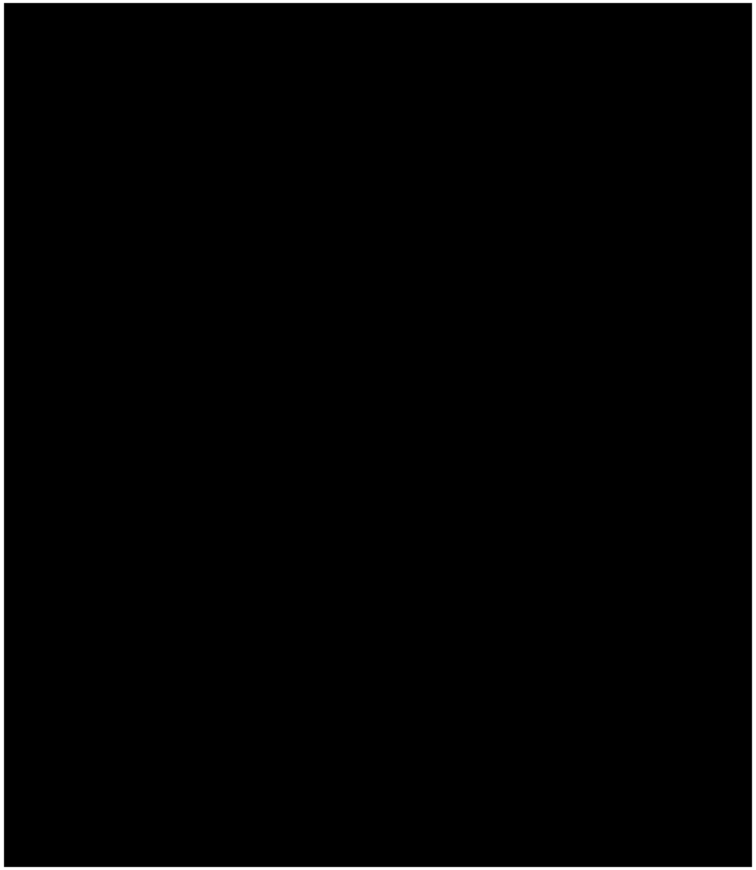
Automatic 3D Mapping for Tree Diameter Measurements in Inventory Operations

Jean-François Tremblay, Martin Béland, François Pomerleau, Richard Gagnon, Philippe Giguère

Université Laval, Centre de recherche industrielle du Québec

Norlab



- Northern Robotics Laboratory
- Université Laval’s department of computer science and software engineering
- Focused on field robotics in difficult environments
- Access to the biggest research forest in the world
- Led by François Pomerleau

Context

- Forestry suffers from labor shortages
- Automation is part of the solution
- Forests: difficult for autonomous robots
- We focused on forest inventory:
  - **diameter measurements**, height, species
- *Manual diameter measurement is slow*
- Use cases:
  - carbon stock inventory
  - selective cutting
  - intelligent forest machines

Overview

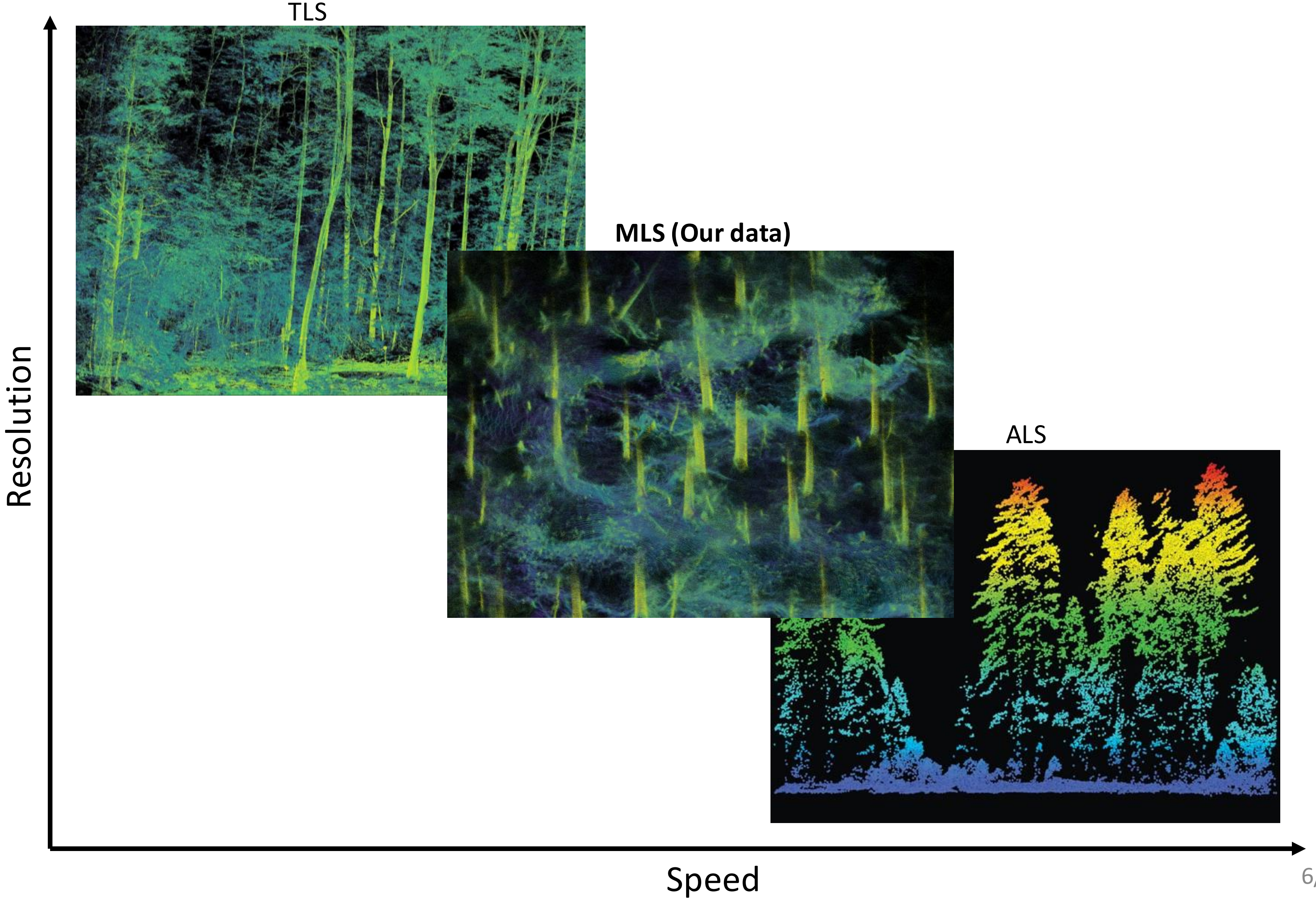
- 3D Mapping with Lidar and ICP
- Tree segmentation and determination of breast height
- Experiments and dataset
- Results

Project Highlights

- Large-scale forest 3D mapping experiments
  - 4 sites, 1.4 ha (14 000 m^2)
  - 11 trajectories
  - Ground truth diameter for 943 trees
  - Natural forests, rough terrain, GPS denied
- In-depth comparison of diameter extraction algorithms from point clouds

Authors	Year	Number of trees	RMSE
McDaniel *et al.*	2012	113	13.1 cm
Tsubouchi *et al.*	2014	6	2.1 cm
Seki *et al.*	2017	7	1.6 cm

Lidar



ICP Mapping

- Study how ICP mapping performs in forests
- Software based on `ethz_icp_mapper`
- No real-time operation: focus on **map quality**

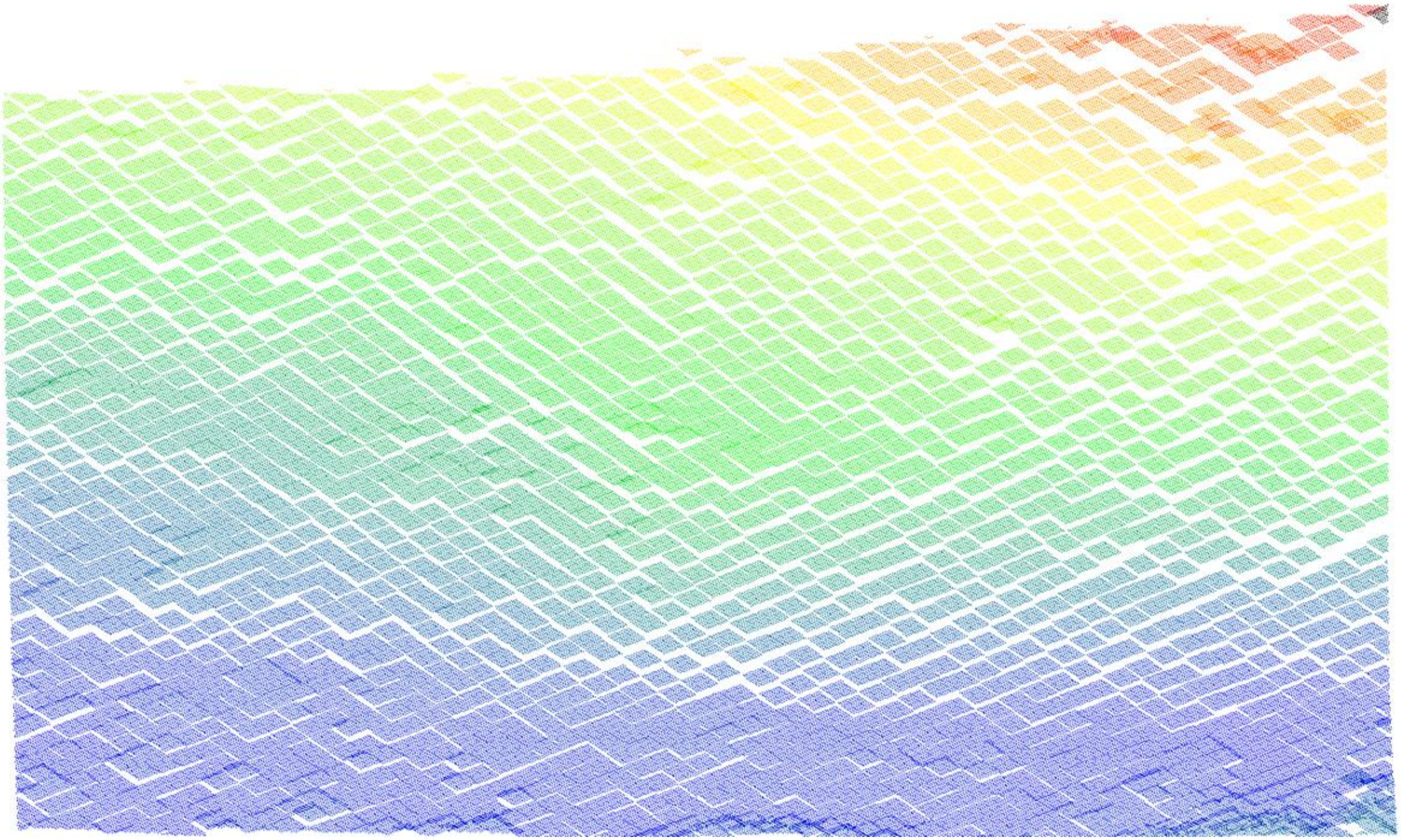
Where to Measure the Diameter? (1)

- Manual segmentation bounding boxes
  - Avoids bias by testing only on easily detectable trees
- Build a digital terrain model $h(x, y)$
- Breast height: 1.3 meters
- Choose points in the bounding boxes according to their height $z - h(x, y)$
- Fit cylinder to the selected points

Where to measure the diameter? (2)

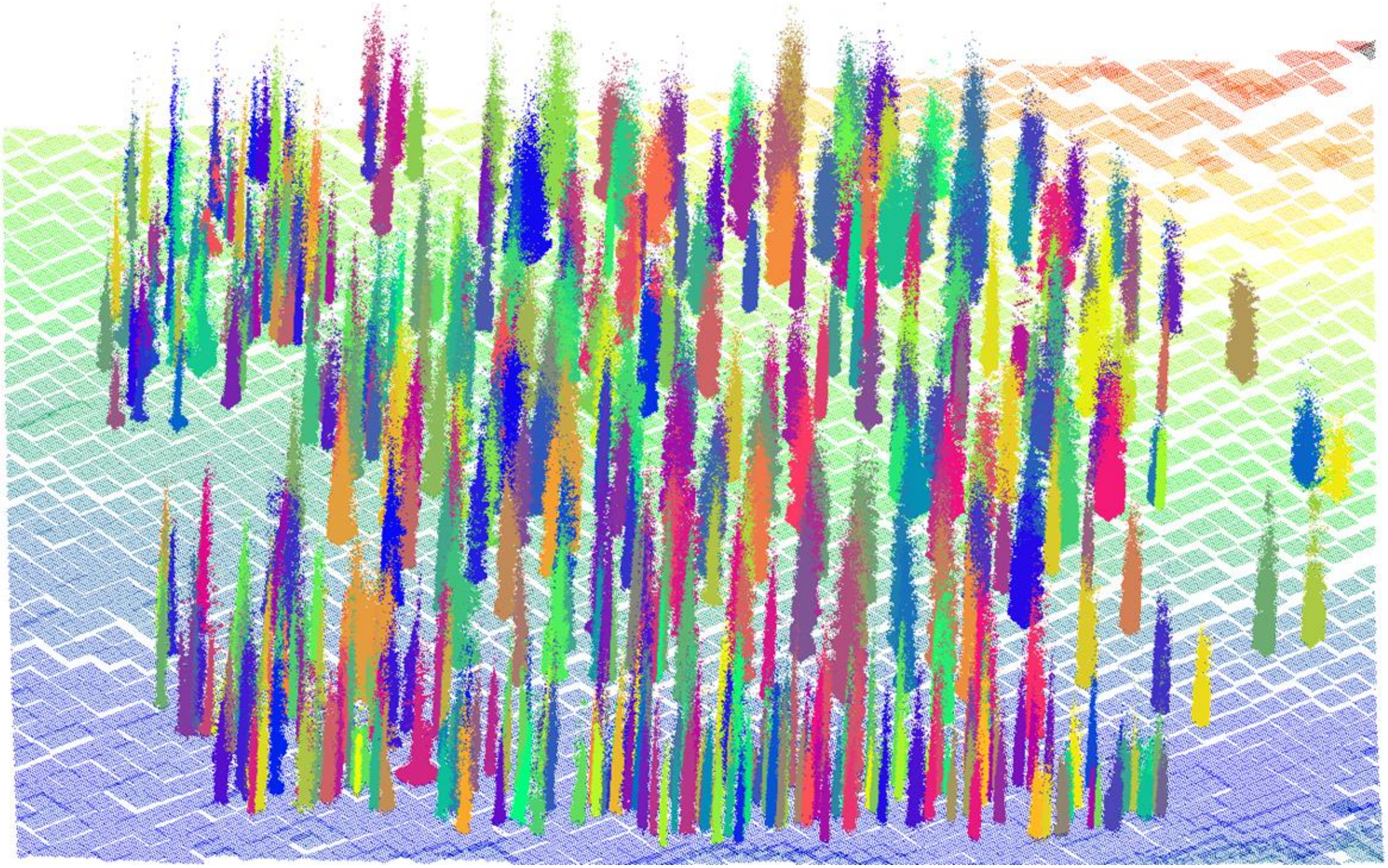
Full map

Where to measure the diameter? (3)



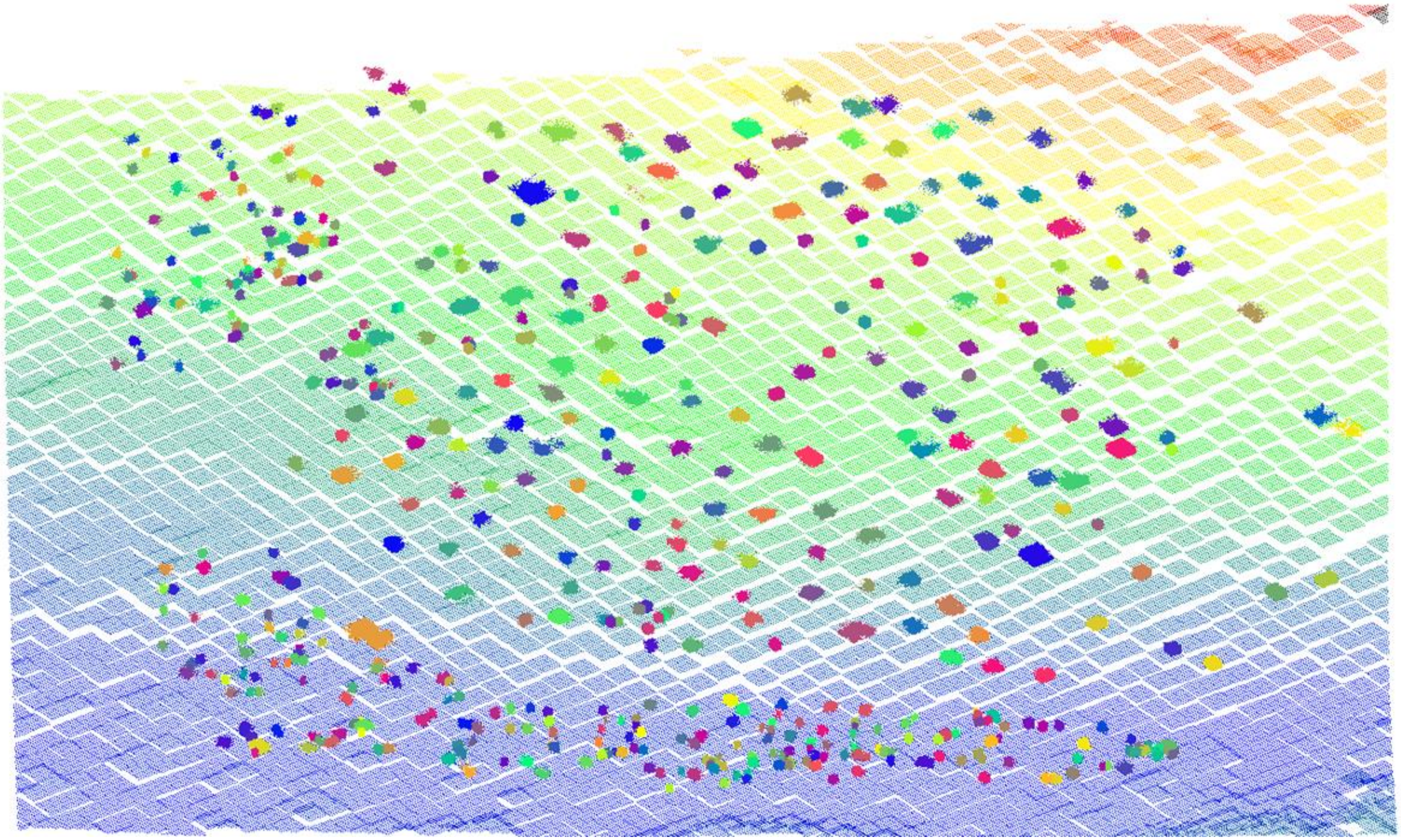
Digital terrain model

Where to measure the diameter? (4)



Tree segmentation

Where to measure the diameter? (5)



Final point selection

Cylinder Fitting: 3 Approaches

- Linear least squares fitting, using normals
- Non-linear least squares fitting, *with* and *without* normals
- Mean and median of fittings at different heights h

Experiments

- **Forêt Montmorency** – 3 sites, 7 trajectories
- **Université Laval Campus** – 1 site, 4 trajectories
- 943 trees, with 588 > 10 cm diameter
- Total of 1458 *observations* of trees > 10 cm, from different trajectories

Test sites (1)

Young

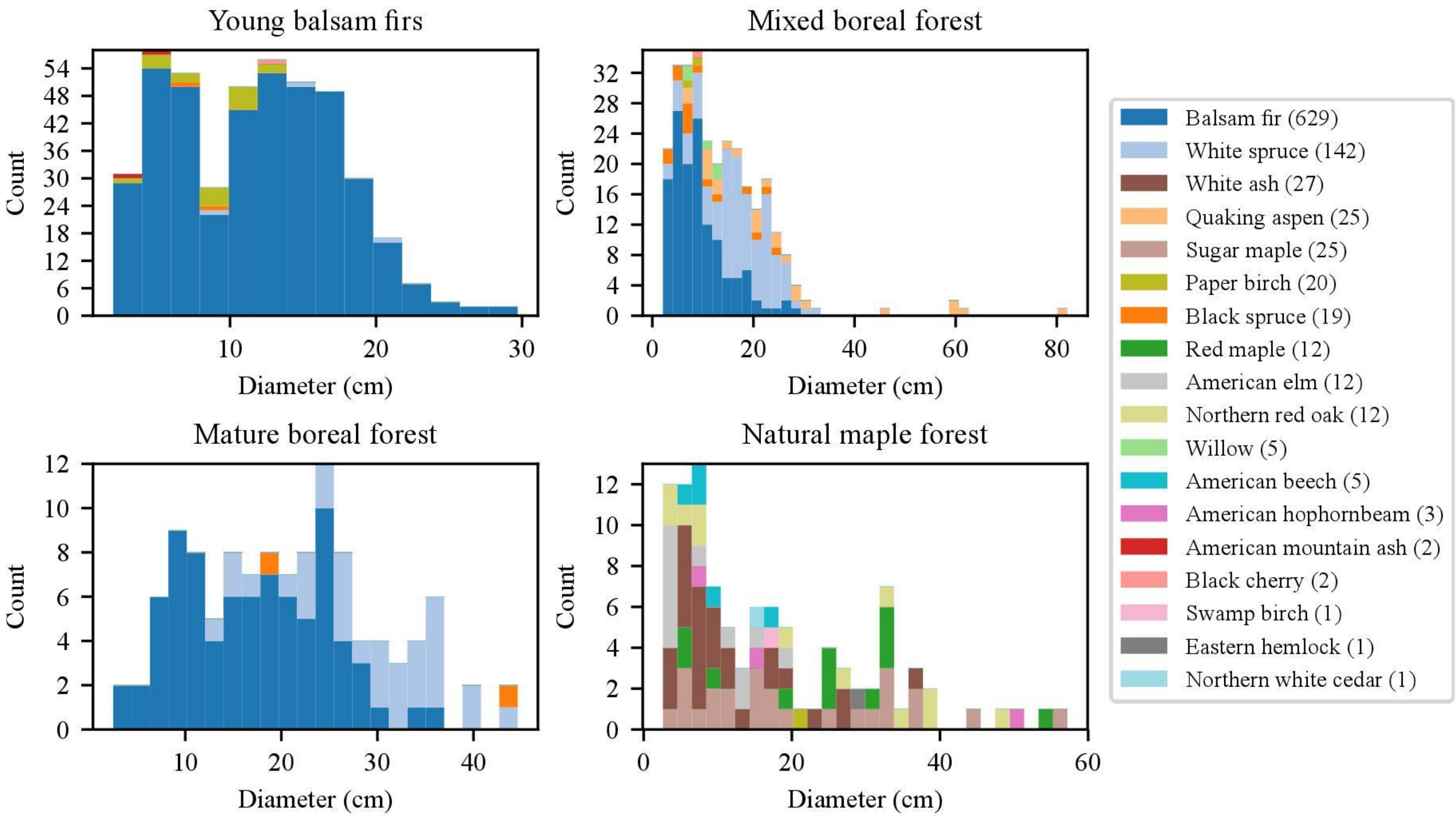
Mixed

Test sites (2)

Mature

Maple

Ground-truth data



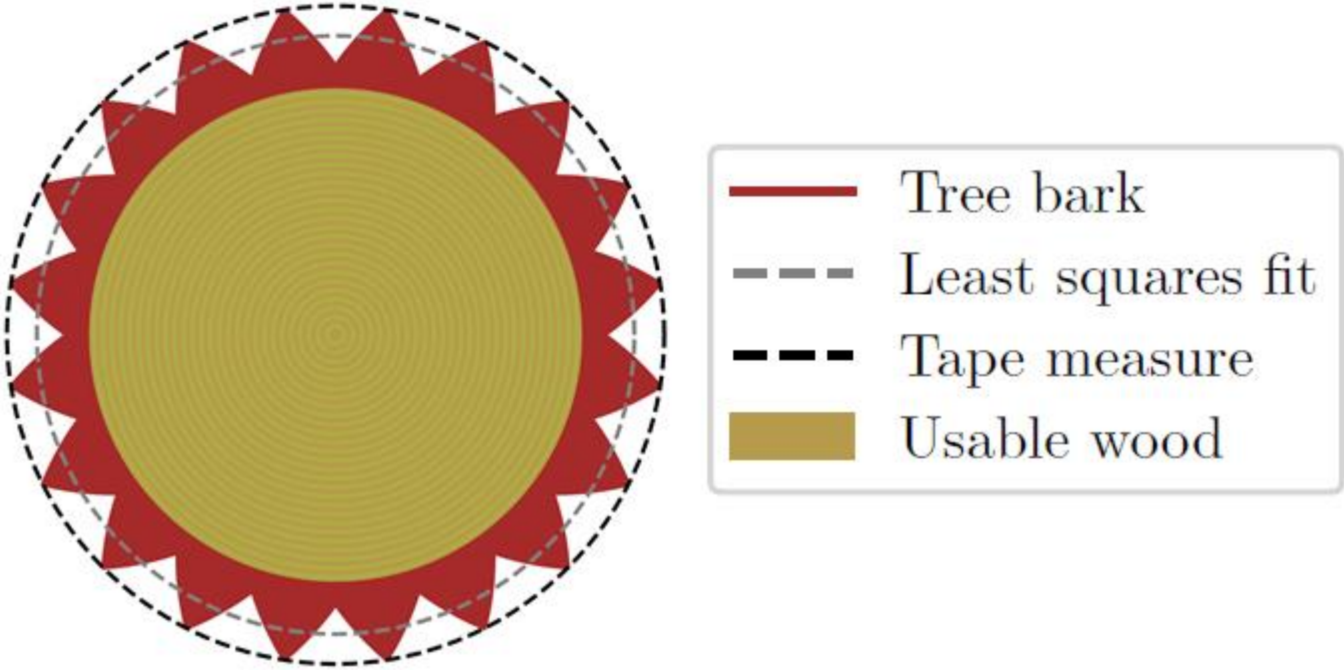
Varied in: *i*) Species *ii*) Age *iii*) Density *iv*) Terrain *v*) Leaves on/off

Mapping results

Here is shown the robot camera view, the lidar map and the external video.

Diameter results (1)

- Best performing site: **Mature** with 2.04 cm of RMSE
- 3.45 cm for whole dataset of 1,458 tree observations
- Negative bias for ***Maple*** (-3 cm), caused by bark texture



Diameter results (2)

- Mean of multiple cylinders does not help, median does
- Leaves have a negative effect *if tree is far*

	$A_{LLS} + C_{NLS}$	$A_N + C_{NLS}$	$A_{LLS} + C_{NLSN}$	$A_N + C_{NLSN}$
RMSE (cm)	3.76	**3.45**	3.86	3.66
Bias (cm)	-0.62	-0.41	-0.18	**0.00**
Fail rate (%)	**6.23**	6.46	6.54	7.53
n_{cyls}	5	5	3	5

Conclusion

- ICP mapping *works* in boreal forests
- Accurate enough to:
  - produce consistent maps as large as one ha
  - extract diameters with accuracy as good as 2 cm
- Best for diameter estimation:
  - initial estimate with normals + least squares + median of multiple fits
  - stay within 10 m of trees: **closer is better**

Future work

- Part of a bigger project for automation in forestry (P. Giguère)
- Integrating work for species identification [1]
- Identify grasp locations in point clouds
- Real time mapping
- Continuous-time trajectory

Credits: Komatsu

[1] Carpentier *et al., Tree Species Identification from Bark Images Using Convolutional Neural Networks*, IROS, 2018