

ABSTRAK

Penelitian ini menyoroti pentingnya tahapan praproses citra dalam meningkatkan akurasi klasifikasi foraminifera mikroskopik, aspek yang sering diabaikan dibandingkan fokus pada arsitektur model atau pemanfaatan model pra-latih. Foraminifera merupakan mikroorganisme laut yang berperan besar dalam studi paleoklimatologi dan biostratigrafi. Namun, klasifikasi otomatis terhadap foraminifera masih menghadapi tantangan karena kemiripan morfologi antarspesies dan kualitas citra mikroskopis yang rendah. Untuk mengatasi hal tersebut, penelitian ini mengusulkan pendekatan praproses berjenjang yang terdiri dari tiga tahap utama, yaitu segmentasi, penajaman, dan perbaikan kontras, dengan tujuan meningkatkan kejelasan objek, mempertajam detail morfologi, serta menyeimbangkan distribusi intensitas citra.

Tahap segmentasi diterapkan untuk memisahkan objek foraminifera dari latar belakang menggunakan empat metode yang diuji, yaitu Otsu Thresholding, Adaptive Gaussian Thresholding, K-Means Clustering, serta kombinasi Adaptive Gaussian Thresholding dengan Otsu. Tahap penajaman dilakukan untuk memperjelas tepi dan tekstur citra menggunakan Unsharp Masking (USM), Local Laplacian Filtering (LLF), High-Frequency Emphasis (HFE), dan Adaptive Bilateral Filter (ABF). Sementara itu, perbaikan kontras diterapkan untuk menormalkan pencahayaan dan menonjolkan struktur visual menggunakan Histogram Equalization (HE), Adaptive Histogram Equalization (AHE), Contrast Limited Adaptive Histogram Equalization (CLAHE), Multi-Scale Retinex (MSR), dan Single-Scale Retinex (SSR).

Dari setiap tahap, dipilih satu metode terbaik berdasarkan pengaruhnya terhadap performa klasifikasi menggunakan skema k-fold cross-validation. Hasil penelitian menunjukkan bahwa kombinasi terbaik diperoleh dari segmentasi dengan Adaptive Gaussian Thresholding Overlap Otsu yang meningkatkan akurasi sebesar 1,32%, penajaman menggunakan LLF sebesar 2,10%, dan perbaikan kontras dengan CLAHE sebesar 0,90%. Secara keseluruhan, penerapan ketiga tahapan praproses tersebut meningkatkan akurasi model CNN (ResNet50, ResNet101, DenseNet121, dan VGG19) sebesar 4,3–5,55%, presisi 3,8–6,14%, recall 0,67–9,1%, dan F1-score 1,9–8,6%. Pendekatan ini terbukti mampu memperbaiki kualitas visual citra sekaligus mempertahankan fitur morfologi penting, sehingga memberikan kontribusi nyata terhadap peningkatan performa sistem klasifikasi foraminifera berbasis deep learning.

Kata kunci: Foraminifera, praproses citra, segmentasi, penajaman citra, perbaikan kontras, *convolutional neural network* (CNN), *Local Laplacian Filter*.

ABSTRACT

This study highlights the importance of image preprocessing in improving the accuracy of microscopic foraminifera classification, an aspect often overlooked compared to the focus on model architecture or the use of pre-trained models. Foraminifera are marine microorganisms that play an important role in paleoclimatology and biostratigraphy studies. However, their automatic classification still faces major challenges due to morphological similarities among species and the poor quality of microscopic images. To address these issues, this research proposes a multistage preprocessing approach comprising segmentation, sharpening, and contrast enhancement to enhance object clarity, emphasize morphological details, and balance the image intensity distribution.

The segmentation stage was applied to separate foraminiferal objects from the background using four tested methods, namely Otsu Thresholding, Adaptive Gaussian Thresholding, K-Means Clustering, and a combination of Adaptive Gaussian Thresholding with Otsu. The sharpening stage was used to enhance edges and surface textures through Unsharp Masking (USM), Local Laplacian Filtering (LLF), High-Frequency Emphasis (HFE), and Adaptive Bilateral Filter (ABF). Meanwhile, contrast enhancement was performed to normalize illumination and highlight visual structures using Histogram Equalization (HE), Adaptive Histogram Equalization (AHE), Contrast Limited Adaptive Histogram Equalization (CLAHE), Multi-Scale Retinex (MSR), and Single-Scale Retinex (SSR).

From each stage, the best-performing method was selected based on its impact on classification performance using a k-fold cross-validation scheme. The results showed that the optimal preprocessing combination consisted of segmentation using Adaptive Gaussian Thresholding Overlap Otsu, which improved accuracy by 1.32%, sharpening using LLF by 2.10%, and contrast enhancement using CLAHE by 0.90%. Overall, the implementation of these three preprocessing stages increased the accuracy of CNN models (ResNet50, ResNet101, DenseNet121, and VGG19) by 4.3–5.55%, precision by 3.8–6.14%, recall by 0.67–9.1%, and F1-score by 1.9–8.6%. This approach not only enhances the visual quality of the images but also preserves essential morphological features, demonstrating that a well-structured preprocessing strategy contributes significantly to improving the performance of deep learning-based foraminifera classification systems.

Keywords: Foraminifera, image pre-processing, segmentation, image sharpening, contrast enhancement, *convolutional neural network* (CNN), *Local Laplacian Filter*