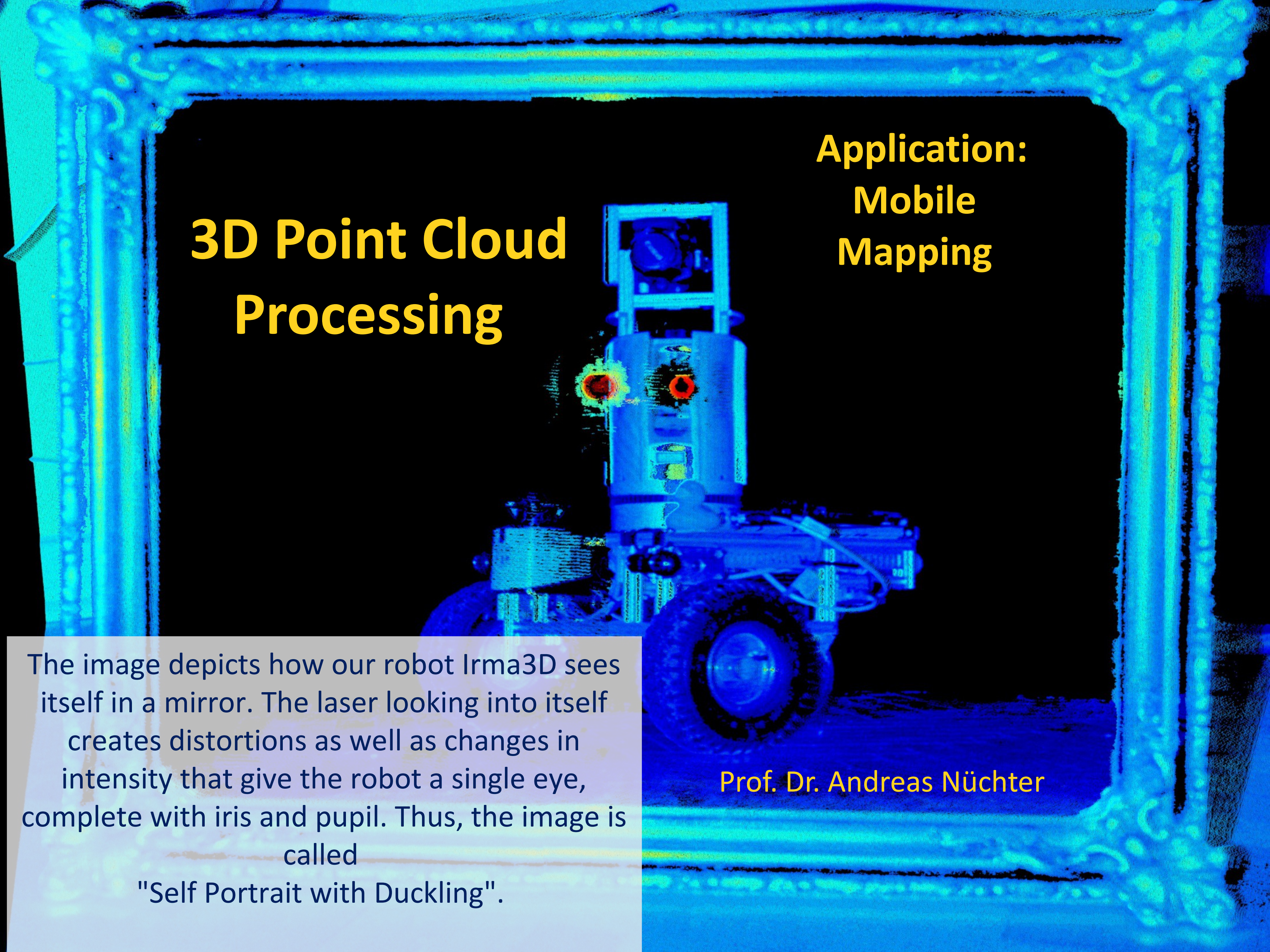
3D Point Cloud Processing

Application: Mobile Mapping



The image depicts how our robot Irma3D sees itself in a mirror. The laser looking into itself creates distortions as well as changes in intensity that give the robot a single eye, complete with iris and pupil. Thus, the image is called
"Self Portrait with Duckling".

Prof. Dr. Andreas Nüchter

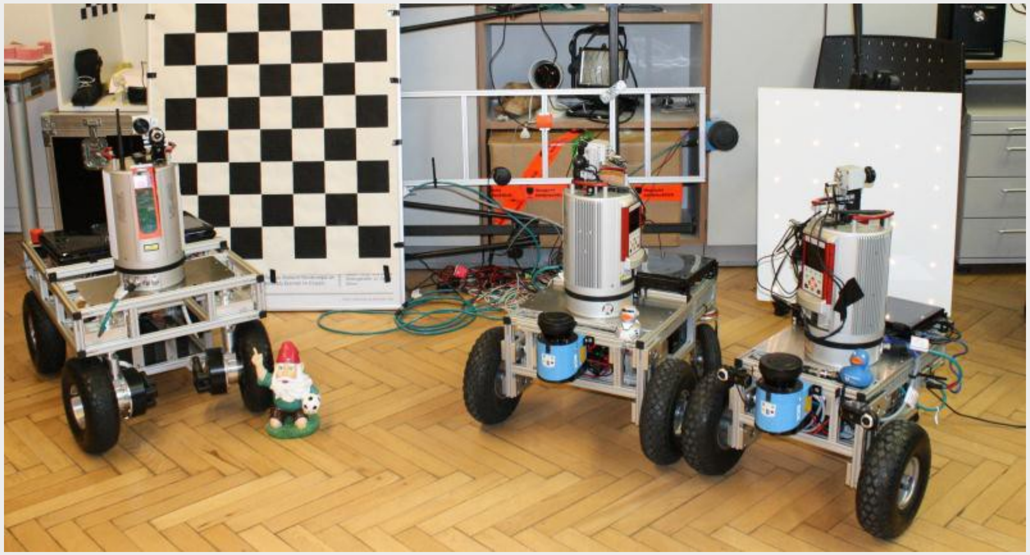
Scanning while Driving

(video)

Mobile Laser Scanning Systems

Experimental

Professional



State of the Art

- For all sensors determine the position and orientation on the vehicle (calibration)
- Data Acquisition
- Extract the trajectory of the vehicle from the sensor data (Kalman-Filter)
- “Unwind” the laser measurements with the trajectory to create a 3D point cloud.

Automatic System Calibration

- Construct a calibration vector

$$\mathbf{C} = (a, w, \mathbf{W}_0, o_0, \ldots, \mathbf{W}_n, o_n)$$

- Treat the „unwinding“ as a function $f(M, \mathbf{C})$
- The point cloud represents samples from a probability density function

$$d(\mathbf{l}) = \frac{1}{n} \sum_{j}^{n} G(\mathbf{l} - \mathbf{p}_j, \sigma^2 \mathbf{I})$$

- Simplified entropy measure $-\sum_{i}^{n} \sum_{j}^{n} G(\mathbf{p}_i - \mathbf{p}_j, 2\sigma^2 \mathbf{I})$
-

Efficient Calibration

- Evaluating the entropy is in $O(n^2)$
- Reduction of the point cloud
  - n becomes smaller
  - Smaller contribution to the error function in the search space
- Reduction of point pairs
  - Consider only pairs with **minimal time difference**
  - Consider only **closest points**
- Minimization of the error function

$$\hat{\mathbf{C}} = \operatorname*{argmax}_{\mathbf{C}} E(f(M, \mathbf{C}))$$

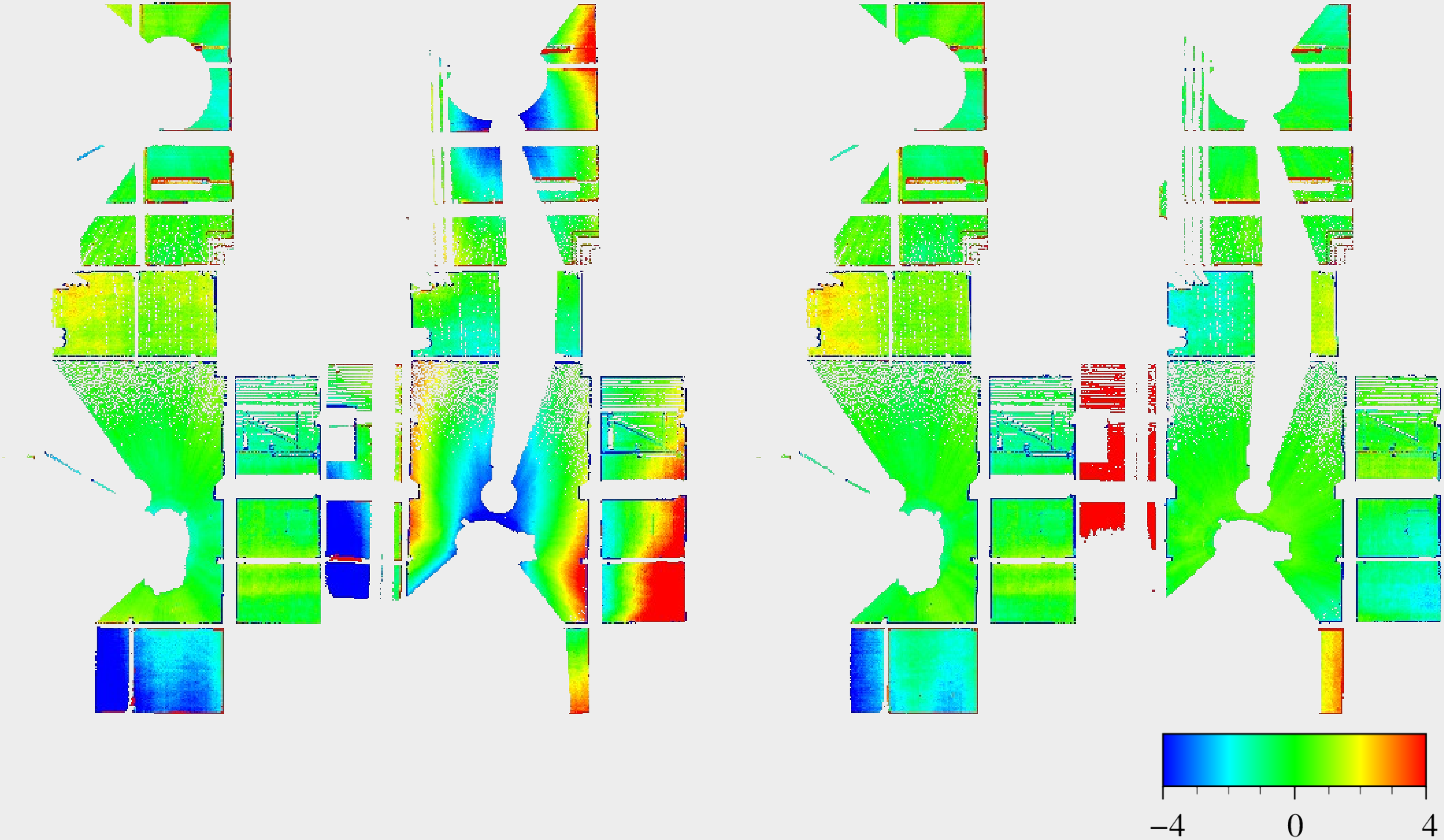
where $$E(f(M,\mathbf{C})) = -\sum_{i}^{n} G(\mathbf{p}_i - \mathbf{q}_i, 2\sigma^2 \mathbf{I})$$

is in O(n log n)   (~20 minutes with Powel‘s algorithm)

Calibration Experiment (1)

- Reference model: 3D plane model from terrestrial scanning
- Compare point cloud with model

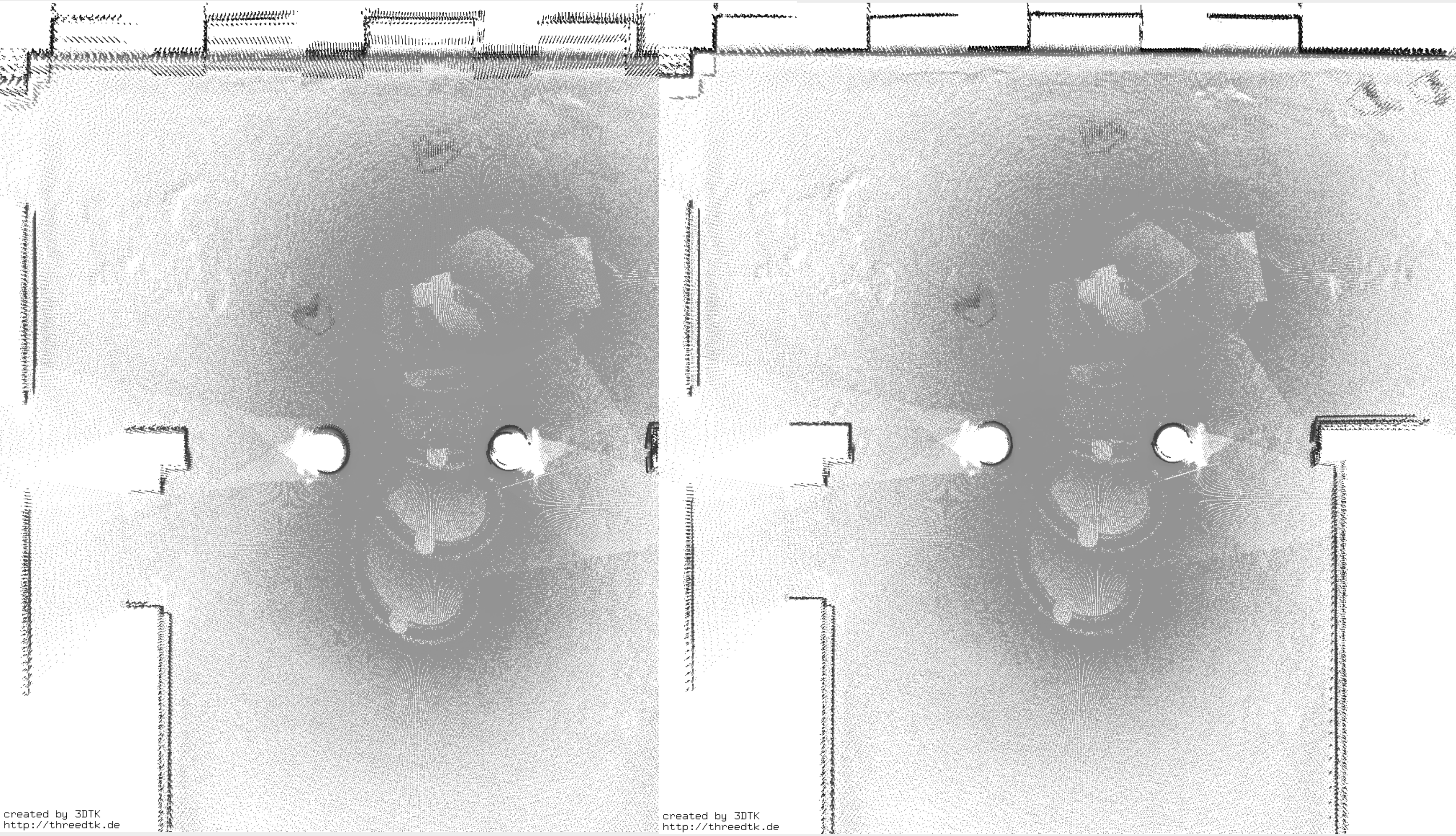
Calibration Experiment (1)



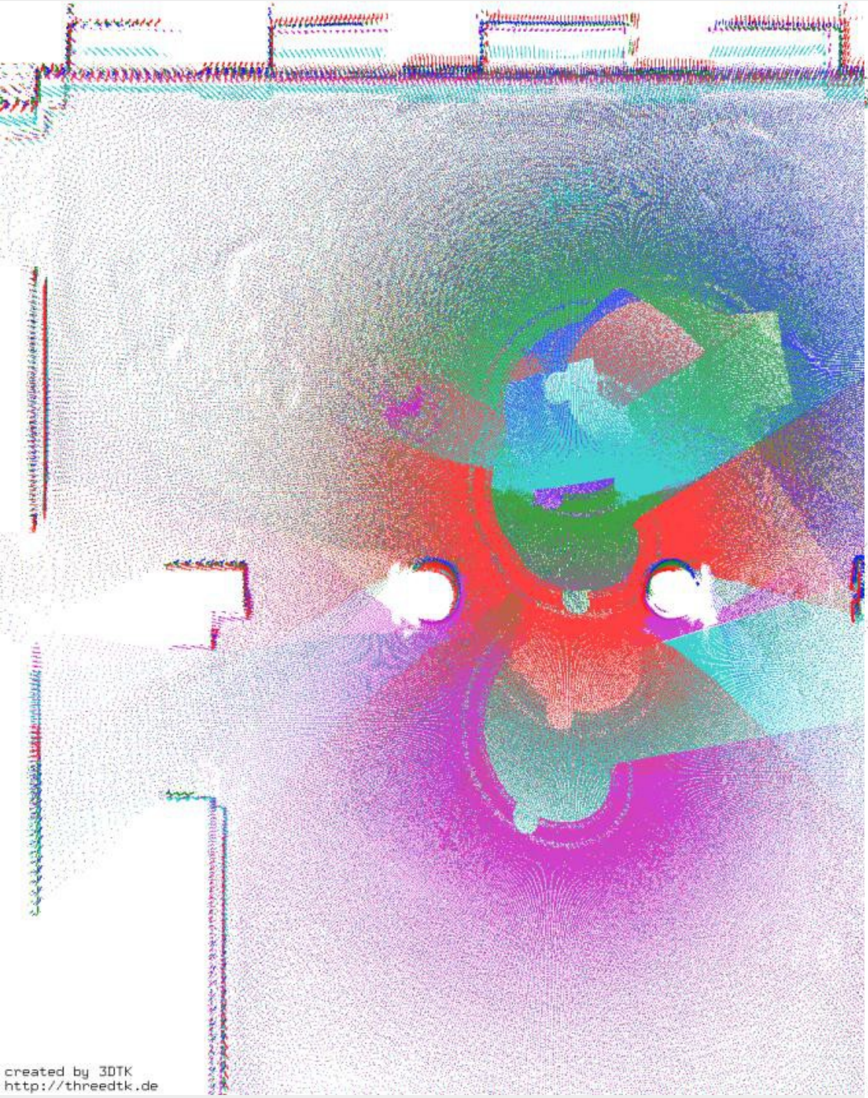
Calibration Experiment (2)

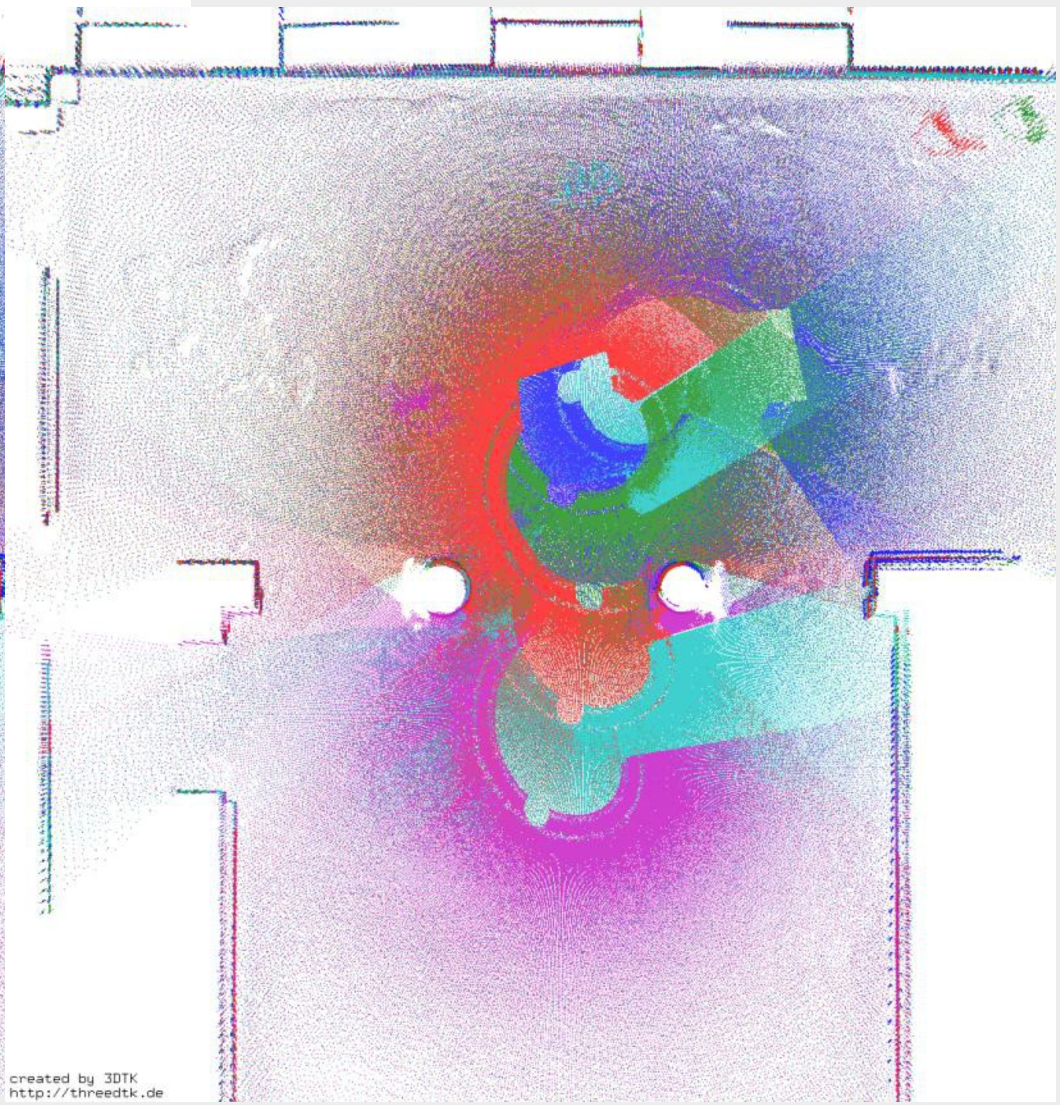
- Ostia Antica in Rom
- Environment less structured
- No ground truth model available

Calibration Experiment (2)

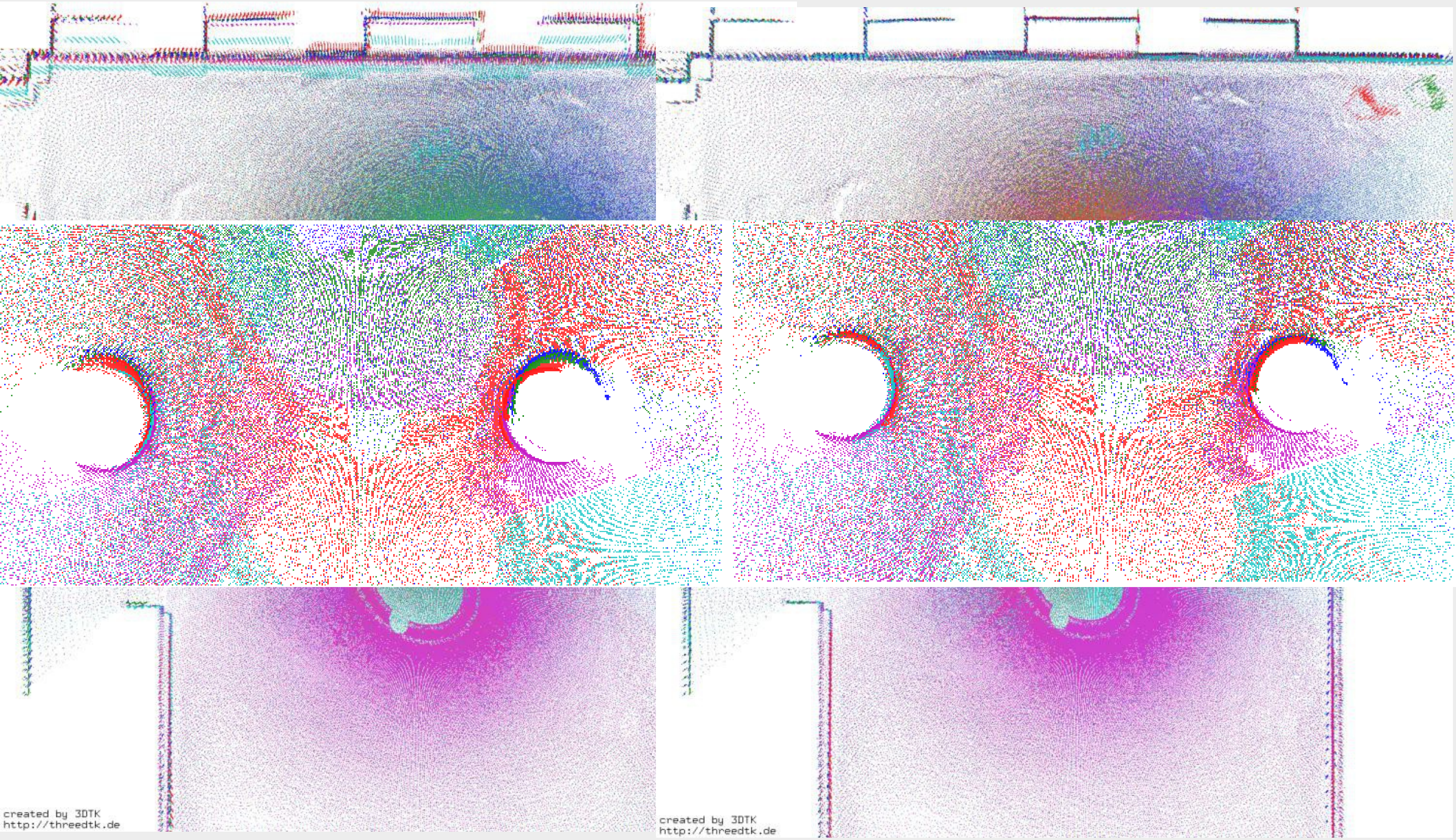


Calibration Experiment (2)





Calibration Experiment (2)



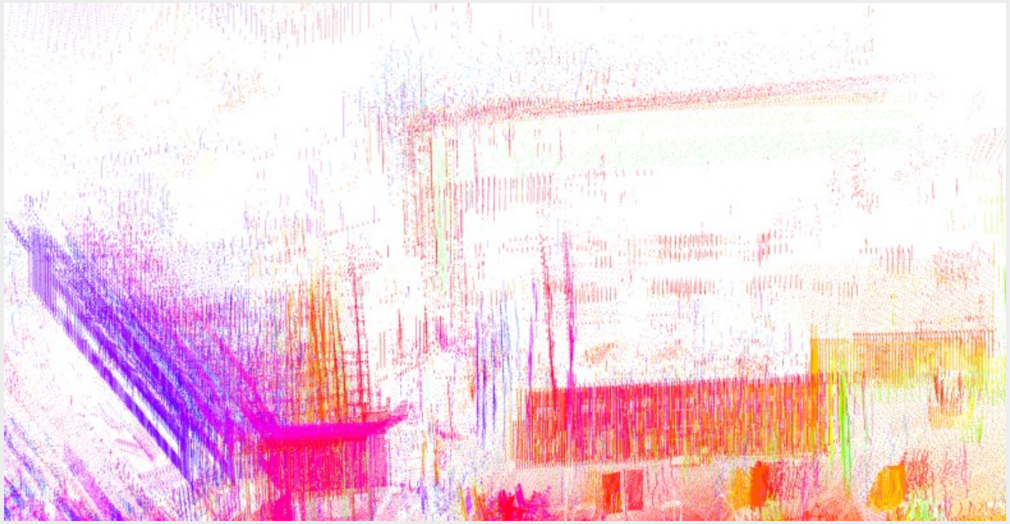
Further Sources of Errors

no GPS

„lousy“ IMU

bad GPS

no IMU



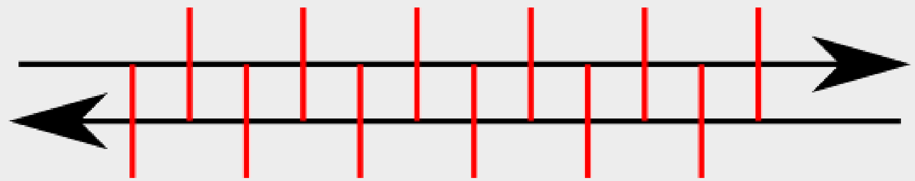
Semi-Rigid Registration

- Goal:
  - Optimize trajectory
  - No or only small time discretization (< 10 ms)
  - Ideal discretization at every point measurement
- Ansatz:
  - Extension of the global ICP algorithm / Graph-SLAM
- Modeling
  - Trajectory $T = \{\mathbf{V}_0, \ldots, \mathbf{V}_n\}$
  - Every $\mathbf{V}_i$ is a vehicle pose at time t_i
  - IMU / odometry estimate $\mathbf{V}_i \rightarrow \mathbf{V}_{i+1}$
  - GPS estimate $\mathbf{V}_0 \rightarrow \mathbf{V}_i$
  - Laser scanner / scan matching $\mathbf{V}_i \rightarrow \mathbf{V}_j$

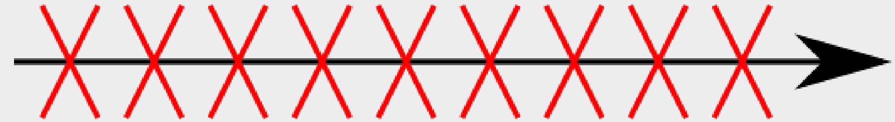
Calculation of $\mathbf{V}_i \rightarrow \mathbf{V}_j$

- "Unwind" the laser measurements with the trajectory to create an initial 3D point cloud.
- Compute correspondences using a modified nearest-neighbor search
- Consider the following scenarios:

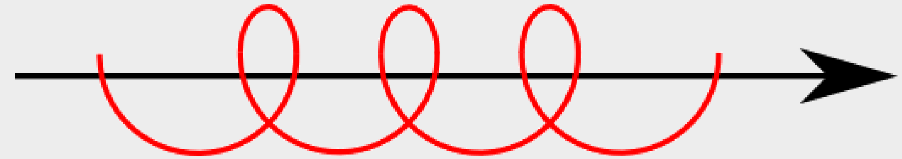
1 2D scanner



2 2D scanners



1 rot. 3D scanner



Optimization of the Trajectory

- Global error function

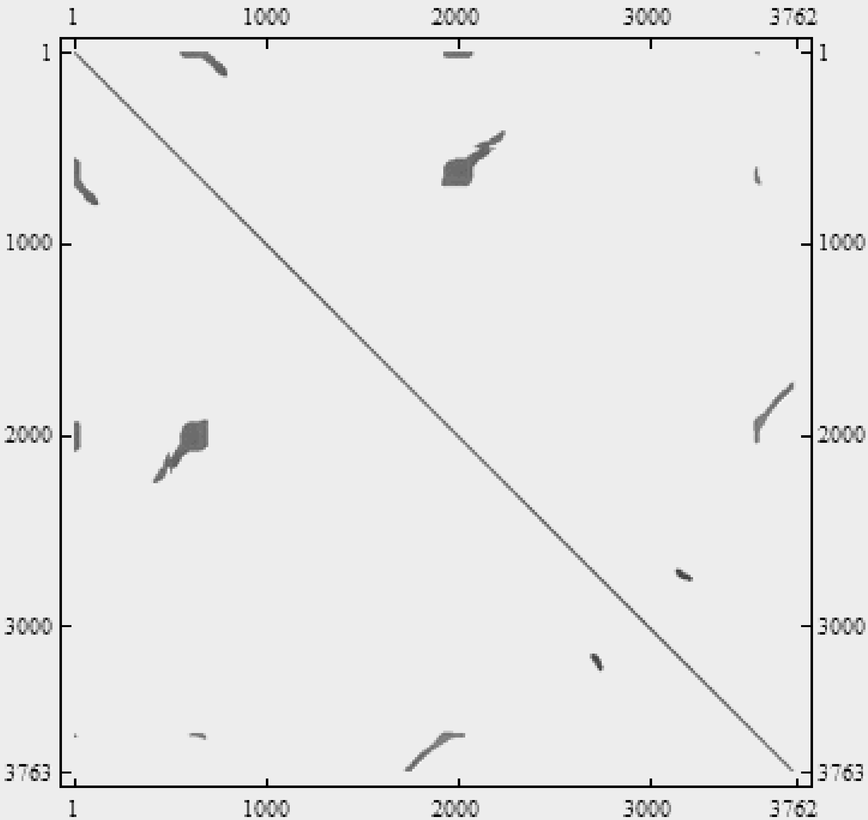
$$W = \sum_i \sum_j (\bar{\mathbf{V}}_{i,j} - (\mathbf{V}'_i - \mathbf{V}'_j))\mathbf{C}_{i,j}^{-1}(\bar{\mathbf{V}}_{i,j} - (\mathbf{V}'_i - \mathbf{V}'_j))$$

- Minimization by

$$(\mathbf{H}^T\mathbf{C}^{-1}\mathbf{H})\mathbf{V} = \mathbf{H}^T\mathbf{C}^{-1}\bar{\mathbf{V}}$$

- Solving by Sparse Choleskey Decomposition by T. Davis

- Also possible: global ICP



Overview: Algorithm Semi-Rigid SLAM

1. Calculate the pose estimates

   $\mathbf{V}_i \rightarrow \mathbf{V}_{i+1}$ and $\mathbf{V}_0 \rightarrow \mathbf{V}_i$

2. Extract a 3D point cloud from a current trajectory estimate and the system calibration

3. Calculate an oc-tree for storing the 3D points (including the time stamp)

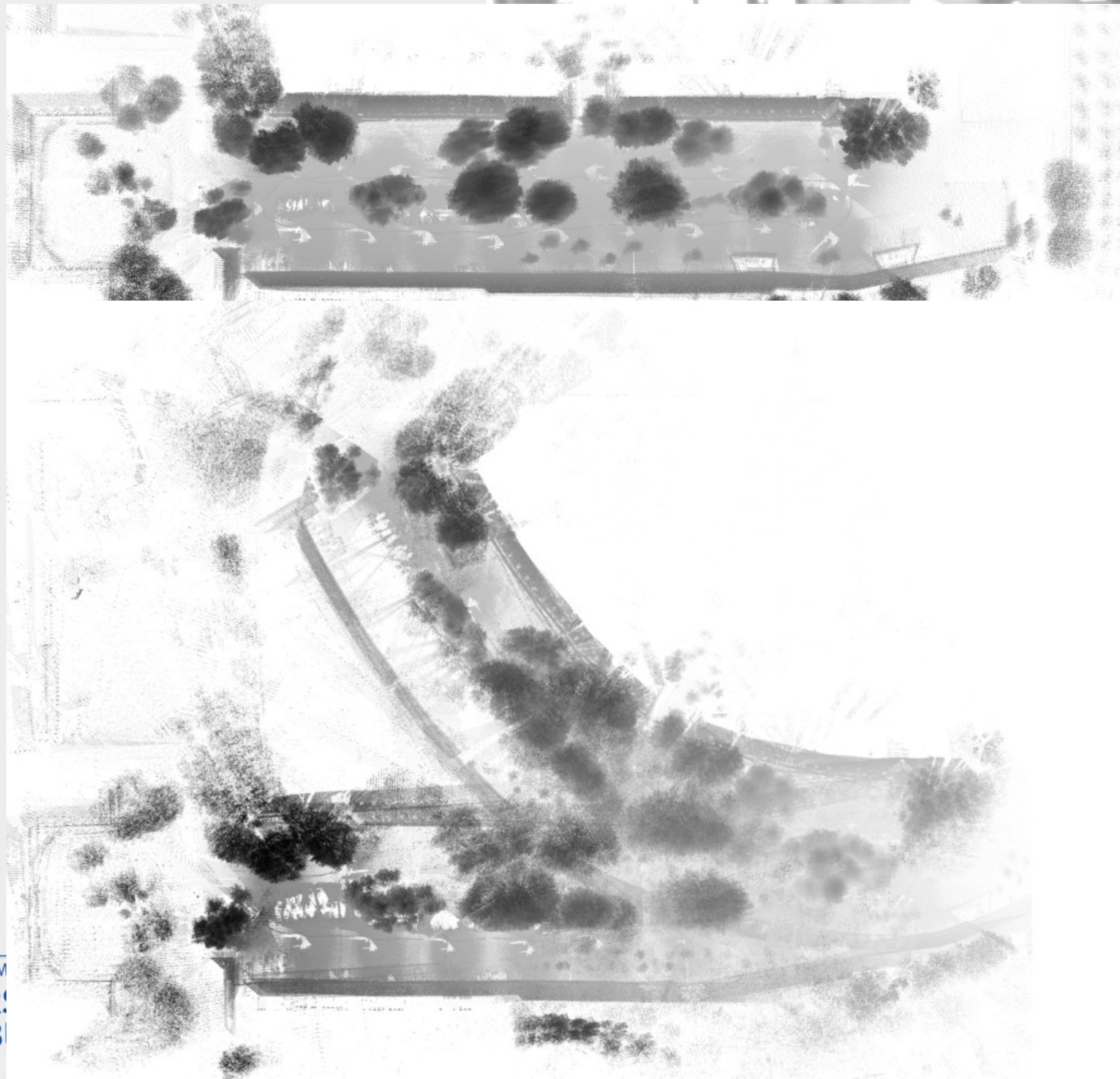
4. Compute closest points and an estimate for

   $\mathbf{V}_i \rightarrow \mathbf{V}_j$

5. Update the trajectory

6. Repeat step 2 – 5 until convergence

Experiment I

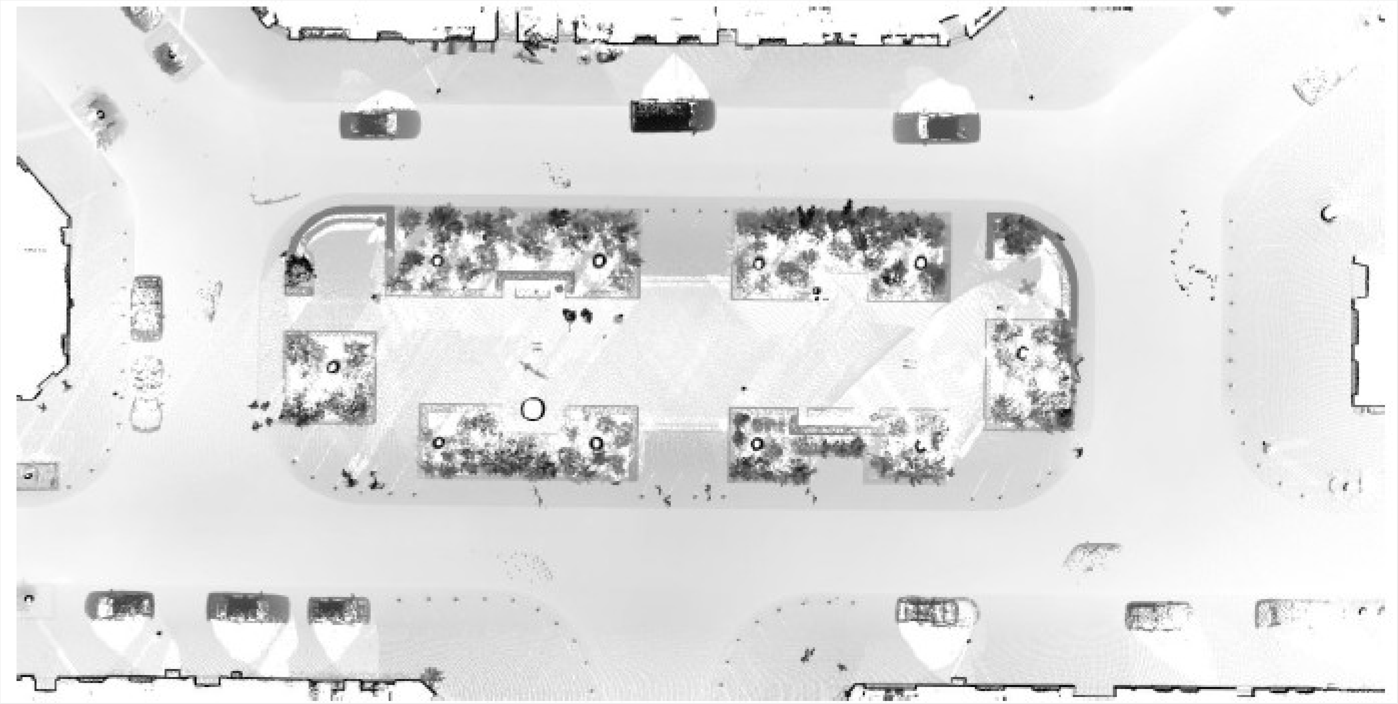


Experiment II

- Data and analysis done by TopScan GmbH, Rheine (Dr. Joachim Lindenberger)

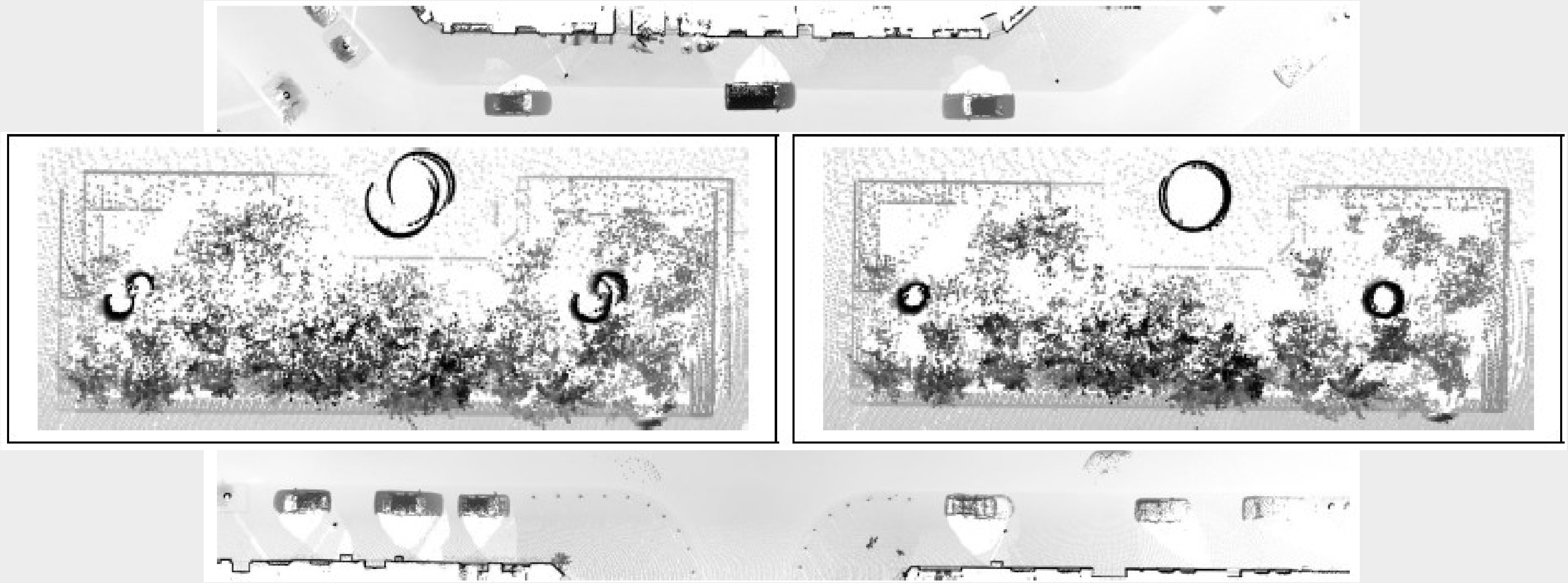
Experiment II

- Data and analysis done by TopScan GmbH, Rheine (Dr. Joachim Lindenberger)

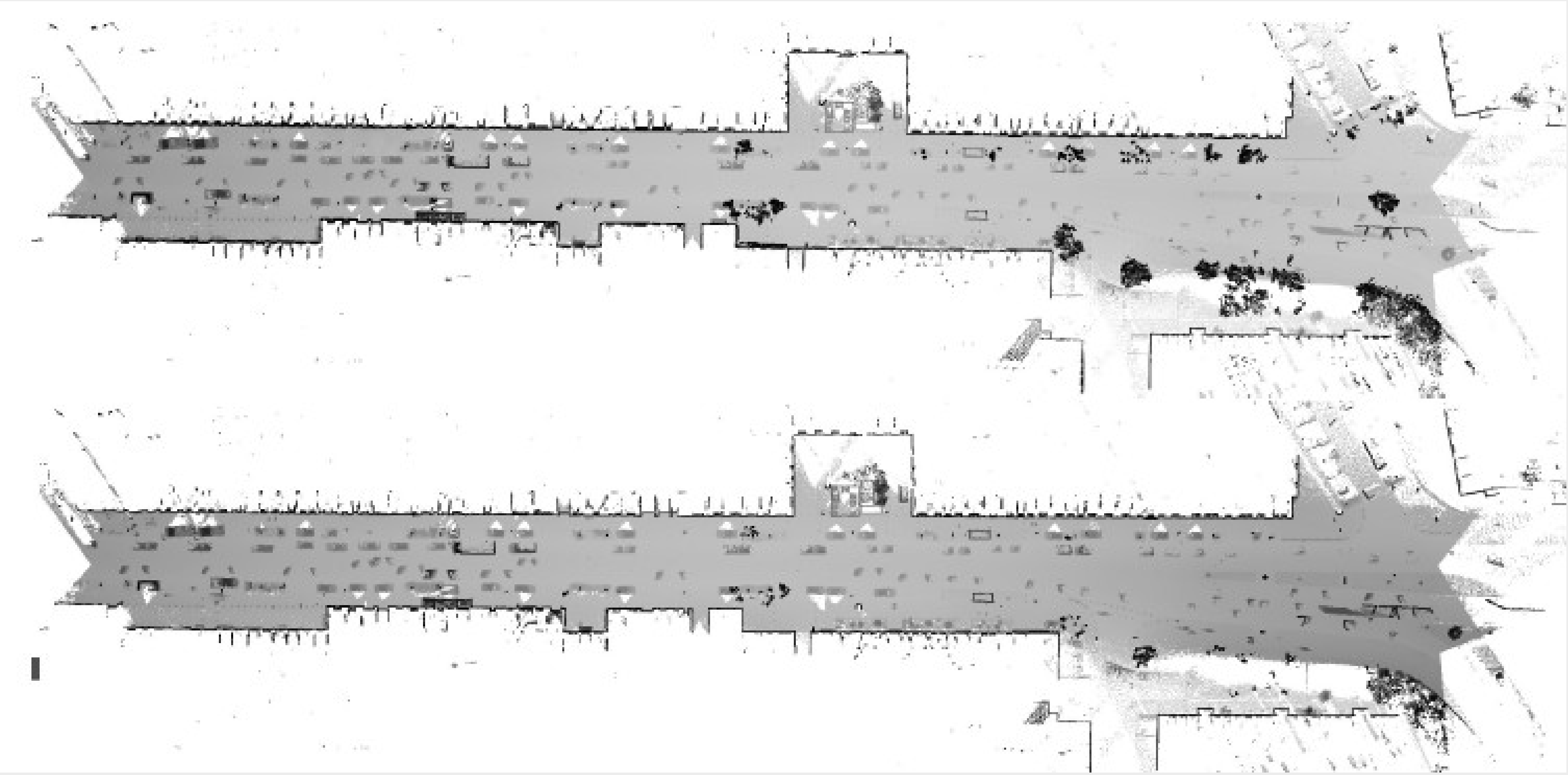


Experiment II

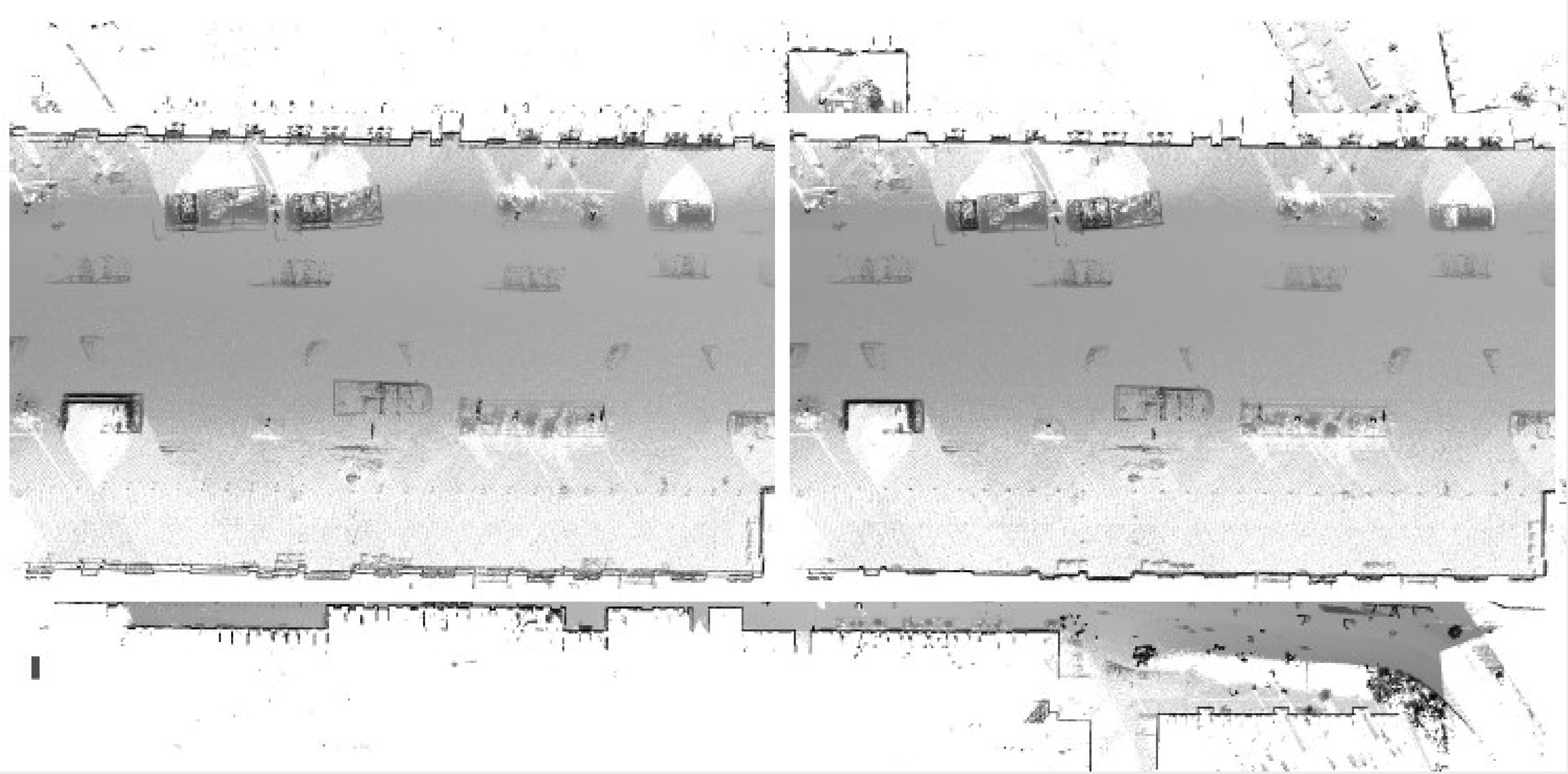
- Data and analysis done by TopScan GmbH, Rheine (Dr. Joachim Lindenberger)



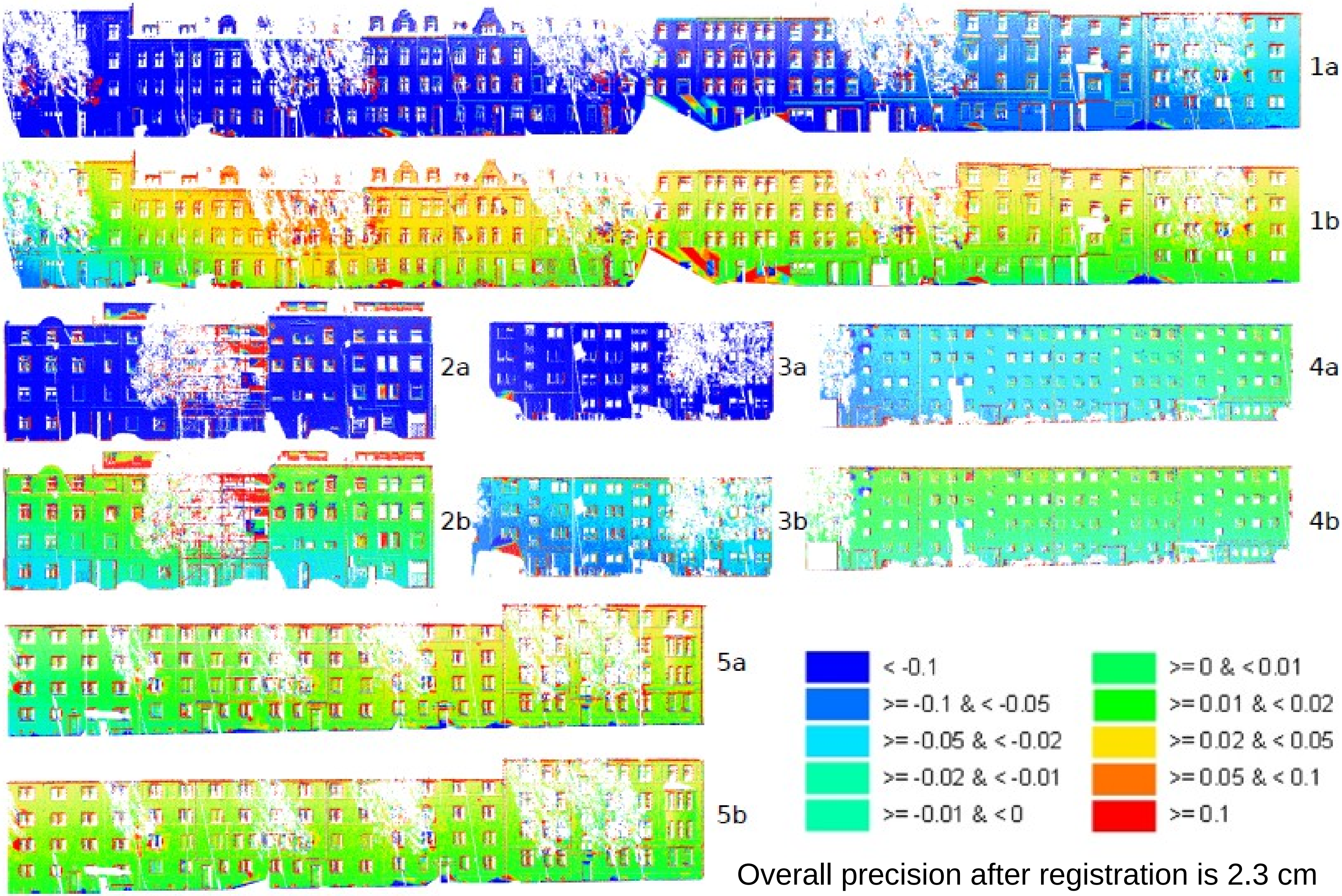
Experiment II



Experiment II

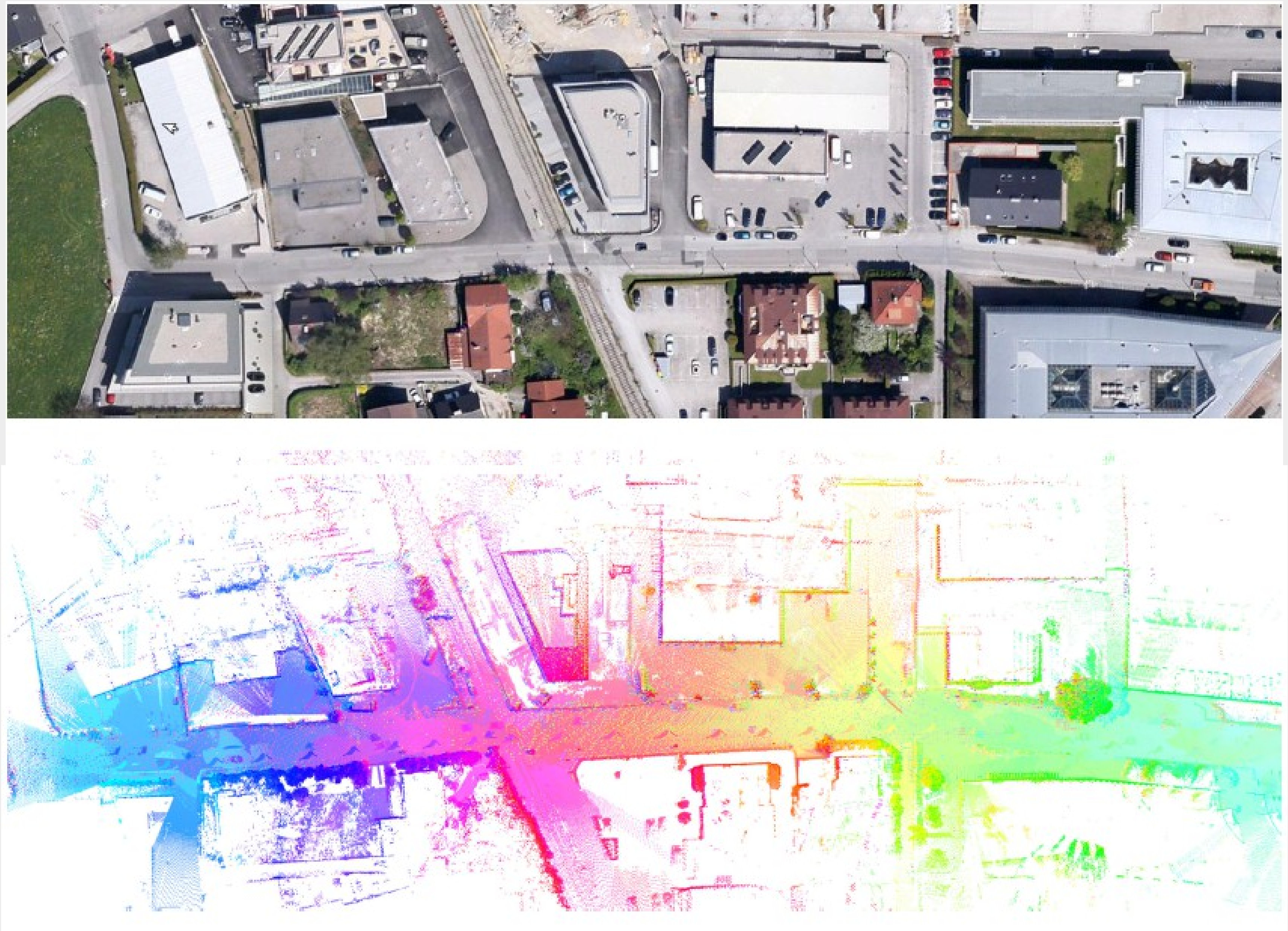


Experiment II



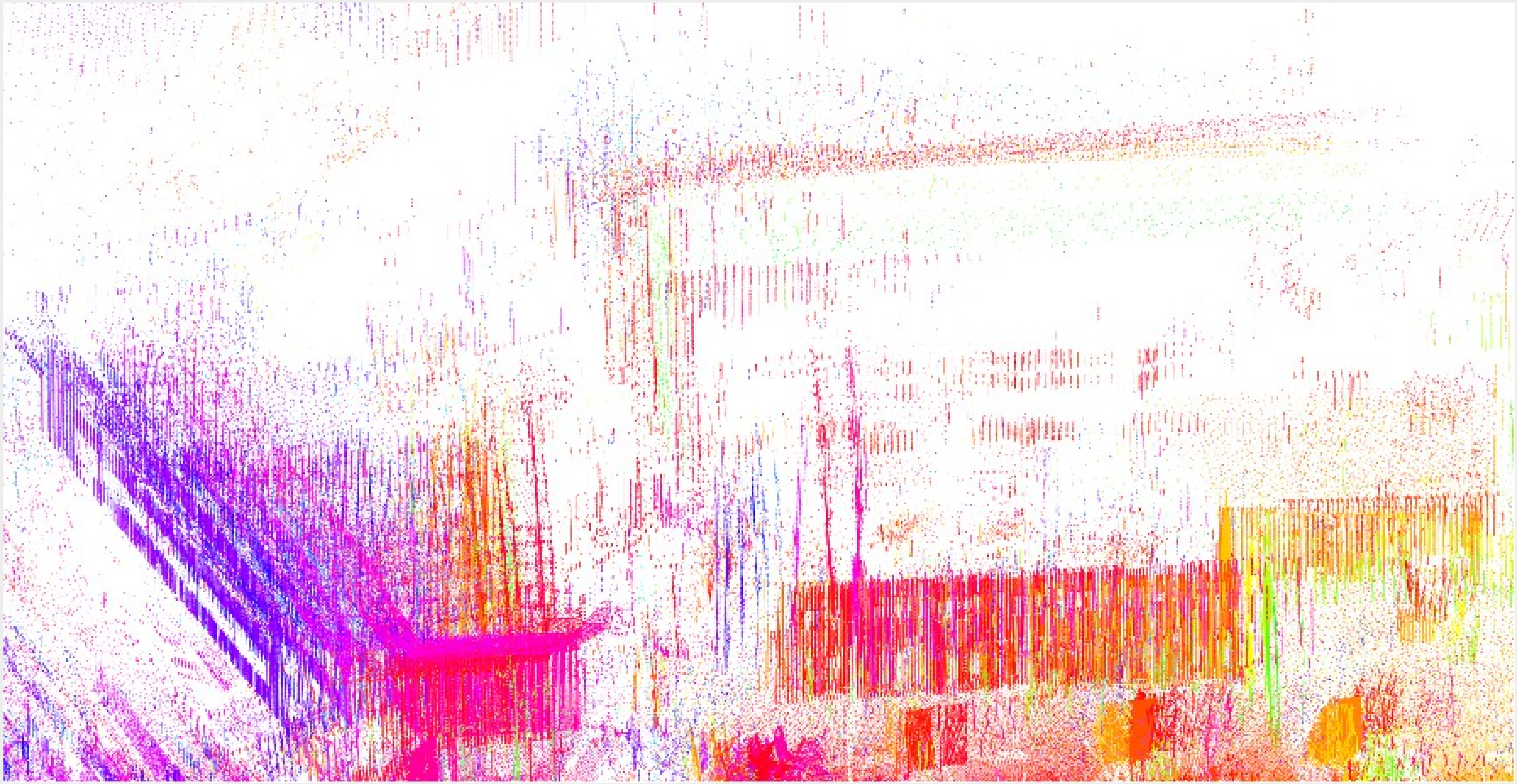
Overall precision after registration is 2.3 cm

Experiment III



Experiment III

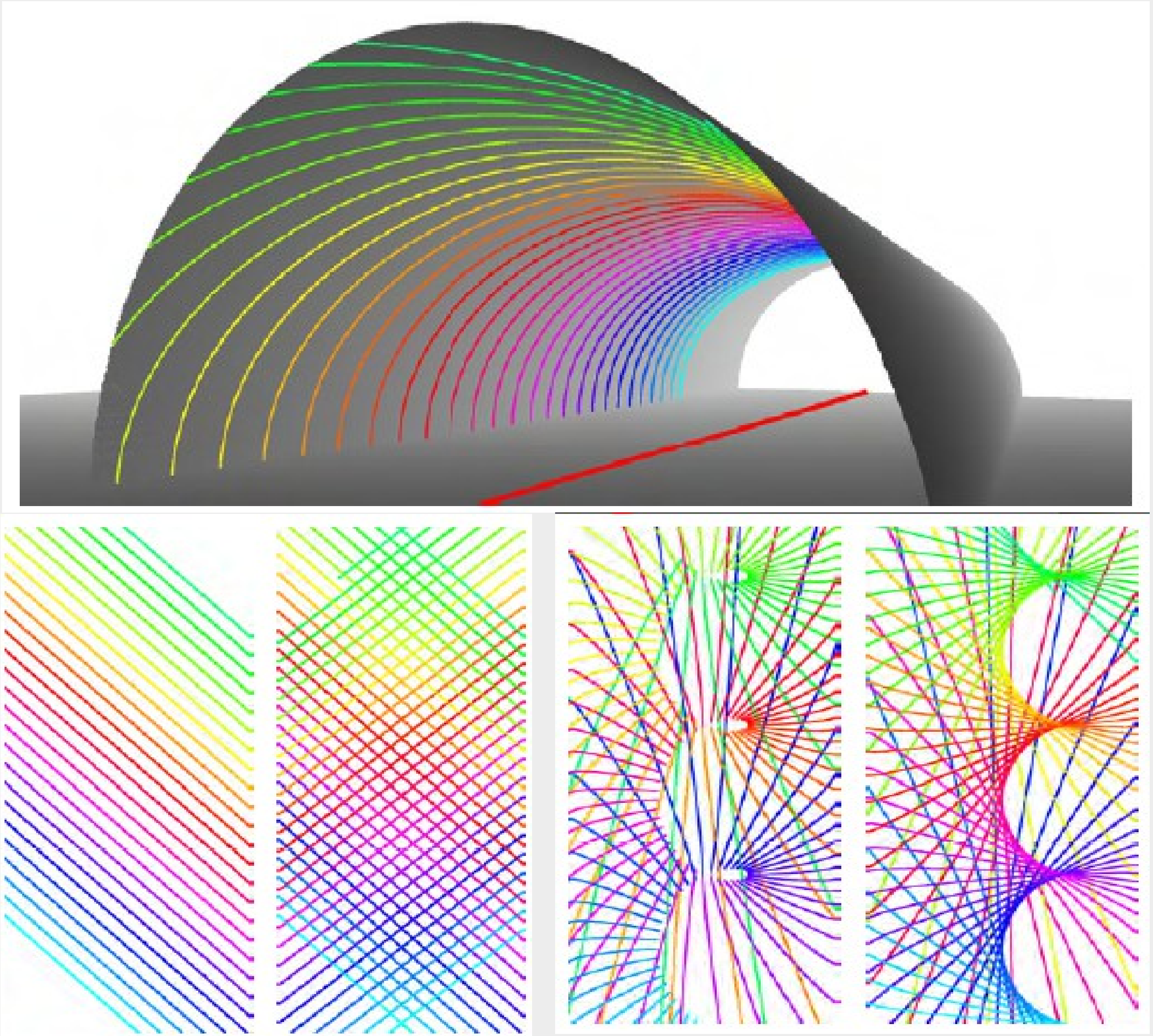
- Acquired by Riegl GmbH in Salzburg



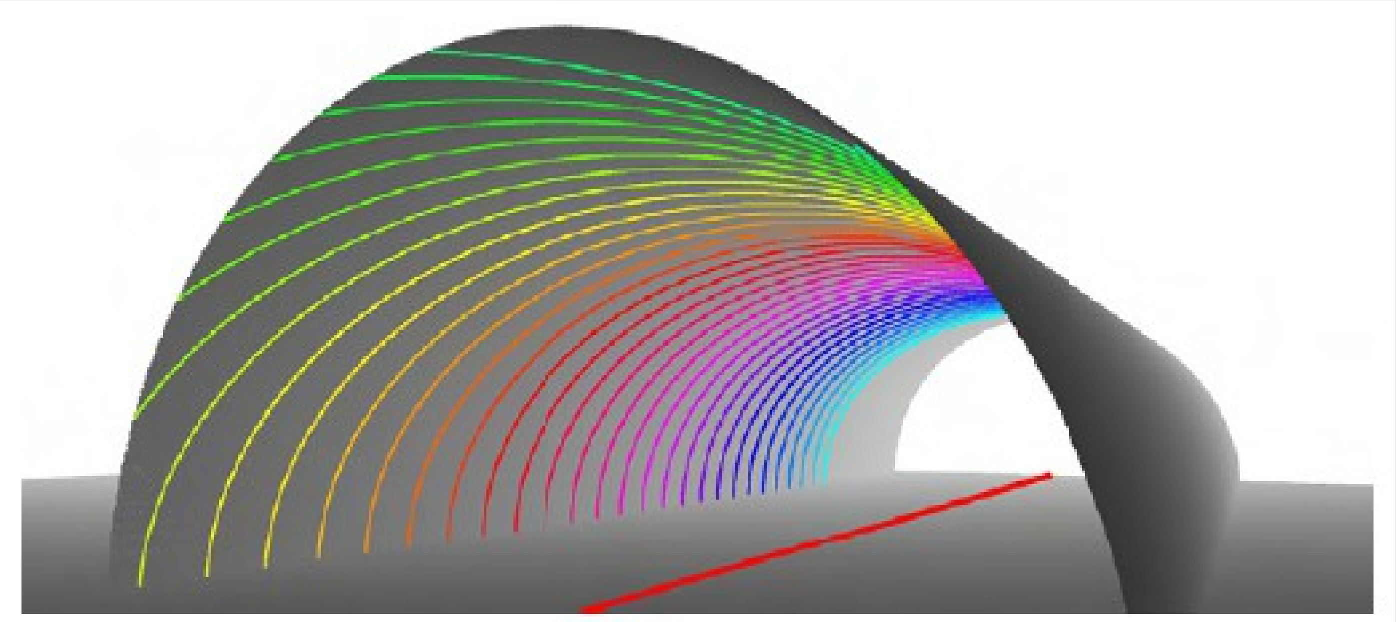
Experiment III

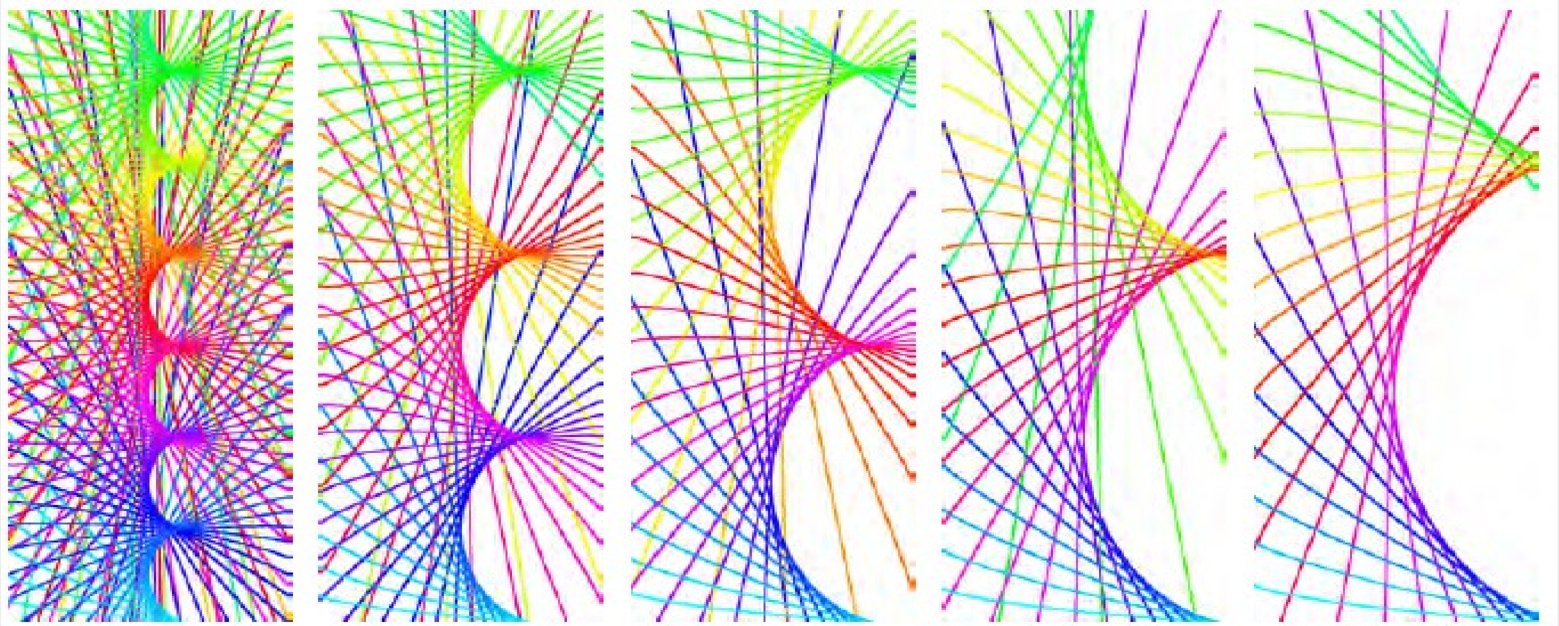
- Acquired by Riegl GmbH in Salzburg

Scan Patterns

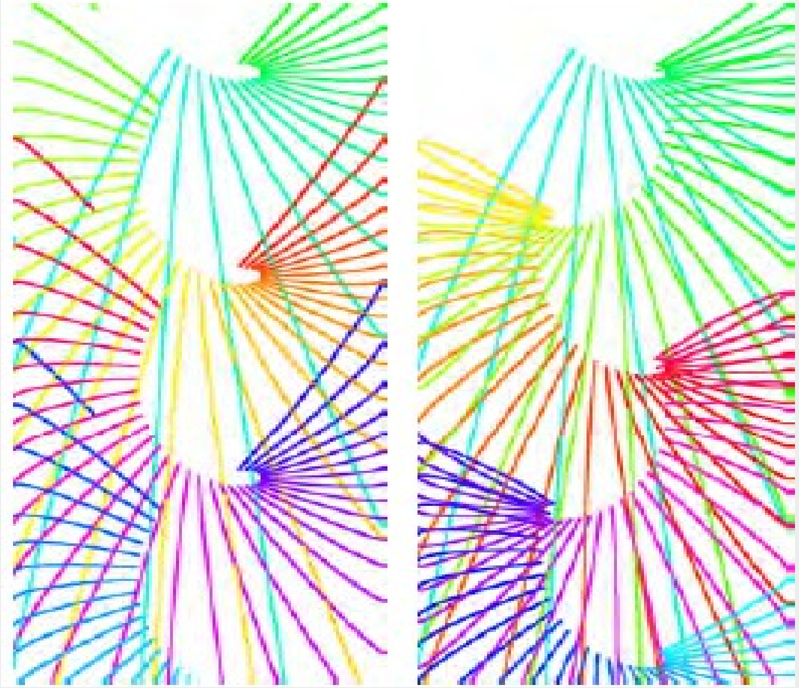


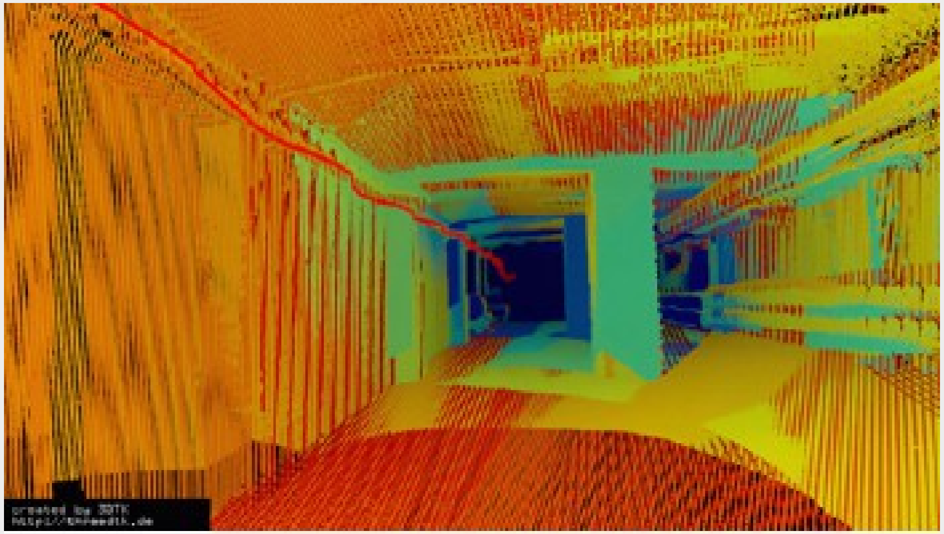
Scan Patterns





Scan Patterns





(video)