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PLANER
Ground Plane Removal

PROJECT TEAM
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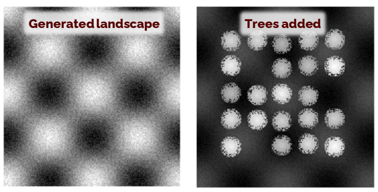
To improve orchard management, tree heights can be extracted from digital elevation models (DEMs)—raster height maps where pixel intensity represents ground height. DEM data can be collected via drones. Ground plane removal involves extracting tree heights from DEMs by subtracting the absolute height of tree canopies from the height of the ground beneath them. As tree canopies occlude the ground in DEMs, ground height must be estimated. Tree segmentation is used to determine areas of occlusion and DEM generation is required for testing—only height data is used. This project was proposed by **Aerobotics (Pty) Ltd**. who provided us with sample DEM data.

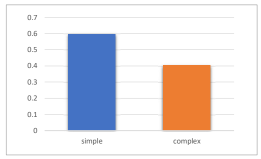
DEM Generation

- Orchards DEMs were produced with 30 varying landscapes and tree types, to evaluate our tree segmentation and ground estimation methods, by generating an underlying landscape and then adding trees.
- Both steps were performed using per pixel height calculations.

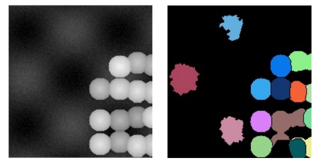


Figures showing the build process

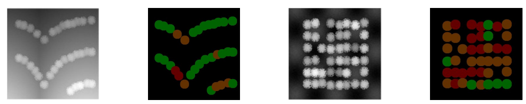
Results

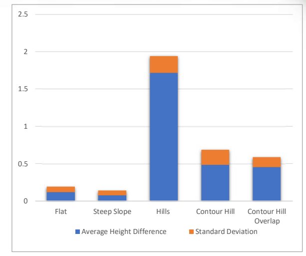


Graph showing accuracy of segmentation of simple versus complex tree types.


Figures showing the effect of non-uniform terrain on tree segmentation; hilltops were falsely flagged as trees.

Results showed tree segmentation is less effective with hills in the landscape and complex canopies, while ground estimation struggled with varying slope angles.


Figures showing the evaluation of ground estimation with red and orange indicating a large and moderate average differences respectively

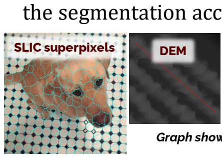


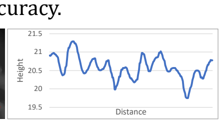
Graph showing height differences between actual and estimated terrain by landscape type.

We were able to create varying DEMs to simulate tree orchards. Generated DEMs effectively found flaws and improvements in image processing methods.

Tree Segmentation

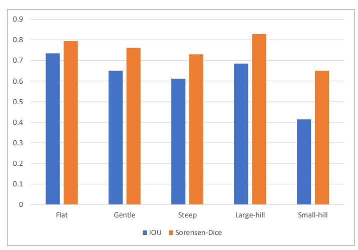
- Trees were identified from DEMs to aid ground estimation. The performance of segmentation methods was also evaluated.
- Segmentation methods: **Simple Linear Iterative Clustering (SLIC) –** identifies superpixels (similar, neighbouring pixels); **Watershed segmentation**
- Evaluation methods:
  Intersection Over Union (IOU) – pixel accuracy of segmentation.
  Sorensen-Dice coefficient (SD) – ratio of correct and incorrect tree identifications.
- The low-fidelity nature of DEMs impacted the segmentation accuracy.



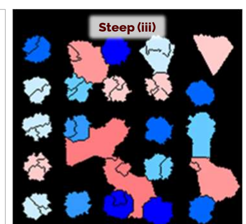


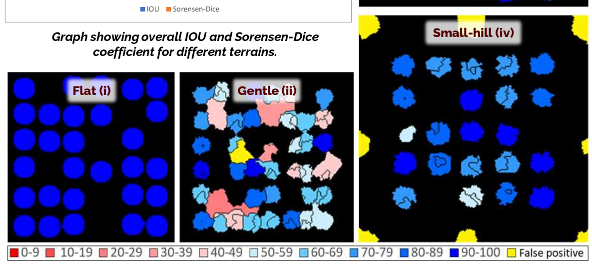
Graph showing the height profile of a DEM.

Results

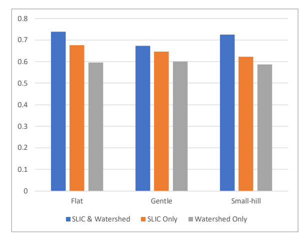


Graph showing overall IOU and Sorensen-Dice coefficient for different terrains.





Figures showing segmented DEMs (i)–(iv) representing segmentation accuracy as a percentage, using a colour scale (see legend).



Graph showing mean IOU obtained by different segmentation techniques for different terrains.

Segmentation worked well for flat orchards (IOU: 0.73). It performed poorly, due to noise, tree proximity and false positive identifications, for small-hilled orchards (IOU: 0.41). Using SLIC and watershed together improves segmentation, although SLIC has longer execution times.

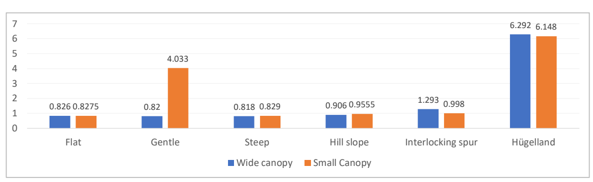
Ground Estimation

- Estimate missing terrain points in a DEM using interpolation methods: **Contextual Void Patching** (CVP) and **Local Modified Shepard**—an inverse distance weighting method (IDW).
- Evaluated using (per pixel) **RMSE** and Cohen's **Kappa** statistic — a measure of agreement between the estimated and original terrain DEMs.

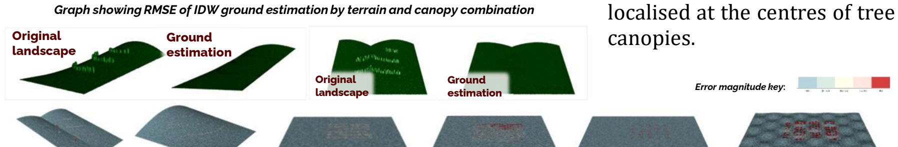
Terrain type:	Flat	Gentle	Steep	Hill slope	Interlocking spur	Hügelland
IDW:	0.6669	0.4639	0.6713	0.6638	0.6213	0.3136
CVP:	0.6536	0.5312	0.1682	0.2873	0.2054	0.2877

Table showing the average Kappa statistic (∈[-1,1]) by terrain type and estimation method

Results



Graph showing RMSE of IDW ground estimation by terrain and canopy combination



Figures showing error distribution across different terrain types.

Estimation methods produced generally consistent results on different terrain types, but fared worse for the complex hügelland (small "hills") DEM. Noise in the data contributed to increased error, and areas of high magnitude error were localised at the centres of tree canopies.

In conclusion, this project has investigated the extraction of tree height from DEMs, with success dependant on the types of DEMs used—low-noise images performed better. We found that height resolution of DEMs plays a large factor in the accuracy of ground plane removal.