LSGI RESEARCH SEMINAR

Advancing 3D Remote Sensing Inversion: Gradient-Based and Differentiable Radiative Transfer Models for Retrieving Optical, Thermal, and Biochemical Properties

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ABSTRACT

Retrieving accurate land surface properties from satellite imagery is frequently hindered by the presence of mixed pixels and the complex three-dimensional (3D) heterogeneity of urban and vegetation scenes. Traditional one-dimensional models and linear unmixing techniques often fail to account for macroscopic multiple scattering, shadow effects, and non-isothermal conditions. This presentation synthesizes three novel, physics-based methodologies (i.e., US-DART, TRUST-DART, and DRTM) that use 3D radiative transfer (RT) and gradient-based optimization to resolve these inverse problems across the shortwave and thermal infrared (TIR) domains. US-DART (Unmixing Spectral method using DART) is a nonlinear model designed for the shortwave domain. By integrating the Discrete Anisotropic Radiative Transfer (DART) model with a 3D mock-up of the scene, US-DART iteratively refines the optical properties (reflectance and transmittance) of specific scene components (e.g., roofs, roads, canopy) within mixed pixels. Validated against Sentinel-2 and PlanetScope imagery in Basel and Brussels, US-DART effectively addressing spectral confusion in complex urban environments. TRUST-DART (Thermal Remote sensing Unmixing for Subpixel Temperature and emissivity) extends this framework to the TIR domain. Addressing the challenge of non-isothermal pixels, this method simultaneously separates component temperature and emissivity by accounting for the cavity effect and urban geometry. Using ASTER and ECOSTRESS data, TRUST-DART demonstrates high accuracy in retrieving Land Surface Temperature (LST) and Emissivity (LSE) components, providing critical data for urban heat island monitoring and energy balance studies. The Differentiable Radiative Transfer Model (DRTM), a next-generation approach utilizing differential path tracing and automatic differentiation within the Mitsuba 3 framework. Unlike traditional look-up tables or numerical gradients, DRTM calculates analytical derivatives of the loss function, enabling highly efficient, GPU-accelerated retrieval of leaf optical properties, biochemical contents (e.g., chlorophyll, carotenoids), and sensor observation angles. Validated against RAMI benchmarks and in-situ maize campaigns, DRTM proves robust for converting canopy-level observations to foliar-level biochemical traits.

BIOGRAPHY

Prof. ZHEN is an Associate Professor of Geographic Information Systems at Jilin University, specializing in 3D vegetation modeling and radiative transfer simulation. He holds a joint Ph.D. in Geomatics Engineering from Jilin University and the University of Toulouse (France), where he also worked as a postdoctoral researcher. Prof. ZHEN has authored more than 20 SCI-indexed papers in journals such as Remote Sensing of Environment and ISPRS Journal of Photogrammetry and Remote Sensing. He currently leads a National Natural Science Foundation of China Youth Project and serves as the Deputy Secretary-General of the Jilin Province Remote Sensing Society.

Moderator:
Prof. Tiangang YIN, Assistant Professor, LSGI

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