

AI-BASED HIGH-RESOLUTION

WHAT IS IT ABOUT?

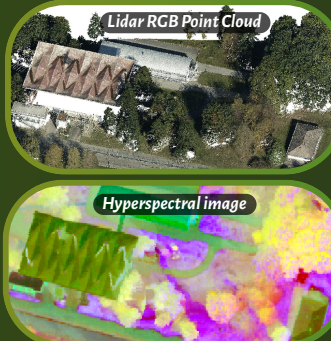
Forestry

- Ecosystems
- Tree health
- Sustainable land use

Artificial Intelligence

- Big data processing
- Fast insights
- Automatic inferences

Together, the mix of forestry and artificial intelligence creates a powerful synergy that combines ecological expertise with advanced data processing, opening the door to smart forestry approaches where forests can be monitored, mapped, and modeled with unprecedented accuracy, efficiency, and scale.



WHY DOES IT MATTER?

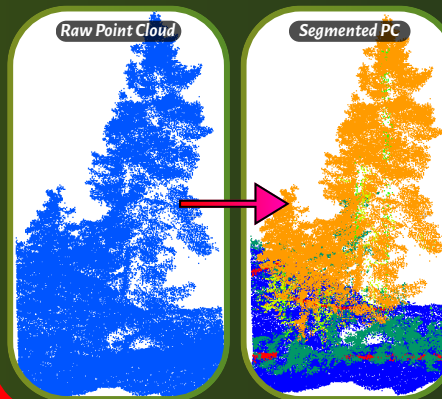
Traditional forestry studies rely mainly on satellite imagery — good for broad coverage, but limited in spatial and spectral resolution. With aircrafts, drones, and terrestrial platforms, we can now capture **3D point clouds at high resolution** (>100 pts/m²) and **hyperspectral imagery** (<1 m of ground sample distance). High-resolution datasets reveal details that satellites simply cannot: **individual tree species, fine-scale forest structure, precise ecosystem dynamics**. When combined with AI, these rich datasets unlock unprecedented potential for **smarter forest monitoring, accurate inventory and resource planning, and detailed ecosystem modeling**.

HOW CAN WE DO THAT?

The way we analyze forests depends on the type and resolution of the data available. With aircrafts, drones, and terrestrial sensors such as LiDAR and hyperspectral cameras, we obtain high-resolution, 3D data that allow us to move from general forest cover to detailed structural and species-level information. By applying AI-driven methods to these rich datasets, this study explores three complementary tasks:

1. **Forest Semantic Segmentation** — distinguishing ground, low vegetation, trunks, branches, foliage, and woody debris using very high-resolution multispectral LiDAR.
2. **Individual Tree Detection** — delineating trees in both 2D and 3D, and assessing how geometric resolution influences accuracy.
3. **Tree Species Classification** — combining hyperspectral imagery with tree delineation to identify species using machine learning models.

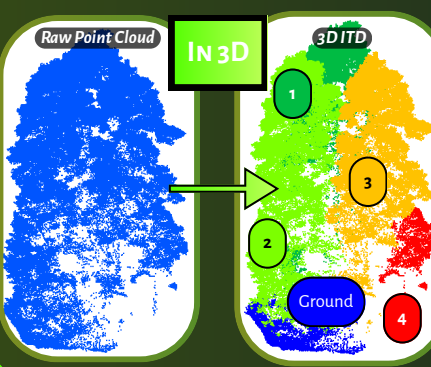
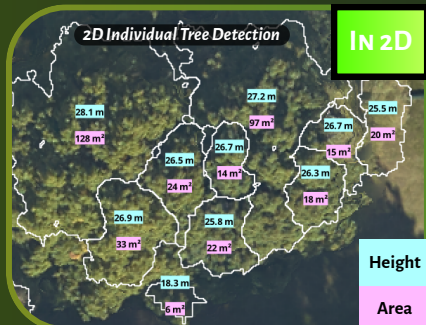
FOREST SEMANTIC SEGMENTATION



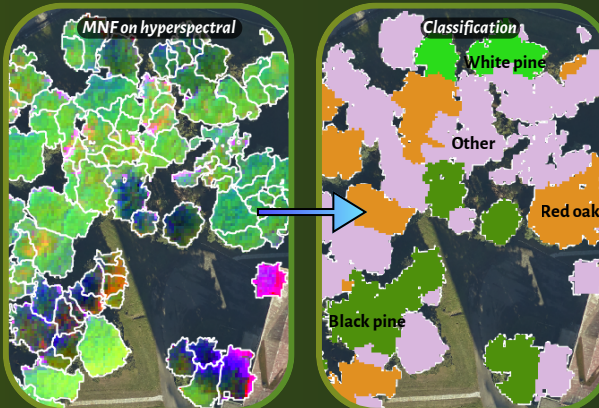
This task becomes achievable when high-resolution multispectral LiDAR exposes the **full 3D structure of the forest**. With point densities over **hundreds of points per square meter**, LiDAR captures **ground, low vegetation, trunks, branches, foliage, and woody debris**. Using deep learning models (from KPConv and ForAInet), each point in the cloud is automatically classified into these categories. The resulting segmentation enables the extraction of detailed forest attributes, providing a comprehensive and data-driven description of forest ecosystems.

INDIVIDUAL TREE DETECTION

Individual Tree Detection (ITD) is achievable with LiDAR data, and the level of detail depends directly on the point density. When the density is low, trees can only be delineated in **2D** from canopy surfaces using a **watershed algorithm**. For high densities, full **3D** delineation becomes possible, capturing the entire tree structure (**3D learning-based methods**). Useful forest attributes such as **tree count, tree height, and crown area** can be extracted, providing detailed information on forest composition and structure. This makes ITD a fundamental step toward precise data-rich forest inventories.



TREE SPECIES CLASSIFICATION



Tree species can be identified if **hyperspectral imagery** is available, capturing hundreds of narrow spectral bands that reveal subtle differences in leaf and canopy reflectance. To handle this complexity, the data are reduced using **Minimum Noise Fraction (MNF)** — a PCA-like process that preserves essential spectral information while minimizing noise. The reduced hyperspectral features are then coordinated with **2D ITD results** and **ground truth species labels**, and classified using a **Random Forest model**. This approach enables reliable species-level mapping, adding a critical ecological dimension to forest inventories by linking spectral diversity to biological diversity.

SO, WHAT DID WE LEARN?

Combining AI with high-resolution geospatial data unlocks new possibilities for forestry, enabling detailed analysis of **forest structure, composition, and dynamics**. These advances support more **objective, adaptive, and sustainable forest management**, compared to satellite data resolution models.

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<https://3dom.fbk.eu>

<https://github.com/3DOM-FBK/3D3>