PLANT LEAF SEGMENTATION FOR ESTIMATING PHENOTYPIC TRAITS

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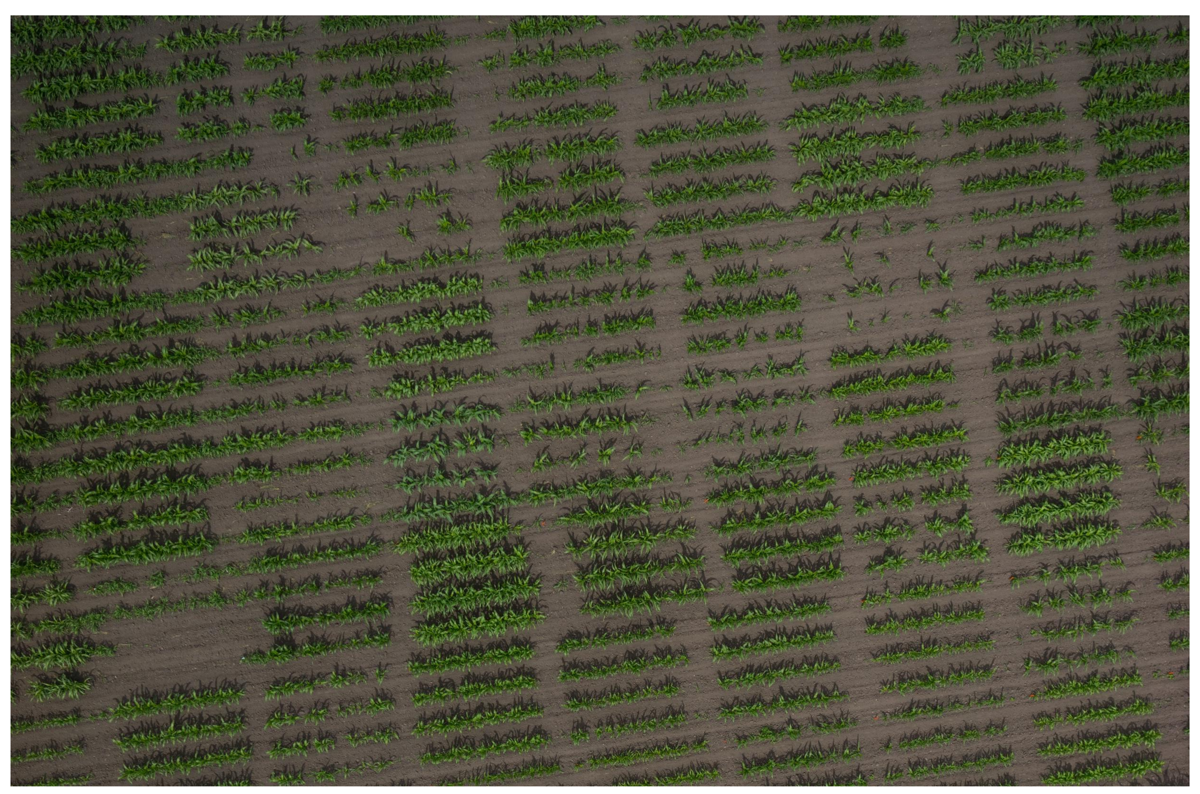
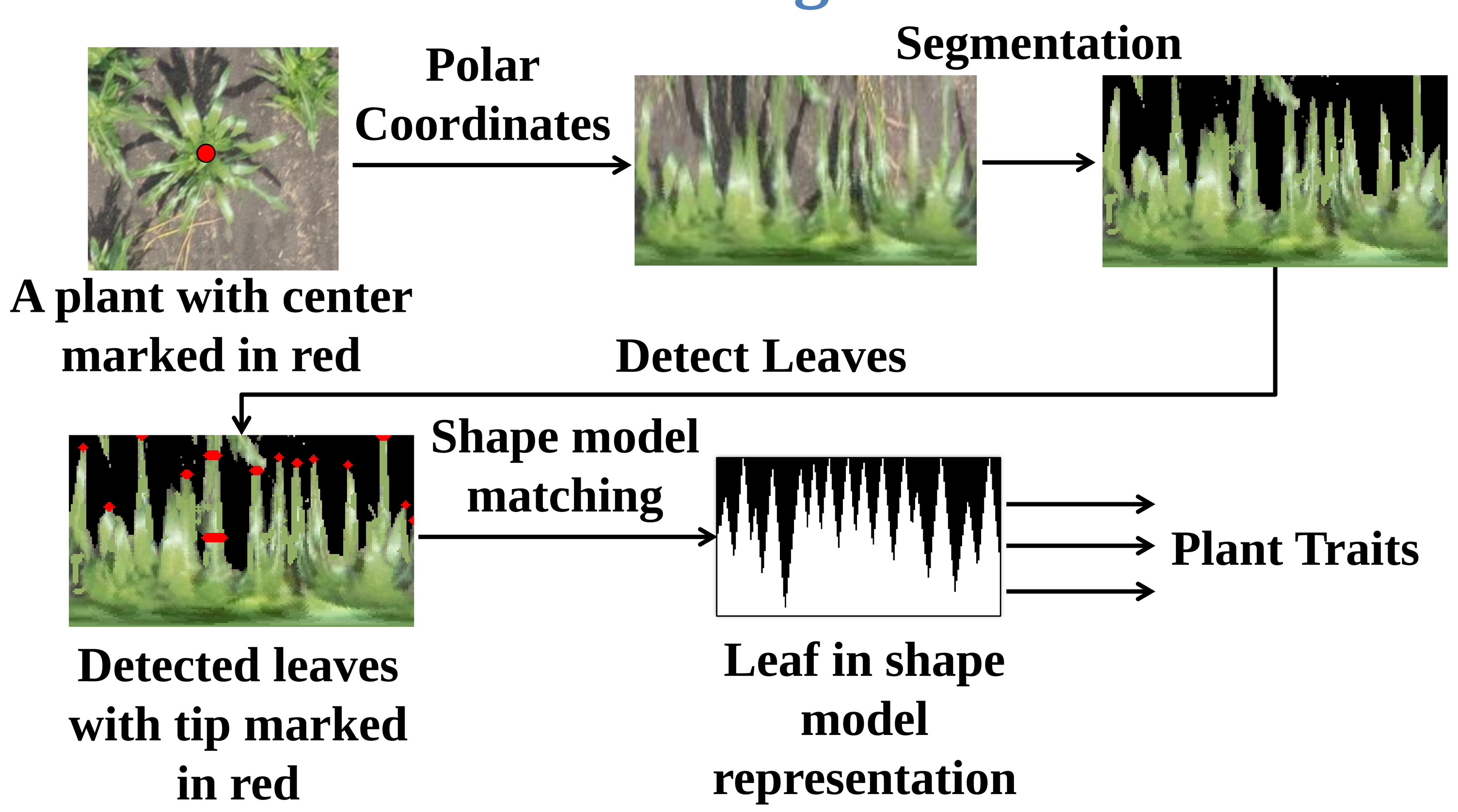
Introduction

- Phenotyping is a set of methodologies for recording, analyzing and measuring characteristic traits of a plant resulting from genetic and environmental factors
- Many phenotyping methods are invasive, thus damaging the plant when measurements are made
- Imaging technologies provide a non-invasive and an effective way for data collection and plant trait estimation
- We describe a method to segment individual leaves and extract phenotypic traits of plants from UAV images



Block Diagram



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Leaf Segmentation

- We transform the image into polar coordinates around the plant center
- We obtain the mask of leaf pixels by thresholding in HSV color space
- A basic element, the slice, is introduced to analyze the leaf morphology
  A slice is a connected set of coordinates in the foreground mask at a constant radius r level
- We represent the leaf slices in a hierarchical way
  By vertically stacking leaf slices, we obtain a leaf shape
- We reconstruct a leaf shape by combining the tips with all their ancestors
- We define an observed leaf shape X as
  $$X = \{x_1, x_2, \ldots, x_{L_X}\}$$
  where L_X is the number of slices in the leaf shape X
  Each slice x_m, $m = 1, \ldots, L_X$ is one pixel thick, and $\boldsymbol{\theta}(x_m)$ degrees wide
- We define the set
  $$A = \{X_1, X_2, \ldots, X_N\}$$
  containing all N reconstructed leaf shapes X_i, $i = 1, \ldots, N$

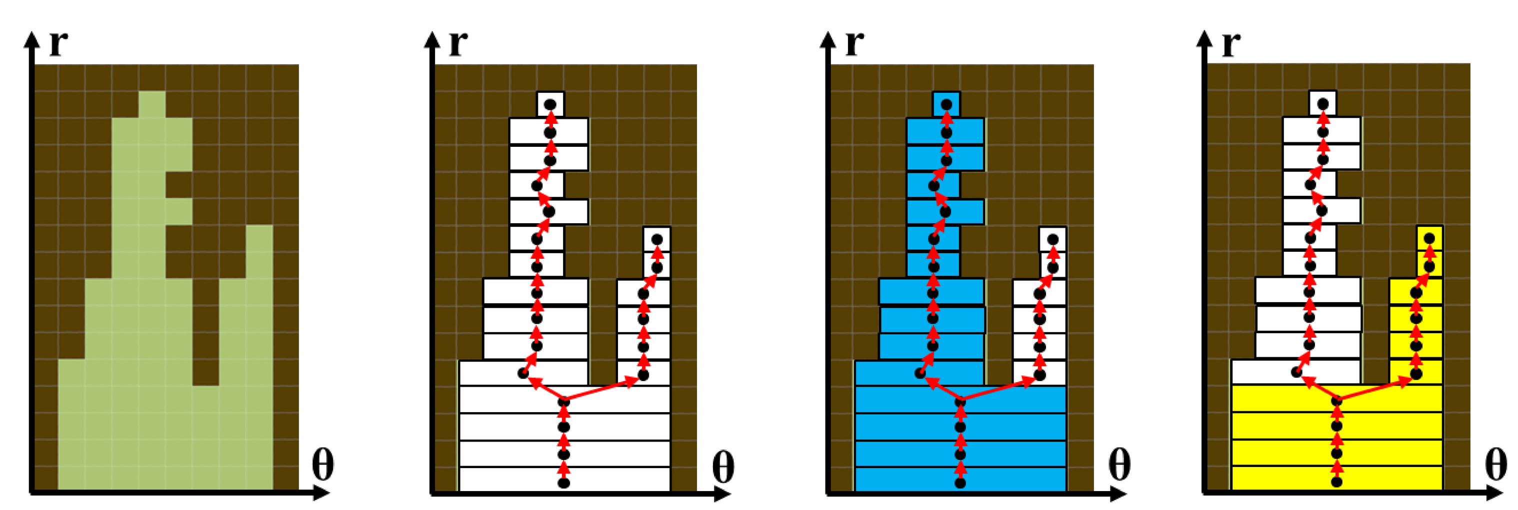
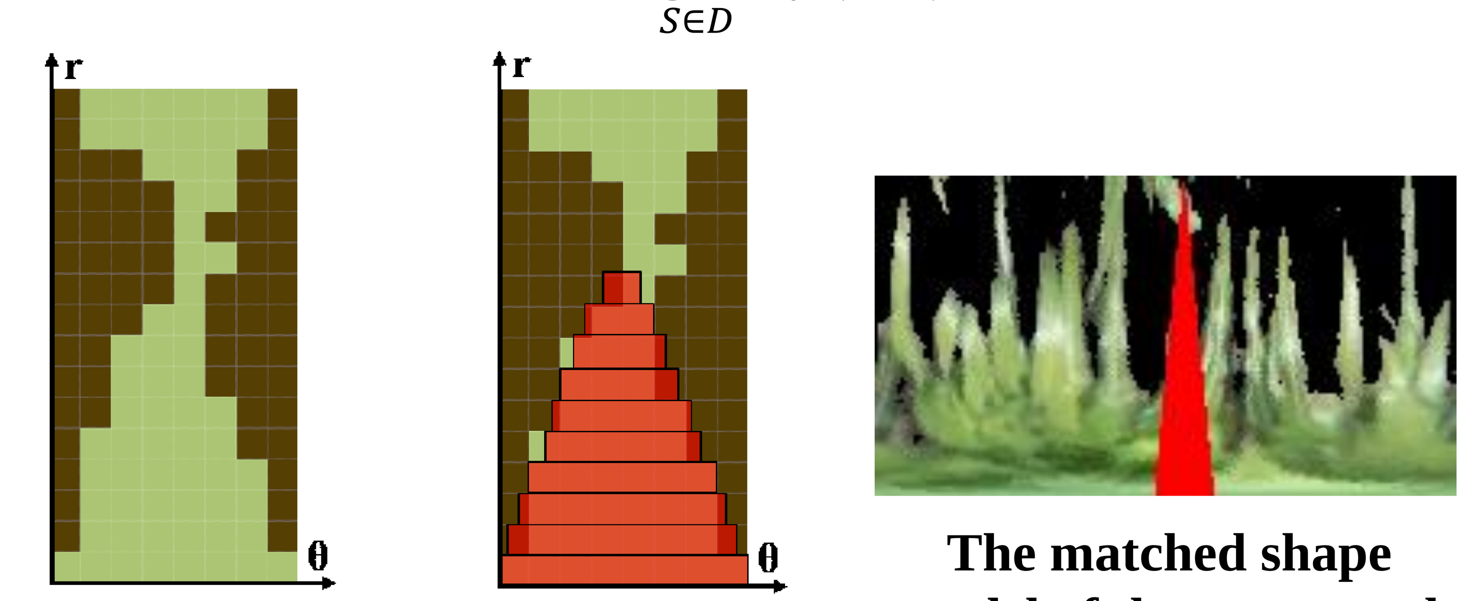


Image of two leaves | Leaf slices in hierarchy | Leaf shape 1 in blue | Leaf shape 2 in yellow

Leaf Modeling

- We match leaf shapes with shape models to avoid noise and occlusion
- A shape model $S \in D$, consists of a set of slices:
  $$S = \{y_1, y_2, \ldots, y_{L_S}\}$$
  where L_S is the number of slices in the shape model S,
  and the finite set D contains all our shape models
- The width W_m, $m = 1, \ldots, L_S$ of the m-th slice, y_m, in shape model S is modeled as random variable with normal distribution
  $$p_{W_m}(w) = \mathcal{N}(\mu_m, \sigma_m^2)$$
  where μ_m and σ_m^2 are the mean and variance, respectively
  We call $p_{W_m}(\cdot)$ the slice matching probability. The parameters μ_m and σ_m^2 of the model are obtained from a pyramidal model of the leaf shapes
- We obtain the match score of an observed leaf shape $X \in A$ with a possible shape model $S \in D$ as
  $$f(X, S) = \sum_{m=1}^{L_S} w_{m,S}\, p_{W_m}(\boldsymbol{\theta}(x_m))$$
  where $w_{m,S}$ is the weight for the m-th slice of the shape model S

- We assume that all slices are equally weighted and normalized, so
  $$w_{m,S} = \frac{1}{L_S}, \qquad m = 1, \ldots, L_S$$
- The shape model $\hat{S}$ that best describes the observed leaf shape X is the model with maximum match score:
  $$\hat{S} = \operatorname*{argmax}_{S \in D} f(X, S)$$



Two leaves from overlapping plants | A possible shape model | The matched shape model of the segmented leaf

Original image | Segmentation of a leaf | Shape model of the leaf | Leaves segmented in colors | Shape model of leaves in colors

Experimental Results

Total number of leaves	82
True positives	57
False positives	18
False negatives	25

Precision	70 %
Recall	76 %

- Traits estimated include width and length of each leaf, leaf count and LAI (Leaf Area Index) of individual plants

Conclusion

- We presented a method to segment leaves of sorghum plants and obtain phenotypic traits from UAV imagery
- Future work will refine our shape models and investigate optimal weights for shape matching. We are collecting much more imagery so that we can also investigate deep learning methods