TREE FUND
Cultivating Innovation

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

3D Tree Mapping
Rethinking the DBH Tape

Dr. Justin Morgenroth

Dr. Christopher Gomez

Mr. Jordan Miller

12.08.2015

NZ School of Forestry

The Need for Accurate Measurement

- Modelling ecosystem services (carbon sequestration and storage, stormwater attenuation, temperature regulation) and resource assessment (value, biomass, volume, and size structure) depend on the ability to accurately determine tree size and structure[1]
- We measure 2D tree metrics
  - Height
  - DBH
  - Crown depth
  - Crown spread
- We can measure, often estimate 3D tree metrics
  - Volume

1 - Nowak, D.J., Crane, D.E., Stevens, J.C., Hoehn, R.E., Walton, J.T., Bond, J., 2008. A ground-based method of assessing urban forest structure and ecosystem services. Arboriculture and Urban Forestry 34, 347-358

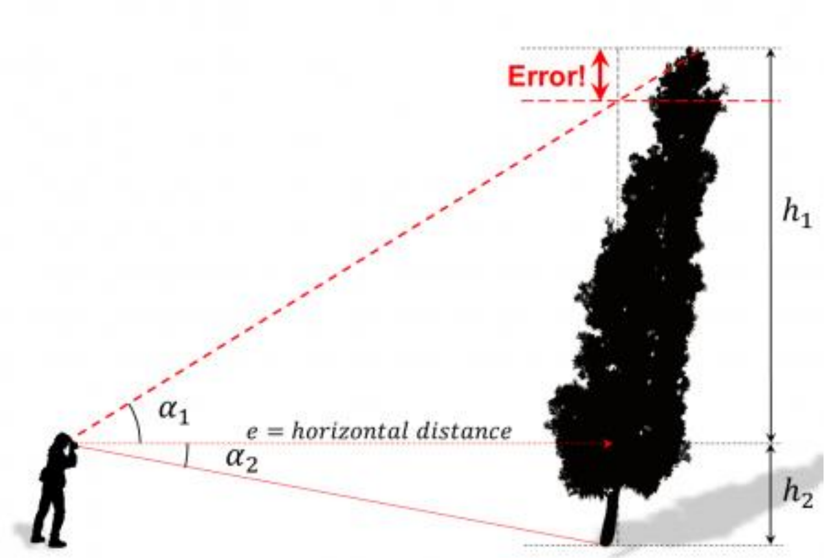
Current Measurement Techniques

- Diameter
  - Diameter tape
  - Caliper
- Height
  - Height pole
  - Clinometer
  - Hypsometer
  - Plumb line
- Volume
  - Xylometry (water displacement)

Error With Current Measurements

Height

- Hypsometers and clinometers assume that angles and distances are measured without error and that the user has correctly identified the highest part of the tree[2]
- Height error discrepancies can exceed 30%![2]

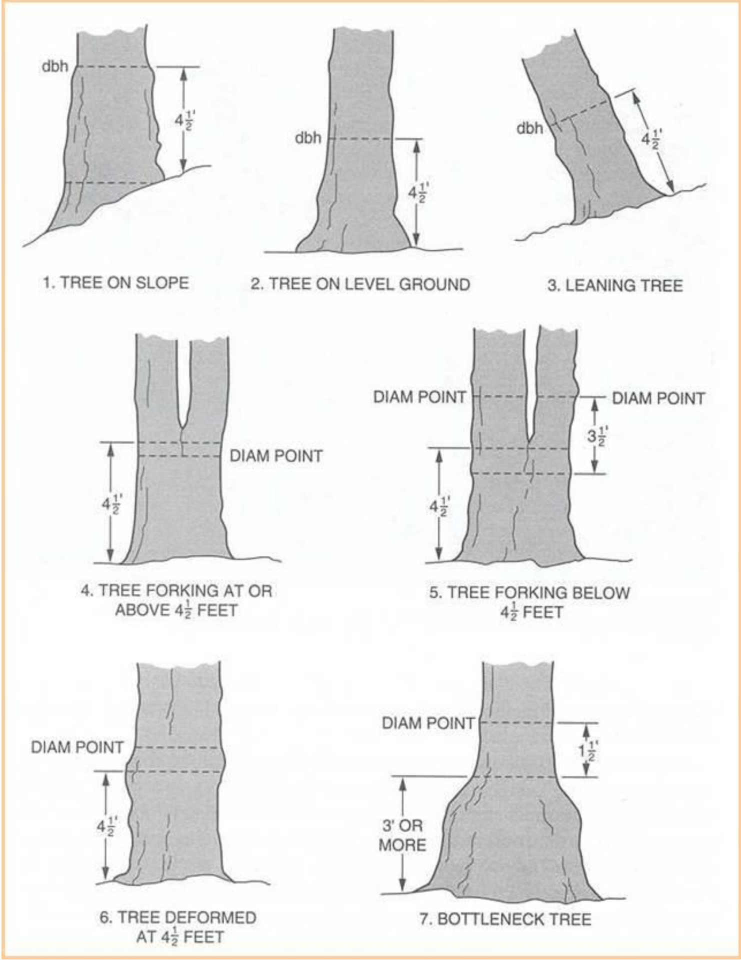


2 - Bragg, D.C., 2008. An improved tree height measurement technique tested on mature southern pines. Southern Journal of Applied Forestry 32, 38-43.

Error With Current Measurements

DBH

- Simple instrument
- Measurement height depends on country
- Tricky for trees on slopes, with multiple stems, or abnormalities
- Repeatability becomes problematic

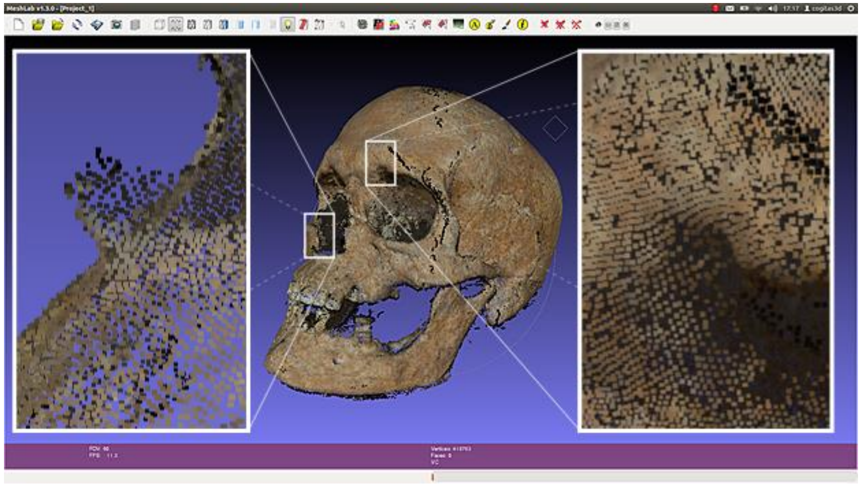


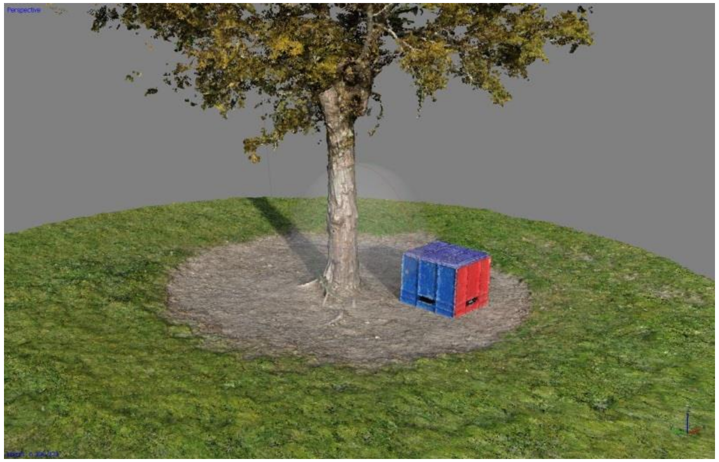
3D Modelling from Remote Sensing

- LiDAR (terrestrial laser scanning)
  - Produces point cloud based 3D model
  - Highly accurate
  - Costly ($5K – 250K)
  - Specialist knowledge
- SfM-MVS (structure-from-motion multi-view stereophotogrammetry)
  - Produces point cloud based 3D model
  - Cheap (Free - $1K)
  - Intuitive with simple software
  - Not well tested

Research Question

- Can SfM-MVS produce accurate estimates of 2D/3D tree metrics?





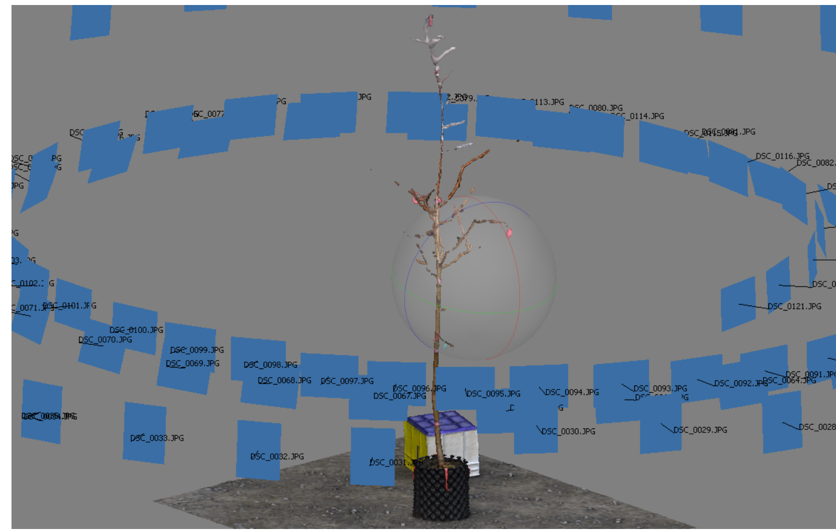
Study Details

- Christchurch City Council nursery, NZ
- 30 trees in 25 L or 50 L plastic pots
  - 12 large-leaved linden (Tilia platyphyllos), 10 field maple (Acer campestre), 5 walnut (Juglans regia) and 3 red maple (Acer rubrum)
- Photographed after leaf fall

Ground Truth Data	Units	Mean	SD	Max	Min
Height	m	2.98 m	0.716	4.53	1.64
Average Crown Spread	m	1.14 m	0.446	3.06	0.52
DBH	mm	19.3 mm	4.5	28	5

Methods – Photography

- Any camera will do
  - Body: Nikon D5000
  - Lens: AF-S NIKKOR 35 mm
  - Tradeoff between pixel density and processing speed
- 150-180 photos per tree
- Lots of overlap needed
- Red tape placed at measurement points



Methods – Processing

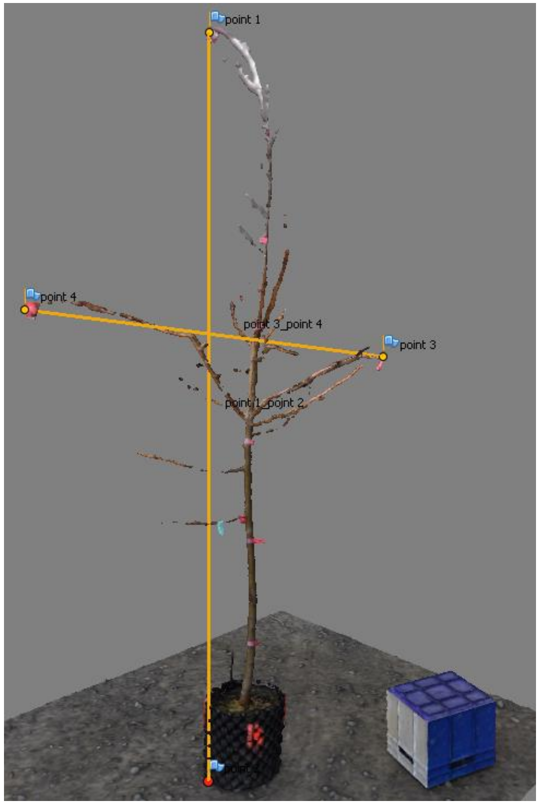
- Software: Agisoft Photoscan Professional
- Simple GUI
- 3 easy steps
  - Image alignment → sparse point cloud
    - Pixel matching
  - Dense point cloud
  - Mesh surface model

3D Model Measurements

Point markers created for 2D estimates

Water-tight model for 3D estimates

Aspatial 3D models need calibration



Methods – Ground-truth Data Collection

- Height → lay each tree on its side and measure from the base of the pot to highest point of the main stem
- Crown diameter → average two perpendicular measurements through the crown
  - Visible crown spread and true crown spread (red tape)
- Stem diameter (incl. DBH) → average two perpendicular measurements with Vernier callipers
- Volume → xylometry (water displacement)
  - Main stem and branches measured separately

Statistical Analysis

- R^2 used to assess how well tree size estimates (SfM-MVS) correlated with measured values
- Accuracy of estimated tree metrics were evaluated using root mean square error (RMSE) and bias:

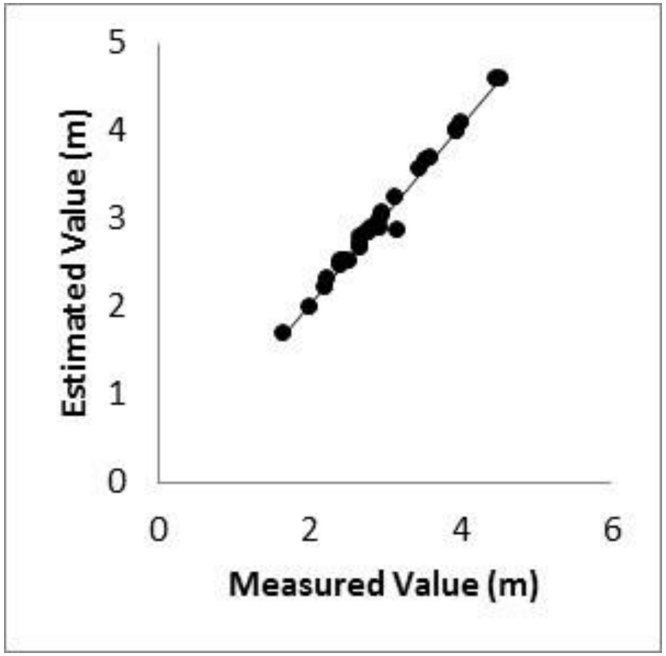
$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n}}$$

$$\text{Bias} = \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)}{n}$$

n is the number of estimates, y_i is the value estimated by SfM-MVS and $\hat{y}_i$ is the ground truth value.

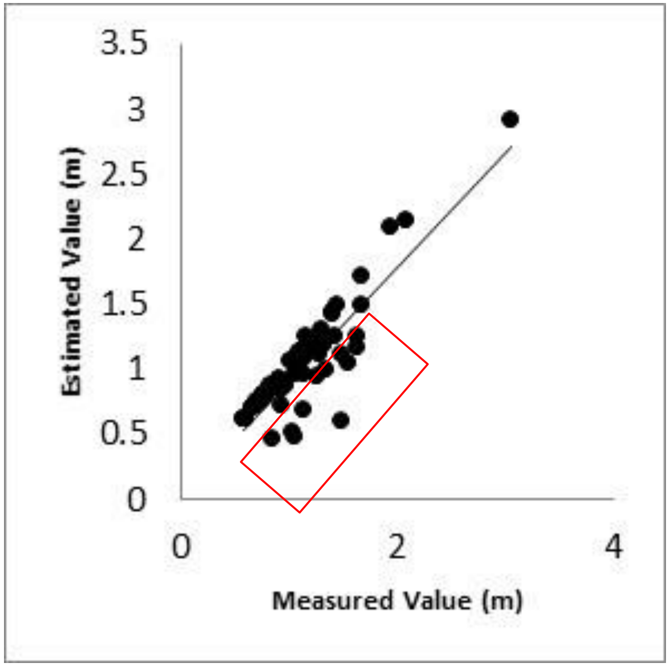
Result - Height

- Height R^2=0.988
- RMSE = 7.8 cm (2.6%)
  Bias = -6.1 cm (-2.1%)
- Height was slightly underestimated by SfM-MVS

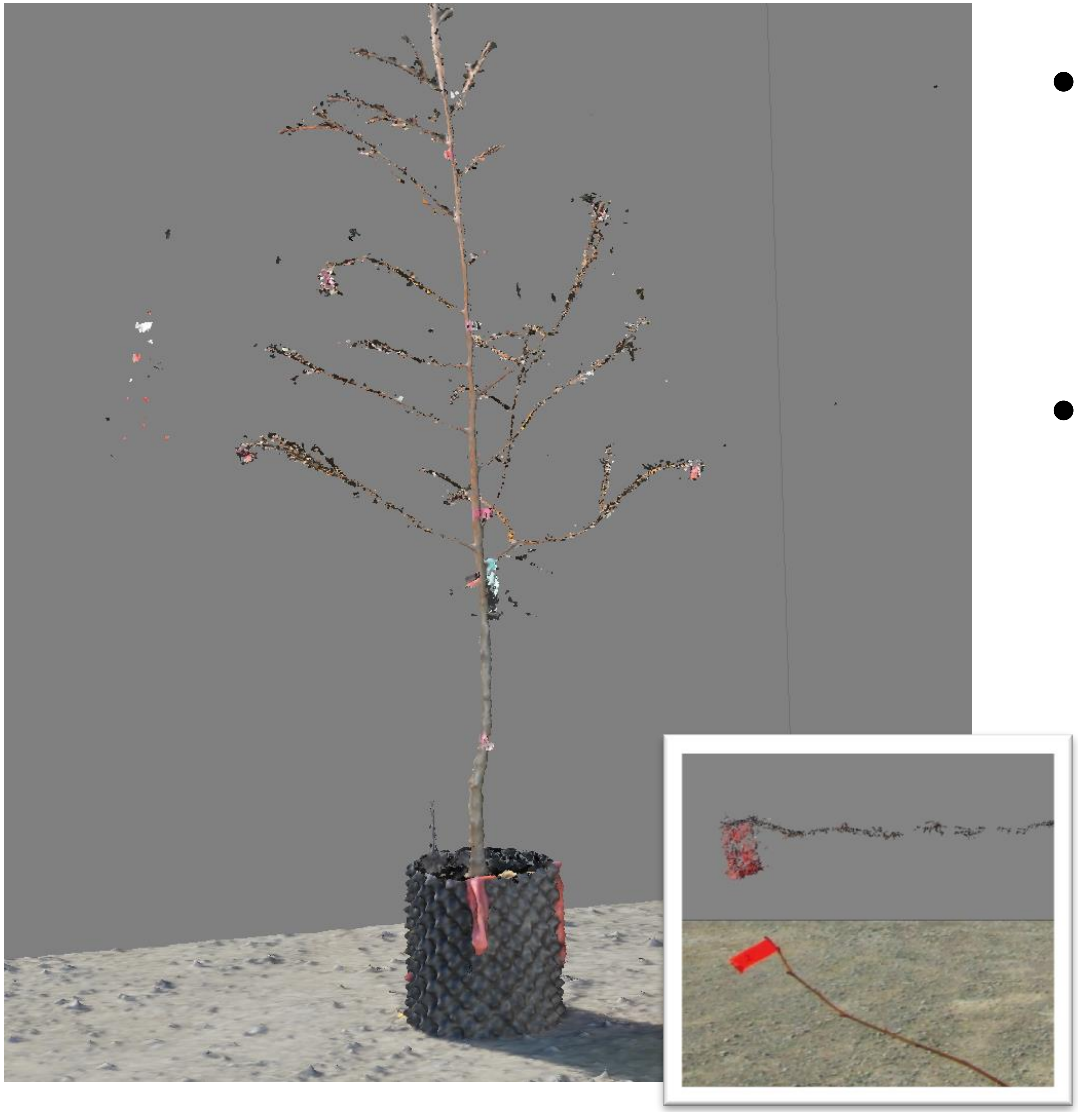


Result – Visible Crown Spread

- VCS $R^2 = 0.782$
- RMSE = 23.3 cm (20.4%) Bias of -10.3 cm (-9%)
- VCS was underestimated by Sfm-MVS
- Why were VCS estimates so poor?



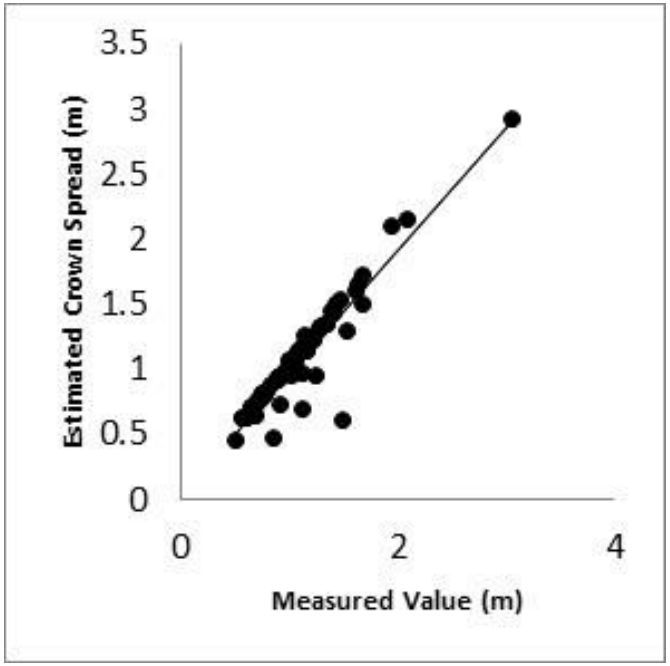
Issue with Visible Crown Spread



- Visible crown spread in 3D model does not represent reality
- Measurements made based on visible extent of branches, not true extent
    - Hence the red tape to measure true crown spread

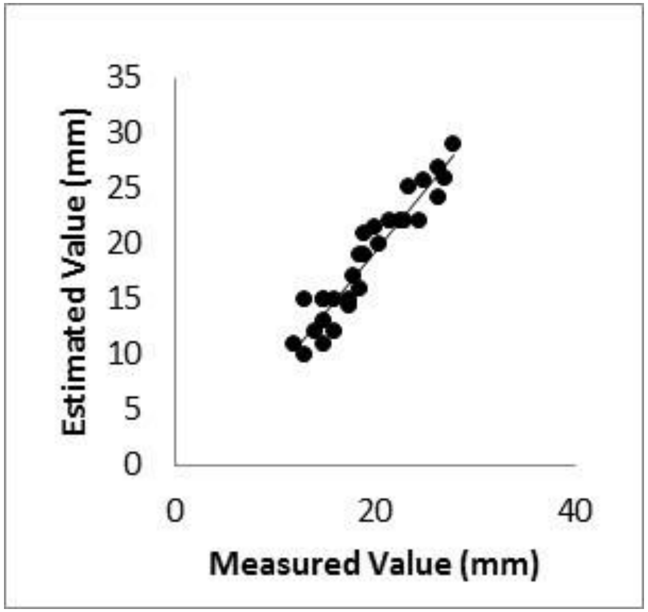
Result – True Crown Spread

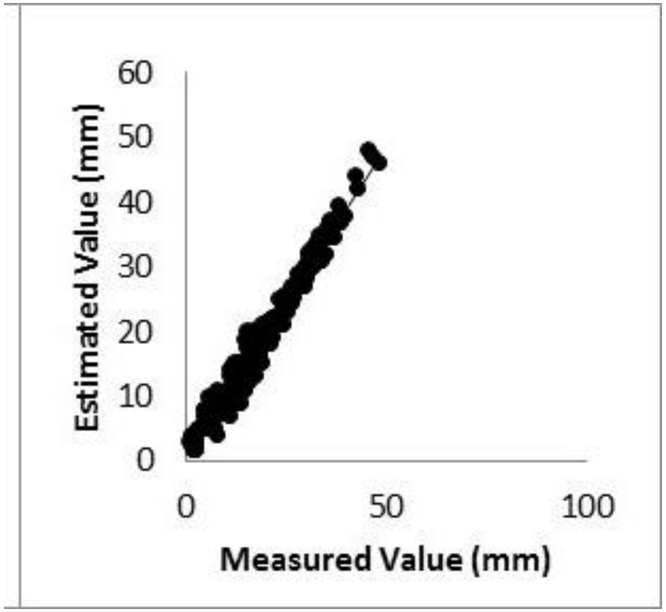
- TCS $R^2 = 0.874$
- RMSE =16.6 cm (14.8%) Bias of -3.9 cm (-3.5%)
- TCS was underestimated by SfM-MVS
- Improvement over VCS



Result – Stem Diameter

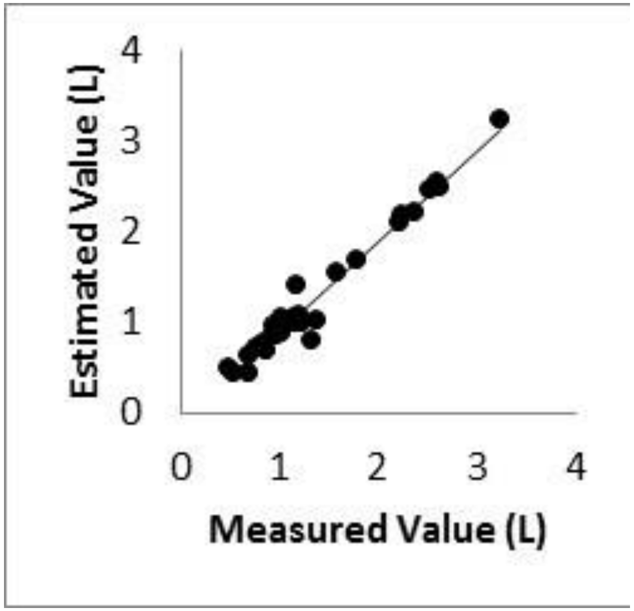
- DBH $R^2 = 0.905$
- DBH:
  RMSE = 1.9 mm (10%)
  Bias of 4.3 mm (0.8%)
- Combined stem diameters
  R^2=0.976
- Combined stem diameters:
  RMSE = 1.9 mm (10.6%)
  Bias of 0.2 mm (1.2%)
- Stem diameters were slightly overestimated by SfM-MVS

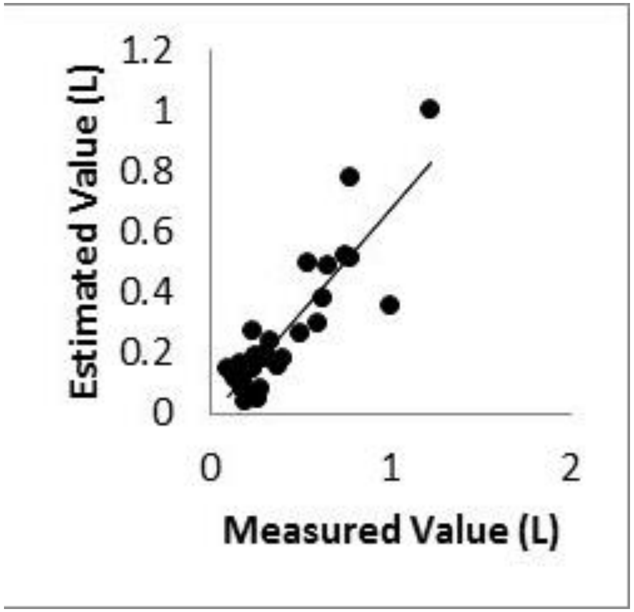




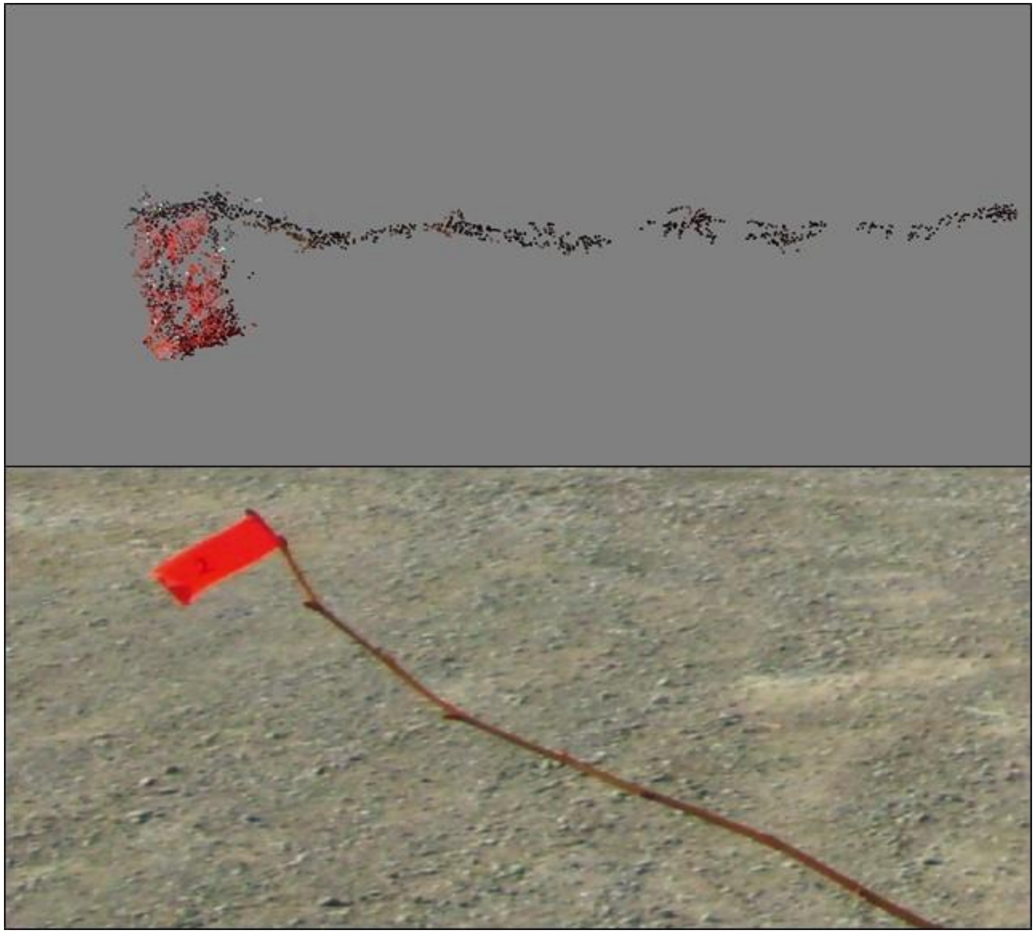
Result - Volume

- Main stem $R^2 = 0.969$
- Main stem RMSE = 0.174 L (12.3%) Bias = -0.115 L (-8.2%)
- Branches $R^2=0.77$
- Branches RMSE = 0.195 L (47.5%) Bias of -0.139 L (-33.8%).
- Total volume $R^2=0.953$
- Total volume RMSE = 0.195 L (10.7%) Bias = -0.254 L (-14%).
- SfM underestimates volume





Known Issue – Slender Branches



- Slender branches not captured by a sufficient number of pixels
- Tape impractical
- Less of an issue for larger trees

Known Issues – Light and Wind

- Shadow prevents pixel matching
- 3D model quality affected
- Volume most severely affected
- Shoot in diffuse light and over a short time period

- Wind creates blur prevents pixel matching

Summary

- SfM-MVS provides a cheap, easy solution to 3D tree modelling
- Produces estimates in line with TLS
- Unlikely to replace traditional inventory methods, but has niche uses
- Great way to obtain volume/biomass estimates

TREE FUND
Cultivating Innovation

Acknowledgements

UC
UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

- We are grateful to the TREE Fund for funding this research through the John Z. Duling research grant.
- We thank the Christchurch City Council, namely Joe Cartman and Mike Smith for providing 30 trees to destructively sample and for allowing us to conduct research at their nursery.
- We appreciate the technical help of Mr. Lachlan Kirk and Mr. Paul Bealing who provided support throughout this research.