**Motivation & Objectives**

- **Motivation**
  - Tree canopy measurements, including height, width, and volume
  - Modeling of tree profile
  - 3D reconstruction and visualization of agricultural crops
  - Plant Phenotyping

- **Objectives**
  - World coordinate system setup for stereo cameras
  - Metric 3D reconstruction and visualization of plant/tree canopy
  - Canopy volume calculation based on 3D reconstruction

**Available Tools**

- Ultrasonic
- Laser
- Time-of-Flight camera
- Kinect (RGB-D camera)
- Bumblebee Stereo
- Self-designed stereo camera

**Comparisons among these tools**

<table>
<thead>
<tr>
<th>Ultrasonic</th>
<th>Laser</th>
<th>Kinect (RGB-D camera)</th>
<th>Bumblebee Stereo</th>
<th>Self-designed camera</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection</td>
<td>Distance</td>
<td>Distance + color</td>
<td>Distance + color</td>
<td>Distance + color</td>
</tr>
<tr>
<td>Price</td>
<td>Expensive</td>
<td>Expensive</td>
<td>Expensive</td>
<td>Expensive</td>
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<tr>
<td>Usage</td>
<td>Indoor +</td>
<td>indoor</td>
<td>Indoor +</td>
<td>indoor +</td>
</tr>
<tr>
<td>Environment</td>
<td>outdoor</td>
<td>outdoor</td>
<td>outdoor</td>
<td>outdoor</td>
</tr>
</tbody>
</table>

**Materials**

- **Tools & Materials**
  - Self-designed stereo cameras & Laptop
  - One hexagon box, three plants: croton plant (big leaves), jalapeno pepper plant (median leaves), and lemon tree (small leaves)

- **Image Acquisition**
  - Use self-designed stereo cameras to take the images around the target. Adjacent images should have overlap.

**Methods**

- **Stereo Camera Calibration**
  - Camera Matrix: P1 and P2
- **Multiple image pairs**
  - Feature detection and matching
  - Correspondences
  - SfM
- **First pair of images**
  - Metric 3D points for first two images
  - Projective 3D points for first two images
  - Rigid transformation (H)
- **Projective camera matrices and 3D points**
  - Metric 3D points for all of the images
- **Metric 3D dense points**
  - CMVS

**Control Test Results**

**3D Reconstruction and Visualization**

- 3D reconstructed Croton and surrounding cameras
- Reconstructed Croton with bounding box
- Reconstructed Pepper with bounding box
- Reconstructed Lemon with bounding box

**Discussion**

From reconstruction results of these three plants, we can see that all leaves of the croton were fully reconstructed due to its big leave size and its sparseness. The leaves of pepper plant is also well reconstructed due to median leaf size and its sparseness. But for the lemon tree, some leaves were not reconstructed due to the leaves’ density. But for all these three targets, the reconstruction is real size. The texture were also well presented.

**Volume Calculation**

Method to calculate the volume of complicated plant/tree canopy: Divide the bounding box into small voxels, if there is one or more than one 3D points in a voxel, keep it; otherwise delete this voxel.

**Estimated length vs. actual length**

**Estimated height vs. actual height**

**Volume of these three plants**

<table>
<thead>
<tr>
<th>Plant</th>
<th># of Voxels hits / # of total 3D points</th>
<th>Voxels size (mm$^3$)</th>
<th>Volume (mm$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Croton</td>
<td>161361/19579</td>
<td>28.46</td>
<td>1.23x10$^8$</td>
</tr>
<tr>
<td>Pepper</td>
<td>285911/38773</td>
<td>12.61</td>
<td>3.61x10$^7$</td>
</tr>
<tr>
<td>Lemon</td>
<td>48609/96680</td>
<td>3.76</td>
<td>1.83x10$^6$</td>
</tr>
</tbody>
</table>

**Conclusions**

- Stereo cameras calibration in world coordinate system
- Metric (real size) 3D reconstruction from multiple images
- Canopy volume calculation using voxel