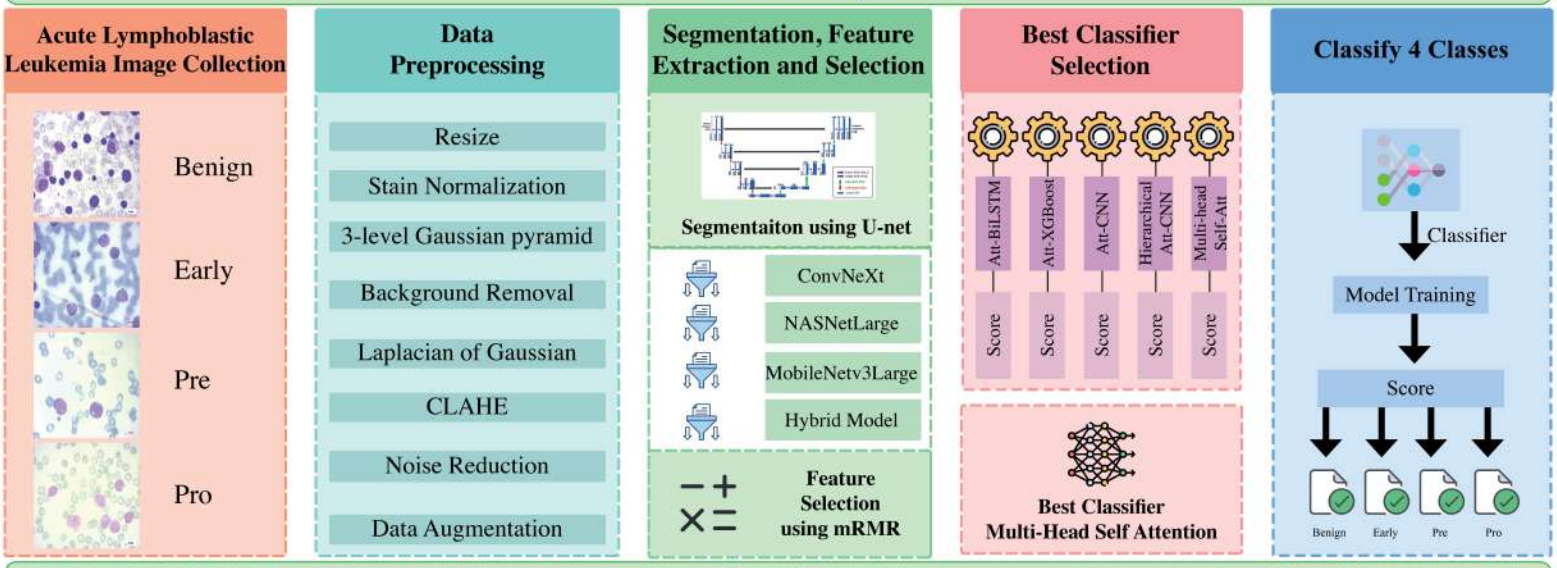
Problem Statement

- Inadequate discrimination of benign hematogones vs. malignant lymphoblasts in multi-cell peripheral blood smears
- Insufficient hierarchical feature extraction capturing global-local cellular morphology
- Lack of interpretable decision mechanisms for clinical validation
- Absence of scalable real-time diagnostic deployment infrastructure

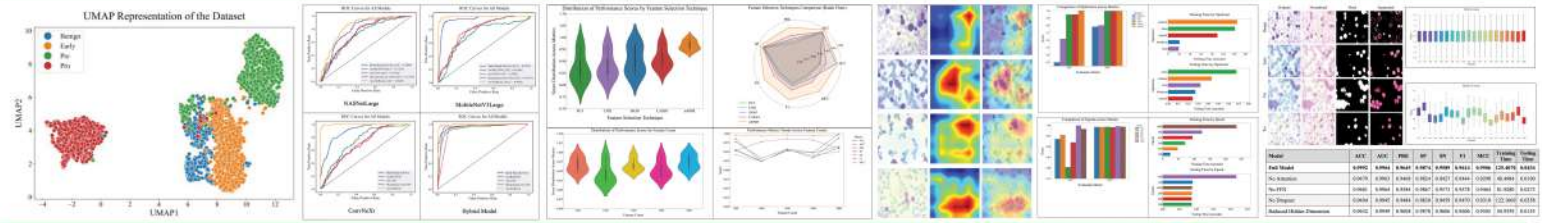
Objectives

- Develop four-phase framework: attention-based segmentation + HybridCN-NAS + multi-head self-attention
- Achieve >99% accuracy via mRMR feature selection and 2000-dimensional optimization
- Deploy web-based system with real-time classification and attention visualization
- Validate through ablation studies and statistical testing (t-tests, Wilcoxon)

Methodology



Results



Conclusion

The HybridCN-NAS framework with multi-head self-attention achieved exceptional classification performance (99.92% ACC, 99.64% AUC, 99.79% MCC) in differentiating benign hematogones from malignant lymphoblasts across 3,256 peripheral blood smear images. Validated through statistical analysis and deployed as a web-based clinical system, this robust diagnostic model advances automated leukemia detection with practical implications for pathological workflows.

Future Work

Future work will focus on expanding the dataset with multi-center validation to ensure broader clinical generalizability and integrating molecular biomarker data with image analysis for comprehensive multimodal diagnostic predictions. Additionally, we aim to develop patient-specific treatment recommendation systems that leverage longitudinal microscopic image analysis to monitor treatment responses and disease progression in real-time clinical settings.

References

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