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Machine Learning Microscopy Analysis for Rapid Sample Biogeochemical Assessment: Applications from Agricultural Soils to Exobiology

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Optical microscopy is one of the oldest methods for assessing microbiology and microscopic features of soil and mineral samples. Despite its utility, adoption in modern biochemical analytical workflows has been limited by intensive time requirements, specialized training needs, and the increasing availability of alternative methods leveraging specialized equipment such as qPCR, XRD, XRF, and Raman spectroscopy. Recent advances in semiconductor technology, computational capacity, and machine learning algorithms greatly reduce the operating costs and expertise requirements associated with optical microscope analyses. This work explores the viability of using neural network computer vision methods with optical microscopy methods for rapid, automated measurement of soil bacterial and fungal biomass along with rapid estimation of carbon content. We developed a low-cost automated robotic system for sample collection, microphotography, and embedded analysis, fulfilling the requirements of the University Rover Challenge ‘Science Mission.’ Our results demonstrate the broader utility of automated optical microscopy methods in scalable biogeochemical assessment under hardware constraints, with applications ranging from agricultural soil analysis to potential deployment in planetary exploration.