12th FSR conference, Tokyo, 2019

Large-scale 3D Mapping of Subarctic Forests

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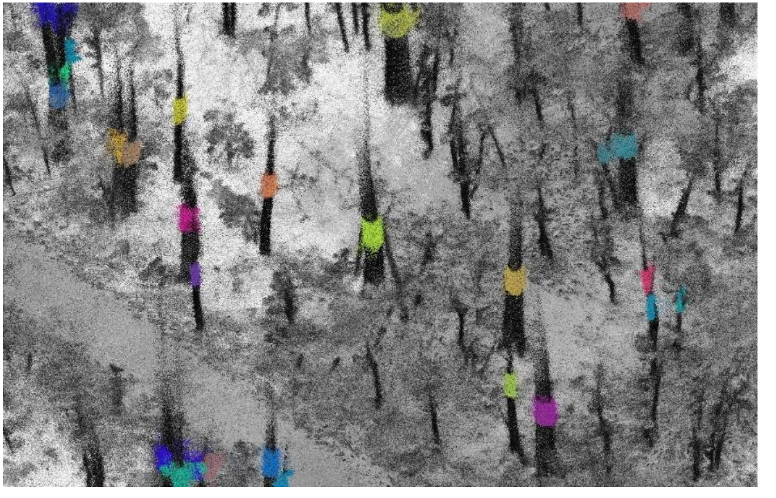
Subarctic Boreal Forest: Research Opportunity

Naive approach

Our approach

Applications



Challenge of Field Tests

Snow Fall

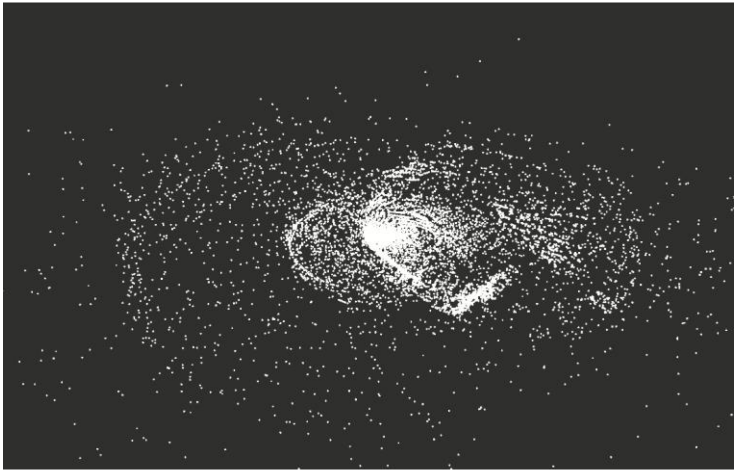
Path obstacles

Uneven Path

Local Wildlife

Mapping of Subarctic Boreal Forest - Challenges

- Unstructured environment → hard to map
- Cold temperatures → noisy sensor
- Few visual features due to snow → bad for vision based approaches



Related Work

Williams et al., 2009

Paton et al., 2016

Contributions

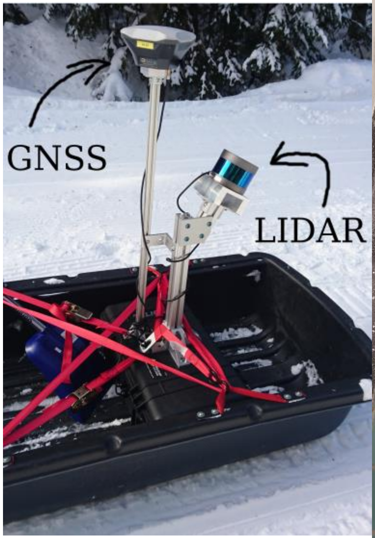
- Large-scale mapping of difficult environments
- Novel fusion of IMU and GNSS measurement inside of ICP
- Generated maps are crisp and without long term drifts
- Introduced optimization to scale to large map

Dataset Environment

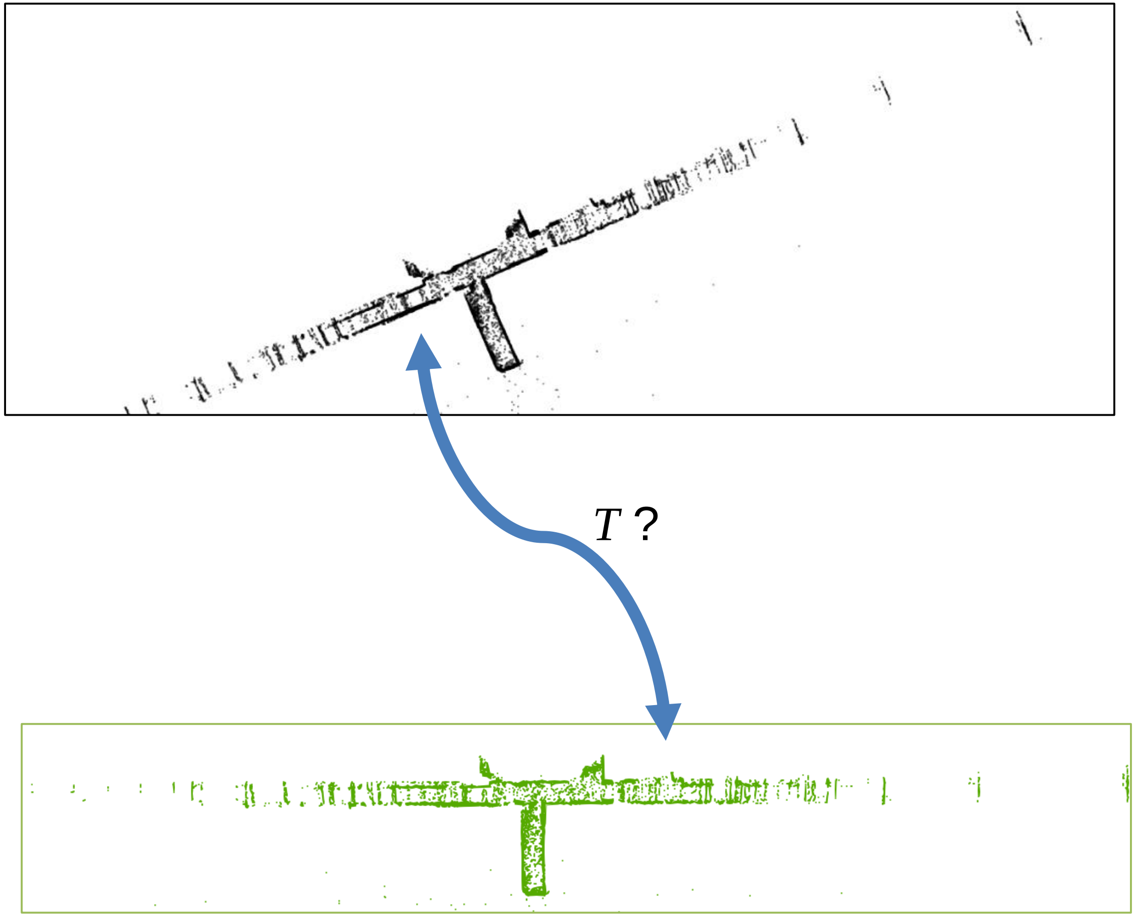
4.1 km of forest path

Data Acquisition Platform

- GNSS station (RTK)
- RS-16 lidar
- MTI-30 IMU
- 10h of battery life



Iterative Closest Point (ICP)



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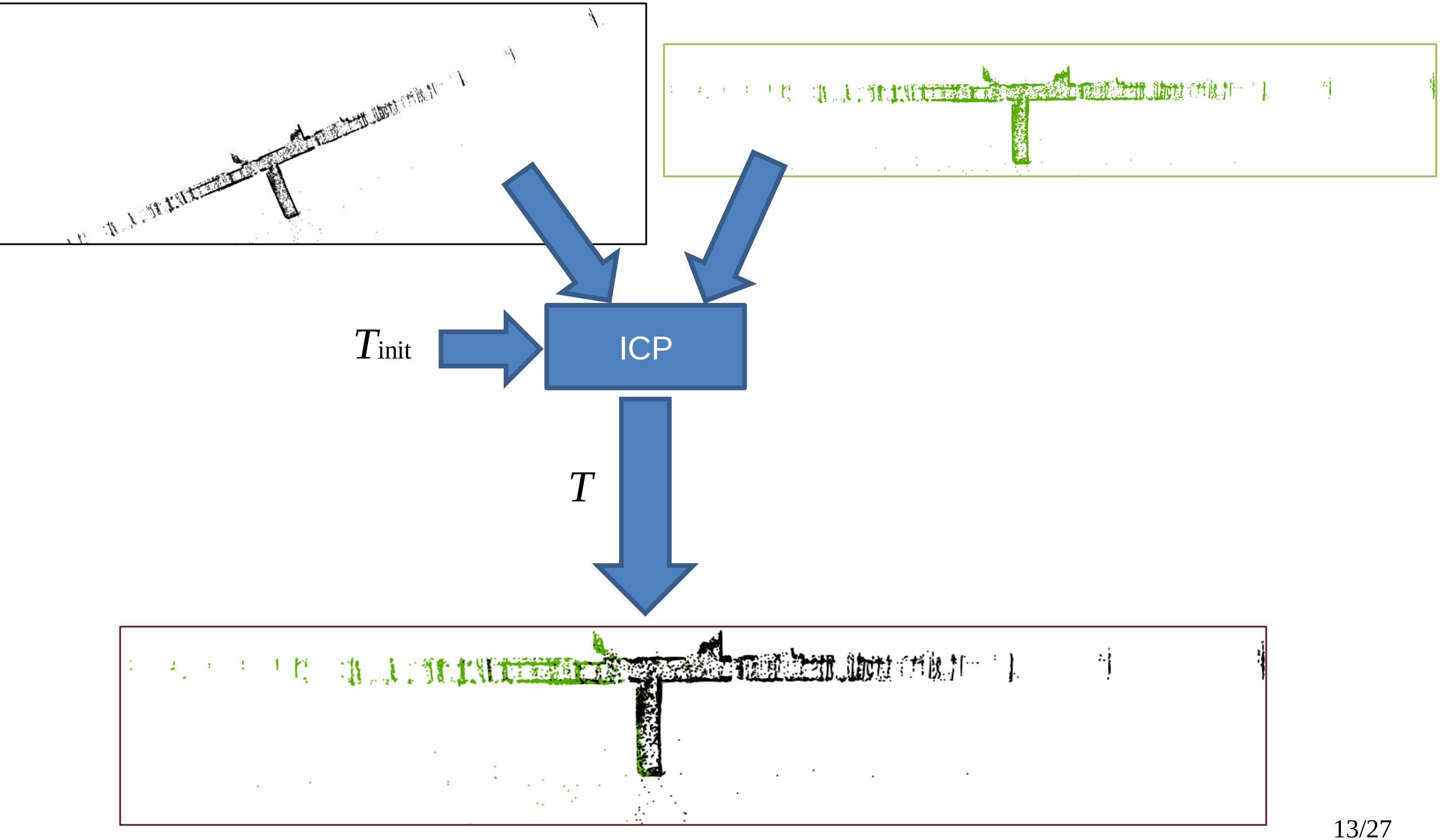

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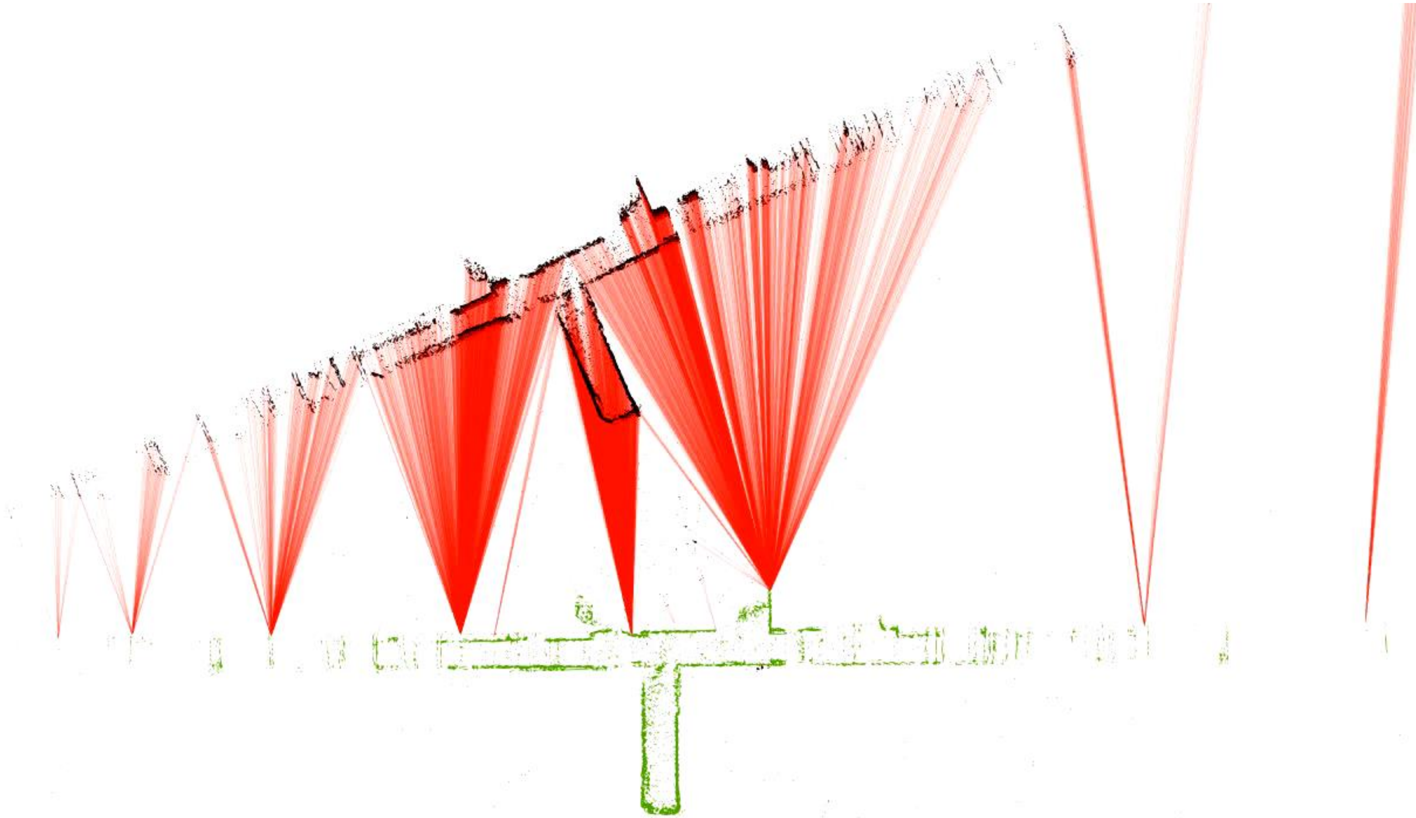
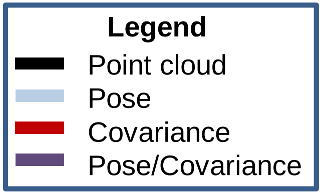
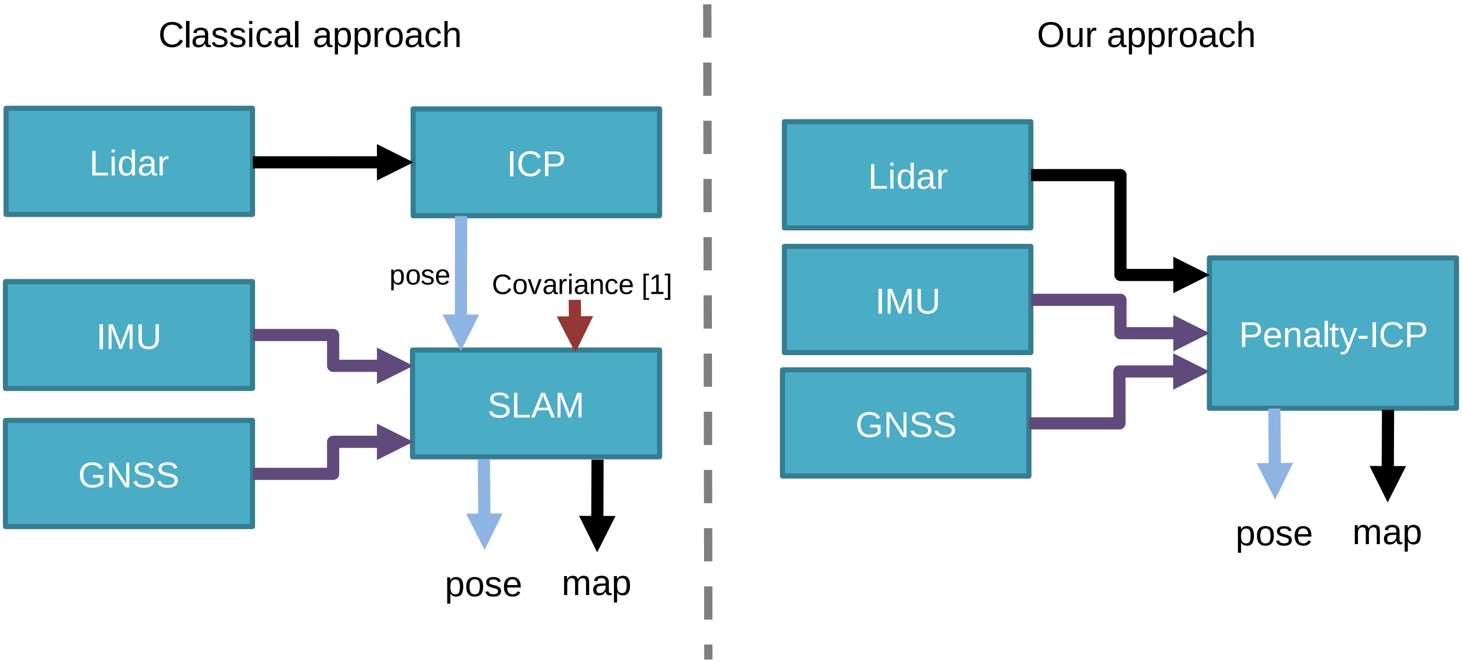


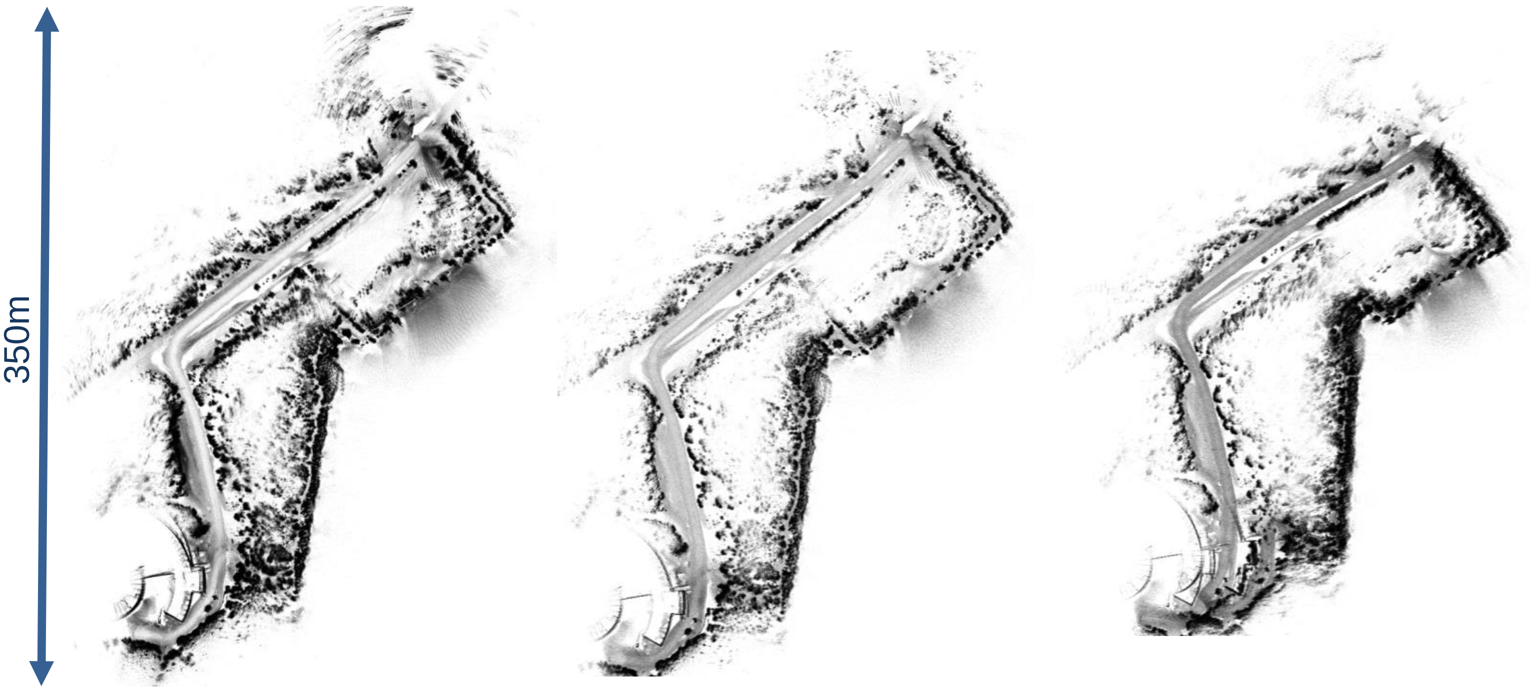
Sensor Fusion





[1] D. Landry, F. Pomerleau, and P. Giguère. CELLO-3D: Estimating the Covariance of ICP in the Real World. In ICRA, 2019

Map of `lake` Dataset



Prior

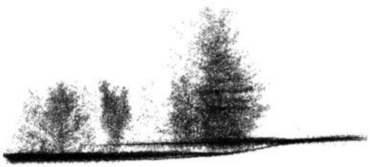
ICP with penalty

ICP no penalty

ICP with penalty

ICP no penalty

Prior



ICP With penalties

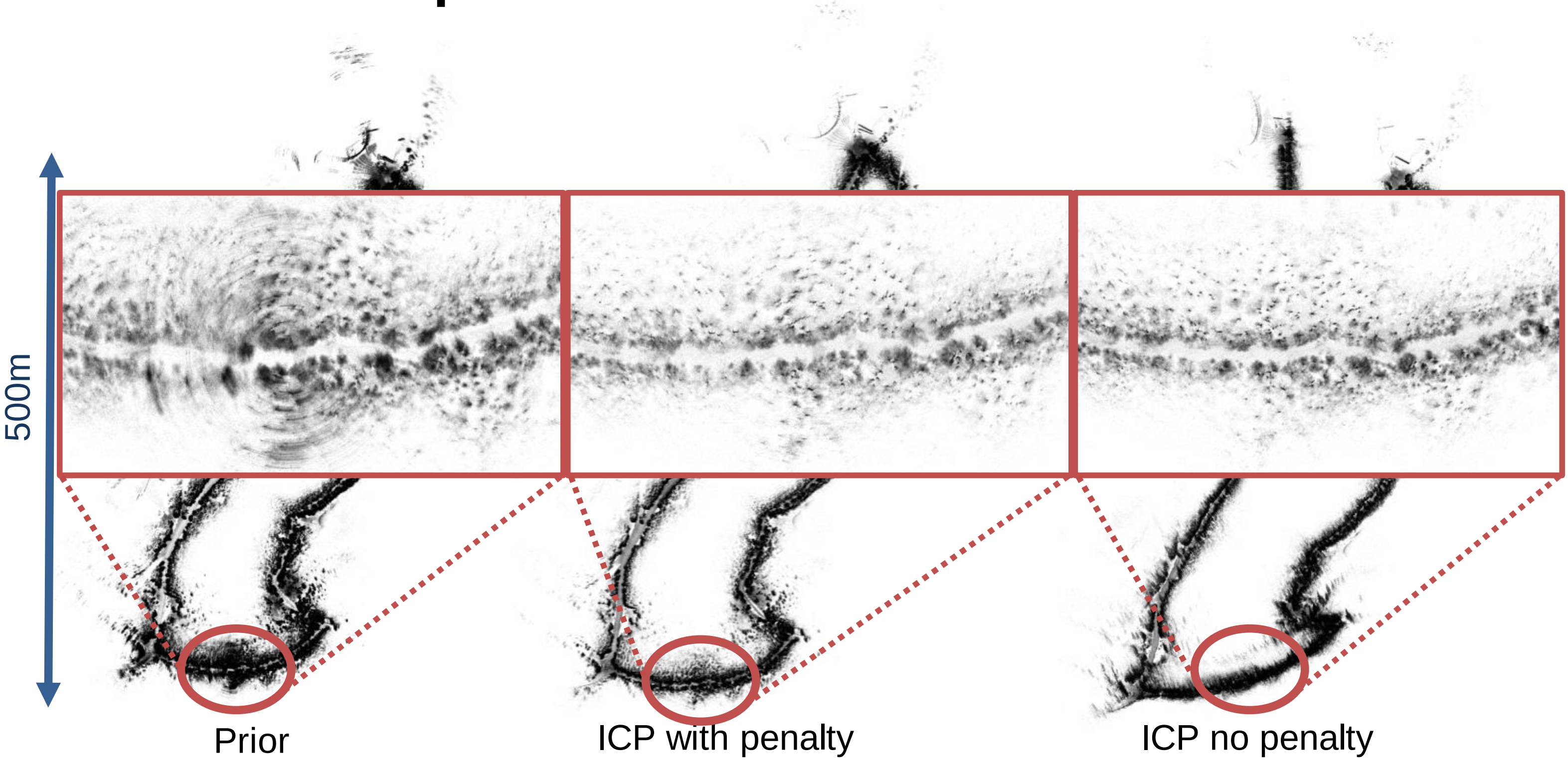
ICP Without Penalties

Crispiness
locally consistent

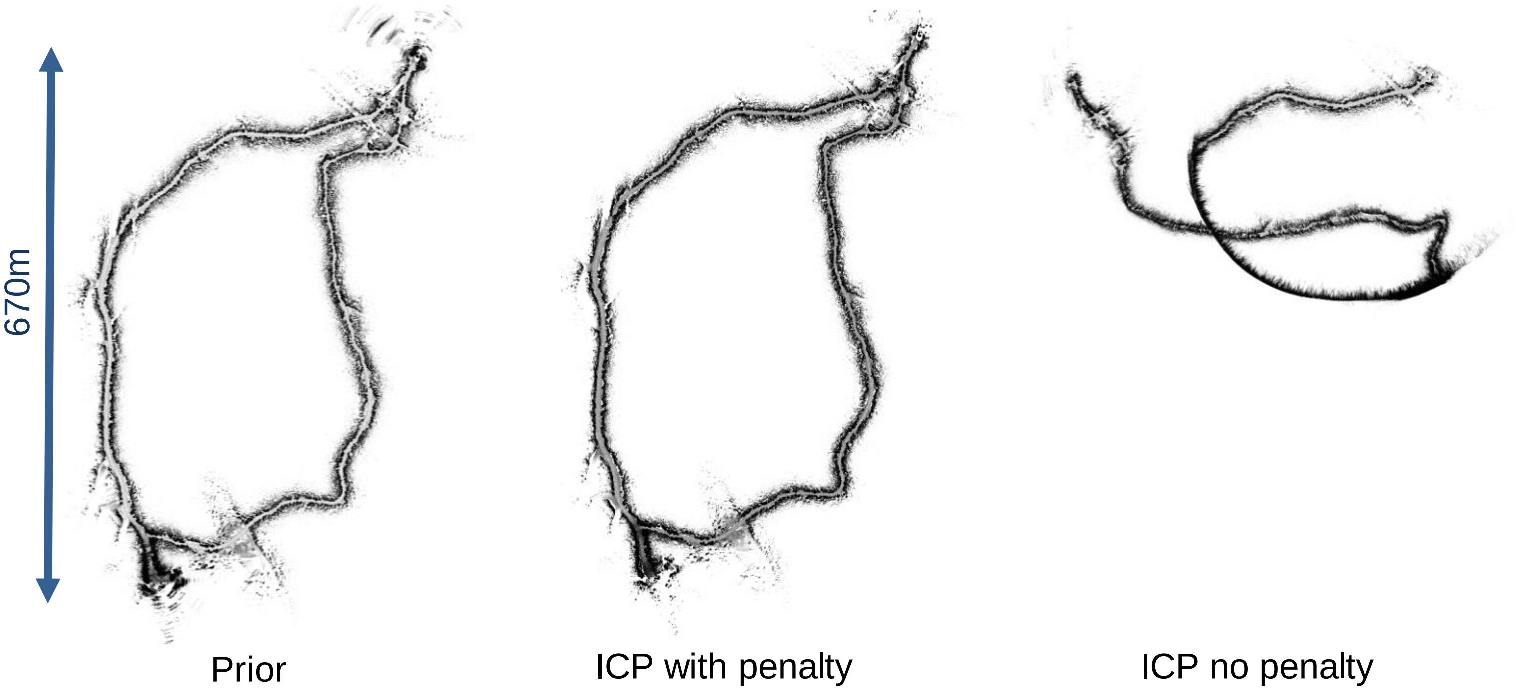
Map of `forest` Dataset

Prior ICP with penalty ICP no penalty

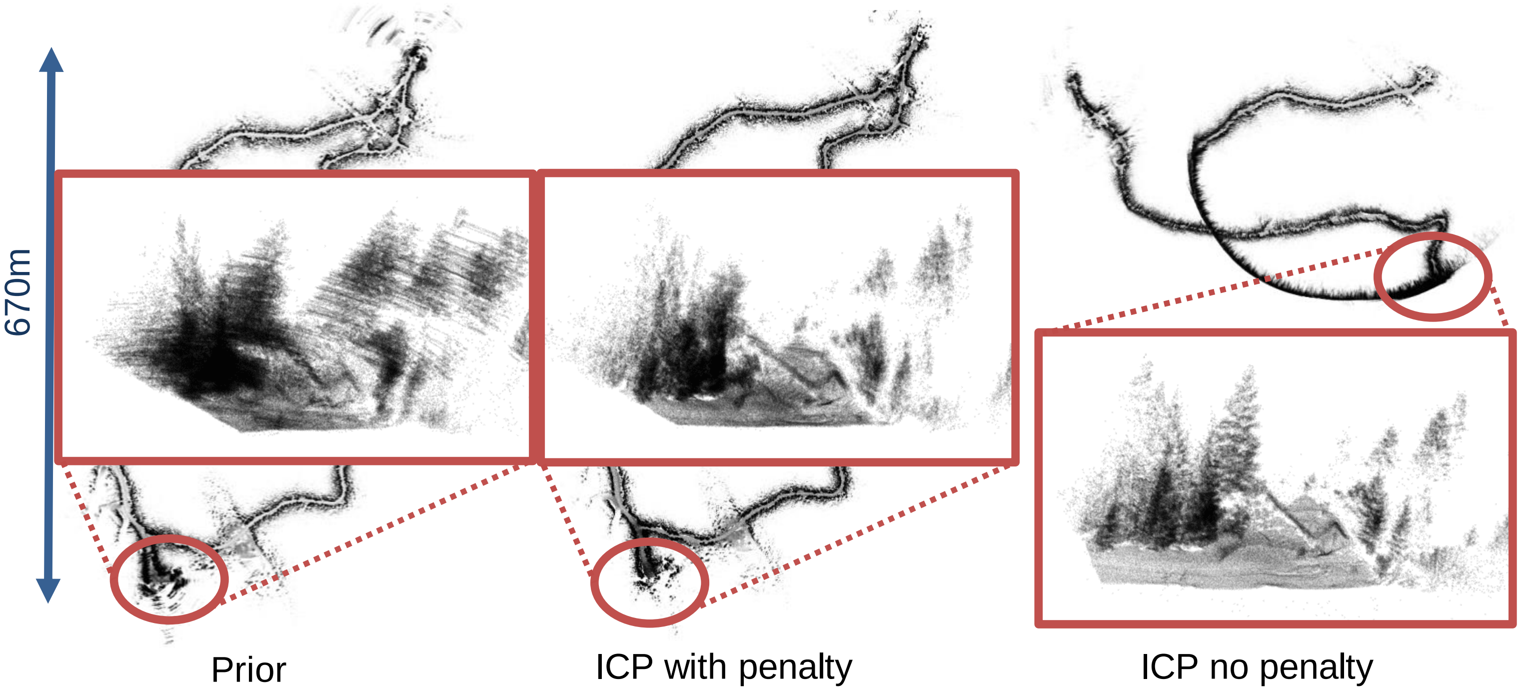
Map of `forest` Dataset



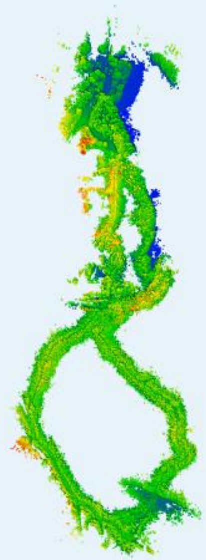
Map of `skidoo` Dataset



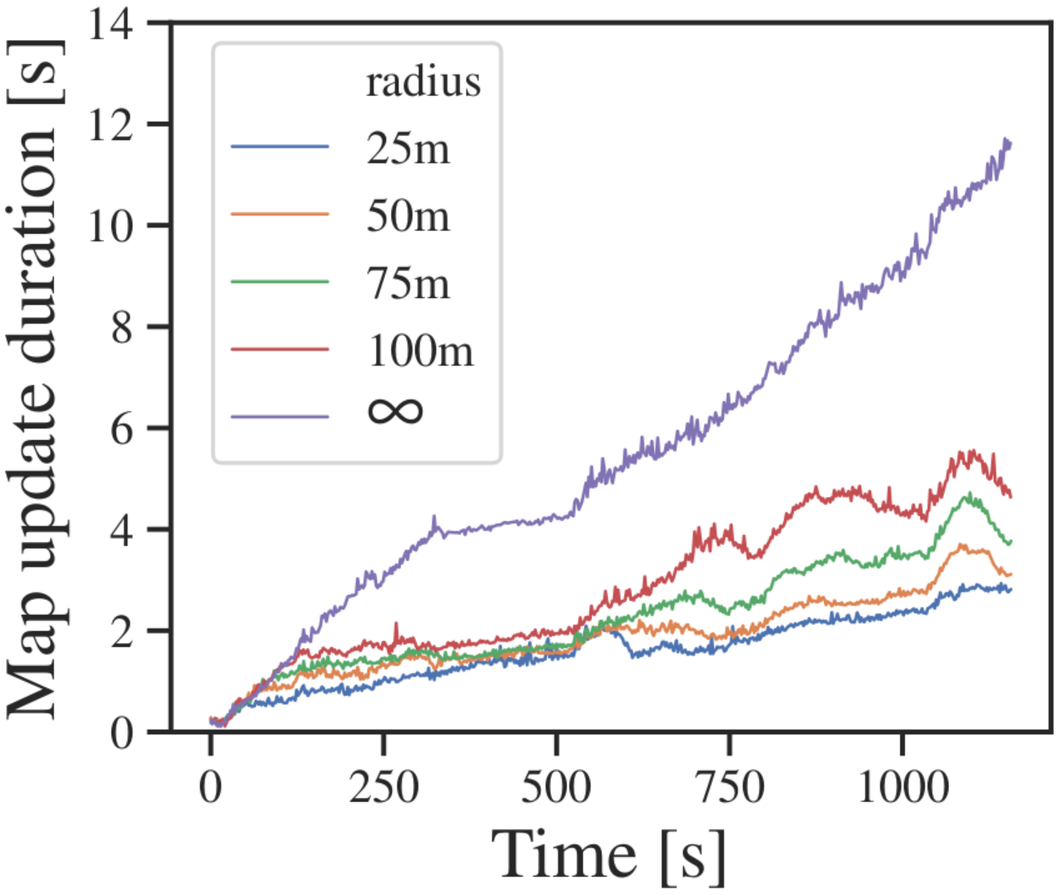
Map of `skidoo` Dataset



Full Map with Penalty



Performance improvements



Future work

Future work – Project SNOW

Questions?

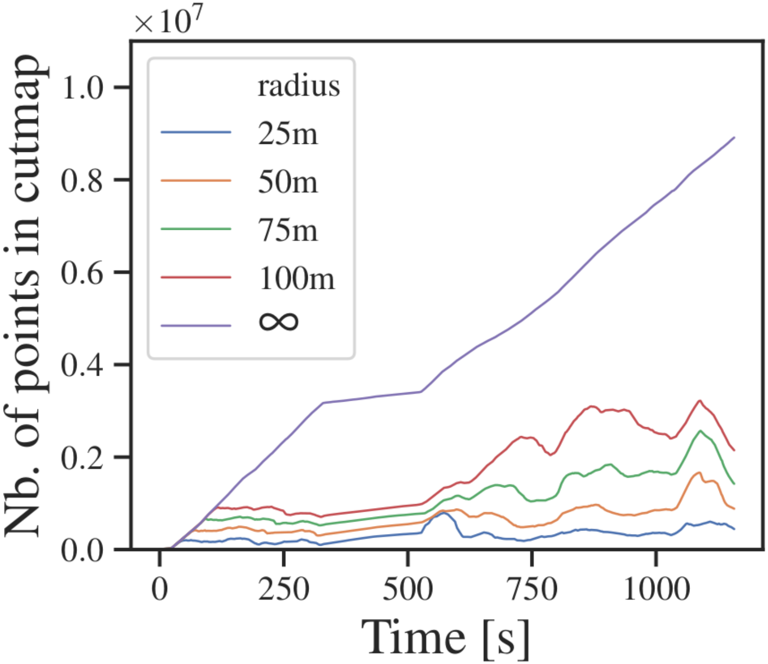
$$J_{\text{p-n}} = \sum_{i=1} \sum_{j=1} w_{ij} (\boldsymbol{e}_{ij}^T \boldsymbol{n}_i)^2, \quad \text{and} \quad \boldsymbol{e}_{ij} = \boldsymbol{q}_i - \check{\boldsymbol{R}} \boldsymbol{p}_j - \check{\boldsymbol{t}}, \tag{2}$$

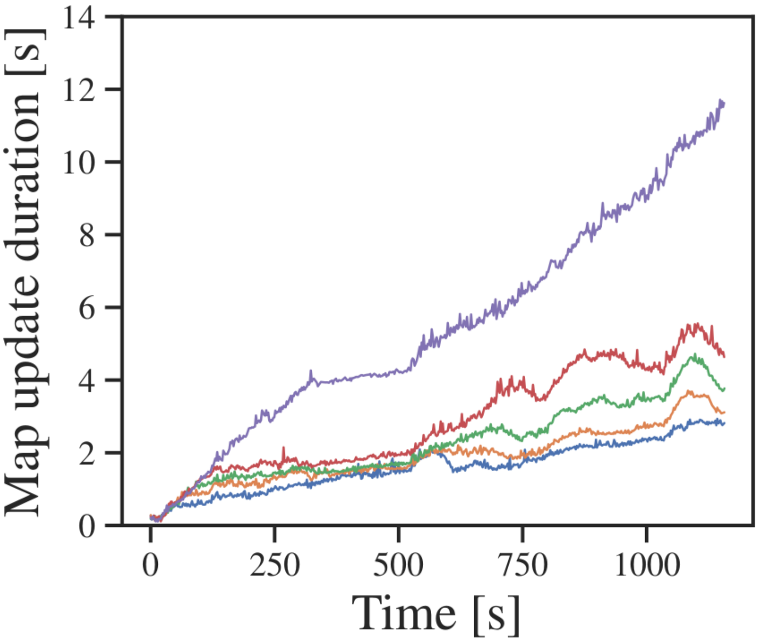
$$\boldsymbol{W} = \boldsymbol{N} \boldsymbol{\Lambda} \boldsymbol{N}^T \Rightarrow \boldsymbol{W}^{-1} = \boldsymbol{N} \boldsymbol{\Lambda}^{-1} \boldsymbol{N}^T. \tag{3}$$

$$\begin{aligned} \mathrm{J}_{\text{p-g}} &= \boldsymbol{e}^T \boldsymbol{N} \boldsymbol{\Lambda}^{-1} \boldsymbol{N}^T \boldsymbol{e} \qquad (4) \\ &= \boldsymbol{e}^T \left[\boldsymbol{n}_1 \ \boldsymbol{n}_2 \ \boldsymbol{n}_3 \right] \operatorname{diag}\left(\tfrac{1}{\lambda_1}, \tfrac{1}{\lambda_2}, \tfrac{1}{\lambda_3} \right) \left[\boldsymbol{n}_1 \ \boldsymbol{n}_2 \ \boldsymbol{n}_3 \right]^T \boldsymbol{e} \\ &= \underbrace{\frac{1}{\lambda_1} \left(\boldsymbol{e}^T \boldsymbol{n}_1 \right)^2}_{\mathrm{J}_{\text{p-n}}} + \frac{1}{\lambda_2} \left(\boldsymbol{e}^T \boldsymbol{n}_2 \right)^2 + \frac{1}{\lambda_3} \left(\boldsymbol{e}^T \boldsymbol{n}_3 \right)^2, \qquad (5) \end{aligned}$$

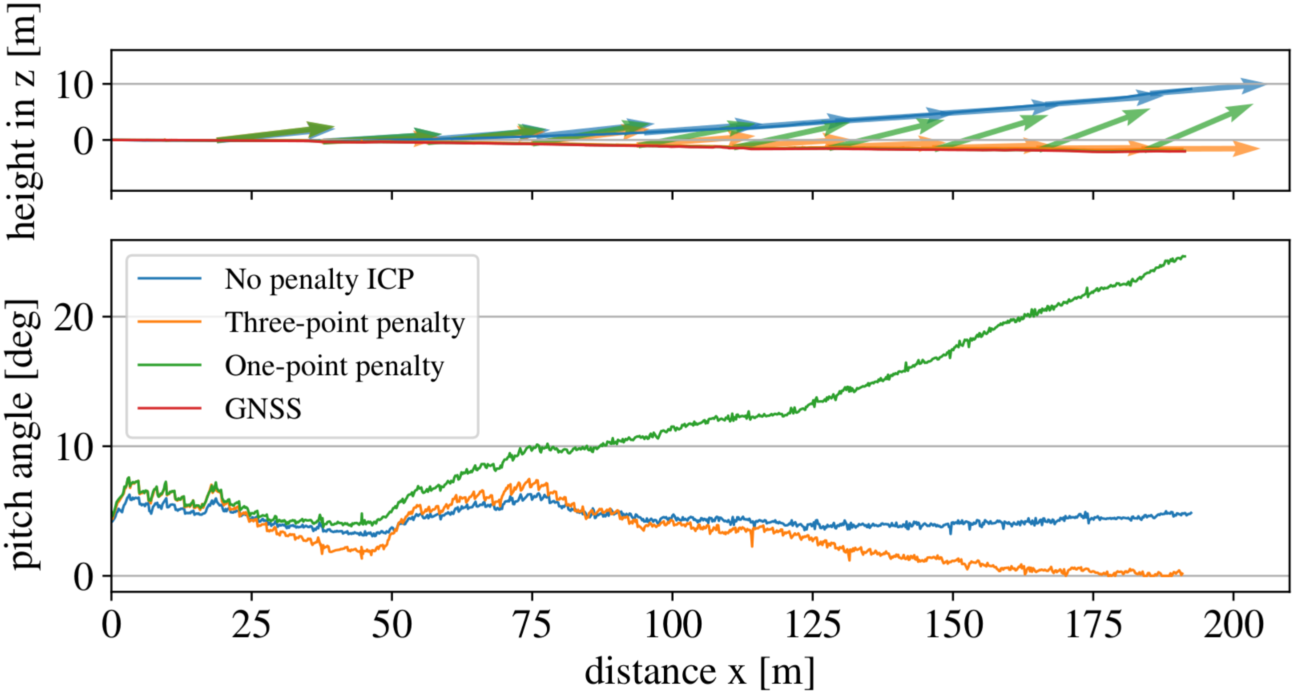
$$\widehat{\boldsymbol{T}} = \arg\min_{\boldsymbol{T}} \underbrace{\frac{1}{M} \sum_{m=1} \left(w \boldsymbol{e}^T \boldsymbol{W}^{-1} \boldsymbol{e} \right)_m}_{\text{point clouds}} + \underbrace{\frac{1}{K} \sum_{k=1} \left(\boldsymbol{e}^T \boldsymbol{W}^{-1} \boldsymbol{e} \right)_k}_{\text{penalties}}, \tag{6}$$

Performance improvements





Results: effect of penalties



Penalty-ICP

- Leverage ICP’s minimizer for sensor fusion
- Add penalty term based on GNSS and IMU estimate
- Introduced a point to Gaussian cost function
- Minimize Mahalanobis distance instead of the Euclidian distance

Full Map