

Editorial

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AI in microscopy: shaping the future of imaging

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Microscopy has long been an indispensable tool for biological and materials science research, profoundly transforming our understanding of complex biological structures and processes. With recent advances in imaging technology, the scale and complexity of microscopy datasets have grown dramatically, leading to significant analytical challenges. Artificial Intelligence (AI), particularly through deep learning, has emerged as a groundbreaking solution, enabling researchers to extract detailed insights from vast amounts of multidimensional imaging data with unprecedented speed and accuracy.

AI has become crucial in microscopy due to its capacity to handle vast and complex datasets that traditional analysis methods find overwhelming. High-throughput imaging techniques generate terabytes of data, often spanning multiple imaging modalities and dimensions. Traditional manual and semi-automatic analysis methods are labor-intensive, subject to human bias, and struggle to maintain consistency across varied imaging conditions. In contrast, AI, particularly deep learning models, can efficiently process and interpret these massive datasets, automating tasks such as image segmentation, feature detection, classification, and enhancement. This not only improves accuracy and reproducibility but also greatly accelerates the pace of scientific discovery and innovation, enabling analyses previously deemed impractical.

This special issue of *Methods in Microscopy* showcases cutting-edge research that illustrates the transformative impact of AI on microscopy techniques. Bhattiprolu provides a comprehensive overview of how AI-driven methods are reshaping microscopy workflows, moving beyond traditional analytical bottlenecks and highlighting real-world applications where AI has significantly accelerated scientific discovery.

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Addressing the challenge of limited training data, Volman Stern et al. introduce an innovative workflow using generative AI techniques (Vector Quantised-Variational AutoEncoder combined with PixelCNN) to produce synthetic microstructure images along with precise segmentation masks. This approach significantly reduces the dependency on extensive labeled datasets and demonstrates marked improvements in segmentation accuracy, presenting a promising generalizable solution across various microscopy modalities.

Bukka et al. explore the powerful capabilities of deep-learning-based resolution recovery methods applied specifically to X-ray Microscopy images. Their novel algorithm (DeepNet) effectively learns spatially varying point spread functions, surpassing classical and existing deep-learning benchmarks by successfully recovering high-resolution details even under substantial degradation conditions, thus facilitating accurate, high-quality analyses in both simulated and real microscopy scenarios.

Jeremias and Pape revisit the critical task of object counting in biomedical imaging by proposing the STACC method, which integrates object size into a density-based regression framework. Their method outperforms current state-of-the-art segmentation and detection-based counting approaches and is further complemented by an intuitive, user-friendly tool designed for broad practical applications in cell and microbial counting tasks.

Bon et al. introduce μ PIX, a personalized generative adversarial network (GAN) that addresses low image quality of old microscopes. By significantly enhancing image signal-to-noise and binary segmentation accuracy, μ PIX demonstrates the ability to rejuvenate aging microscopy equipment, providing a sustainable, cost-effective alternative to hardware upgrades. This generative deep learning approach not only restores image quality but also maintains critical quantitative imaging fidelity, fostering longevity of microscopes and continued innovation on AI applied to microscopy.

Lastly, Jansche et al. deliver a thorough review of deep learning-based image super-resolution techniques specifically tailored for light and electron microscopy. Their structured analysis covers a broad spectrum of architectures, evaluation metrics, and application examples across multiple microscopy techniques, including

fluorescence and scanning electron microscopy. This comprehensive overview highlights current advancements, identifies existing methodological challenges, and provides practical guidance for method selection, underscoring the ongoing evolution and immense potential of AI-driven microscopy.

The articles in this issue collectively emphasize AI's critical role in advancing microscopy technologies and

methodologies. By automating complex analytical tasks, enhancing image quality, and reducing data acquisition limitations, AI stands poised to significantly broaden the horizons of microscopic research. We extend our sincere thanks to all authors and reviewers who contributed their expertise and efforts, and we invite the scientific community to engage deeply with these innovations to further accelerate discoveries in microscopy.