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Context-Aware 3D Deep Learning for Individual Tree Inventory from Terrestrial LiDAR

Forests face mounting pressures from climate change, requiring precise monitoring to understand how they're changing. Traditional forest inventory – where foresters measure trees one by one with tapes and notebooks – is exhausting work that can take months to cover even small areas. While satellites help by photographing forests from above, they only capture the canopy, missing the tree trunks and undergrowth that tell us about forest health and biodiversity.

A breakthrough technology called Terrestrial Laser Scanning (TLS) is transforming how we study forests. These scanners emit millions of laser pulses per second, creating detailed 3D maps of everything around them – every trunk, branch, and shrub captured with millimeter precision. In minutes, they collect more information than field teams could gather in weeks. However, this creates a new challenge: massive clouds of millions of 3D points that need sophisticated analysis to reveal which points belong to which tree and what species each tree represents.

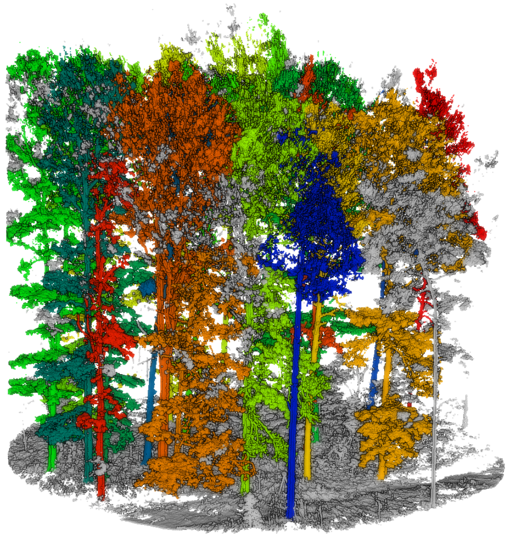

Figure 1: Manually segmented trees from TLS data we will use to train Deep Learning models

This is where artificial intelligence enters the picture. Our project develops deep learning systems – similar to those that recognize faces in photos – to automatically identify individual trees and their species from these complex 3D point clouds. But forests are far more intricate than urban environments where such AI typically operates. Trees intertwine, branches overlap, and dense vegetation creates ambiguities that challenge even the most advanced algorithms.

Our innovation lies in combining AI with decades of forestry expertise. Polish State Forests maintain digital maps containing rich information about every forest stand – soil conditions, elevation, moisture levels, and known species distributions. We're teaching our AI to use this knowledge, just as experienced foresters know that oaks prefer certain soils while spruces thrive in others. This fusion of modern technology with existing knowledge makes our approach uniquely powerful.

We're also implementing hierarchical classification that mirrors how botanists identify trees. When the AI is confident, it can identify the exact species. When uncertain, it provides broader classifications – distinguishing conifers from broadleaf trees, or identifying the genus rather than forcing a species guess. This approach ensures reliable results even when data quality varies.

Our research builds on a new and unieque dataset we developed: 10,000 individual trees from Polish forests, each manually segmented by experts. This unprecedented resource allows us to train AI systems that work reliably across different forest types and conditions. The impact will be transformative. Instead of sporadic surveys every decade, forest managers will be able to have frequent, detailed assessments of their forests. They'll be able to track individual tree growth, detect diseases early, and observe real-time responses to climate change. This isn't just about efficiency – it's about having the precise information needed to make informed decisions about forest conservation and management.

By bridging cutting-edge 3D sensing, artificial intelligence, and traditional forestry knowledge, we're creating tools for a new era of forest monitoring. As forests become increasingly vital for climate regulation and biodiversity conservation, these technologies ensure we can understand and protect them with unprecedented precision and scale.