

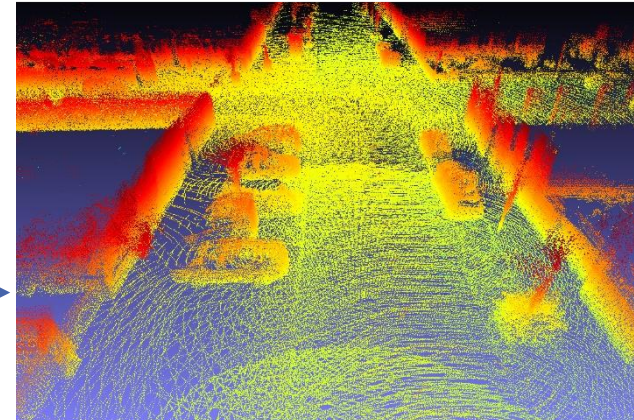
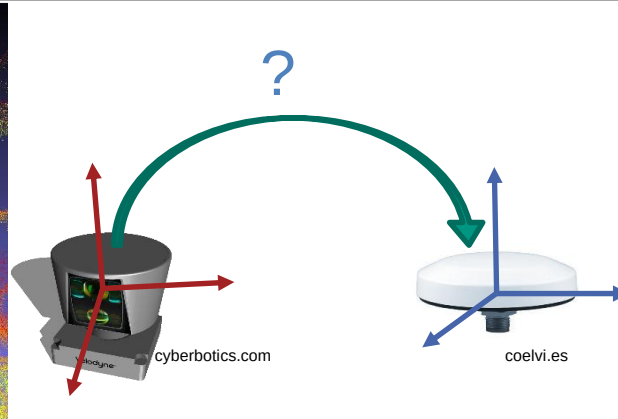
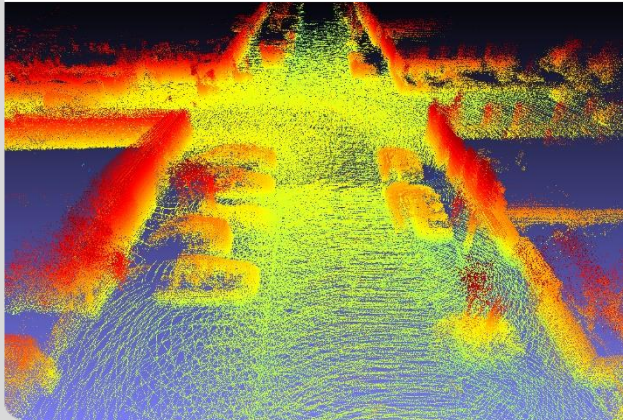
Self-Calibration for LiDAR-based Mobile Mapping Systems

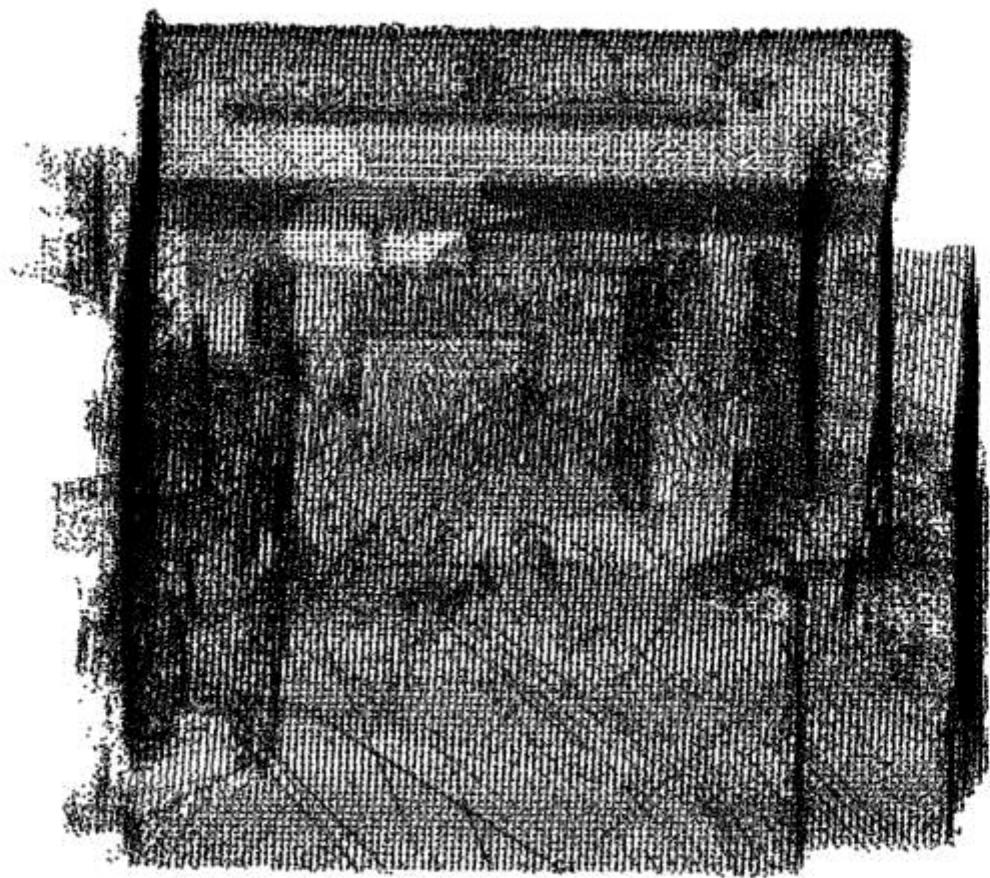
Boris JUTZI

2nd International Workshop on *Point Cloud Processing*, Stuttgart

joint research together with Markus HILLEMANN

Institute of Photogrammetry and Remote Sensing





Content

- **LiDAR-based Mobile Mapping Systems**
- **Extrinsic Calibration**
 - Examples
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 - Semi-automatic calibration with calibration targets
 - Fully-automatic calibration
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- **Results**
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LiDAR-based Mobile Mapping Systems

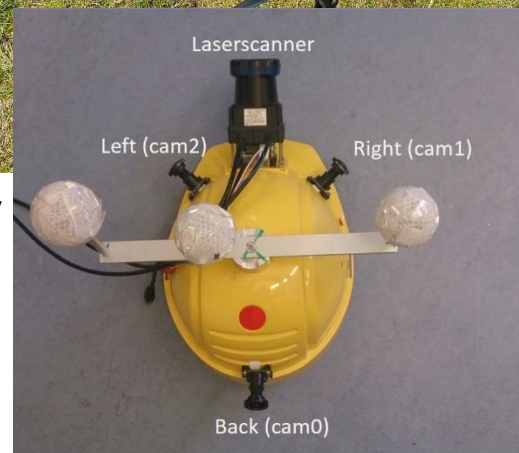


Vehicle

Backpack System (Blaser et al., 2019)



UAV

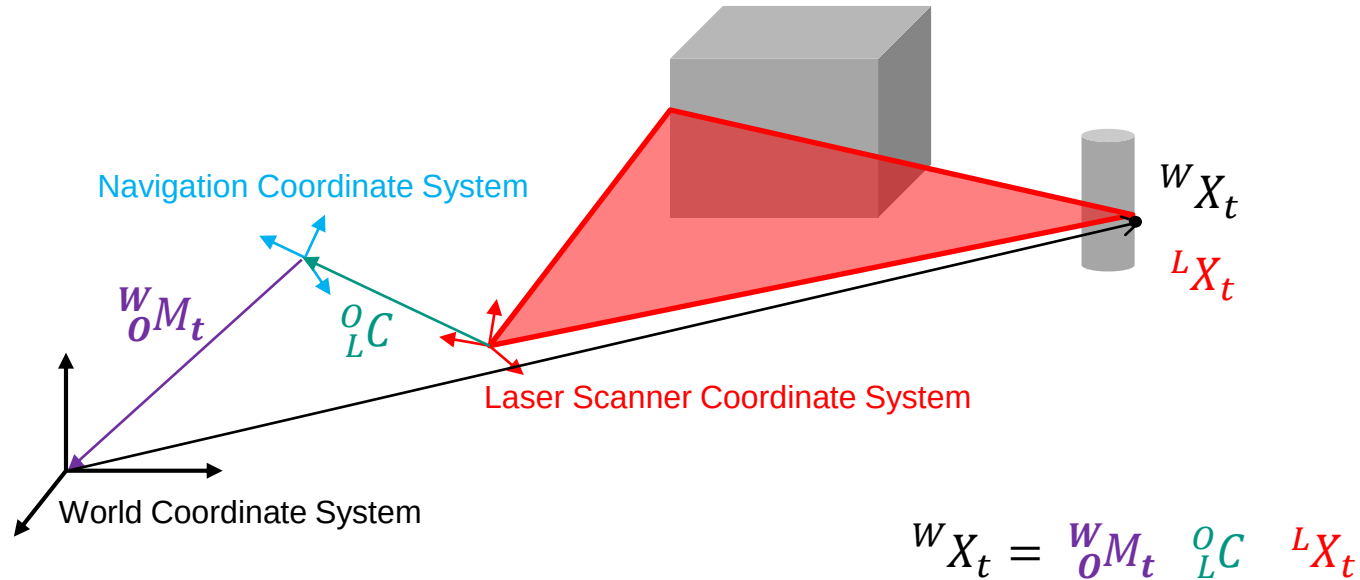


Helmet System (KIT)



**Trolley System
(NavVis.com)**

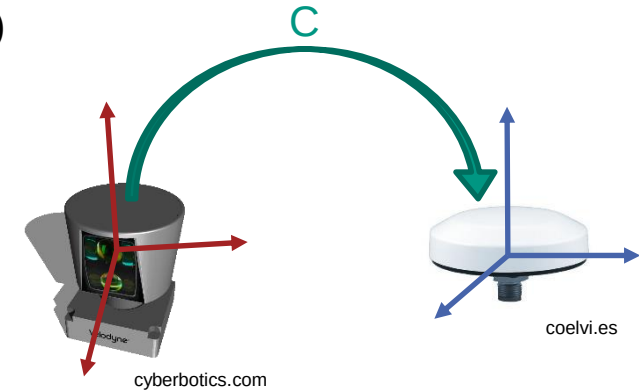
LiDAR-based Mobile Mapping Systems



- **Laser Scanner**: precision, ranging accuracy, synchronicity, ...
- **Pose M** of the **Navigation Unit**: GNSS/IMU, cameras, ...
- **Relative Orientation C** between the **Laser Scanner** and the **Navigation Unit**

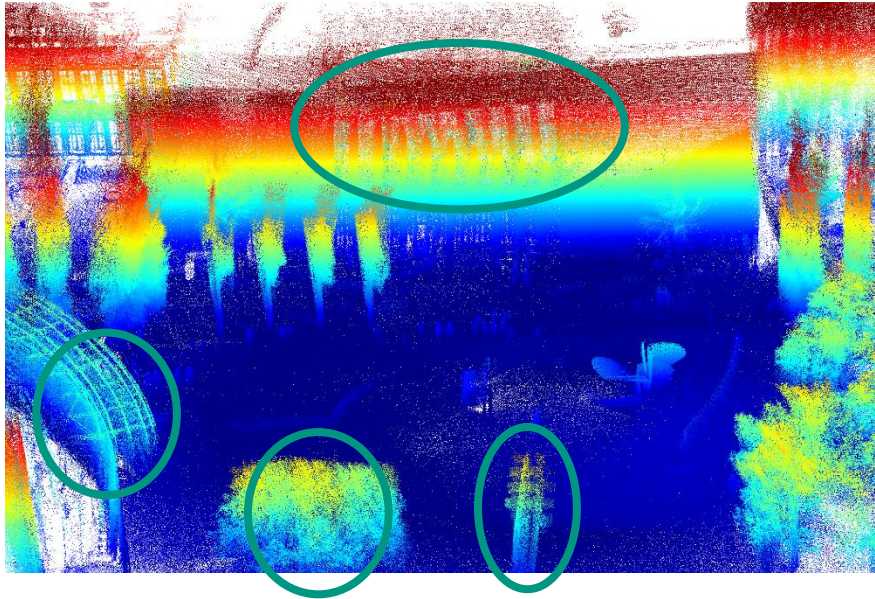
Extrinsic Calibration

- Relative Orientation C between Laser Scanner and Navigation Unit
- **Extrinsic Calibration** is the process to determine the relative orientation
- Relative orientation with six degrees of freedom (6DoF)
 - 3 translations ($\Rightarrow$ lever-arm)
 - 3 rotation angles ($\Rightarrow$ bore-sight)
- **Manual calibration**
 - Measure translation ($\Rightarrow$ lever-arm)
 - Determine coarse rotation angles ($\Rightarrow$ boresight)
 - Check resulting point cloud, refine by trial and error

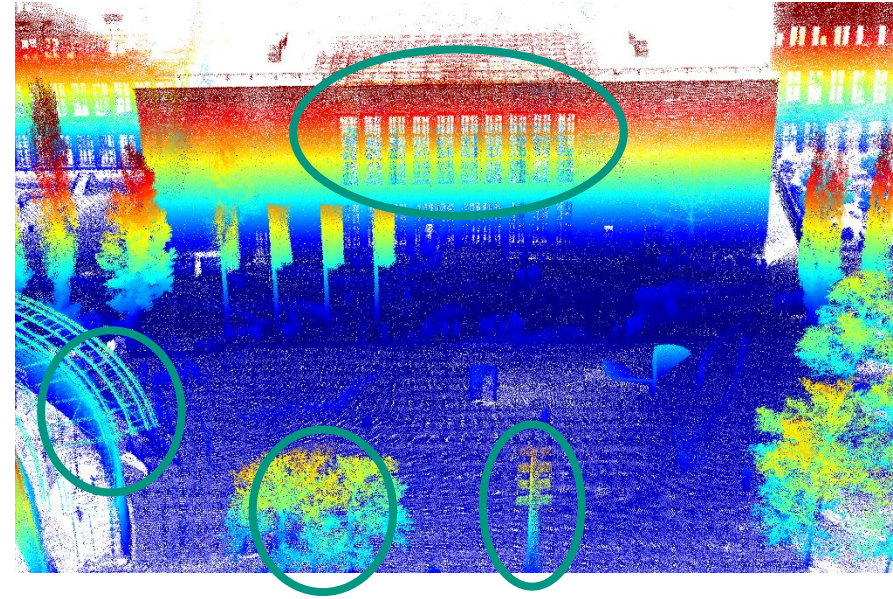


Extrinsic Calibration

Bad calibration



Good calibration



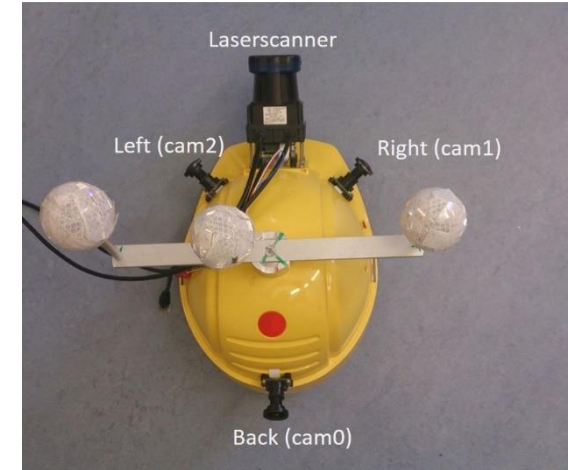
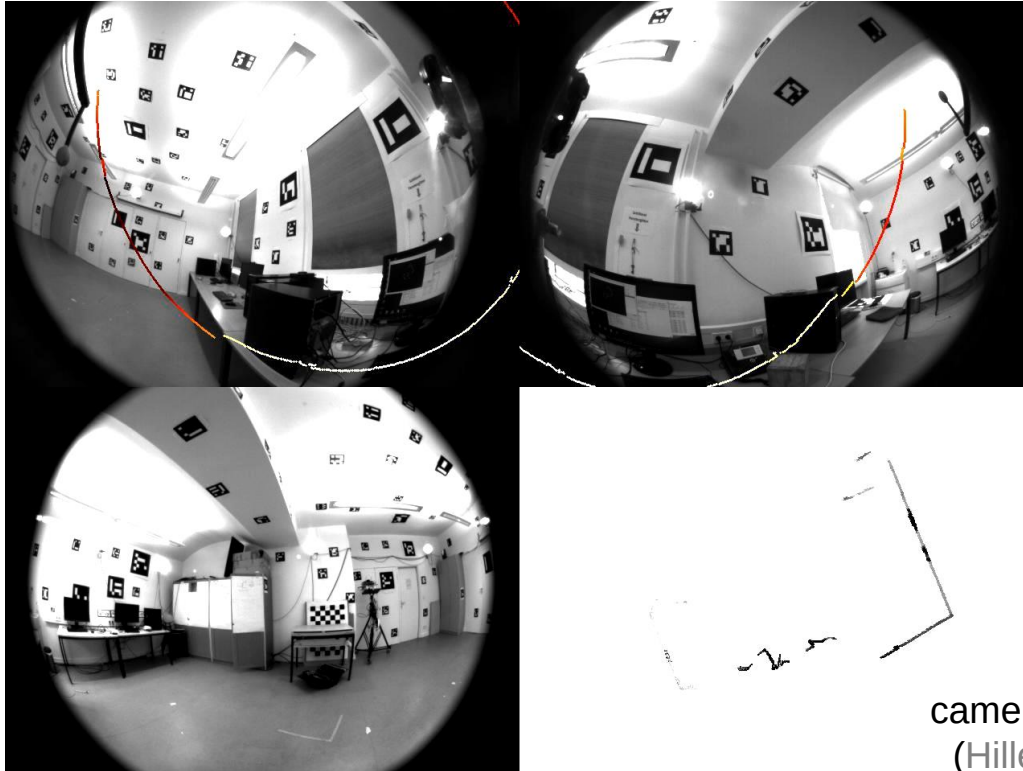
Color depicts height above ground. Blue is low, red is high.

Extrinsic Calibration

- **Relative Orientation C** between **Laser Scanner** and **Navigation Unit**
- **Extrinsic Calibration** is the process to det. the relative orientation
- Relative orientation by six degrees of freedom (6DoF)
 - 3 translations ($\Rightarrow$ lever-arm)
 - 3 rotation angles ($\Rightarrow$ bore-sight)
- **Manual calibration**
- **Semi-automatic calibration with calibration targets**
 - Specific calibration targets combined with different sensor types
 - Pose by GNSS/IMU and laser scanner (Heinz et al., 2017)
 - Pose by camera(s) and laser scanner (Vasconcelos et al., 2012, [Hillemann & Jutzi, 2017](#))



Extrinsic Calibration



Example for pose by
cameras and laserscanner
(Hillemann & Jutzi, 2017)



Extrinsic Calibration

- Relative Orientation **C** between **Laser Scanner** and **Navigation Unit**
- **Extrinsic Calibration** is the process to determine the relative orientation
- Relative orientation by six degrees of freedom (6DoF)
 - 3 translations (=> lever-arm)
 - 3 rotation angles (=> bore-sight)
- **Manual calibration**
- **Semi-automatic calibration with calibration targets**
- **Fully-automatic (self) calibration**
 - **Self** in this context means the calibration **only based on the captured data**
 - **No additional** sensors or specific calibration targets are **required**

Hillemann, M., Weinmann, M., Mueller, M. S., & Jutzi, B. (2019). Automatic Extrinsic Self-Calibration of Mobile Mapping Systems Based on Geometric 3D Features. Remote Sensing, 11(16), 1955. <https://doi.org/10.3390/rs11161955>

Which rabbit do you prefer?

Jeff Koons, Rabbit (1986)

Boris Jutzi, Rabbit (2019)

Geometric Properties

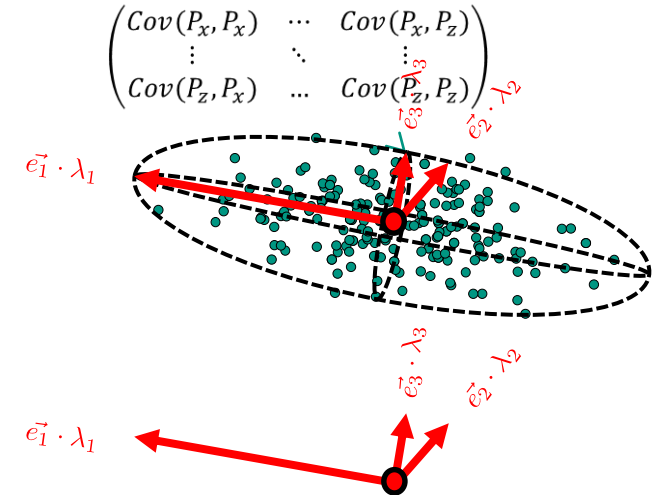
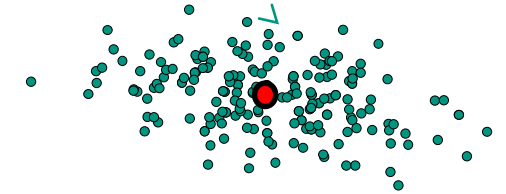
- Jeff Koons' **rabbit** is usually preferred ...
- ... I assume the **representation** seems to be an issue.
- Obviously the representation of the **real physical scene** (rabbit!) is relevant.
- The **real physical scene**
 - is represented best by a **point cloud**
 - only if the **maximum order** of the point cloud is given.
- To **maximize the order** we utilize **geometric properties** (like omnivariance or eigenentropy), which are associated to the order of a point cloud.
- By **minimizing a cost function** on geometric properties the **maximum order** is processed and the parameters of the **extrinsic calibration** are estimated.

Geometric Properties – Excursion on eigenvalues

■ Eigenvalue analysis for 3D points

- Select a number k of nearest 3D points
- Calculate by 3D points the covariance matrix
- Determine eigenvalues $\lambda_1, \lambda_2, \lambda_3$

⇒ Three eigenvalues represent the extension of a 3D ellipsoid along its principal axes



Gross H, Jutzi B, Thoennessen U (2009) *Classification of Elevation Data based on analytical versus trained Feature Values to determine Object Boundaries*. 29. Wissenschaftlich-Technische Jahrestagung der DGPF, 2009 (18): 315-326

Geometric Properties – Excursion on eigenvalues

■ Eigenvalue analysis for 3D points

■ Eigenvalue based features

■ *Linearity*

■ *Planarity*

■ *Scattering*

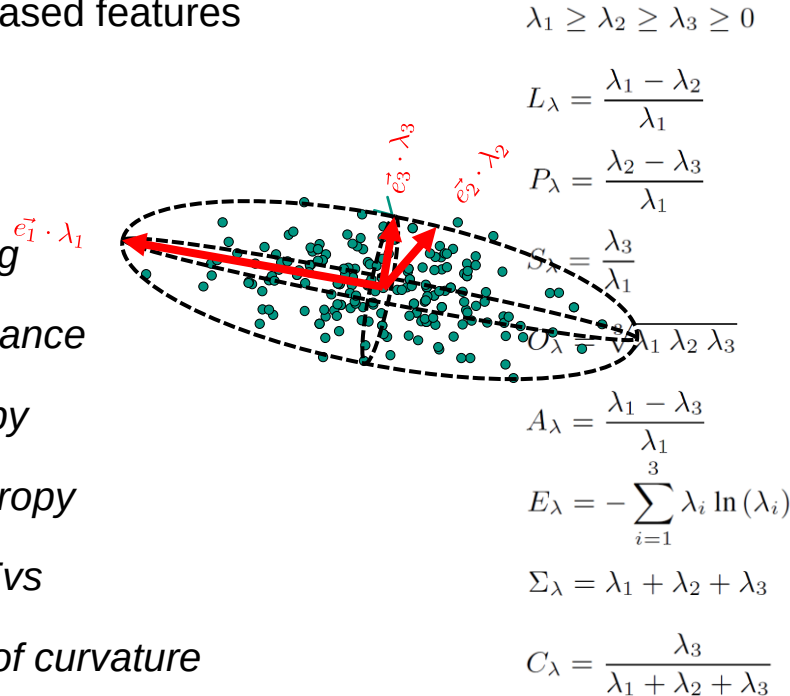
■ *Omnivariance*

■ *Anisotropy*

■ *Eigenentropy*

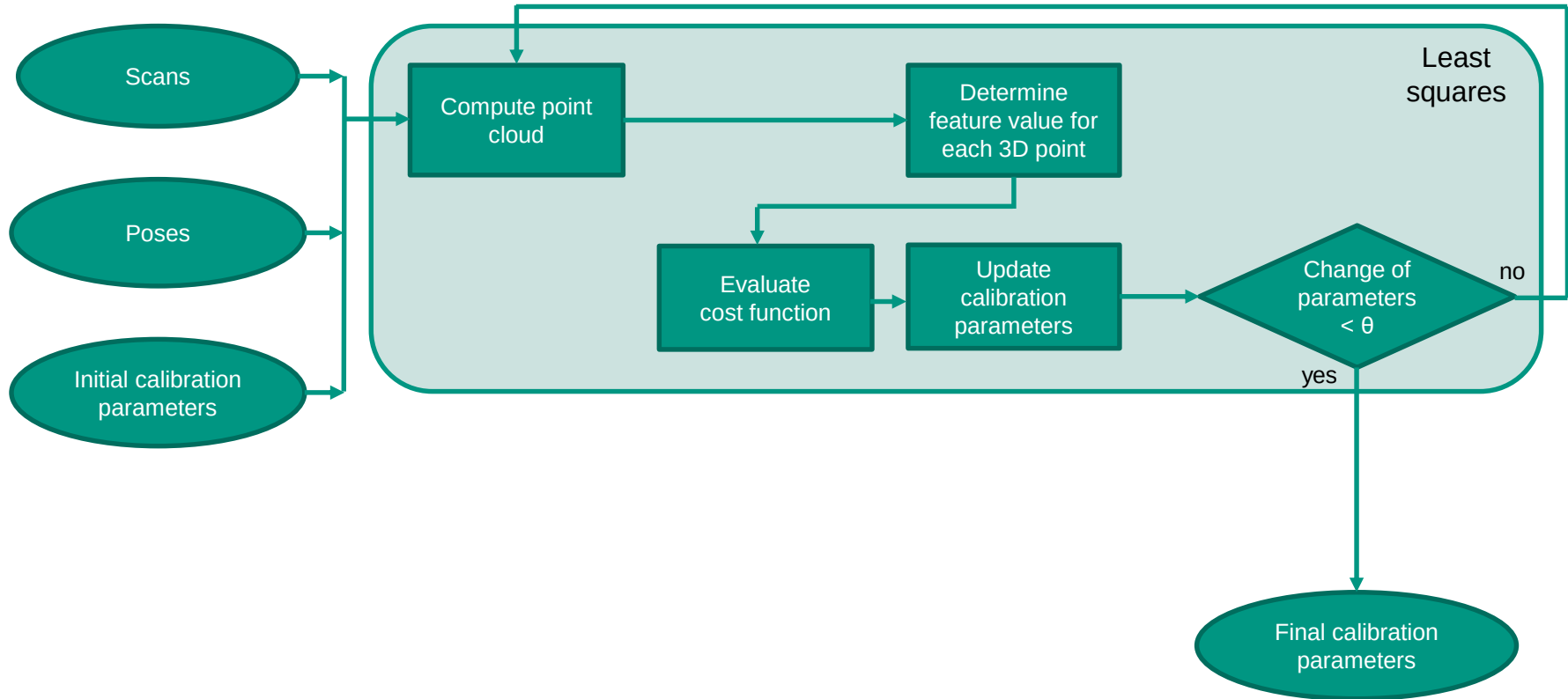
■ *Sum of Evs*

■ *Change of curvature*



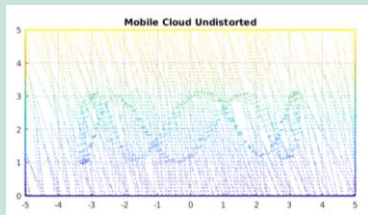
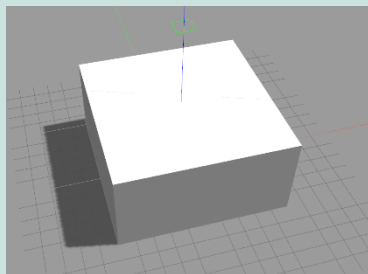
Weinmann M, Urban S, Hinz S, Jutzi B, Mallet C (2015)
Distinctive 2D and 3D Features for Automated Large-Scale Scene Analysis in Urban Areas.
Computers & Graphics 49: 47-57

Self-Calibration

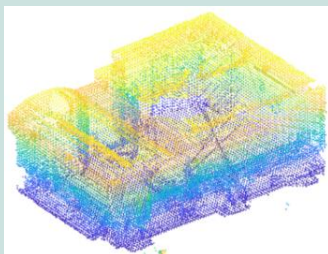


Results - Datasets

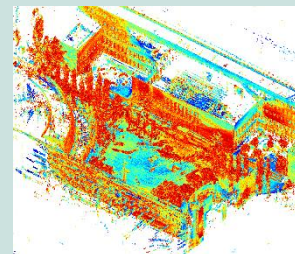
Synthetic data
(2D Laser Scanner)



Small scale indoor
(2D Laser Scanner)



Medium scale outdoor
(3D Laser Scanners)



Large scale outdoor
(3D Laser Scanners)



Results – Synthetic data

■ Proof which **geometric property** is preferable?

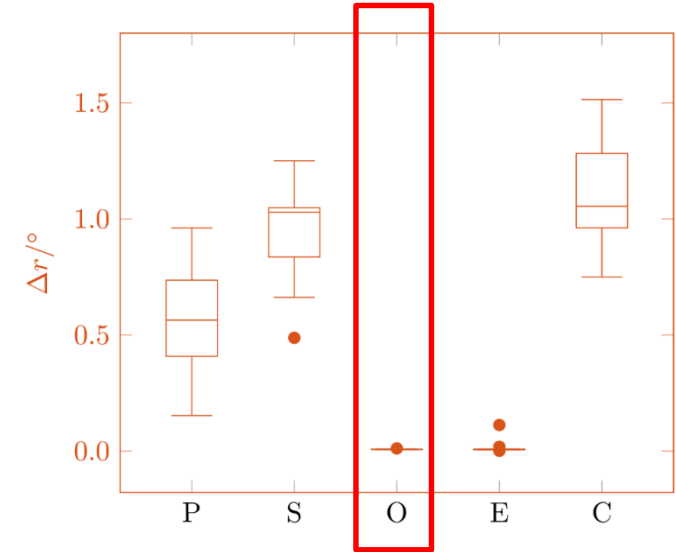
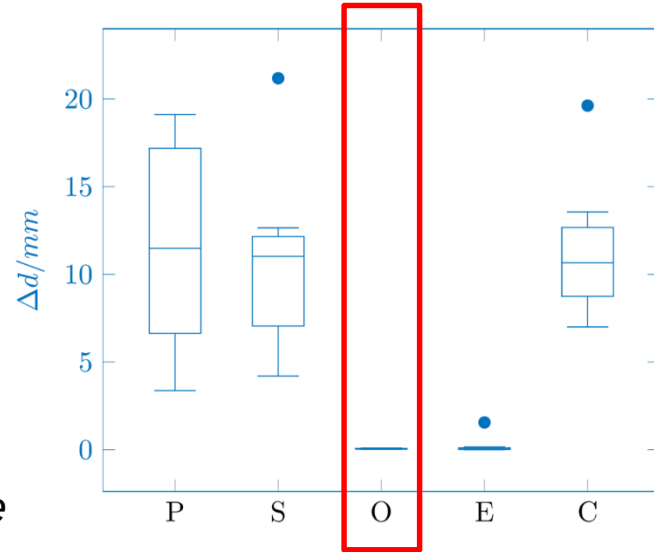
■ *Planarity*

■ *Scattering*

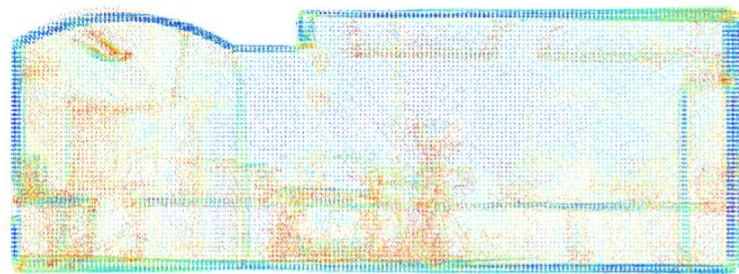
■ *Omnivariance*

■ *Eigenentropy*

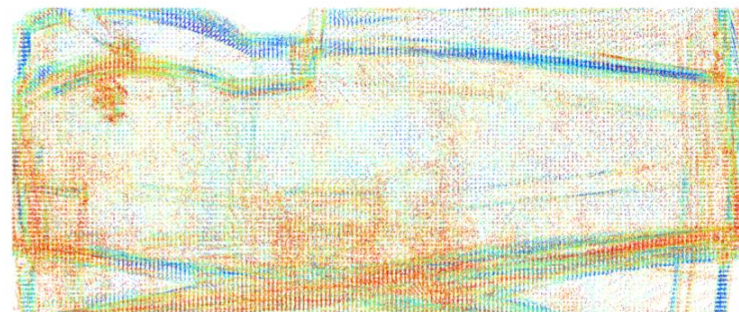
■ *Change of curvature*



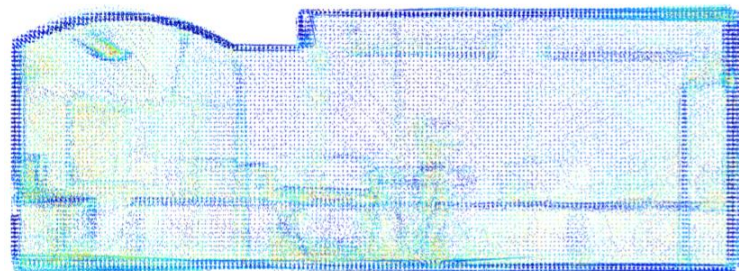
Results – Small scale indoor (Planarity, Scattering)



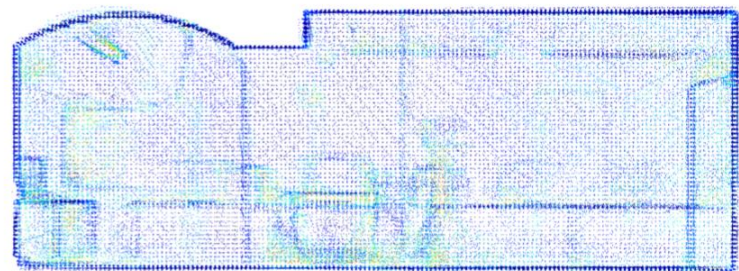
(e) Target-Calibration, g_P



(f) Self-Calibration, g_P

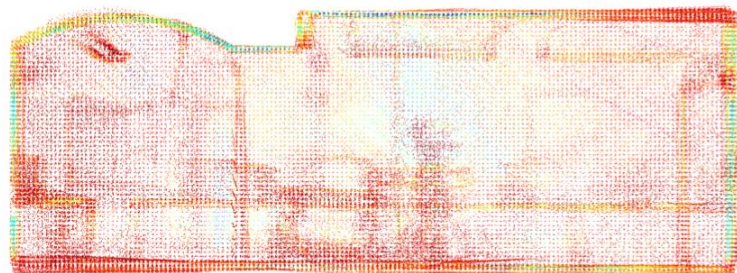


(g) Target-Calibration, g_S

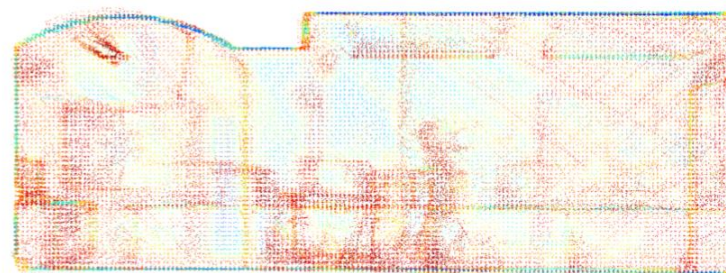


(h) Self-Calibration, g_S

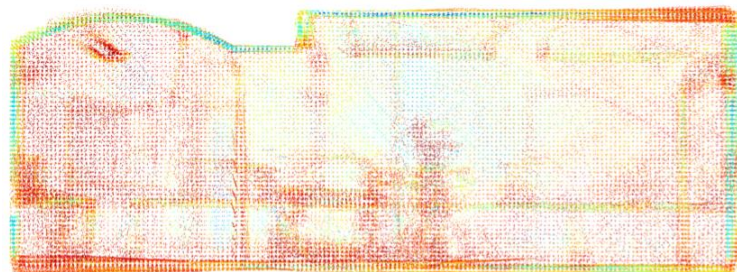
Results – Small scale indoor (Omnivariance, Eigenentropy)



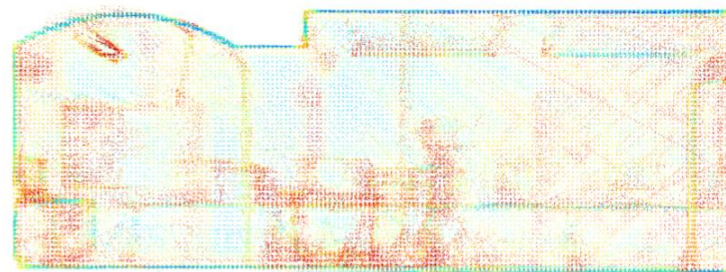
(a) Target Calibration, g_O



(b) Self-Calibration, g_O

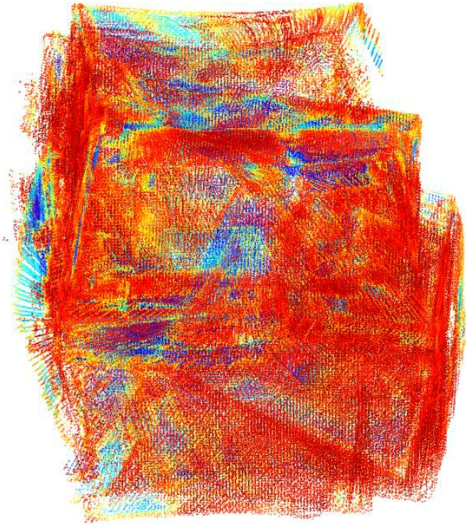


(c) Target Calibration, g_E

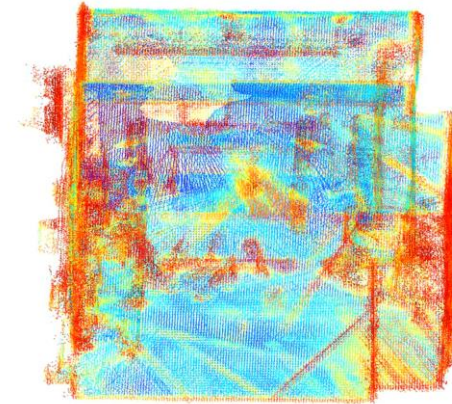


(d) Self-Calibration, g_E

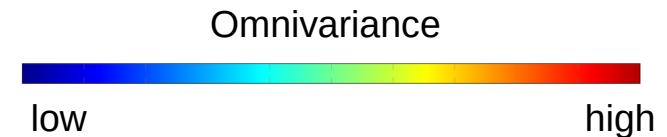
Results – Small scale indoor (Omnivariance)



Processing: Minimizing the cost function

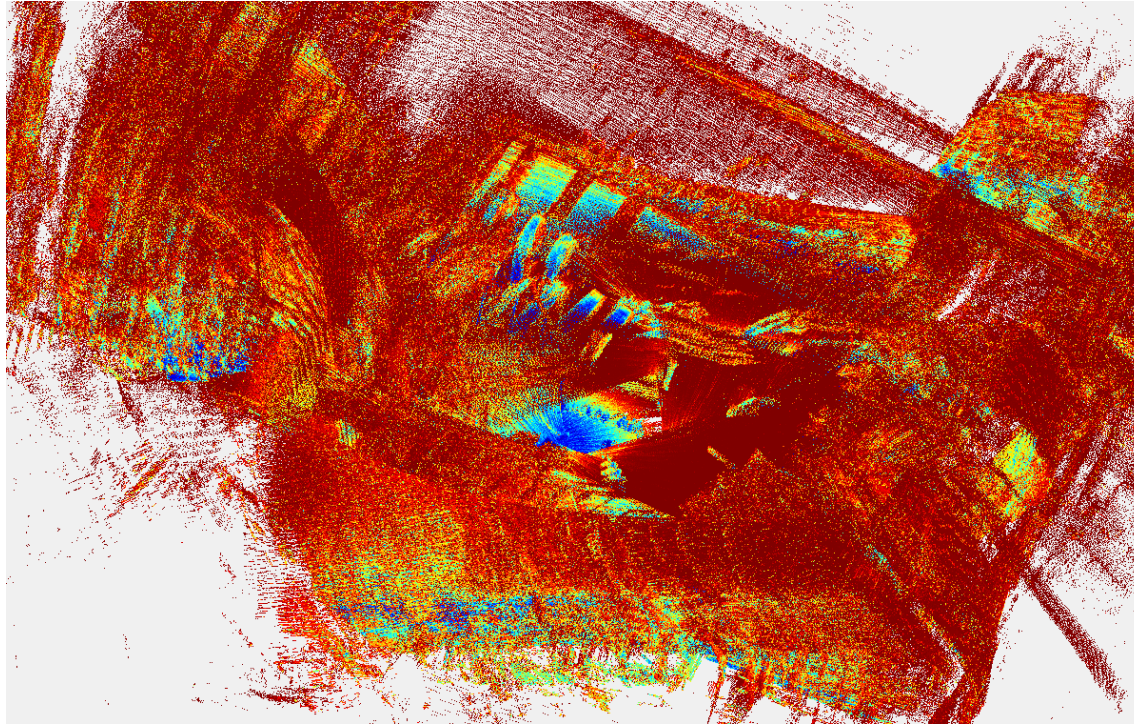


Result: Maximum order

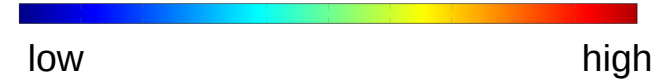


Results – Medium scale outdoor (Eigenentropy)

Iteration 0

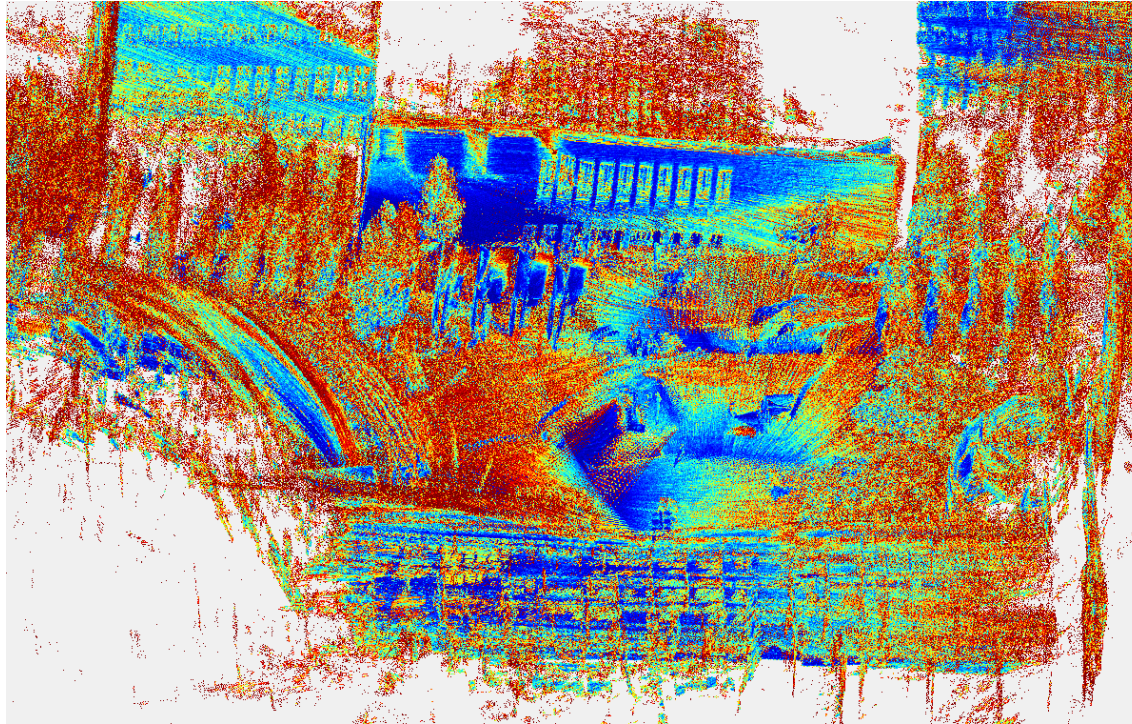


Eigenentropy



Results – Medium scale outdoor (Eigenentropy)

Iteration 1

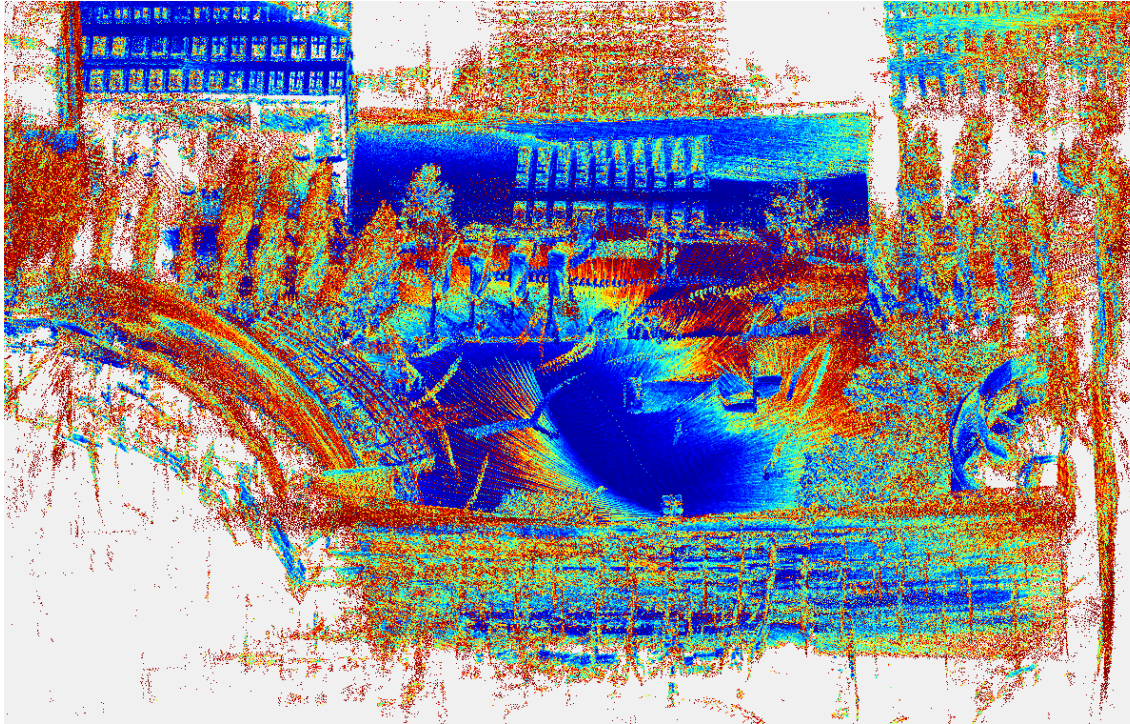


Eigenentropy



Results – Medium scale outdoor (Eigenentropy)

Iteration 2

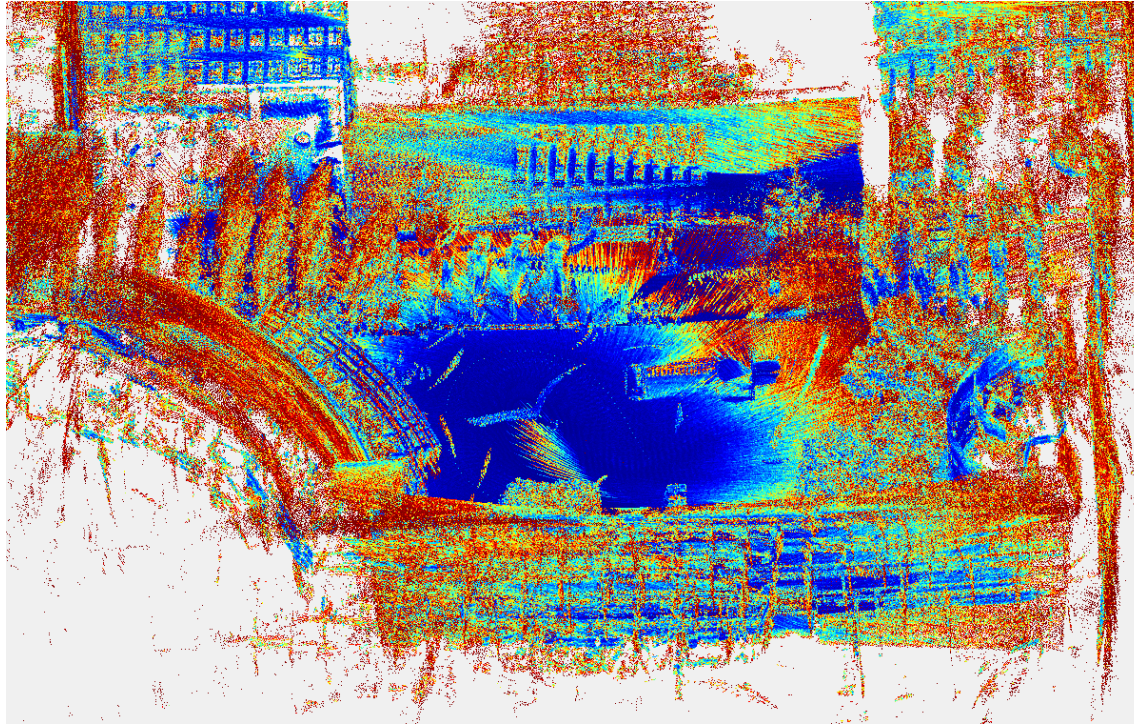


Eigenentropy



Results – Medium scale outdoor (Eigenentropy)

Iteration 3

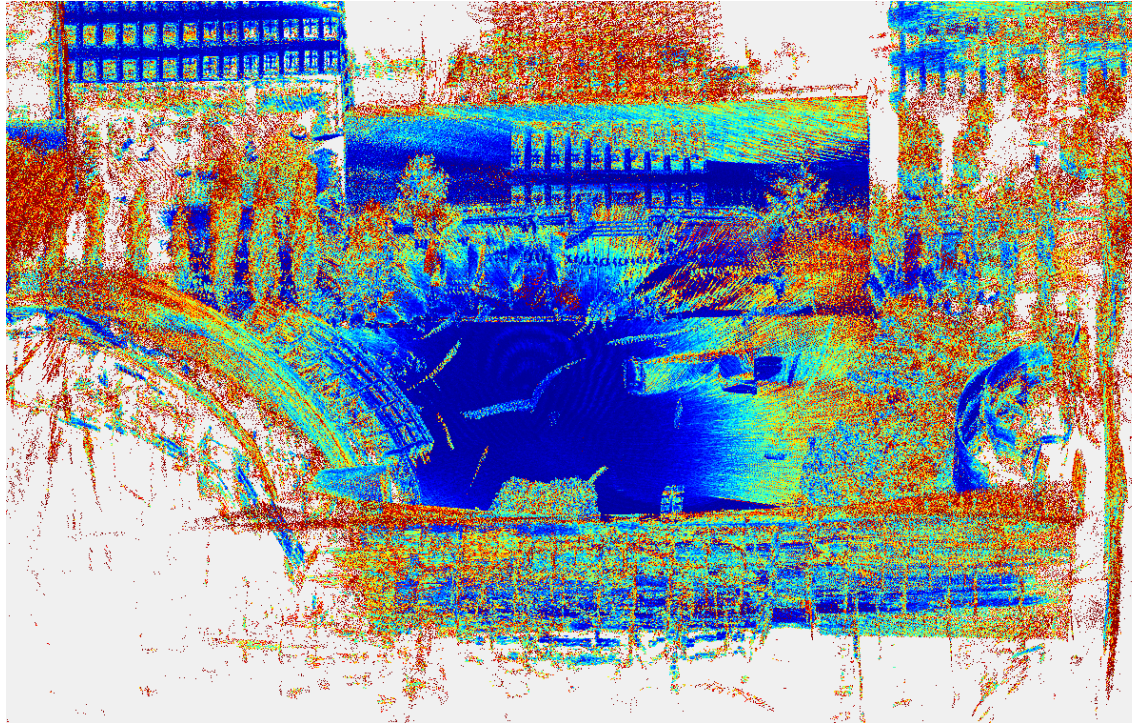


Eigenentropy



Results – Medium scale outdoor (Eigenentropy)

Iteration 4

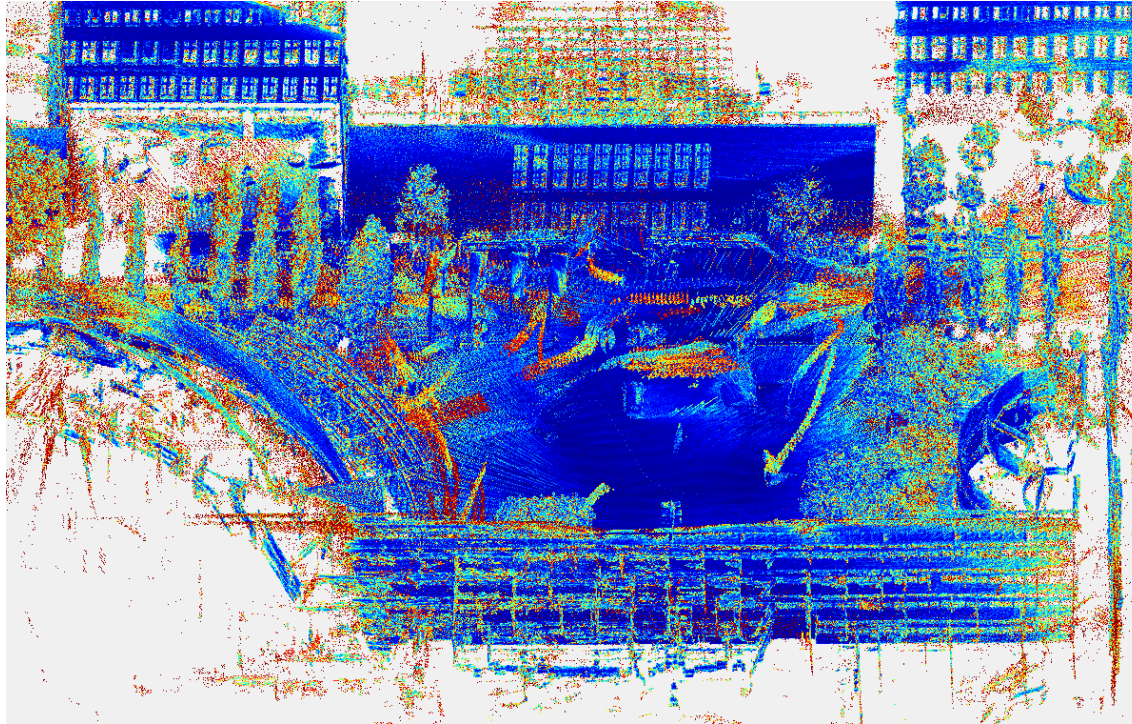


Eigenentropy



Results – Medium scale outdoor (Eigenentropy)

Iteration 5

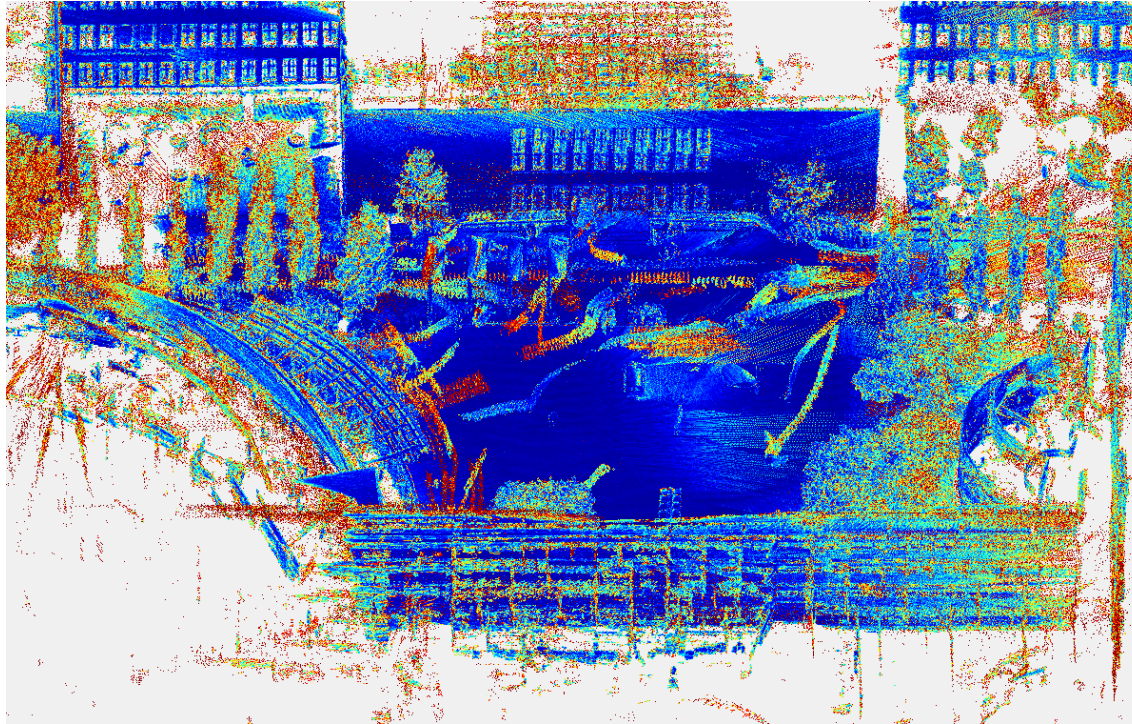


Eigenentropy



Results – Medium scale outdoor (Eigenentropy)

Iteration 6

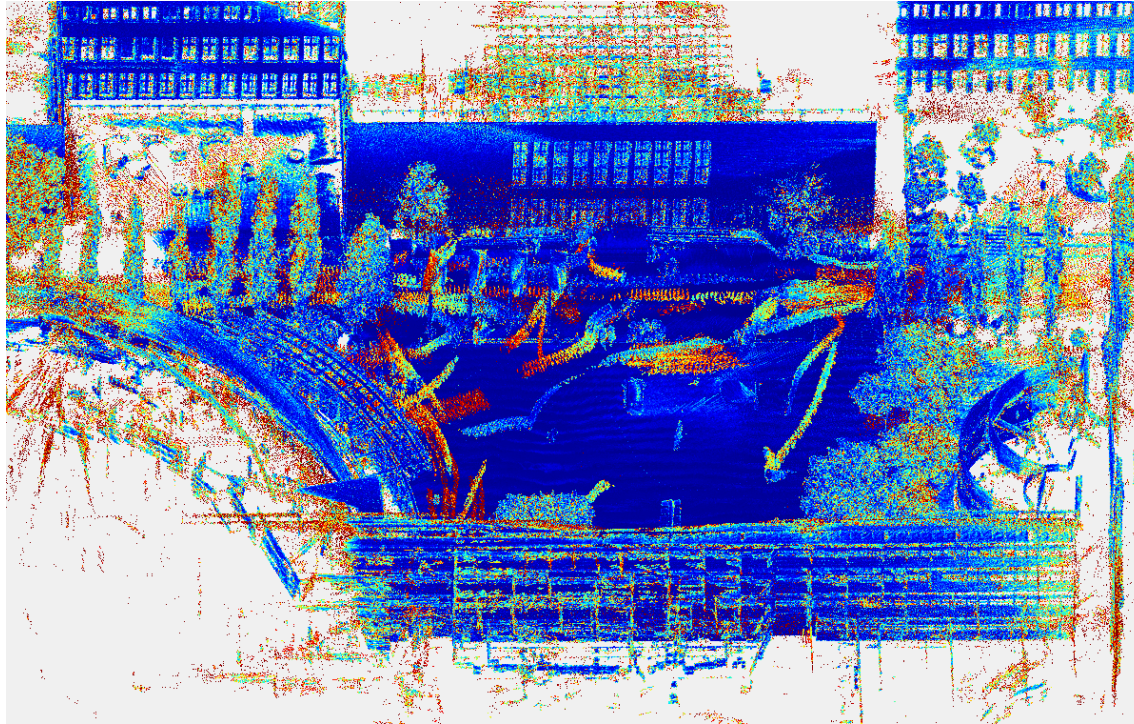


Eigenentropy



Results – Medium scale outdoor (Eigenentropy)

Iteration 7

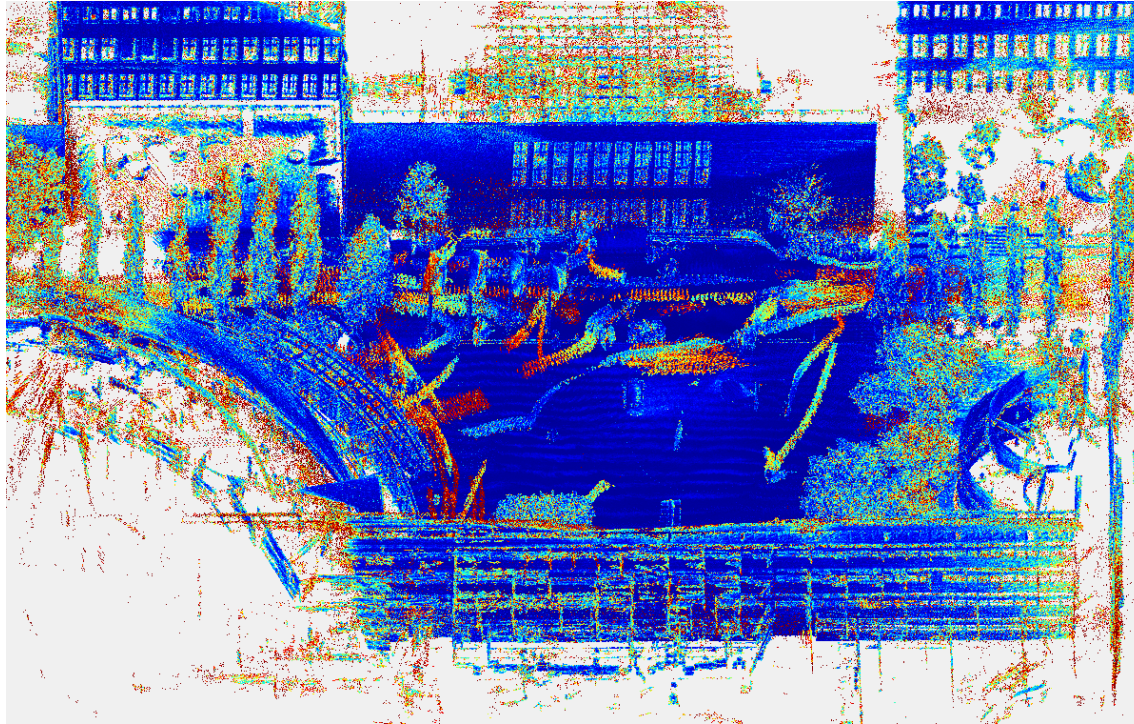


Eigenentropy



Results – Medium scale outdoor (Eigenentropy)

Iteration 8

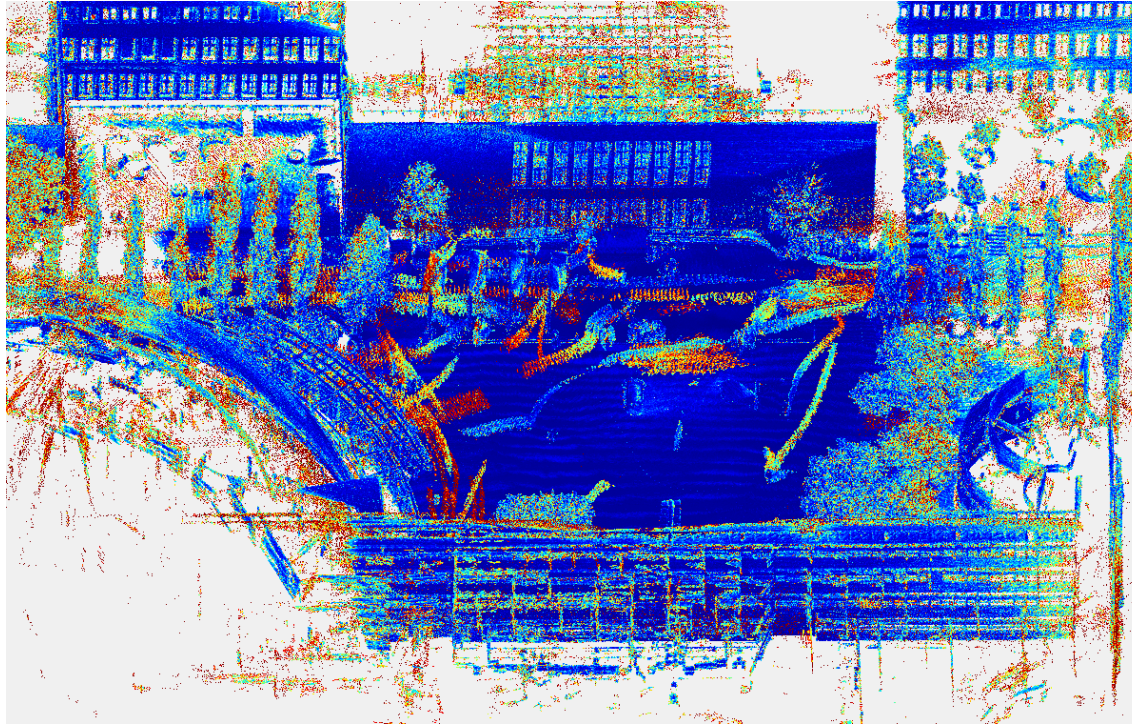


Eigenentropy



Results – Medium scale outdoor (Eigenentropy)

Iteration 9

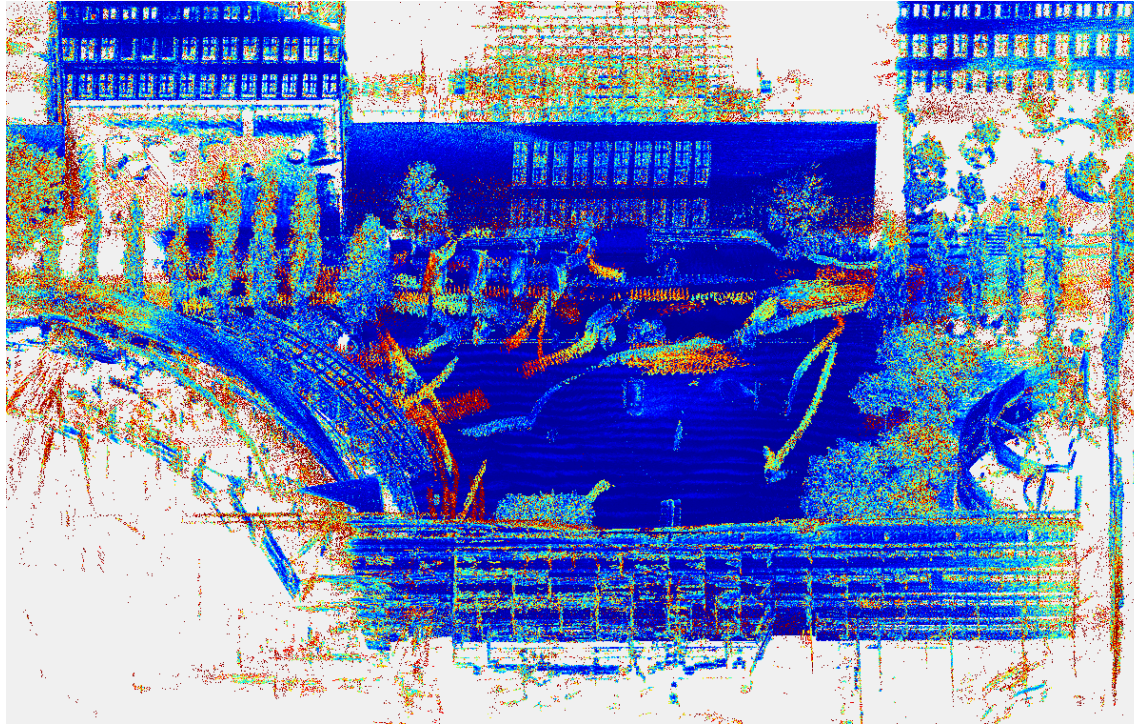


Eigenentropy



Results – Medium scale outdoor (Eigenentropy)

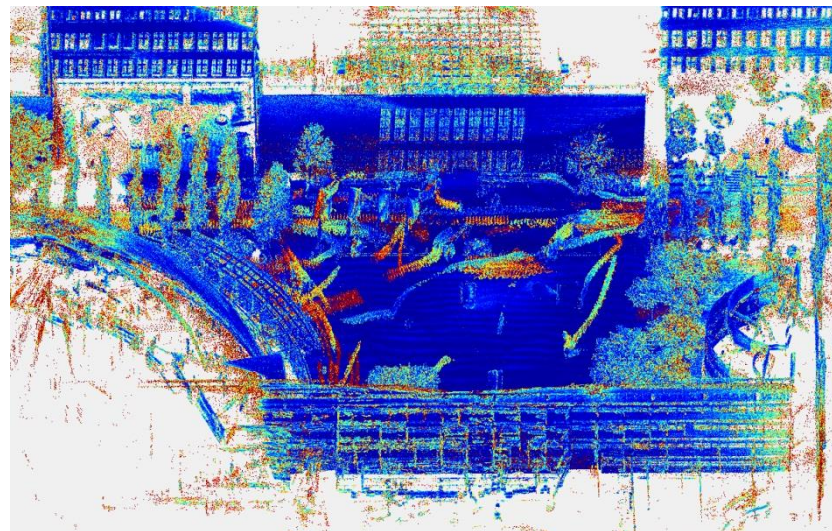
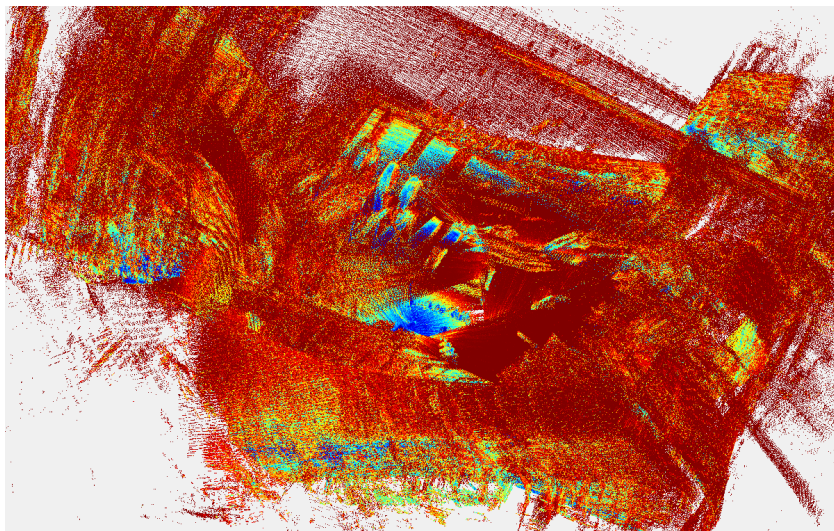
Iteration 10



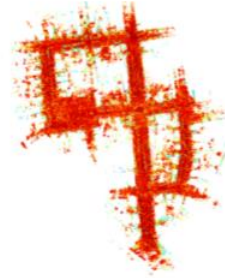
Eigenentropy



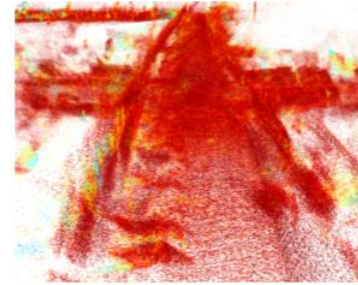
Results – Medium scale outdoor (Eigenentropy)



Results – Large scale outdoor



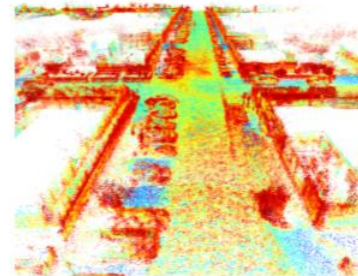
(c) Falsified initial calibration



(d) Detail view of (c)



(e) Optimized calibration



(f) Detail view of (e)



Conclusion

- **Self-Calibration** algorithm to automatically calibrate LiDAR-based Mobile Mapping Systems.
- Idea: Use **geometric properties of the point cloud** (Planarity, Scattering, Omnivariance, Eigenentropy, etc.) for the self-calibration task (originally known from classification).
- **No need** for artificial targets or additional sensors.
- The self-calibration can be accomplished even **during or after the data is captured**.
- **Accuracy** is comparable to state-of-the-art solutions but being **more universally applicable**.
- Suitable for **any kind of pose estimation** (GNSS/IMU, VI-SLAM, Lidar-Odometry, Motion Capture System, etc.)
- Suitable for **2D and 3D Laser Scanners**.

FeatCalibr

- Hillemann, M.; Weinmann, M.; Mueller, M. S.; Jutzi, B. (2019) Automatic Extrinsic Self-Calibration of Mobile Mapping Systems Based on Geometric 3D Features . *Remote sensing*, 11 (16), Article: 1955. [doi:10.3390/rs11161955](https://doi.org/10.3390/rs11161955)

- FeatCalibr
<https://github.com/markushillemann/FeatCalibr>

