Automated Canopy Estimator (ACE): Enhancing Crop Modelling and Decision Making in Agriculture

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Outline

- Motivation
- Evaluation
- Results
- Validation
- Conclusion
Motivation

How much of this photograph is covered by corn plants?
Several measures of crop development can be estimated by determining the amount of canopy cover (CC); these are useful for:

- Determining Nutritional status
- Identifying Growth characteristics
- Crop identification
- Crop Modelling
Motivation

- Canopy cover is a key input to the AquaCrop model

Flowchart of AquaCrop indicating the main components of the soil-plant-atmosphere continuum (Steduto, 2008).
Motivation

- Estimating CC from digital photographs is becoming increasingly important.
- Using image processing software, such as Photoshop, it is possible to segment the green canopy from the background material.
- This is clearly labour intensive.
- The issue of subjectivity also arises.
Motivation

- There exist other tools for segmenting images

- Existing approaches are either:
  - Inaccurate
  - Time consuming
  - Subjective, or
  - A combination of all three

- The aim was to develop a simple, low cost, automated, and accurate method for segmenting digital images and estimating canopy cover
Existing Approaches

- Traditional techniques can be separated into two groups: threshold based approaches and machine learning approaches.

- Thresholding approaches typically plot a histogram of colour values and attempt to find a value that demarcates green from background.

- Machine learning approaches use more sophisticated techniques, such as neural networks and other pattern recognition algorithms.
Existing Approaches

- A comparison of CC estimates (derived from the photo above) for different approaches

<table>
<thead>
<tr>
<th>Approach</th>
<th>Method</th>
<th>Canopy Cover (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photoshop</td>
<td>Threshold (Ground Truth)</td>
<td>58.5</td>
</tr>
<tr>
<td>Colour Index of Vegetation Extraction (CIVE)</td>
<td>Threshold</td>
<td>63.8</td>
</tr>
<tr>
<td>Extra Green (ExG)</td>
<td>Threshold</td>
<td>33.1</td>
</tr>
<tr>
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<tr>
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<td>Threshold</td>
<td>69.5</td>
</tr>
<tr>
<td>Bai et al. (2013)</td>
<td>Machine Learning</td>
<td>53.7</td>
</tr>
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</table>
Limitations of Current Approaches

- They do not work well when photos taken with multiple cameras are analysed together
- Most are very sensitive to differences in illumination
- Closed and open canopies are difficult to segment
- Not all are fully automated
- Some need to be retrained for new crops
Automated Canopy Estimator (ACE) is a thresholding approach that overcomes many of the limitations listed above.

ACE differs from other thresholding techniques in two aspects:
- The method of estimating the threshold, and
- The colour space in which it performs segmentation
ACE

- ACE works in the CIE L*a*b* colour space
  - Lab space separates illuminance from colour information

- The a* channel is of interest because it represents colours on the spectrum from red to green

- ACE extracts the a* channel and processes it in order to segment green from background
ACE

- The probability distribution of a* values is plotted and the threshold is determined to be the point on the x-axis that best delineates green and background.
ACE

- The threshold isn’t always obvious, so ACE estimates a Gaussian mixture model from the data.

- If the distribution is not strongly bi-modal, the inflection point is detected and used as the threshold.
Evaluation

- Four separate crops, photographed with two different cameras are chosen for evaluation. The crops are oat, flax, corn and rapeseed.

- The four are chosen because they have different leaf shapes, sizes, orientations, a variety of growth patterns and are photographed under varying lighting conditions

- 80 images are included in the evaluation
Results

- Demonstration of the segmentation output from ACE

Un-segmented

- Oat
- Rapeseed
- Flax
- Corn

Segmented

- Oat
- Rapeseed
- Flax
- Corn
### Results - Segmentation

- Comparison of mean segmentation accuracy estimated by ACE and eight other tools

<table>
<thead>
<tr>
<th></th>
<th>Corn</th>
<th>Oat</th>
<th>Flax</th>
<th>Rapeseed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\mu$(%)</td>
<td>$\sigma$ (%)</td>
<td>$\mu$(%)</td>
<td>$\sigma$ (%)</td>
</tr>
<tr>
<td>CIVE</td>
<td>40.0</td>
<td>18.0</td>
<td>63.0</td>
<td>8.0</td>
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<tr>
<td>ExG</td>
<td>67.0</td>
<td>8.0</td>
<td>58.0</td>
<td>9.0</td>
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<tr>
<td>VVI</td>
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<td>45.0</td>
<td>9.0</td>
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<tr>
<td>MS</td>
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<td>9.0</td>
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<tr>
<td>MSCIVE</td>
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<tr>
<td>MSEXG</td>
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<td>7.0</td>
<td>62.0</td>
<td>25.0</td>
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<tr>
<td>MSVVI</td>
<td>32.3</td>
<td>9.0</td>
<td>55.0</td>
<td>7.0</td>
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<tr>
<td>Bai et al</td>
<td>88.0</td>
<td>5.0</td>
<td>85.0</td>
<td>6.4</td>
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<tr>
<td>ACE</td>
<td><strong>89.4</strong></td>
<td><strong>3.0</strong></td>
<td><strong>90.0</strong></td>
<td><strong>5.0</strong></td>
</tr>
</tbody>
</table>
Results - Segmentation

- A graphical representation of the comparison of segmentation accuracy estimated by ACE and eight other tools.
Results – Canopy Cover

- Comparison of ground truth and ACE-estimated canopy cover values for corn (a), rapeseed (b), flax (c) and oat (d)
Validation – AquaCrop Simulation

- **TOP** - Simulated (line) versus measured (filled circles) canopy cover
- **BOTTOM** - Biomass (filled squares) of sweet potato for rainfed and irrigated treatments at Devon, Manchester (2012).
- CC measured using the Green Crop tracker (Liu and Pattey, 2010)
Validation – AquaCrop Simulation

- **TOP** - Simulated (line) versus measured (filled circles) canopy cover
- **BOTTOM** - Biomass (filled squares) of sweet potato for rainfed and irrigated treatments at Devon, Manchester (2012).
- CC measured using ACE

Figure 3. Simulated (line) versus measured canopy cover and biomass (filled squares) of sweet potato for rainfed and irrigated treatments at Devon, Manchester (2012). CC measured using the ACE (Coy, Rankine et al. 2014)
Validation – AquaCrop Simulation

- Canopy cover estimates are used in the parameterization of Sweet potato in AquaCrop (Rankine et al., 2015)

- With CC measured by ACE there is excellent agreement between simulated and measured CC

- AquaCrop creditably simulates the biomass at both locations and for the two treatments using the input of CC estimated by ACE

- When CC is well estimated, Biomass is well simulated
Conclusions

- ACE is an accurate method for segmenting digital photographs and estimating CC

- It overcomes many of the limitations of previous approaches

- It is an automated method for estimating CC from digital photographs and is potentially beneficial for many applications, including crop modelling.
### In case you were wondering …

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Availability of ACE

- ACE is online: http://173.230.158.211