



Doctoral thesis position – 2022

Title: Learning temporally-consistent 3D mesh models of growing plants

Host team: IGG (Computer Graphics and Geometry Group), ICube laboratory

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Funding: Doctoral contract (about 1675 EUR per month, net salary)

Location: Strasbourg area, France

Keywords: Computer Vision, Computer Graphics, Image Processing, Data Science

Desired skills:

- Computer Vision, and/or Computer Graphics or Image Processing, or Data Science
- Basic skills in machine and deep learning

Abstract (Max. 1500 characters)

This doctoral thesis position is proposed in the context of a research project with biophysicists from the University Paris Diderot and ENS Lyon. This project aims at modeling plant growth movements during leaf development and understanding the underlying physical and biological mechanisms at play. In this context, measurements of both plant movements and magnitude of local growth are required. This is currently achieved with the help of photogrammetry only at a coarse scale, considering small sets of markers painted on the leaves. A key challenge of this project is to develop an approach to reconstruct 3D+t (i.e. temporally-consistent) mesh models of growing plants suitable for accurate measurements at fine scales, which involves both high-resolution reconstruction and point-to-point correspondences issues. The goal of this thesis is to address this challenge following a three-part approach: 1) the estimation of optical and scene flows from photographs for fine-scale correspondences between time steps, 2) the combination of different acquisition

modalities (photogrammetry, laser scanning and structured light scanning) for high-resolution 3D reconstruction, and 3) the definition of either fine-scale statistical geometric templates for leaves or a neural network architecture for shape interpolation. The developed models and methods will rely on recent machine learning techniques. Several datasets of photographs and 3D reconstructions of growing plants will be provided.

1. Context and problem statement

The movement of a growing plant is often complex, and sometimes spectacular [RDD17]. Together with a research group in Biophysics from the University Paris Diderot and ENS Lyon, we are involved in a research project that aims at modeling plant growth movements during leaf development, and understanding the underlying physical and biological phenomena for either simple or compound leaves [DBC+18, RCP+20]. In this context, measurements of both plant movements and magnitude of local growth are required, which is currently achieved by biophysicists with the help of photogrammetry. A study to analyze the growth movements of a given plant starts with the acquisition of synchronized sequences of photographs taken from multiple viewpoints, focusing on a particular leaf, with controlled lighting and a set of markers of fluorescent paint. At each time step, multiview stereo reconstruction techniques [FH15] are used to reconstruct a 3D mesh model of the plant (see Fig. 1 for an example). So far, the reconstructed 3D models obtained with this approach have no temporal coherence, and only a small set of markers can be tracked reliably over time, which restricts the measurements at a coarse scale. The goal of the project is to develop an approach to reconstruct 3D+t (i.e. temporally-consistent) mesh models of growing plants suitable for accurate measurements at fine scales, which involves both *high-resolution reconstruction* and *point-to-point correspondences* issues.



Fig. 1: 3D+t mesh models of an *Averrhoa Carambola* compound leaf. Left: 5 consecutive overlapping meshes. Right: Textured meshes.

There has been recent work on point-to-point registration of 3D point clouds of growing plants based on a skeleton [PHW+21]. However, this approach cannot be applied in our context, since no such topological structure can be extracted for leaves. Our main idea to address this challenge consists of three parts:

1. Better leveraging of color and texture information in photographs through the estimation of optical and scene flows.
2. Combination of different 3D acquisition modalities from our digitization platform: photogrammetry, structured light scanning, and laser scanning.

3. Definition of fine-scale statistical geometric templates for the leaves of a specific set of plants and registration to acquired data, or design of an appropriate neural network architecture and training dataset for shape interpolation.

The optical flow of an object seen in two consecutive 2D images is the 2D vector field representing the movement of the object from the first to the second image. The scene flow corresponds to the 3D extension of the optical flow. Recent methods to estimate the optical or the scene flow are based on Convolutional Neural Networks (CNN) [LLW+20]. Though they are more robust to intensity variations than older variational methods and are constraint-free regarding the movements, they require appropriate *synthetic* or *real* training datasets including ground truth flow fields. However in our case, no such training dataset is available for growing plants.

Laser scanning enables reconstruction of accurate geometric models, but in a time-consuming way, which is scarcely compatible with motion tracking. There is a need for a method to merge 3D models obtained through laser scanning with reconstructions provided by photogrammetry or structured light scanning in order to get high-resolution 3D mesh models at all time steps.

Template models are common to track shapes over time, and provide temporally-consistent 3D reconstructions from acquired data. However, the literature addresses only geometrically simple objects (like e.g. humans [OBB20]) with almost isometric deformations, hence no growth. The issue of point-to-point correspondences in the non isometric case has been addressed very recently with the help of a specific neural network architecture designed for shape interpolation, without requiring a template model [ENK+21]. In our context, there is a need to either define templates equipped with non isometric deformations for plant leaves, or develop a neural network for interpolation of reconstructed leaves.

2. Goal of the thesis project

The goal of this thesis project is to address the challenge of developing a method for the reconstruction of temporally-consistent 3D mesh models of growing plants at fine scale, following the approach previously described. The work will be carried out in the following stages.

1. The first stage will consist of a critical review of previous work, including 3D reconstruction, temporally-consistent 3D reconstruction, optical flow and scene flow estimation, shape correspondence, and template-based shape registration.
2. The second stage will consist in developing a new method for the estimation of the optical flow from sequences of photographs of a growing plant, and if possible extend it to the estimation of the scene flow. The method will rely on CNN-based techniques.
3. Next, a method to combine high-resolution 3D reconstructed models with coarse models obtained with photogrammetry will be studied.
4. Lastly, template models and shape interpolation will be investigated. First, the feasibility of devising a template with non isometric deformation will be studied for a specific plant, taking inspiration from recent template models developed for humans. Recent shape interpolation methods based on neural networks will also be studied, and adapted.

The doctoral student will be given access to a desktop computer and several datasets of photographs of growing plants, in addition to high-resolution 3D reconstructions obtained from laser scanning. Most of the developments will be performed in Python with the help of vision and machine learning libraries.

3. References

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