

Hitting Rock Bottom!

A Lab-to-Field Pipeline for Subsurface Reconstruction

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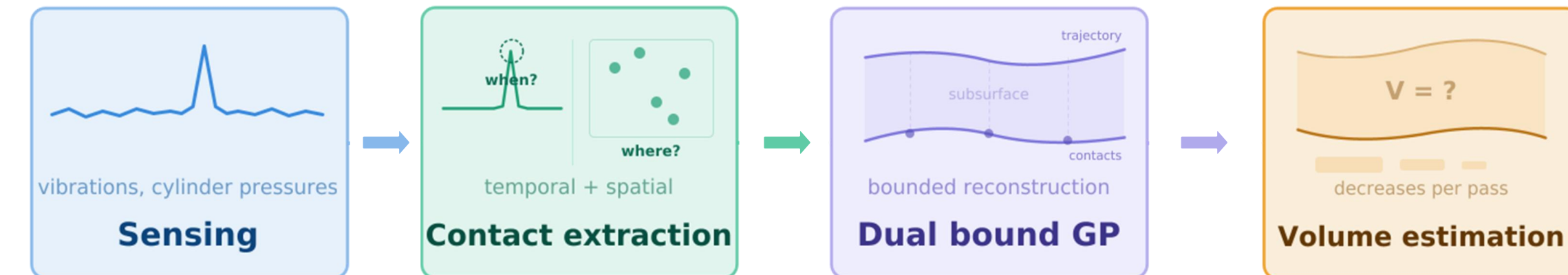
Motivation

RQ1: Can we detect subsurface contact before it's visible? [1]

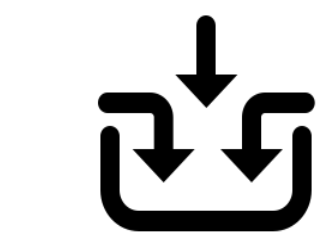
RQ2: Can we estimate remaining volume to coordinate fleets and switch machines? [2]



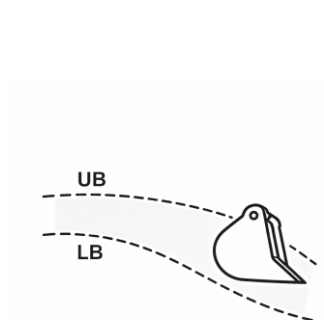
Approach



Extract subsurface contact events from proprioceptive sensors



Fuse temporal information via Bayesian update



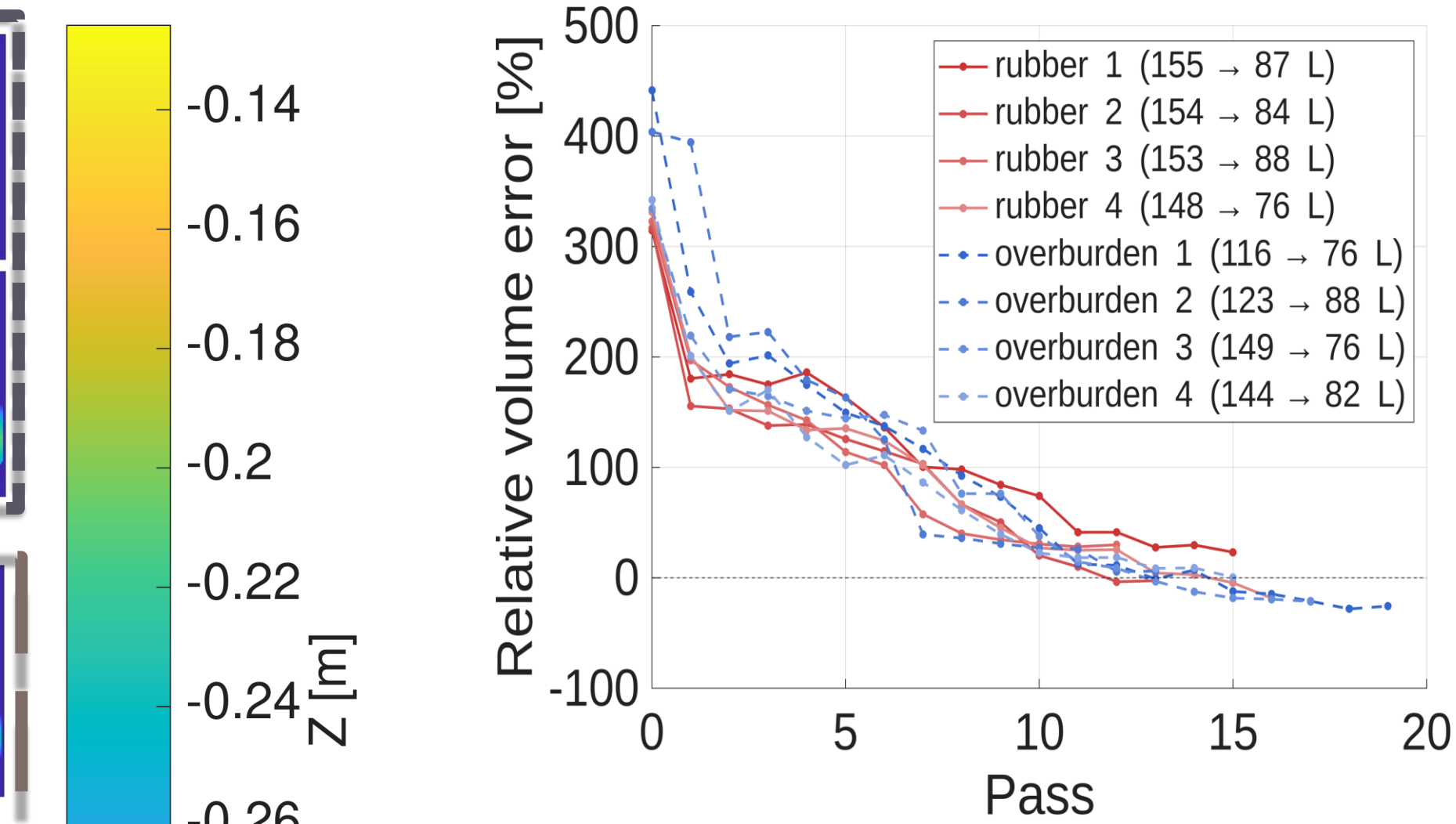
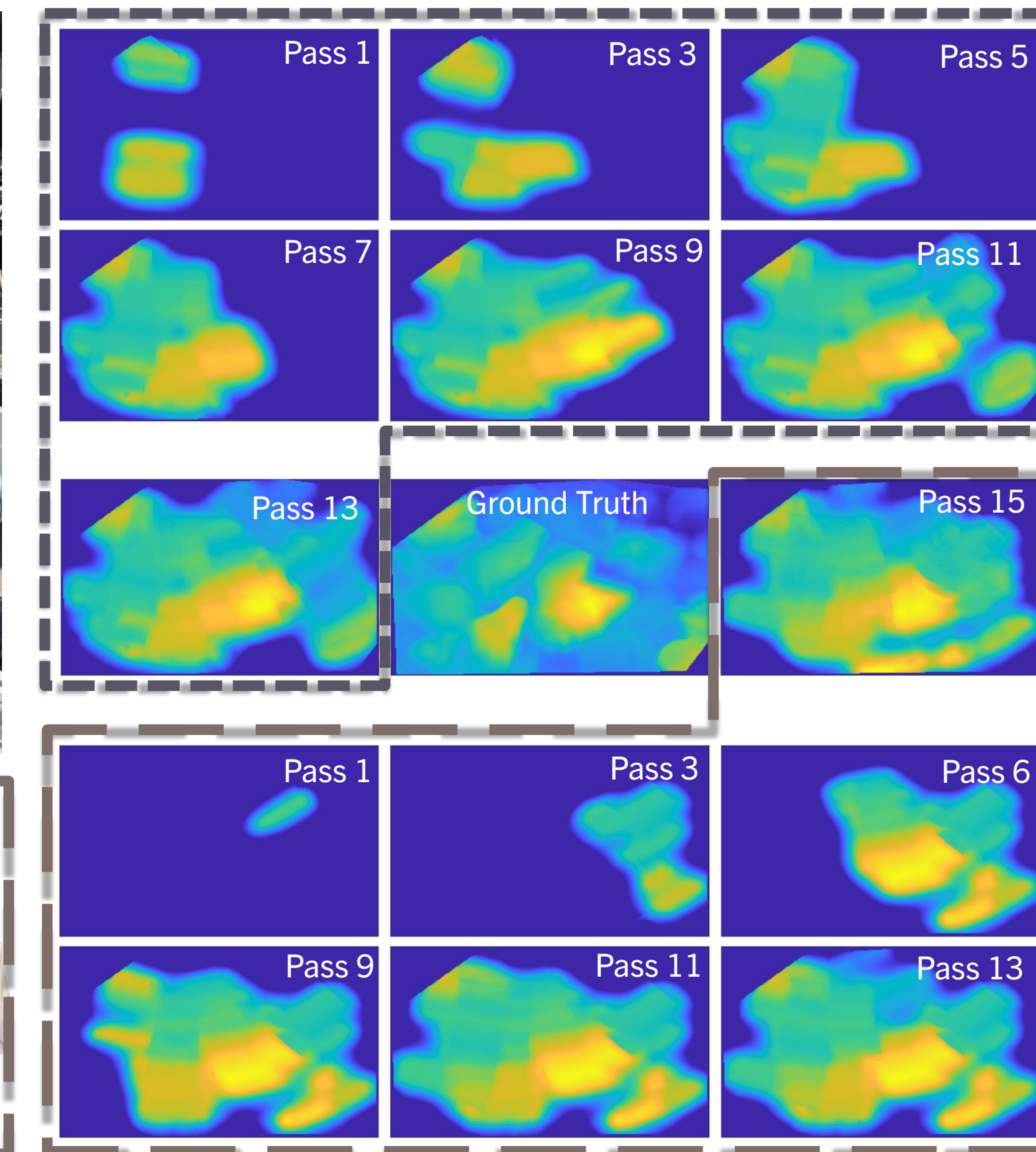
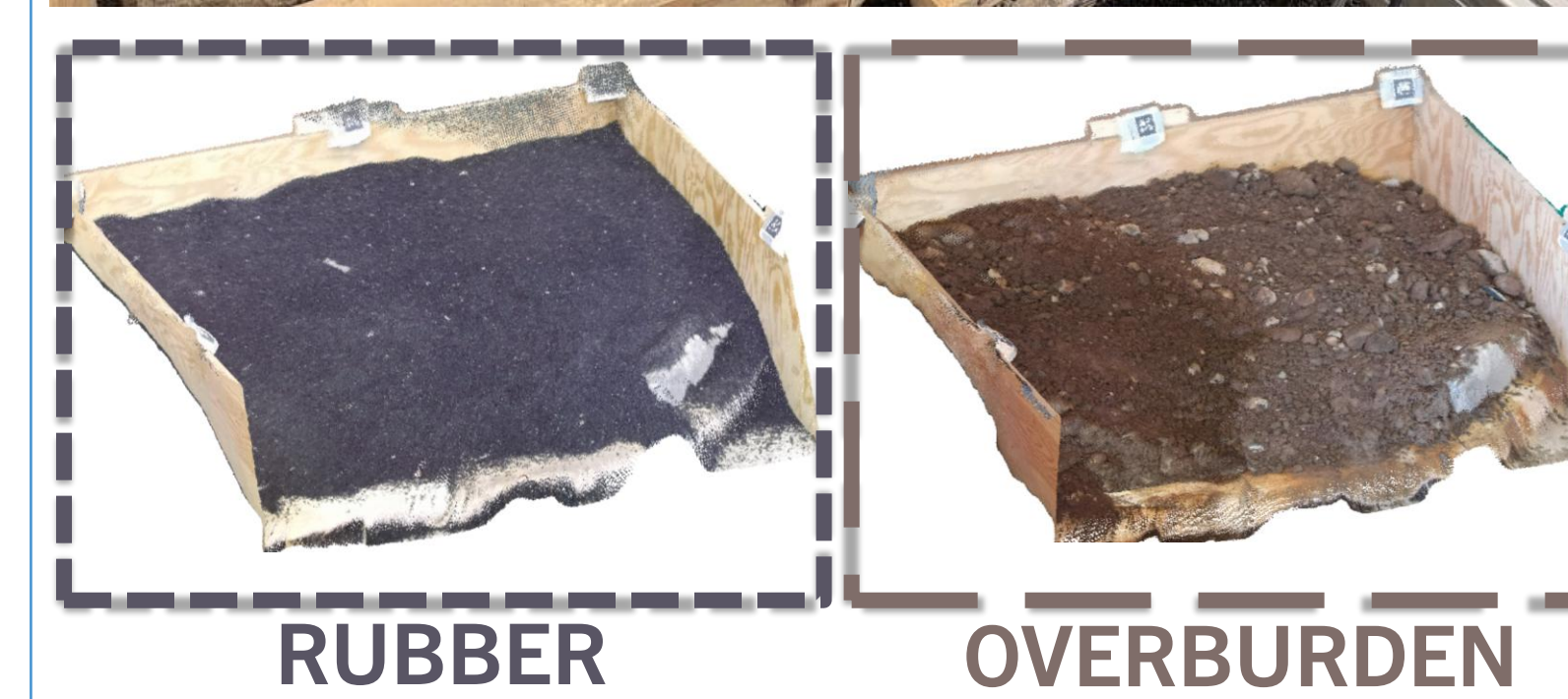
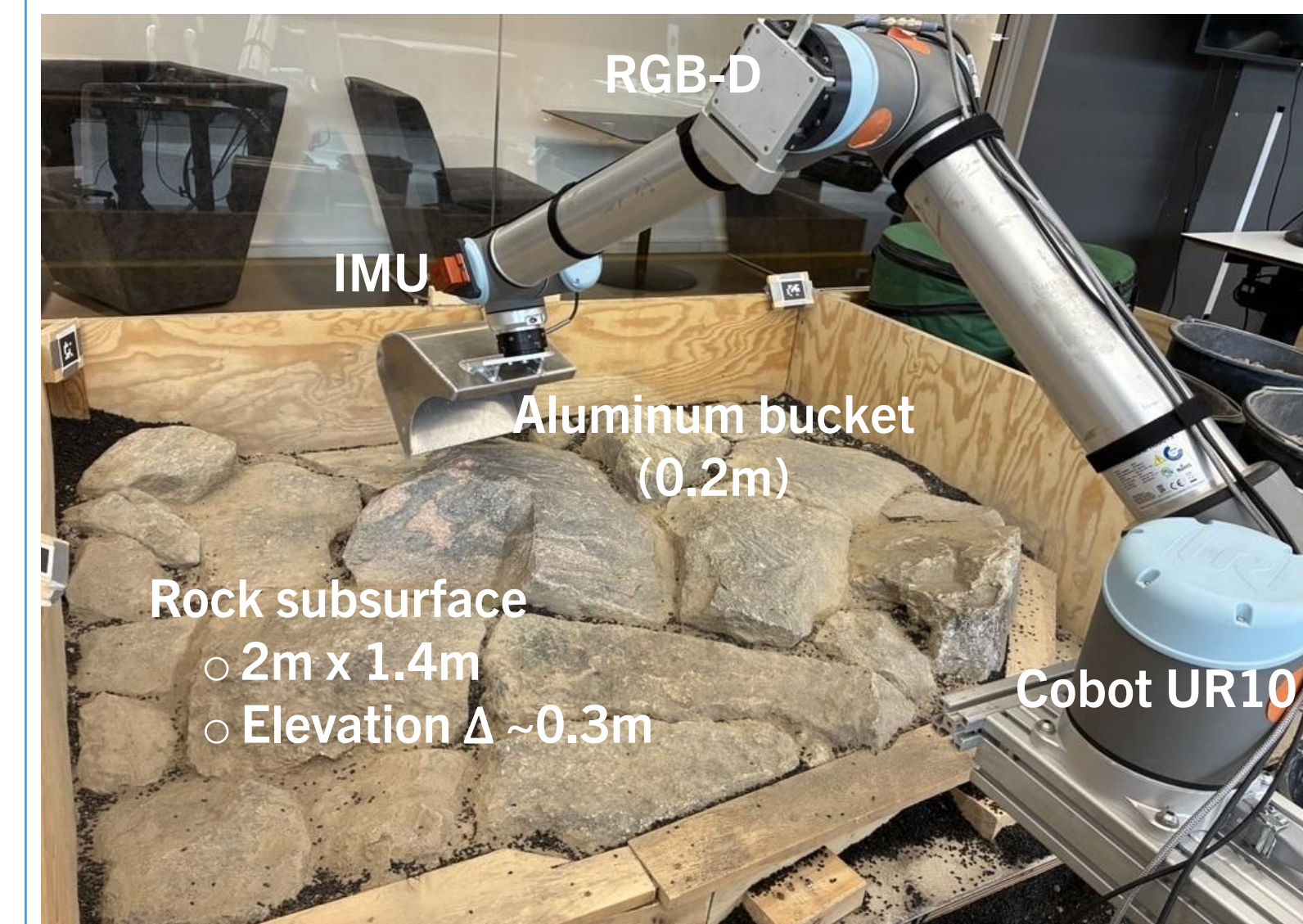
Estimate a lower bound (LB) on contact points and an upper bound (UB) on bucket trajectory. [3,4]



Goal: Subsurface estimate converges with each excavation pass with contacts.



Proof of Concept

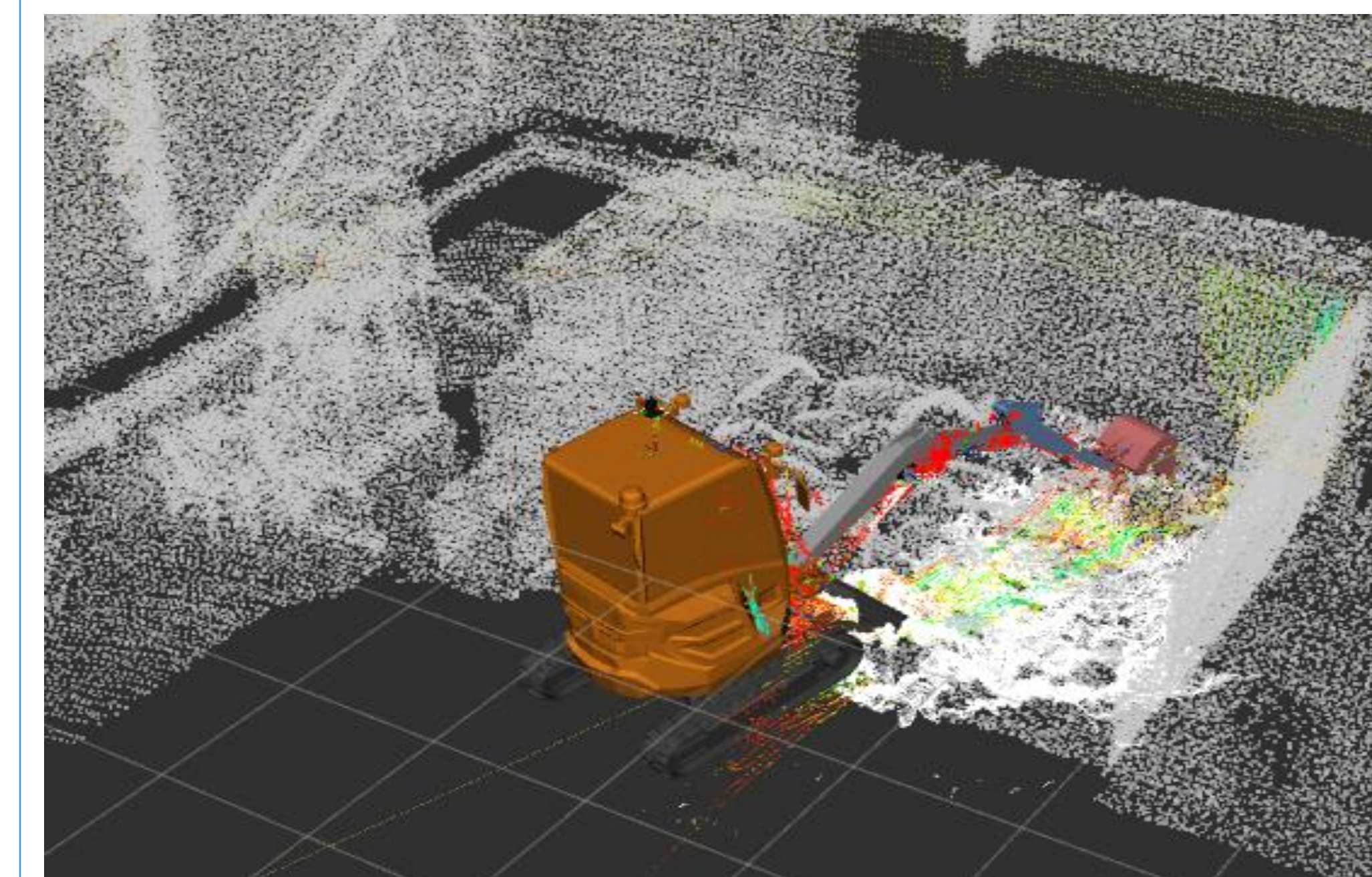


Results

- Trajectory UB and contact LB converge
- Volume estimate converges to 16% ± 11%
- Contact threshold material-dependent
- Contact localization 2mm ± 5mm



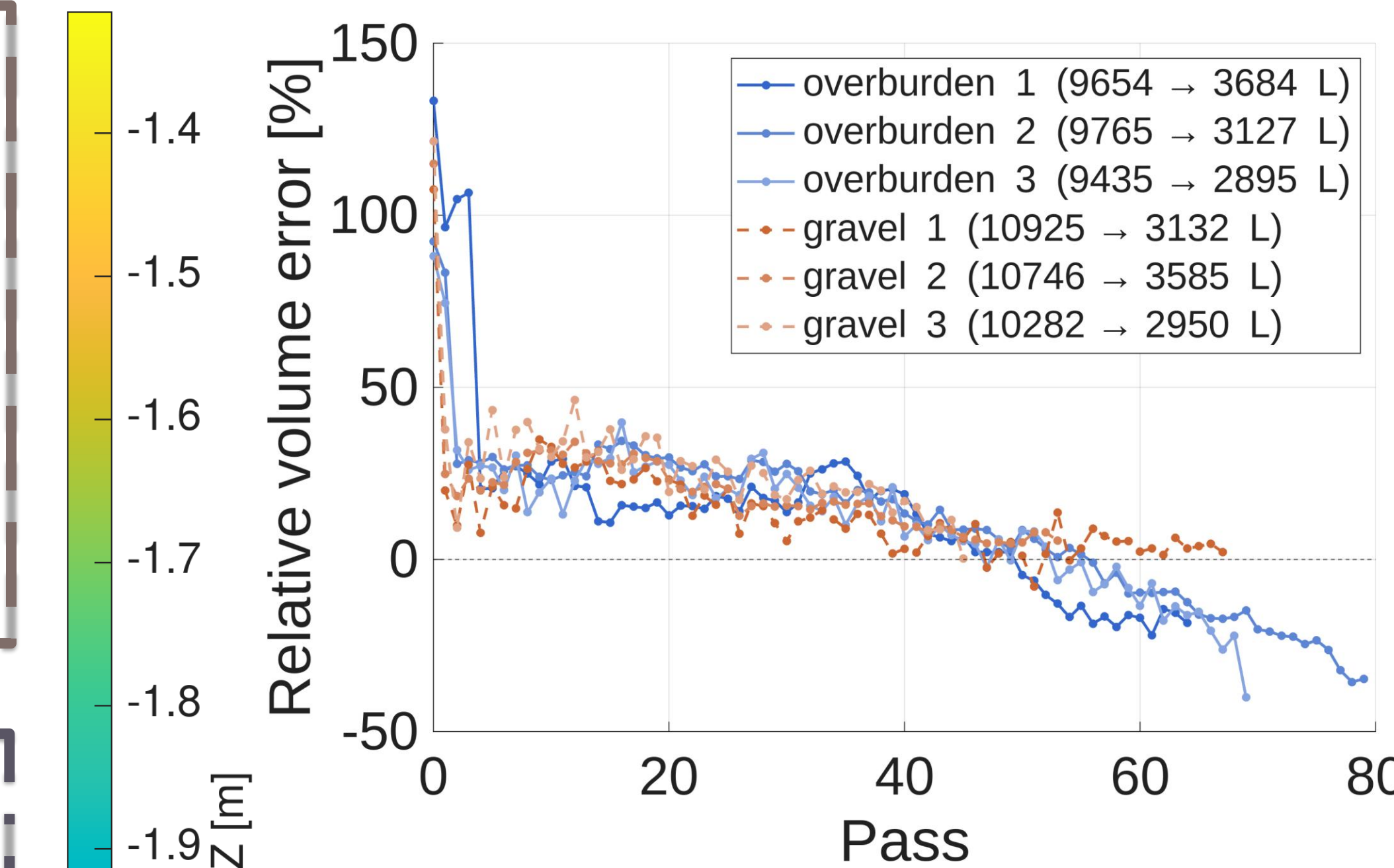
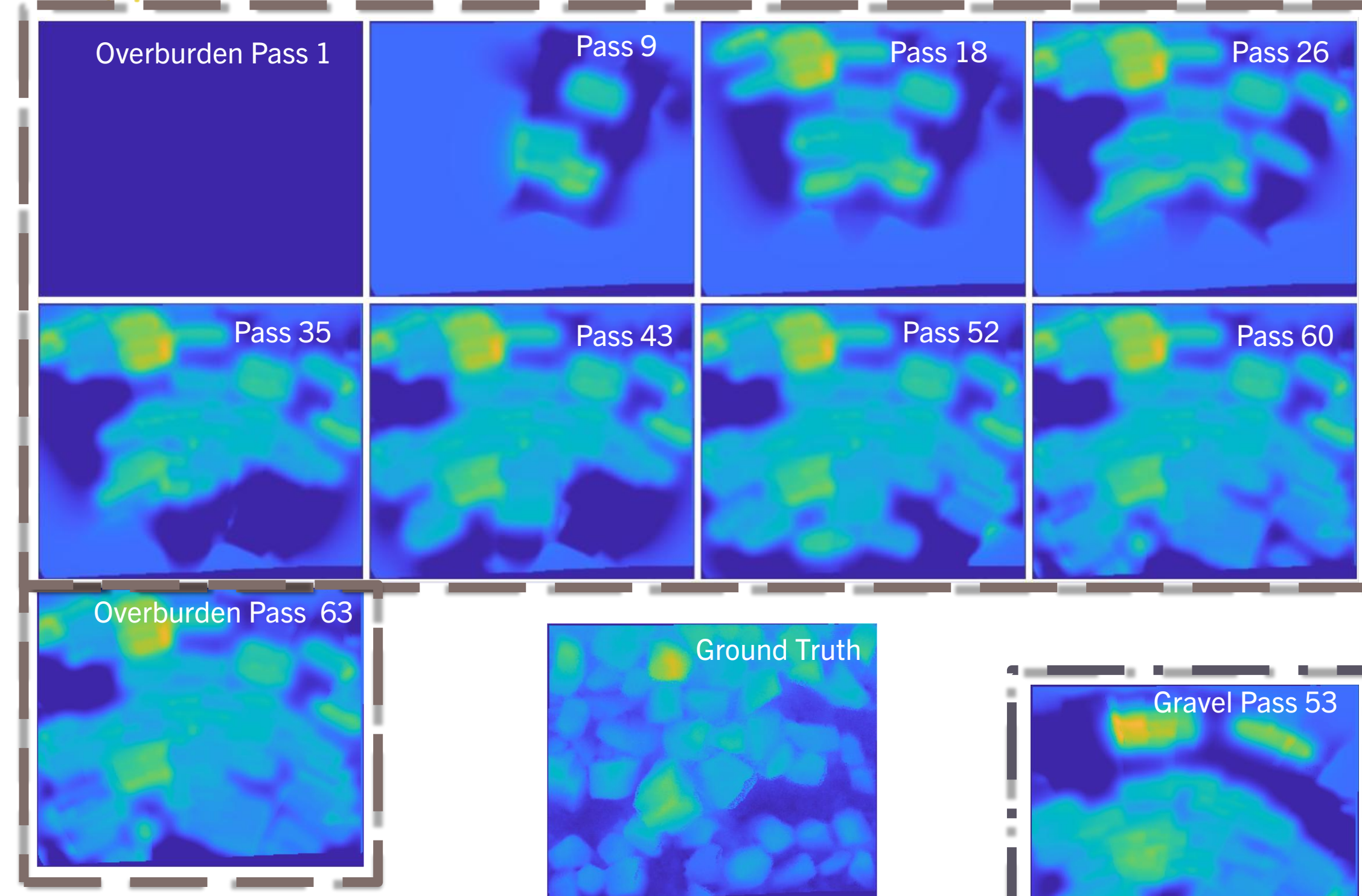
Field Experiments



4.7m x 4m subsurface and elevation $\Delta \sim 0.8\text{m}$

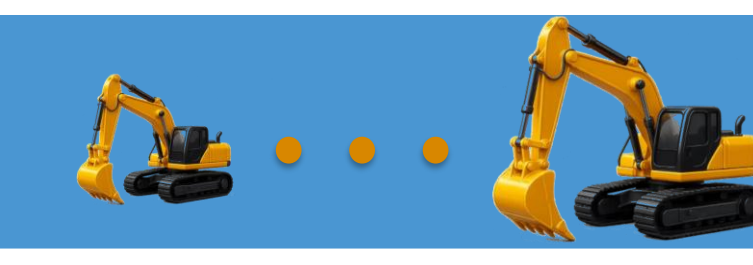
Challenges:

- Worn linkages
- Calibration
- Fast machine motion
- Non-rigid subsurface

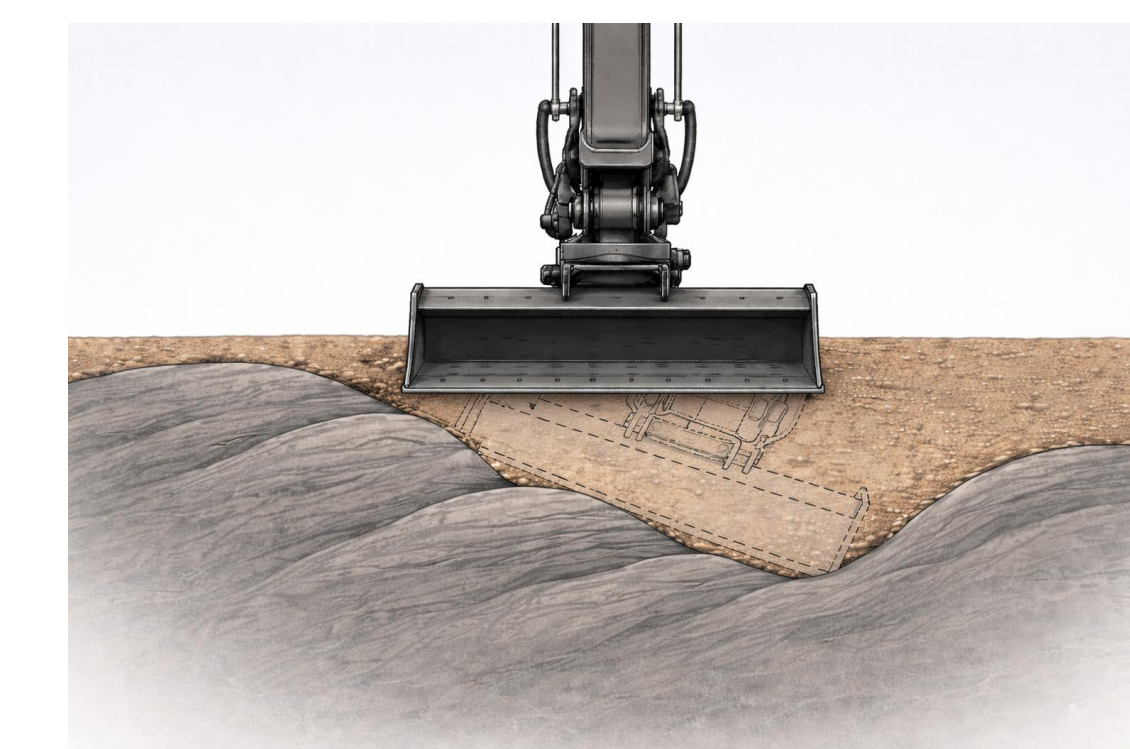


Results

- Pipeline transfers from lab to field
- Volume estimate converges to 12% ± 15%
- Contact localization 5mm ± 25mm
- Site-specific GP and threshold tuning



Informed Excavation Planning



- Adaptive bucket trajectories from real-time subsurface estimates
- Zone-based machine assignment and excavation time estimation for optimized scheduling [2,5]

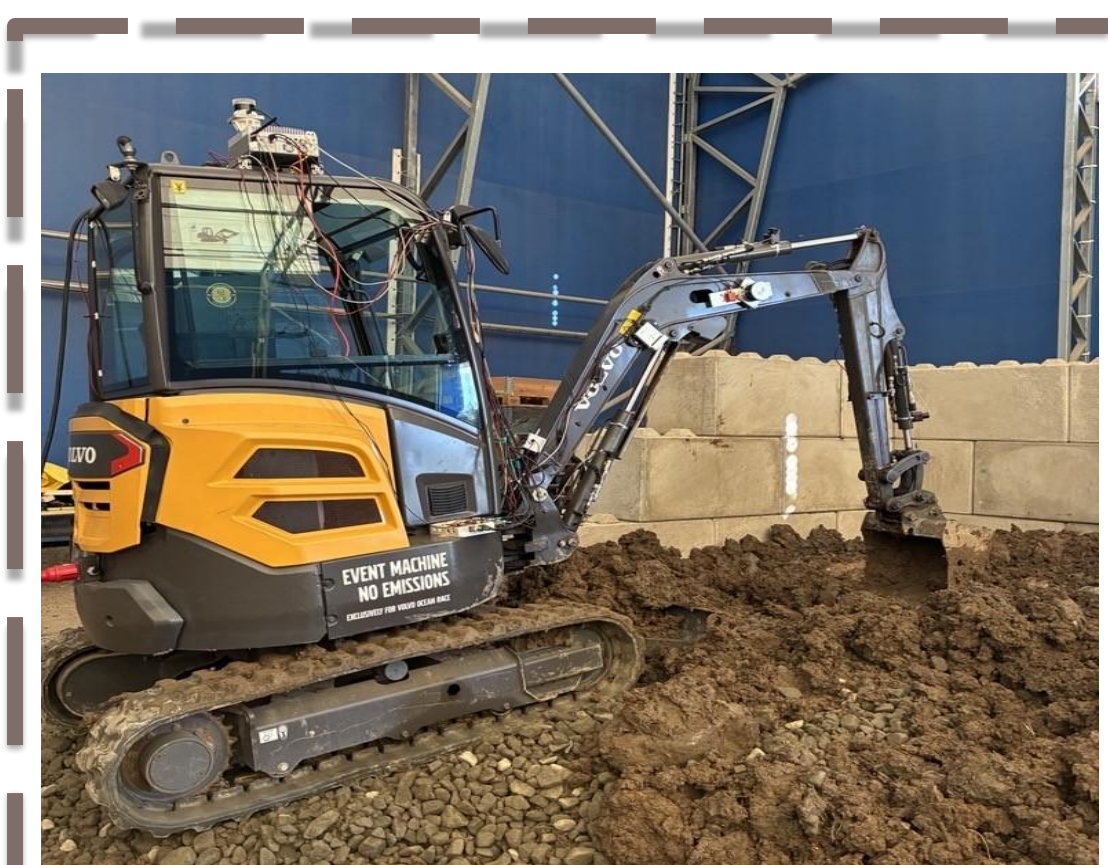
Future Work

- Location of *contact* on bucket edge
- Automatic adjustment of hyperparameters using vision feedback



References

- [1] U. Artan, M. Magnusson, and J. A. Marshall, "Digging for data: Experiments in rock pile characterization using only proprioceptive sensing in excavation," IEEE Trans. Field Robot., vol. 3, pp. 237–251, 2026.
- [2] L. Terenzi and M. Hutter, "Toward autonomous excavation planning," IEEE Trans. Field Robot., vol. 1, pp. 292–317, 2024.
- [3] C. E. Rasmussen and C. K. I. Williams, Gaussian processes for machine learning. Cambridge, MA: MIT Press, 2006.
- [4] S. Vasudevan, F. Ramos, E. Nettleton, H. Durrant-Whyte, and A. Blair, "Gaussian process modeling of large scale terrain," in Proc. IEEE Int. Conf. Robotics and Automation (ICRA), 2009, pp. 1047–1053.
- [5] D. Jud, G. Hottiger, P. Leemann, and M. Hutter, "Planning and control for autonomous excavation," IEEE Robot. Autom. Lett., vol. 2, no. 4, pp. 2151–2158, 2017.



OVERBURDEN



GRAVEL