This presentation is also available at:
`https://cmp.felk.cvut.cz/~moravj34/ocamo`

On-line LiDAR-Camera Calibration Monitoring and Rotational Drift Tracking

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Problem Introduction

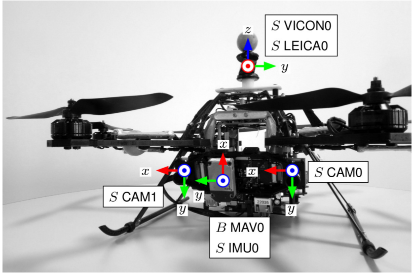
Sensor Calibration

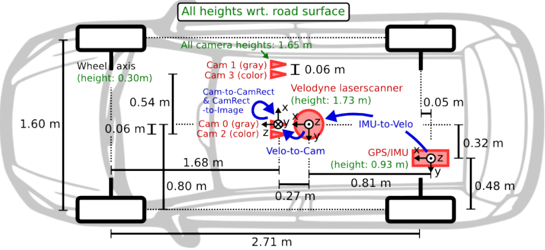
- sensors are not colocated and have their own internal parameters

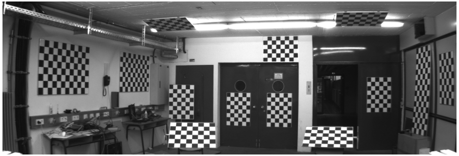
  $\Rightarrow$ needed for proper sensor fusion
- standard approach is the off-line calibration

  All data D $\longrightarrow$ $\text{argmin}_\theta f(\theta|D)$

  - collect all data and then calibrate
  - in calibration room or from infrastructure
  - high precision
  - time-consuming (hard to setup)





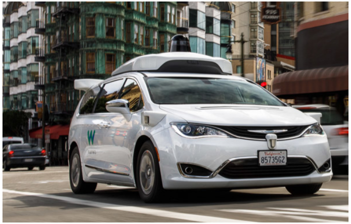


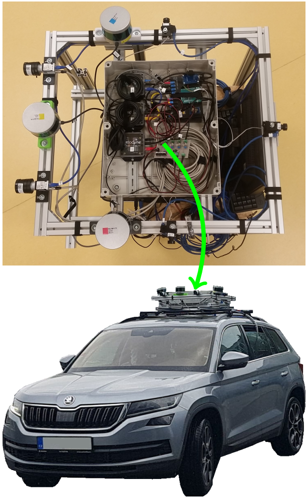
Problem Introduction

Calibration Monitoring and Tracking

- the reference calibration is not stable due to vehicle twisting, thermal dilations or moving parts

  $\Rightarrow$ the calibration monitoring and recalibration could be neccessary





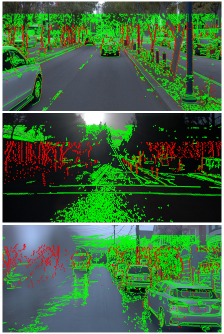
Problem Introduction

Taxonomy of Calibration

off-line calibration

All data D → $\text{argmin}_\theta f(\theta|D)$

We DO on-line calibration



→ **Data preselection**
mini-batch B_0

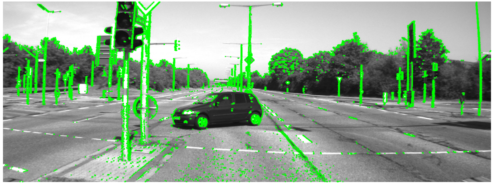
→ **Calibration tracking**
$\text{argmin}_\theta \mathbb{E}\left[f(\theta|B_0)\right]$ → $\hat{\theta}$

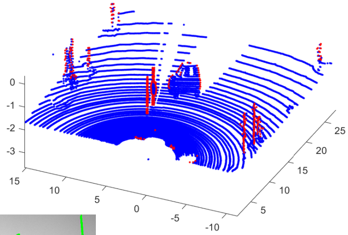
θ^{ref} → **Calibration monitoring**
$P(\theta^{\text{ref}}|B_0)$ → V

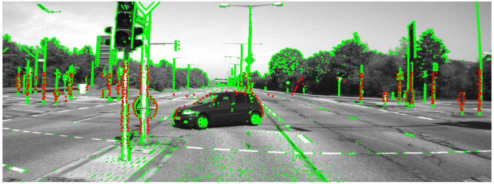
Methods

Loss Function for LiDAR-Camera Relative External Parameters

- local optimization of alignment between low-level features from different modalities
  - kernel correlation: 1:1 correspondence-free, robust







OCaMo calibration tracking

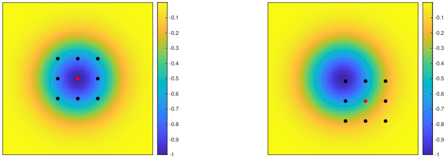
mini-batch B_0 → $\text{argmin}_\theta \mathbb{E}\left[f(\theta|B_0)\right]$

- stochastic gradient-based optimization with adaptive learning rate [Schaul et al. 2013]

LTO calibration monitoring

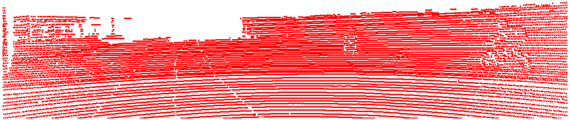
reference θ^{ref}, mini-batch B_0 → validity $P(\theta^{\text{ref}}|B_0)$

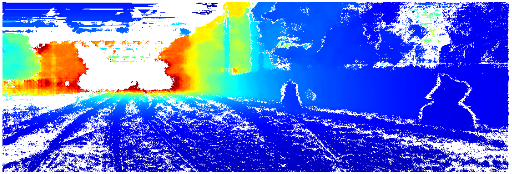
- grid-based examination of the loss function around the reference θ^{ref} [Levinson and Thrun]



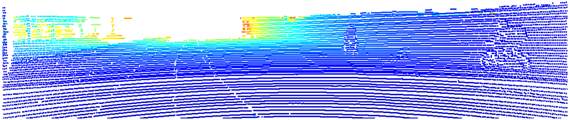
Experiments

OCaMo Tracking for Sensor Fusion Depth Consistency





stereo depth

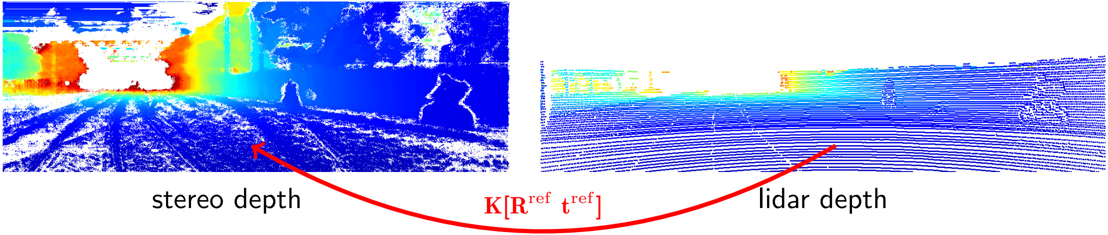


lidar depth

Experiments

OCaMo Tracking for Sensor Fusion Depth Consistency

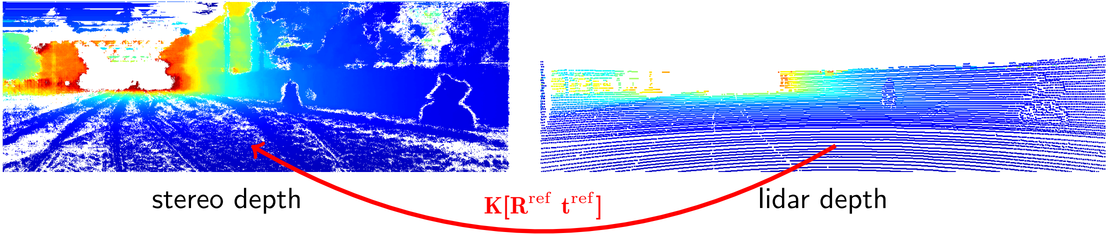
		without decalibration
MAE [m]	uncompensated	0.715 (± 0.15)



Experiments

OCaMo Tracking for Sensor Fusion Depth Consistency

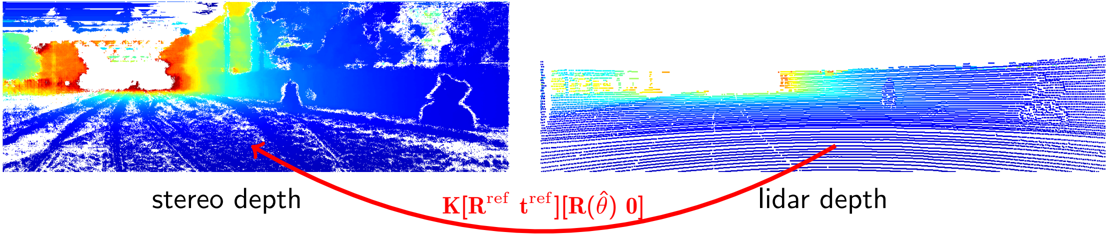
		without decalibration	per-frame rotational decalibration drift of		
			$\pm 0.02^\circ$	$\pm 0.04^\circ$	$\pm 0.08^\circ$
MAE [m]	uncompensated	0.715 (± 0.15)	0.952 (± 0.27)	1.465 (± 0.58)	2.706 (± 1.37)



Experiments

OCaMo Tracking for Sensor Fusion Depth Consistency

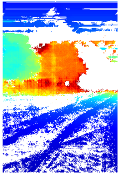
		without decalibration	per-frame rotational decalibration drift of $\pm 0.02°$	per-frame rotational decalibration drift of $\pm 0.04°$	per-frame rotational decalibration drift of $\pm 0.08°$
MAE [m]	uncompensated	0.715 ($\pm$ 0.15)	0.952 ($\pm$ 0.27)	1.465 ($\pm$ 0.58)	2.706 ($\pm$ 1.37)
MAE [m]	OCaMo	0.700 ($\pm$ 0.15)	0.703 ($\pm$ 0.15)	0.712 ($\pm$ 0.15)	0.749 ($\pm$ 0.17)

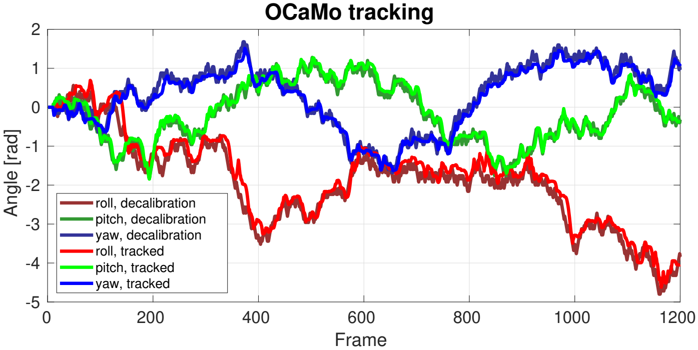


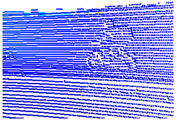
Experiments

OCaMo Tracking for Sensor Fusion Depth Consistency

		without decalibration	per-frame rotational decalibration drift of ±0.02°	±0.04°	±0.08°
MAE [m]	uncompensated	0.715 (± 0.15)	0.952 (± 0.27)	1.465 (± 0.58)	2.706 (± 1.37)
	OCaMo	0.700 (± 0.15)	0.703 (± 0.15)	0.712 (± 0.15)	0.749 (± 0.17)



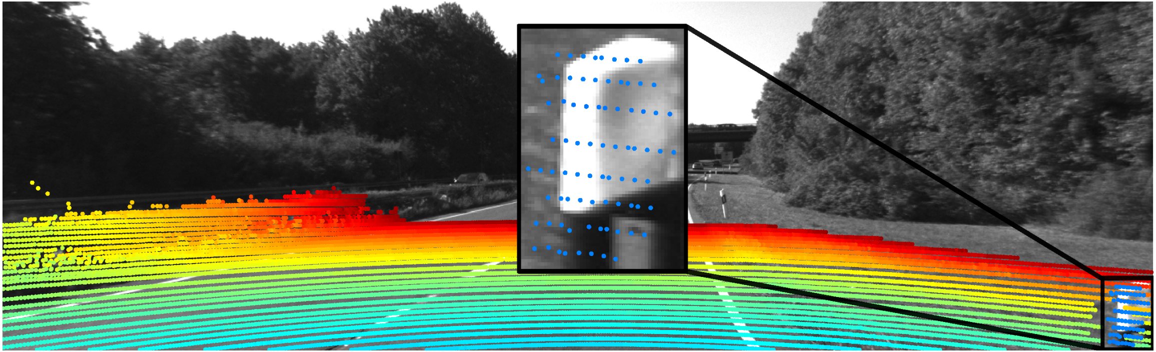




Experiments

LTO Monitoring for Visual Odometry Error Prediction

- one of the highway sequnces in KITTI dataset shows a decalibration [Cvišić et al. 2023]



Experiments

LTO Monitoring for Visual Odometry Error Prediction

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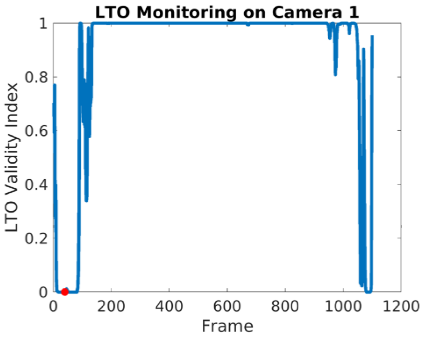
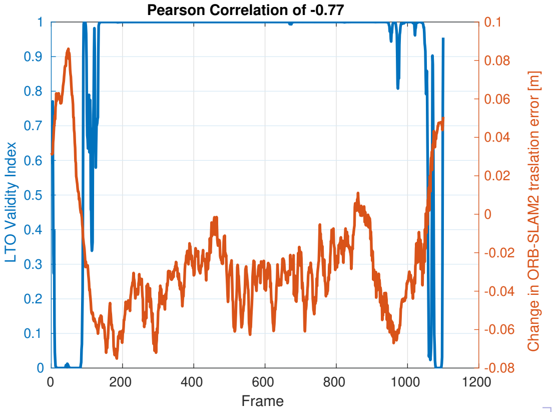
  - LTO monitoring reports a low validity index in the beginning and end of the sequence
  -



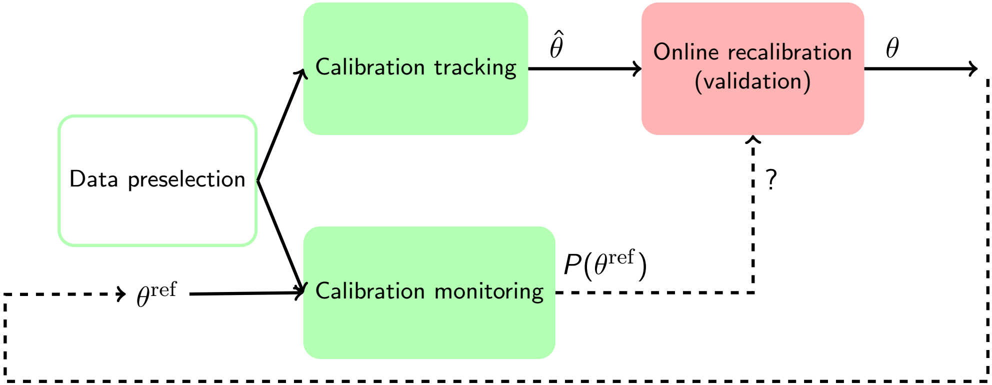
Experiments

LTO Monitoring for Visual Odometry Error Prediction

- one of the highway sequnces in KITTI dataset shows a decalibration [Cvišić et al. 2023]
  - LTO monitoring reports a low validity index in the beginning and end of the sequence
  - Change in ORB-SLAM2 translation error suggests a similar issue



Future Work & Conclusion



References I

[Cvišić et al. 2023] Igor Cvišić, Ivan Marković, and Ivan Petrović. “SOFT2: Stereo Visual Odometry for Road Vehicles Based on a Point-to-Epipolar-Line Metric”. In: *IEEE Transactions on Robotics* 39.1 (2023), pp. 273–288.

[Levinson and Thrun] Jesse Levinson and Sebastian Thrun. “Automatic Online Calibration of Cameras and Lasers”. In: *Proceedings Robotics: Science and Systems Conference*. Art. no. 29. 2013.

[Schaul et al. 2013] Tom Schaul, Sixin Zhang, and Yann LeCun. “No More Pesky Learning Rates”. In: *International Conference on Machine Learning (ICML)*. Vol. 28. 3. 2013, pp. 343–351.