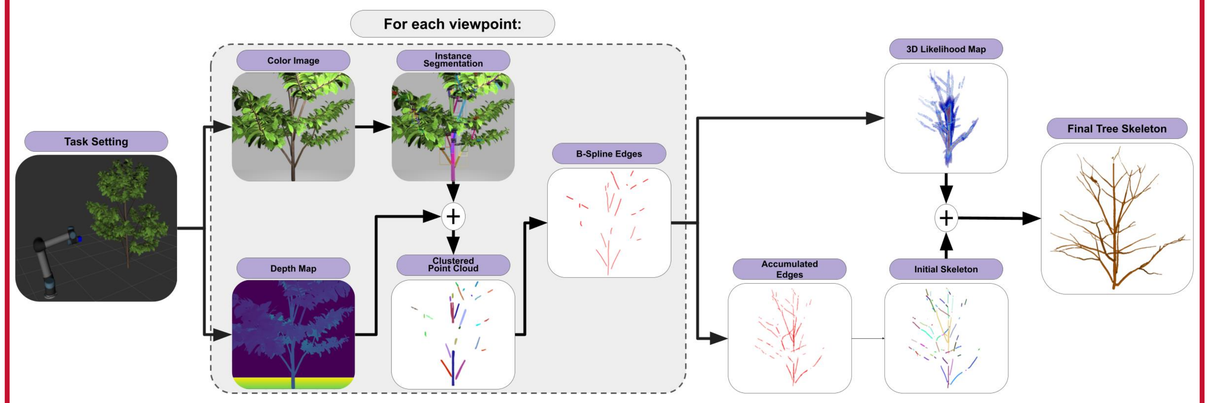
Occlusion Reasoning for Skeleton Extraction of Self-Occluded Tree Canopies

Chung Hee Kim and George Kantor
Carnegie Mellon University, Pittsburgh, USA

Motivation

Our goal is to obtain a digital representation of tree crops in the form of a **tree skeleton** that captures useful information such as branch geometry, positions and hierarchy. This is particularly difficult when branch structures are self-occluded by fruits, leaves, and other branches. We propose a method to predict the presence of occluded branches even with high occlusion. The digitized model of a tree canopy presents promising avenues in research into safe and robust agricultural manipulation.

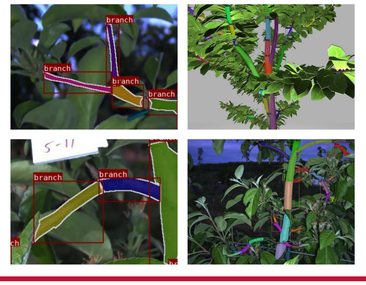
System Pipeline



Our vision pipeline takes as input a series of RGB-D images of a self-occluded tree from multiple viewpoints, and outputs the underlying tree skeleton. The pipeline consists of three key modules including:

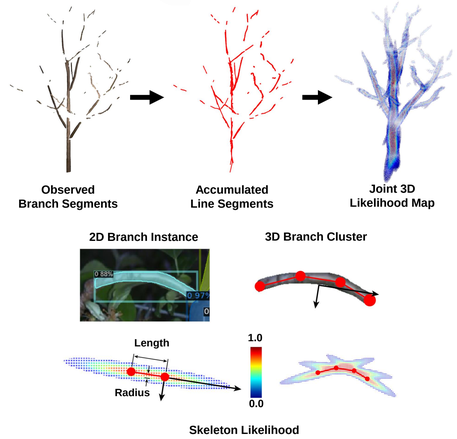
- **Instance segmentation network** to detect visible branch structures,
- **Heuristic 3D occupancy map** containing the probability of skeleton occupancy in 3D space,
- **Skeleton extraction** through minimum cost path searches to predict the final skeleton

Instance Segmentation



We use the Mask R-CNN instance segmentation network, which takes as input an RGB image and outputs branch instances with a corresponding confidence score. The instance masks are combined with the depth image to generate a semantic point cloud of visible branch clusters.

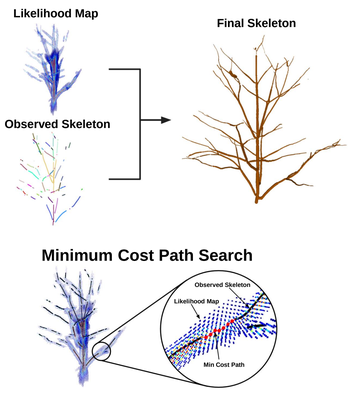
3D Occupancy Map



We estimate a 3D likelihood map of skeleton occupancy by creating an occupancy grid from a semantic point cloud of branch clusters. Our map is based on the heuristic assumption that a branch segment is more likely to extend further along its visible growth direction. Concretely:

1. Line segments are extracted by fitting B-spline curves onto the branch clusters
2. Branch properties such as length and radius are estimated
3. The likelihood map with an elliptical contour is fitted onto each line segment

Skeleton Extraction



To create the final branch skeleton, we overlay the joint 3D occupancy map with the observed branch structure. Using a series of minimum cost path searches in the occupancy map space, we estimate the presence of branch structures that were not directly observable due to occlusion. Hence, the resulting skeleton includes both the observed branch structures from the image, as well as the previously unobservable structures.

Field Results

Chung Hee Kim, chunghek@andrew.cmu.edu
George Kantor, gkantor@andrew.cmu.edu

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