Large-scale 3D reconstruction of forest canopy from aerial and satellite imagery

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1. Context

Estimating the height of the forest canopy is indicative of the biomass content and as such it is a key parameter in monitoring climate change and ensuring sufficient carbon stocks worldwide [1]. In France, where nearly half of the renewable energy is extracted from wood [2], efficient management and monitoring of forest growth is crucial.

On a global scale, dedicated missions such as the ICESat GLAS or NASA's GEDI LiDAR instruments deliver canopy height prediction at low resolution (e.g. 1 km grid) [4]. The latter coupled with a Sentinel-2 image can enhance the spatial resolution of the product by a factor of 40 (or ~25m pixel size). The global height canopy model produced in this way is unprecedented, with two caveats: (1) sensors' geolocation inaccuracies can induce height errors, and (2) the prediction model is trained on sparse data points, thus it is insensitive to high frequency height changes [4].

At national level, high-resolution airborne LiDAR remains the most robust but also expensive technique to map forest canopies. In the past few years photogrammetry (aerial and satellite) has attracted increased attention as a cost-effective alternative to LiDAR [3,5]. The major limitation impeding photogrammetry from being considered on par with LiDAR is its limited robustness in predicting the geometry from stereo matching over vegetated scenes.

The traditional stereo matching techniques assume that corresponding image pixels are similar, while vegetation is characterised by highly anisotropic reflectance functions hence violates this principle. The way leaves are captured in the images depends on many factors, including the Sun's position, the camera's viewpoint, local surface roughness and physical parameters such as humidity. The best performing learning-based matching methods, although technically capable of learning any similarity function, are mainly focused on urban environments and reconstruction of man-made structures. This, on the one hand, is driven by the autonomous car industry and on the other hand by the lack of available benchmark datasets to compare to.

2. Objective

The main goal of this thesis is to develop a novel multi-view stereo matching method adapted to 3D surface reconstruction of forest canopies. Relying on purely visual cues to compare pixel patches in images is not sufficient for precise and robust prediction of canopy surfaces (cf. Figure 1). We will therefore turn towards learning based methods to implicitly learn the correspondence between patches. To adapt to the specificity of the forest canopy we address the following issues:

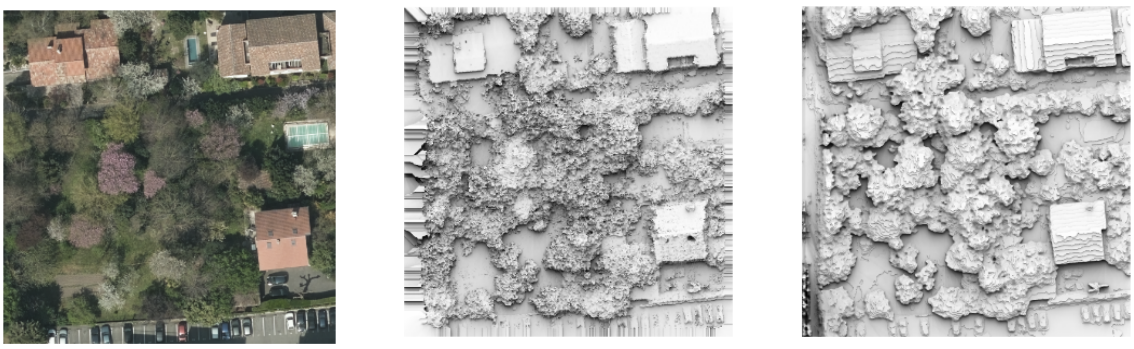
- Separation of the patch representation learning from the depth prediction to **maintain good transferability** to unseen scenes. In other words, we will favour a hybrid approach to an end-to-end pipeline.
- Incorporation of physical parameters in the model as much as possible. For instance, by considering the Sun's position **we will take into account the directional dependence** of the surface reflectance.
- **Increase of robustness** of the depth predictions through multi-view. Best state-of-the-art methods in stereo matching use exclusively pairs of images.

To this end, we tentatively define the matching task along the following points:

1. Learning discriminative and multi-resolution representations with any off-the-shelf convolutional neural network [6].
2. Augmenting those with a priori knowledge such as base-to-height ratio, the Sun's position, the camera viewpoint.
3. Aggregation of multi-view patch representations, for instance with Vision Transformers framework [7].

The (1-3) will be learnt end-to-end, while the depth prediction from aggregated representations will be left to the classical optimization such as semi-global-matching.

Datasets: Our prediction models will be conceived and validated on simultaneous LiDAR and airborne image acquisitions provided by IGN. We will also consider generating simulated 3D and images using the DART simulator [8]. To further push the research in canopy surface reconstruction we will aim at releasing an open benchmark dataset.



(a) RGB image (b) traditional SGM (c) end-to-end learning approach

Figure1. Forest canopy surface, two-view reconstruction. The traditional SGM provides more detailed but noisy predictions, while the learning-based method oversimplifies the canopy shapes. Credit Wu-Teng.

3. Relation to other works in the lab

This work is closely related to two on-going projects :

- 2020-2023, *Similarity learning with convolutional neural networks applied to dense image matching*, PhD Mohamed Ali-Chebbi (IGN-Thales) supervised by MPD and ER where we develop stereo-matching methods for surface reconstruction in urban areas using satellite images. **The PhD thesis on forest canopy reconstruction will be a continuation of work developed in the ongoing doctorate.**
- 2022-2024, *Physics-based photogrammetry for Earth-science applications*, PostDoc Lulin Zhang (IPGP-IGN) supervised by ER and MPD where we develop methods to model realistic surface BRDF from high-resolution satellite imagery through the Neural Radiance Fields (NeRFs) representation. **The PhD thesis on forest canopy reconstruction will benefit from findings of this PostDoc regarding surface reflectance.**

4. Applications / impact

Completing the PhD project could leverage the following applications:

- Cost-effective monitoring of carbon stocks at the national (with airborne imagery) or even global (high-resolution satellite images) scale.
- Images together with reliable geometry of the forest canopy can contribute to
  - finer tree species identification for forest inventory,
  - more efficient forest disturbances monitoring systems.
- Releasing an open benchmark dataset will encourage further research on stereo matching for forest canopy 3D reconstruction.
- The code developed within the project will be released open-source in MicMac

5. Candidate's profile

- Master 2 student in computer science, applied mathematics, photogrammetry or remote sensing
- Good command of Python and/or C++
- Previous experience in deep learning
- Previous experience in aerial/satellite image processing (optional)

6. Contact

Send CV and a letter of motivation to ewelina.rupnik [AT] ign.fr , marc.pierrot-deseilligny [AT] ensg.eu

References

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[2] Ministère de la Transition Ecologique: https://www.ecologie.gouv.fr/biomasse-energie

[3] IGN's CHM-era - Photogrammetric Canopy Height Models to Enhance Forest Resource Assessment: https://inventaire-forestier.ign.fr/spip.php?article913

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