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".
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
  \[ C = (a, w, W_0, o_0, \ldots, W_n, o_n) \]

- Treat the „unwinding“ as a function \( f(M, C) \)

- The point cloud represents samples from a probability density function
  \[ d(l) = \frac{1}{n} \sum_{j}^{n} G(l - p_j, \sigma^2 I) \]

- Simplified entropy measure
  \[ -\sum_{i}^{n} \sum_{j}^{n} G(p_i - p_j, 2\sigma^2 I) \]
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

$$
\hat{C} = \arg \max_C E(f(M, C))
$$

where

$$
E(f(M, C)) = -\sum_{i}^{n} G(p_i - q_i, 2\sigma^2 I)
$$

is in $O(n \log n)$ (~20 minutes with Powell'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 \( T = \{V_0, \ldots, V_n\} \)
  – Every \( V_i \) is a vehicle pose at time \( t_i \)
  – IMU / odometry estimate \( V_i \rightarrow V_{i+1} \)
  – GPS estimate \( V_0 \rightarrow V_i \)
  – Laser scanner / scan matching \( V_i \rightarrow V_j \)
Calculation of $V_i \rightarrow V_j$

- “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
  3. 1 rot. 3D scanner
Optimization of the Trajectory

- Global error function
  \[ W = \sum_i \sum_j (\bar{V}_{i,j} - (V'_i - V'_j))C_{i,j}^{-1}(\bar{V}_{i,j} - (V'_i - V'_j)) \]

- Minimization by
  \[ (H^T C^{-1} H)V = H^T C^{-1} \bar{V} \]

- Solving by Sparse Choleskey Decomposition by T. Davis

- Also possible: global ICP
Overview: Algorithm Semi-Rigid SLAM

1. Calculate the pose estimates
   \[ V_i \rightarrow V_{i+1} \quad \text{and} \quad V_0 \rightarrow V_i \]

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
   \[ V_i \rightarrow V_j \]

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

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Experiment II

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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)