Introducing WPS

• Bas van Eerdt (Manager Business Development)
• Based in the Netherlands, global installed base
• Roots in professional horticulture since 1960
• Multidisciplinary team (65 FTE)
• Highly modularized product portfolio

Core competencies:
•Transport systems, Image acquisition- analysis and Control software
•Project engineering, system integration, project management, service & support

WPS Digital Phenotyping activities

• Been active in high throughput digital phenotyping for over 10 years
• Current clientele primarily in commercial Agro Chemical & Biotech companies
• Limited in disclosure of information on these projects.

model plants: rice, wheat, corn, tomato, potato, sugar beet, soybean, turf, tobacco, etc
plant sizes: few inches – up to >7ft
applications: trait discovery, WUE, NUE, high content screening, chemical screening, molecular breeding.
NextGen Digital Phenotyping

- Need for more and better results
- Individualize system design
- Reduce costs for systems, create lower entry options
- Project specific collaboration between different tech. suppliers, based on project needs

Case study: NextGen image acquisition and analysis

- Model plant: Phalaenopsis (moth orchid)
- Current methods cannot maximize potential revenue of plants
- Pricing per plant strongly depending on phenotype
  - Spikes
  - Flower buds
- End result must be a platform that also can be used for identifying plant features for scientific phenotyping purposes:
  - Ears
  - Tillers
  - Leaves
  - ...

Case study: NextGen image acquisition and analysis: current method

- Measured accuracy for all measurements:
  - Spikes = n [1-5]
  - Height = mm [200-1000]
  - Flower buds = n [1-60]
  - Flowers = n [0-20]

Objective >97% accuracy for all measurements

Results current generation orchid grading

<table>
<thead>
<tr>
<th>Measured plant feature</th>
<th>Spike</th>
<th>Height</th>
<th>Flower buds</th>
<th>Flowers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Results current generation orchid grading</td>
<td><img src="chart.png" alt="Chart" /></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Statistical approach: +
Real time human remote assessment: ++
Local human assessment: --
3D: ++

<table>
<thead>
<tr>
<th>Option</th>
<th>Tech risk</th>
<th>Accuracy</th>
<th>Investment cost</th>
<th>Running cost for user</th>
<th>End result for user</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statistical approach</td>
<td>+</td>
<td>+/-</td>
<td>+</td>
<td>+/-</td>
<td>+/-</td>
</tr>
<tr>
<td>Real time human remote assessment</td>
<td>+/-</td>
<td>+/-</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Local human assessment</td>
<td>--</td>
<td>++</td>
<td>+/-</td>
<td>+++</td>
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<tr>
<td>3D</td>
<td>++</td>
<td>++</td>
<td>++</td>
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</tbody>
</table>

+3D approach: 3D approach is needed in order to make desired step in performance

Bottom line: 3D approach is needed in order to make desired step in performance
Case study: NextGen image acquisition and analysis: Approach

- Conclusion on approach:
  - 3D information required to make the next step

- Setup:
  - NIR Sensor for maximum contrast between different plant features
  - Capture 72 images per plant during rotation on automated precision turntable
  - Analyze individual 2D images
  - Translate and validate features in 3D space

Case study: NextGen image acquisition and analysis: 2D image analysis

- Very limited room for error, how to deal with:
  - Overlapping flowers
  - Irregular shapes (different stages of flowering, different orientations)

- Deep Learning approach:

Case study: NextGen image acquisition and analysis: 3D translation

- Translate 2D to 3D coordinates to validate features (flowers/flower buds)

  - Input is 2D coordinate data from 72 analyzed images
  - Mathematical approach to fit identified features in 2D on 3D path.
  - Feature needs to be confirmed n times before validation
  - Eliminate false positives by confirming predicted location
  - Identify features that are heavily occluded in many views

Case study: NextGen image acquisition and analysis: Results

- Measured accuracy

<table>
<thead>
<tr>
<th>Measured plant feature</th>
<th>Generation 1</th>
<th>NextGen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spikes</td>
<td>99%</td>
<td>99.8%</td>
</tr>
<tr>
<td>Height</td>
<td>95%</td>
<td>99%</td>
</tr>
<tr>
<td>Flower buds</td>
<td>55%</td>
<td>97%</td>
</tr>
<tr>
<td>Flowers</td>
<td>90%</td>
<td>100%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Throughput (Images/plant)</th>
<th>Generation 1</th>
<th>NextGen</th>
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</thead>
<tbody>
<tr>
<td>2500</td>
<td>600</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Raw data/plant (MB)</th>
<th>Generation 1</th>
<th>NextGen</th>
</tr>
</thead>
<tbody>
<tr>
<td>1200</td>
<td>1920</td>
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NextGen Digital Phenotyping
Reduce costs: consider semi-automated systems
- Characterization of semi-automated system:
  - Automation only used for analyzing plants
  - Plants are not necessarily cultivated on automated system

What's to gain:
- Greatly reduce initial investment (in exchange for some manual labor) and increase availability to researchers
- Connect multiple compartments to same imaging sensors
- Allow plants to grow in more representative environments
- Implement systems step-by-step, fully automated can still be achieved.
- Still maintain power and resolution of high throughput digital phenotyping

Recreate field conditions in the greenhouse with benching systems
- Bench = automated mini field plot
- Run experiments in controlled environment, but stimulate plant (root/shoot) interactions within experiment
- Sometimes single plant screening is not representative for the research topic

What's to gain:
- More realistic, but controlled, growing conditions during experiments
  - Increase plant density
  - Rain like and/ or ebb-flood irrigation
  - Grow plants in large pots or tubs
- Combination between realistic growing and individual measurements of plants
- Connect multiple compartments to same imaging sensors
- Very flexible in pot and/or tub sizes
- Still maintain power and resolution of high throughput digital phenotyping

Summary:
Our NextGen 3D Deep Learning Image analysis is currently showing great promise for high resolution counting of anatomical features which we wish to now validate on major crop models- tillers, spikes, ears, panicles etc.

We believe in the power of high throughput imaging to obtain data in a test population in the shortest possible timeframe.

There are new technologies available for HT phenotyping that do not compromise throughput but drastically increase affordability, scalability, and offer alternatives to in-field phenotyping.