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A Model-based Approach to Extract Leaf Features from 3D Scans

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Highlights: We present a flexible and robust method for the extraction of leaf features from 3D point clouds. An adaptable leaf model is automatically fitted to the measured data in order to obtain a precise but compact parameterization of the leaf shape. As an application example the detection of stress using the fitted leaf parameters is demonstrated.

Keywords: Phenotyping, leaf model, vitality monitoring

INTRODUCTION

Modern computer vision technologies allow fast, detailed and yet affordable 3D acquisition of objects. Contactless acquisition methods like stereovision or laser scanning are increasingly used for plant phenotyping systems, as the surface of single plants can be measured at high resolution within seconds (see Seidel 2011, Biskup 2007 or Andersen 2005). The resulting datasets are usually very large containing millions of dense but independent point samples. As they cannot directly be used as interpretable features of the phenotype, a set of comprehensible geometric features e.g. leaf area or orientation has to be extracted from the point cloud. However, the relevant parameters depend on multiple aspects like the research subject or the investigated plant species. Thus the algorithms for feature extraction are highly adapted and customized to the specific problem.

In this paper a flexible method for the extraction of leaf features is presented: We introduce a geometric model, which allows the description of a leaf shape with a small set of parameters corresponding to physical properties. The model can easily be adapted to various plant species. Furthermore, we present a method to automatically match the model with a point cloud of a real leaf. As the model parameters provide a compact but detailed description of the leaf geometry, they can directly be used as features for further analysis of the plant phenotype.

PARAMETRIC LEAF MODEL

The basis of the geometric leaf model is a 2D image of a single leaf of the respective plant species, which is created using a custom flatbed scanner. After separating leaf pixels from the background, a mesh representation of the leaf shape is generated by triangulation of the leaf pixels. To emulate natural leaf deformations in 3D space a series of geometric transformations is defined, which are applied to the initially flat leaf template: Besides a rigid transformation currently 9 leaf-specific transformations are implemented like rolling or bending along the main axis. All transformations are parameterized by a set of currently 26 parameters.

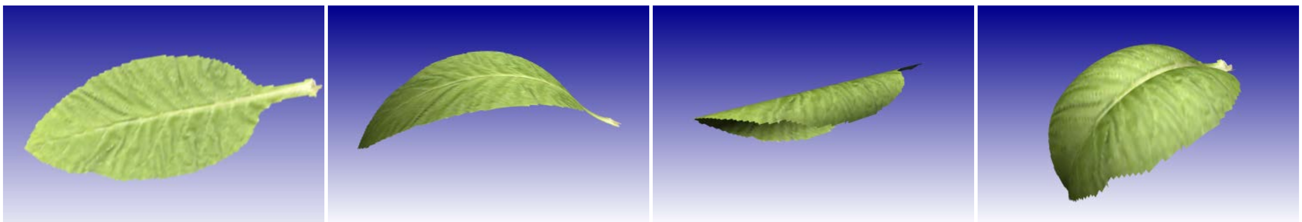

Fig. 1. Examples for different leaf model transformations (from left to right): Flat leaf template, bending along leaf axis, rolling along leaf axis and a combination of multiple transformations.

MODEL FITTING

In order to determine the geometric parameters of the measured leaf, the parametric model representation is fitted to the data. For a set of measured points $\boldsymbol{p} = \{p_1, p_2, \dots, p_n\}$ the model parameters $\boldsymbol{\alpha}$ are determined, such that the distance between the points of the transformed leaf model $\boldsymbol{m}(\boldsymbol{\alpha}) = \{m(\boldsymbol{\alpha})_1, m(\boldsymbol{\alpha})_2, \dots, m(\boldsymbol{\alpha})_n\}$ and the measured points $\boldsymbol{p}$ is minimized. This can be formulated as an optimization problem minimizing

$$d(\alpha) = \sum_{i}^{n} |p_i - m(\boldsymbol{\alpha})_j|$$

with $m(\boldsymbol{\alpha})_j$ being the nearest neighbor to measurement point p_i and $|\dots|$ being the Euclidian distance between two points. As the model transformations contain multiple trigonometric functions and the neighbor relationships change during optimization, $d(\boldsymbol{\alpha})$ is nonlinear. Thus the Levenberg-Marquardt optimization algorithm (see e.g. Madsen 2004) was chosen as a numerical solver and applied iteratively.

EXPERIMENTS

We verified the model-based feature extraction approach with data of a phenotyping system for tobacco plants. The scanning unit covers a maximum size of 1 m^3 and uses multiple sheet-of-light units to acquire the surface of the plant with high coverage at a lateral resolution of approx. 0.5 mm (see Fig. 2). Thereafter the resulting point could is segmented into single leaves. For certain types of plants separation of the measured point cloud into single leaves works nicely using a standard point cloud segmentation algorithm (Rabbani 2006, see Fig 3). Finally a leaf model is fitted to each segmented leaf, which can be seen in Fig. 4 for the example of a *N. tabacum* plant.

The monitoring of a plant during application of stress was chosen as an example to show the potential of our approach. In order to cause a quick stress reaction, a single *N. tabacum* plant was cut at the stem and fixed in a container with saline solution. An initial measurement of the plant was performed immediately after stress induction, a second measurement 35 minutes later. Additionally pictures were taken before each measurement, which are shown in Fig. 5 and Fig. 6.

Fig. 2. Phenotyping hardware setup.

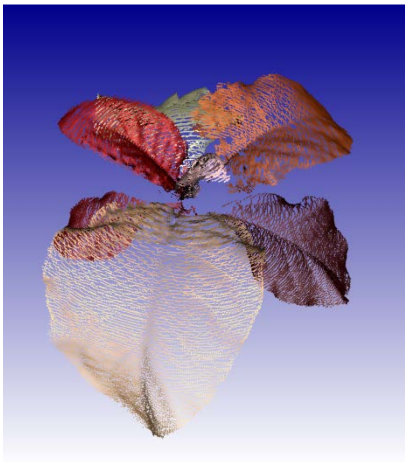

Fig. 3. Point cloud of measured plant with segmented leaves shown in different colors.

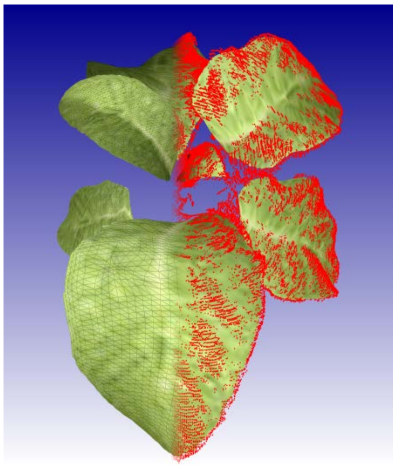

Fig. 4. Leaf model fitted to each segmented leaf. In the right half the measurement points are visible as a red dot overlay.

Fig. 5. *N. tabacum* immediately after stress induction

Fig. 6. *N. tabacum,* 35 minutes under stress

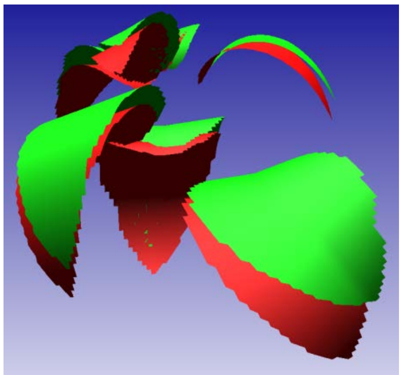

Fig. 7. Leaf models of both measurements. Green: immediately after stress induction. Red: after 35 minutes under stress

RESULTS

Comparing the photographs it is difficult to quantify the differences caused by the stress induction. When the fitted model representations are visualized in a common view as can be seen in Fig. 7, the downward bending of the leaves are already clearly visible. The decline is represented by two parameters in our leaf model: The first parameter indicates bending of the lamina defined as the slope of the straight line between lamina base and leaf apex. The second parameter is the absolute height from the top edge of the pot to the base of the leaf lamina. The difference in this parameter of both measurements represents the decline of the lamina caused by the bending of the petiole. Values of this parameter for each leaf are shown in Table 1, with the bases of all leaf laminas being lower in the second measurement with the exception of leaf #6. This leaf is the youngest and has an almost upright petiole, which tilts inwards under stress resulting in a slightly greater height of the leaf base.

Leaf Index	Absolute height of lamina base [mm]		Height difference [mm]
	t = 0 min	t = 35 min	
1	28	10	17
2	52	45	7
3	77	70	7
4	145	135	10
5	151	144	6
6	153	156	-3
7	156	142	15

Table 1: Comparison of parameter absolute height of lamina base.

CONCLUSION AND OUTLOOK

We presented a leaf model that is adaptable to different plant species simply by exchanging the leaf template. Along with the fitting algorithm a universal approach was presented that has proven to be robust delivering a compact set of parameters representing a plant's phenotype in great detail. The ability to derive information about a plant's state of health simply by reading the appropriate parameters opens up numerous applications, starting with the detection of stress symptoms as shown. By exploring the detailed parametric descriptions of large plant populations during growth, a standard growth behavior and furthermore deviations from this standard growth can be detected. Therefore, this approach is generally suitable for vitality assessment of plants.

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