Imaging and Image Processing for Plant Phenotyping

Hanno Scharr

Institute of Bio- and Geosciences
IBG-2: Plant Sciences
Forschungszentrum Jülich
IBG-2: Plant Sciences

*Dynamic plants in a dynamic environment*

- Founded in 2001
- 160 employees
- Main topics:
  - Plant Phenotyping
  - Sustainable Bio-economy
- Multi-disciplinary: biology, chemistry, physics, mathematics, computer sciences, engineering
Why Plants?

- Plants are socially and industrially relevant
  - 4F: Food, Feed, Fibre, Fuels, but also
  - bio-chemicals like in medical plants etc.
- Industries: Farming, Seed production, plant production, fertilizers

Central Question

How to grow plants optimally under natural or controllable conditions?

Mechanistic understanding of interactions between environmental conditions and plant traits required!
What exactly is phenotyping?

Environment | Plant phenotype | Genome

Dynamics of morphology | Dynamics of physiology

What exactly is phenotyping?
Genotyping

Sequencing cost is falling all the time

Sequencing cost

Source: Rob Carlson

600 Gbases per day

Illumina Hiseq X10
What exactly is phenotyping?

Dynamics of morphology

Dynamics of physiology

Environment

Plant phenotype

Genome

What exactly is phenotyping?
Environmental data

Weather data, Soil Water content

- temperature, light, wind, humidity
- Summarized by day
- Min, max, average etc
- Structure and chemical properties of soil
What exactly is phenotyping?

... but soil is still a problem
Mechanistic understanding of the plant system by variation of

- Environmental factors: Humidity, temperature, CO₂, nutrients, neighboring plants, …
- Arabidopsis, barley, maize, tomato…
- Genotype (regulates biochemistry)

Measurement of phenotype

- Leaf, fruit and root growth
- Photosynthesis, gas exchange, active genes, …
An ideal Experiment

Environment

We will image a lot, and genotype everything
Experiment time 60 days
Sample Size 300 plants
Genotyping Full Sequencing

Sequencing the plants yields ~30 TB of data
• would take about 50 days on the HiSeq X10

Images, 3D models etc. ~300MB per plant per day
• ~6TB per experiment

P = GxE: test many genotypes (species) at many environmental conditions: big data problem
Local data modeling:
- Optical flow and extensions
- Transparent motion and brightness changes
- Dynamic 3D surface reconstruction
- Optimized discretizations

Scene flow estimation from light fields

K. Krajsek, C. Heinemann, H. Scharr, Visapp 2014
T. Schuchert, T. Aach, and H. Scharr. PAMI 2010
T. Schuchert and H. Scharr. ECCV 2010
H. Scharr. Complex Motion 2007
Image Processing @ IBG-2

T. Schuchert, Plant Leaf Motion Estimation Using A 5D Affine Optical Flow Model, Dissertation, 2010
Regularized Riemannian reconstruction of diffusion tensor fields from DTMRI data.

K. Krajsek, M.I. Menzel, and H. Scharr. IJCV 2015 (subm.)
K. Krajsek and H. Scharr. CVPR 2012 (HARDI)
K. Krajsek, M.I. Menzel, and H. Scharr. ICCV 2009 (DTMRI)
Mixture of Gaussian vs. channel representations

K. Krajsek and H. Scharr, (unpublished)
**Image Processing @ IBG-2**

S. Bergsträsser et al., Plant Methods, 2015.
R.C. Meyer et al., Theoretical and Applied Genetics, 2010.

Deep Phenotyping

- Precise analysis of individual traits
- Typically done at organ level

Example: Root

Approach:
Understand key processes of root **structure and function** for resource use efficiency

Basis for novel root trait identification

See e.g. Jahnke et al. 2009, "**Combined MRI-PET dissects dynamic changes in plant structures and functions**", The Plant Journal, Vol. 59, 634-644

Metzner et al., unpublished
Postma et al., unpublished
MRI (Magnetic Resonance Imaging) for structural and functional imaging of roots

Robot systems for automated delivery of plants

Structural analysis of root system architecture in 3D

4.7T magnet, vertically oriented, 30cm opening

Maize
Root System Analysis: 3D MRI

D. Pflugfelder, 2015, unpublished
Screening: Seeds

• Automated measurement of seed properties
• Done individually for each single seed

Approach:
Start with seed properties
Relate to plant performance at an early stage
Basis for experiments with these plants later on
phenoseeder

Arabidopsis seeds
**phenoSeeder**

- 2D projected seed area, length, width
- Scales for weighing
- 3D shape

Reconstructing Seed Shape from Silhouettes

Idea: use simple volume carving

1. **Rotate** seed in front of camera

2. Reconstruct from silhouettes

Reconstructing Seed Shape from Silhouettes

image acquisition

36 grey value images from different viewing angles

mask image

TCP detection

volume carving

surface of reconstructed volume

tool – seed separation

Examples – Different seeds

A

Arabidopsis

Rape Seed

Barley

Maize

Original

B

Reconstruction

V=0.015 mm³

V=2.97 mm³

V=53.1 mm³

V=388 mm³

C

Ellipsoid fit

L=0.46 mm

L=2.01 mm

L=8.33 mm

L=10.92 mm

Screening: Shoot

• Transfer from single plant to stand level

Approach:
Dynamic environment
Photosynthesis and growth control from single plants to stands

Basis for novel shoot trait identification
3-D Canopy structure: Stereo imaging allows quantification of canopy structure

Mapping of spatio-temporal canopy dynamics in the field by imaging spectroscopy and 3-D canopy reconstruction

Corn, sugar beet, and barley
Measurements at 7 m
Area: 1.5 x 2.7 m

Mapping of spatio-temporal canopy dynamics in the field by imaging spectroscopy and 3-D canopy reconstruction

- quantify dynamics in the multidimensional data space
- relate spectral data to structural and functional aspects of canopies

Screening: Roots

- Automated measurement of many plants
- Typically done at single plant level

**Approach:**
High-throughput screening for root system traits

- Apply heterogenous and dynamic conditions
- Screening for optimized root structure and function
- Improve nutrient and water use efficiency

Nagel et al. *Functional Plant Biology* 2012
Screening: Root System Analysis: Rhizotrons

Nagel et al. *Functional Plant Biology* 2012
GARNICS: Robot Gardener

- EU FP7 project – cognitive systems and robotics call
- GARNICS: Gardening with a Cognitive System
- Robot Gardener
  - Measure plant status from images, treatments and environmental data
  - Learn to treat plants optimally

Aksoy et al., Computers and Electronics in Agriculture, Elsevier Science, 78 – 90,110, 2015
Simplified GARNICS Action-Perception Loop with Memory for Plant Treatment History
GARNICS: From Images to Plant Graphs

Aksoy et al., Computers and Electronics in Agriculture, Elsevier Science, 78 – 90,110, 2015
GARNICS: Training Data
GARNICS: Better Treatment Plan Found

- Faster growth by treatment found by the GARNICS system
- Beats best-performing training plants
- Status from day 12 reached at day 10 to 11.
Image Processing @ IBG-2
Imaging and Image Processing for Plant Phenotyping