

Robust Leukocyte Segmentation Under Variable Staining and Illumination Conditions **Using a Hybrid Deep-Learning Framework**

1. Introduction

Accurate leukocyte segmentation is essential for automated blood cancer screening. However, variations in staining quality, illumination, and microscope settings significantly reduce segmentation accuracy in real-world images. Current deep-learning models show high performance on controlled datasets but lack robustness across diverse imaging conditions. This research proposes a hybrid framework combining classical image processing with deep learning to achieve consistent leukocyte segmentation under varied conditions.

2. Problem Statement

Existing segmentation models are highly sensitive to stain inconsistency, uneven lighting, noise, and slide preparation artifacts. There is a need for a generalizable segmentation approach that maintains stability and accuracy across diverse sample conditions.

3. Objectives

- Develop a preprocessing pipeline using classical image processing for color normalization and illumination correction.
- Design an adaptive deep-learning segmentation model optimized for variable staining conditions.
- Integrate both modules into a hybrid framework for robust leukocyte segmentation.
- Evaluate performance across multiple public and real-world datasets.

4. Methodology

Data: Public datasets (ALL-IDB, Raabin-WBC, BCCD, C-NMC) and clinical images (subject to approval).

Preprocessing: Illumination correction (Retinex, homomorphic filter), stain normalization (Macenko/Reinhard), noise removal, morphological refinement.

Deep Learning Model: U-Net/Attention U-Net/Swin Transformer variants, domain adaptation, stain-invariant feature learning.

Hybrid Integration: Classical preprocessing, adaptive DL segmentation, post-processing refinement.

Evaluation Metrics: Dice, IoU, Sensitivity, Specificity, Boundary F1.

5. Expected Outcomes

- A robust, generalizable leukocyte segmentation system.
- Improved performance under real-world staining/illumination variations.
- Prototype tool for clinical use and publications in reputed journals.

6. Significance

The proposed work enhances reliability of automated leukemia screening, supports pathologists, and enables scalable diagnostics in resource-limited environments.