Holistic and Component Plant Phenotyping Analysis using Visible Light Image Sequences

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Introduction

- Image-based plant phenotyping facilitates the extraction of desirable morphological and biophysical traits by analyzing a large number of plants in short time period non-invasively.
- It is broadly classified into: holistic and component phenotypes.
- Holistic phenotypes consider the whole plant as a single object, whereas component phenotypes are computed by considering individual components of a plant, i.e., leaves and stem.
- An algorithm is proposed to track each leaf from its emergence during vegetative stage life cycle and measure its length on each day.

Holistic Phenotypes:

$$\text{Plant Aspect Ratio} = \frac{\text{Height of BR at side view}}{\text{Diameter of MEC at top view}}$$

$$\text{Bi-angular Convex-hull Area Ratio} = \frac{\text{Area}_{\text{Convex-hull}} \text{ at side view } 0^{\circ}}{\text{Area}_{\text{Convex-hull}} \text{ at side view } 90^{\circ}}$$

where, BR: Bounding Rectangle; MEC: Minimum Enclosing Circle

Component Phenotypes:

- To achieve maximum efficiency, the view angle at which line of sight of the camera is perpendicular to the axis of the leaves, is selected.
- The basis of leaf tracking is: (a) leaf emergence strictly alternates in terms of direction; (b) leaves emerge using a bottom-up approach [1].
- The foreground, i.e., the plant, is segmented based on frame differencing technique and color based thresholding.
- The binary plant is skeletonized, i.e., reduced to one-pixel wide lines, using fast marching algorithm [2].
- The skeleton is represented by a graph G={V, E}, where V is the set of vertices and E is the set of edges.
- The vertices with degree 1 are identified as leaf-tips and with degree 3 or more are identified as junctions.
- The stem is formed by iteratively traversing the graph along a connected path of junctions.
- Each leaf is identified by using a graph traversal algorithm from leaf-tip until it meets at the junction.

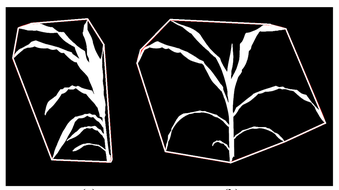

Figure 1: View selection

Figure 1(a) and (b) show the binary images of the same plant enclosed by convex-hulls at side view 0° and side view 90°, respectively. The area of the convex-hull at side view 90° is higher than the area of the convex-hull at side view 0°, hence the image at side view 90° is chosen for that day.

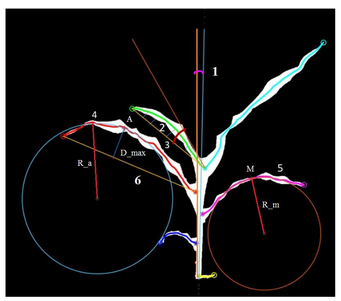

Figure 2: Component phenotypes

1-Stem angle; 2-Leaf angle; 3-Node-tip distance; 4-Apex curvature; 5-Mid-leaf curvature.

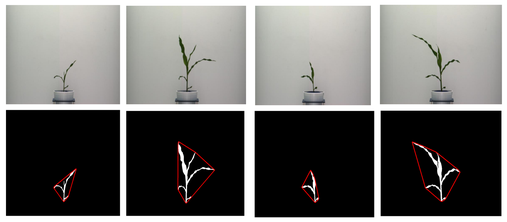

Figure 3: Bi-angular Convex-hull Area Ratio (provides information on phyllotaxy)

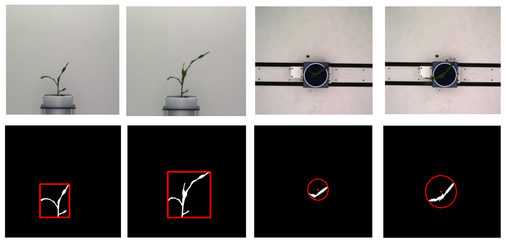

Figure 4: Plant Aspect Ratio (provides information on canopy architecture)

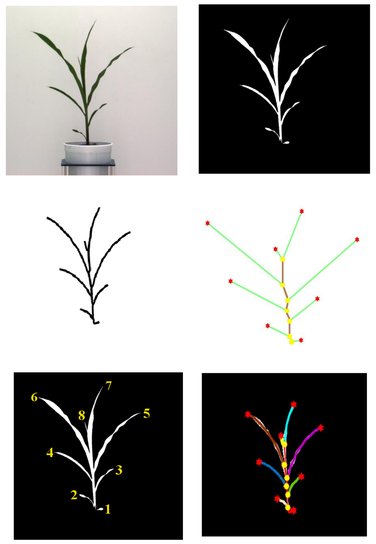

Figure 5: The overall process of leaf detection

Dataset

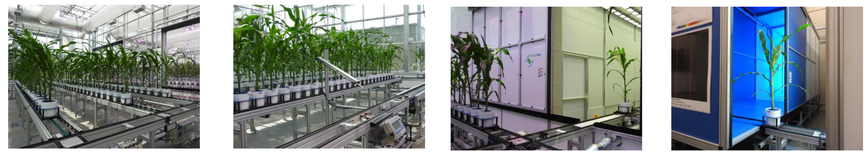

Figure 6: LemnaTec Scanalyzer 3D Plant Phenotyping System

- To evaluate the algorithm, we publicly release a benchmark dataset called University of Nebraska-Lincoln Component Plant Phenotyping Dataset (UNL-CPPD).
- The images of the dataset are captured using LemnaTec Scanalyzer 3D high throughput plant phenotyping facility in the UNL.
- The dataset contains RGB images of 13 maize plants for 27 days.
- We release the following ground-truth information for each original image: (a) the co-ordinates of leaf-tips and leaf-junctions; (b) the total number leaves present (which are numbered in order of emergence).

```
<?xml version="1.0" encoding="UTF-8" standalone="yes"?>
<plant>
    <id>Plant_191-28_SideView0/Day_012.jpg</id>
    <base>
        <x>1290.0</x>
        <y>1838.0</y>
    </base>
    <leaf>
        <id>1</id>
        <status>alive</status>
        <tip>
            <x>1336.0</x>
            <y>1712.0</y>
        </tip>
        <collar>
            <x>1298.0</x>
            <y>1839.0</y>
        </collar>
    </leaf>
    ...
    ..
    .
    <leaf>
        <id>6</id>
        <status>alive</status>
        <tip>
            <x>1314.0</x>
            <y>1365.0</y>
        </tip>
        <collar>
            <x>1287.0</x>
            <y>1665.0</y>
        </collar>
    </leaf>
</plant>
```

Figure 7: UNL-CPPD ground-truth

Results

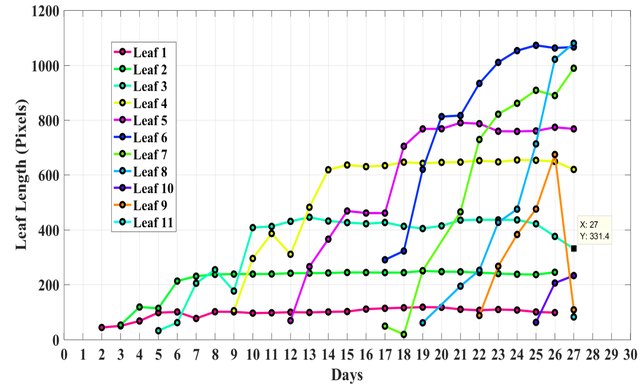

Figure 8: Leaf status report

The graph provides the following phenotyping information with significance in plant science: (1) the total number of leaves emerged during the life cycle; (2) the day on which a particular leaf emerged; (3) the number of leaves present at any point of time; (4) the length of each leaf at any point of time; and (5) the day on which a particular leaf died.

Conclusion

A set of new holistic and component phenotypes are proposed using computer vision techniques.
Individual leaves can be tracked providing growth pattern of leaves.
A benchmark dataset called UNL-CPPD is released with ground-truth.

Acknowledgement

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References

[1] S. D. Choudhury, S. Bashyam, Y. Qui, A. Samal, T. Awada, Holistic and Component Plant Phenotyping using Temporal Image Sequence, Plant Methods, under review, 2017.

[2] M. S. Hassouna, A. A. Farag, MultiStencils Fast Marching Methods: A Highly Accurate Solution to the Eikonal Equation on Cartesian Domains, IEEE Transactions on Pattern Analysis and Machine Intelligence, 29 (9), 1563-1574, 2007.