Evaluation of RGB-D SLAM systems

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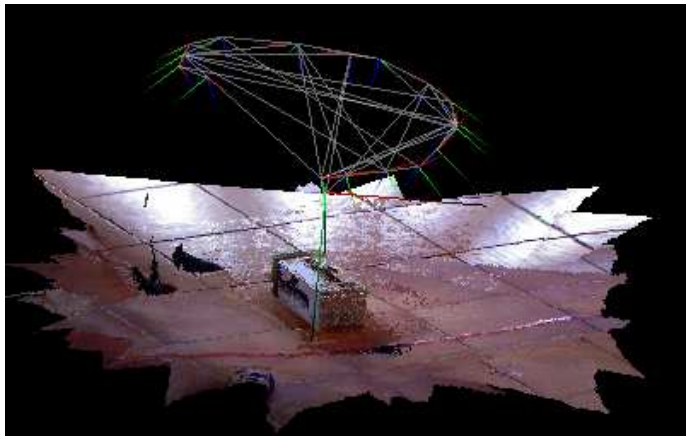
Motivation

- Simultaneous localization and mapping
- Laser-based SLAM [Montemerlo/Olson/Frese/Grisetti/Birk/Nuechter/…]
- Visual (monocular) SLAM [Nister/Davison/Konolige/Strasdat/…]
- Stereo SLAM [Konolige/…]
- RGB-D SLAM [Henry/Engelhard/Newcombe/Fiorario/Rezaiifar/…]

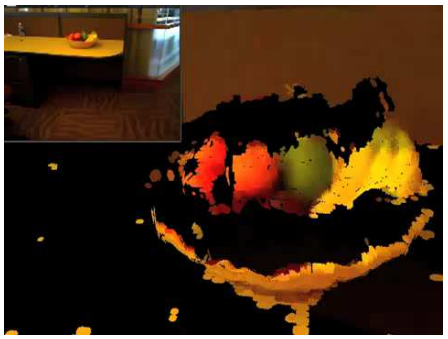
Microsoft Kinect



RGB-D SLAM (open source, try it out!)
[Eurobotics-RGBD '11]

More RGB-D SLAM Results

- Peter Henry, Xiaofeng Ren, Dieter Fox [ISER '10]



- Nikolas Engelhard, Felix Endres, Jürgen Hess, Jürgen Sturm, Wolfram Burgard [Eurobotics-RGBD '11]

- Nicola Fioraio, Kurt Konolige [RSS-RGBD '11]
- Ramin Rezaiifar, Stefano Soatto, Ashwin Swaminathan, Qi Xue, Piyush Sharma [RSS-RGBD '11]
- Richard Newcombe, Andrew Davison
- …

But how can we evaluate (and compare) these approaches?

- 2D laser-based SLAM
  - Intel Dataset
  - Freiburg Dataset
- 3D laser+visual SLAM
  - Newcollege Dataset
- RGB-D SLAM?
  - Visual inspection
  - Ad-hoc evaluations
  - No objective/scientific comparisons exist yet!

[Haehnel et al.]

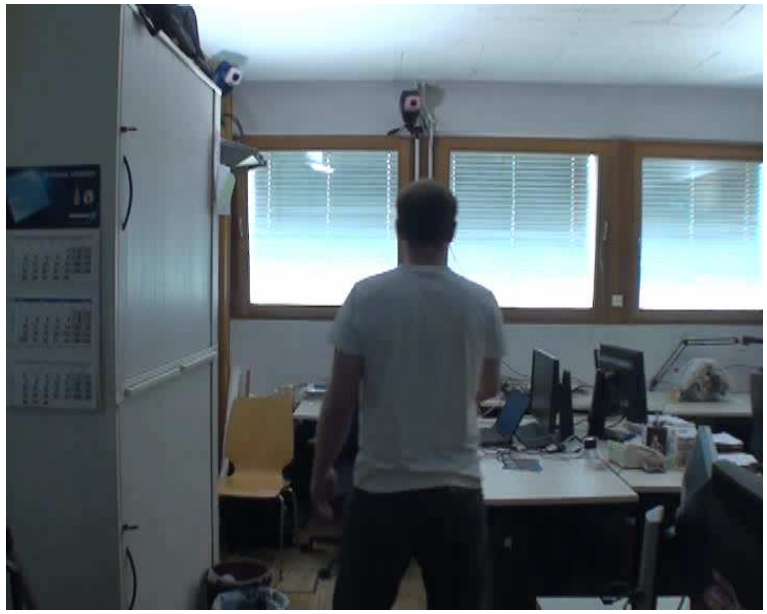
➡ Let’s create such a dataset!

1st step: Record the data

- Motion capture system
  - TF (100 Hz)
- Microsoft Kinect
  - Color images (30 Hz)
  - Depth maps (30 Hz)
  - Point clouds (30 Hz)
  - IMU (500 Hz)
- Calibration
- Record different (office) scenes
  - Various scenes (xyz, desk, room, teddy, plant,…)
  - Variations in camera speed
  - Variations in camera motion

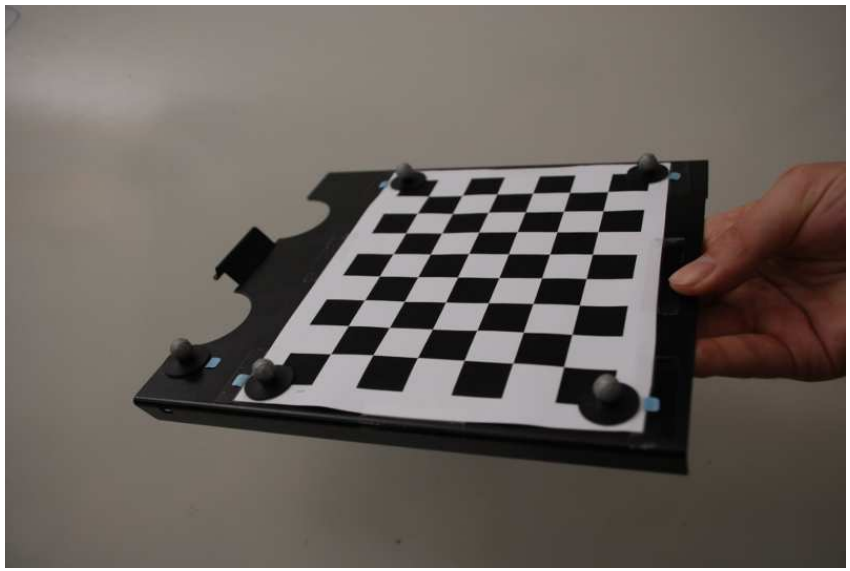
1st step: Record the data

- **Motion capture system**
- Microsoft Kinect
- Calibration (Mocap–Kinect)
- Record different (office) scenes



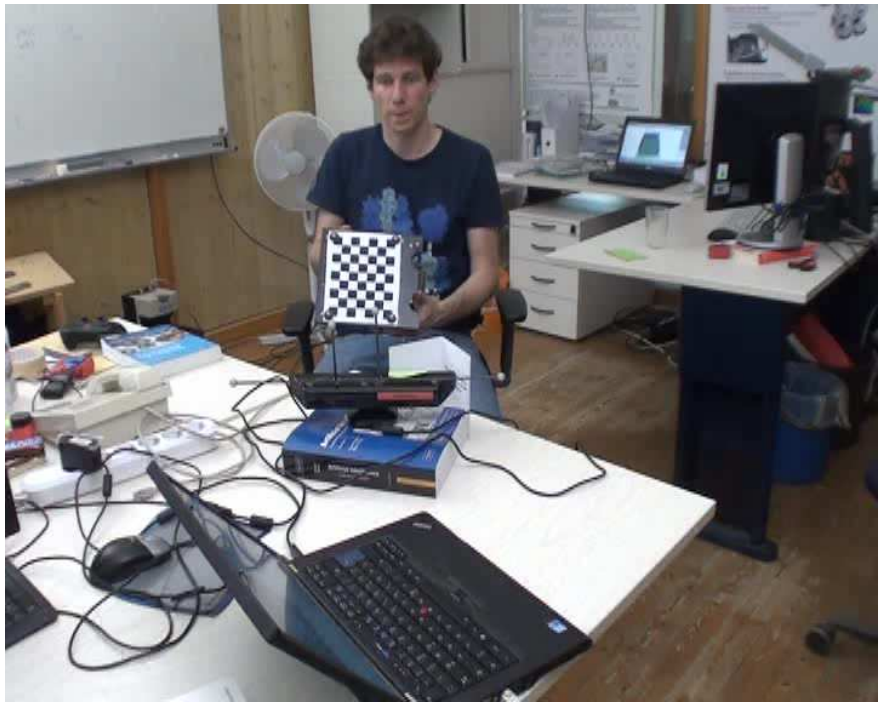
1st step: Record the data

- Motion capture system
- **Microsoft Kinect**
- **Calibration (Mocap–Kinect)**
- Record different (office) scenes



1st step: Record the data

- Motion capture system
- **Microsoft Kinect**
- **Calibration (Mocap–Kinect)**
- Record different (office) scenes

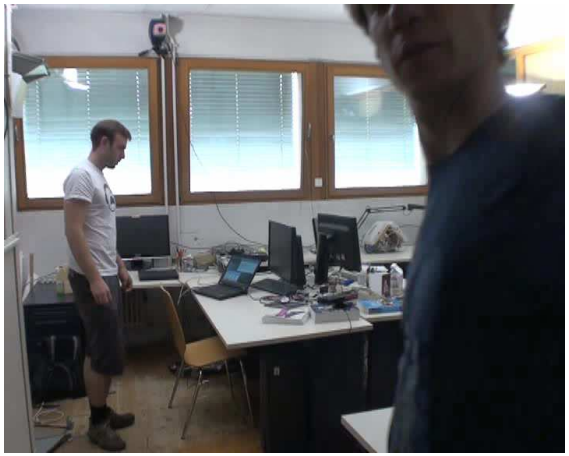


1st step: Record the data

- Motion capture system
- Microsoft Kinect
- Calibration (Mocap–Kinect)
- **Record different (office) scenes**

File: XYZ

File: 360



File: Room …

1st step: Record the data

- Motion capture system
- Microsoft Kinect
- Calibration (Mocap–Kinect)
- **Record different (office) scenes**

File: XYZ

File: Desk

Resulting dataset

- Freely available (Creative Commons)

  https://cvpr.in.tum.de/research/datasets/rgbd-dataset
- ROS bag files (and: zipped list of pngs+traj)
- Movies for visual inspection
  - Color camera
  - Depth map
  - External camera
  - Reconstructed scene

2nd step: Create a benchmark

1. Download the dataset
2. Run your favorite (RGB-D) SLAM approach
3. Compare estimated trajectory with ground truth trajectory

➡ What evaluation metric should we use?

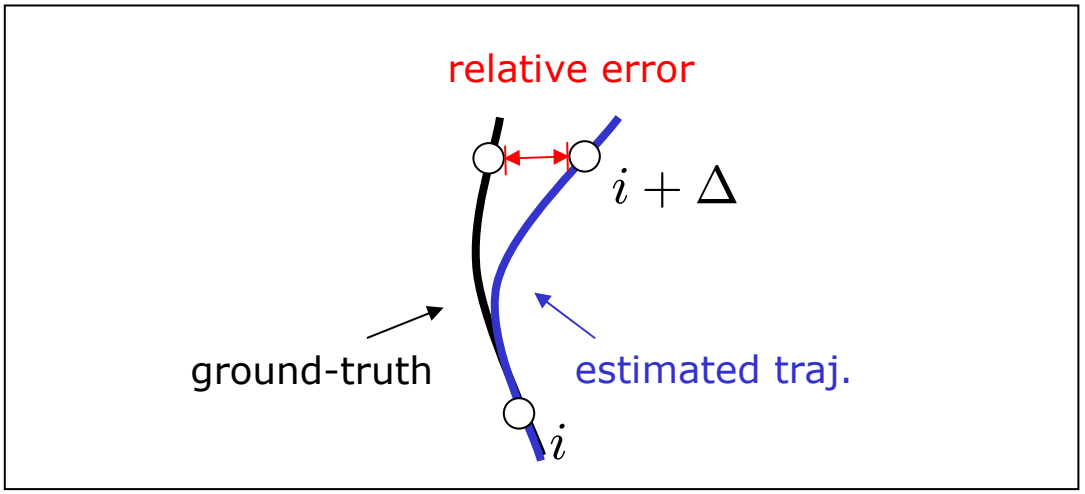
- Automatic evaluation tool
- Avoid overfitting by keeping back second set of data

Evaluation Metric (1)

- Evaluate the quality of the camera trajectory (differences in relative poses)

$$error = \frac{1}{n}\sum_{i=1}^{n}\left[\left(\hat{\mathbf{x}}_{i+\Delta} \ominus \hat{\mathbf{x}}_i\right) \ominus \left(\mathbf{x}_{i+\Delta} \ominus \mathbf{x}_i\right)\right]^2$$

[Kümmerle et al., 2009]



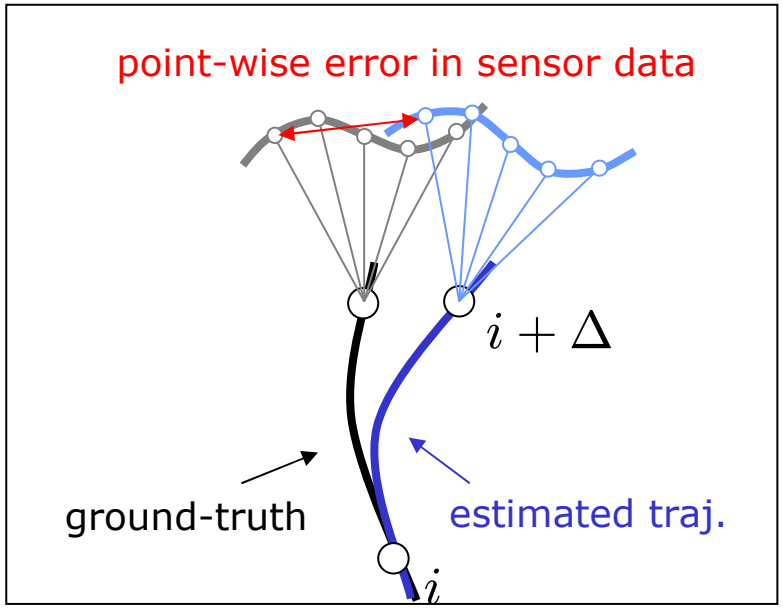
$\hat{\mathbf{x}}_{1:n}$ estimated traj. $\mathbf{x}_{1:n}$ ground-truth traj. $P_{1:n}$ sequence of sensor data (3D point clouds)

Evaluation Metric (2)

Alternative:

- Evaluate the quality of the resulting map (differences in the projected sensor data)

$$error = \frac{1}{n}\sum_{i=1}^{n}\sum_{u=1}^{640}\sum_{v=1}^{480}\left[(\hat{\mathbf{x}}_{i+\Delta} \ominus \hat{\mathbf{x}}_i)P_i(u,v) - (\mathbf{x}_{i+\Delta} \ominus \mathbf{x}_i)P_i(u,v)\right]^2$$



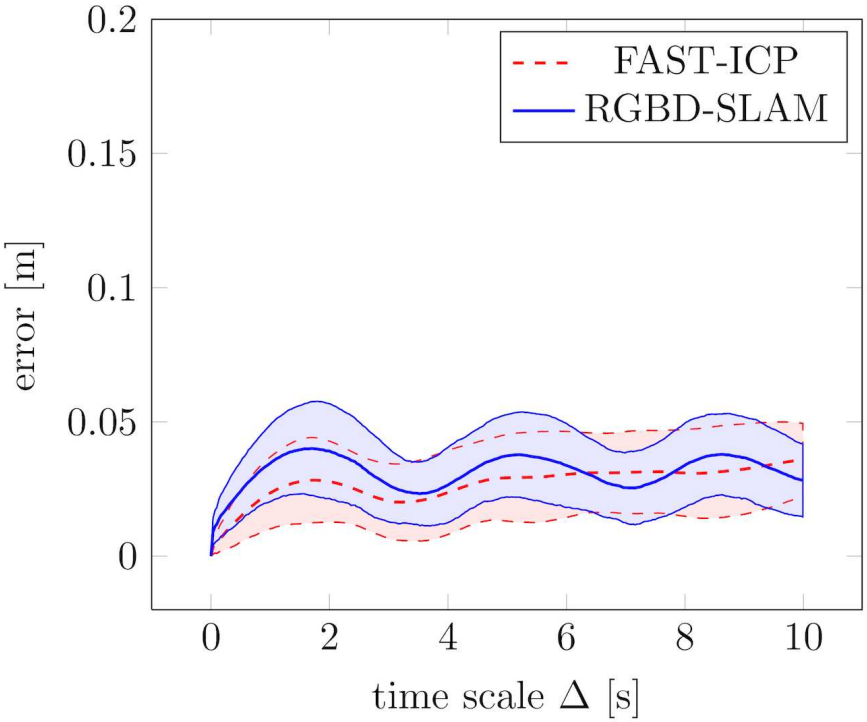
$\hat{\mathbf{x}}_{1:n}$ estimated traj. $\mathbf{x}_{1:n}$ ground-truth traj. $P_{1:n}$ sequence of sensor data (3D point clouds)

Preliminary evaluation results

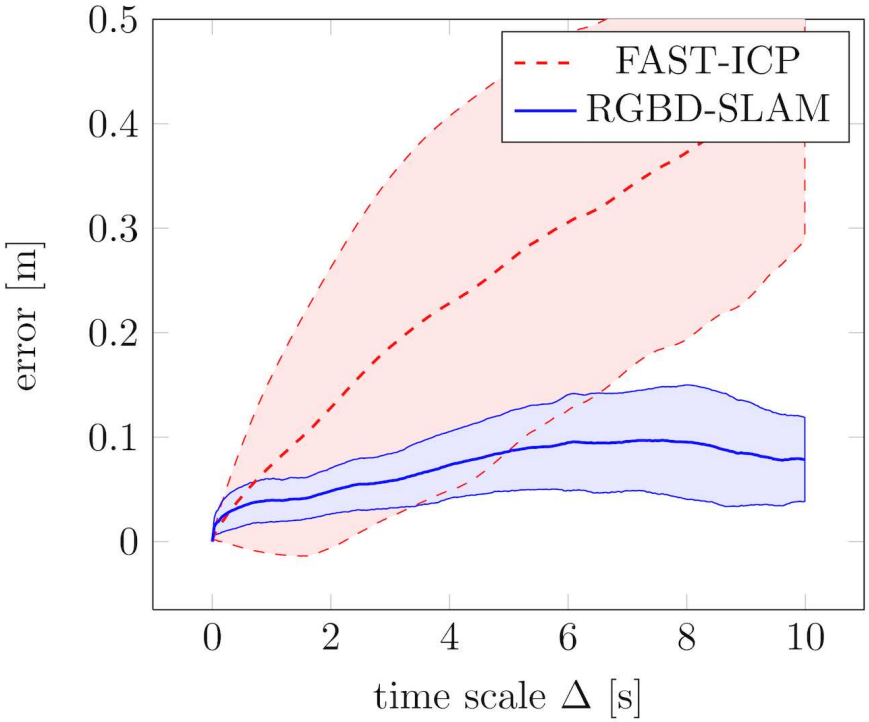
- Two systems
  - Freiburg RGB-D SLAM
  - ETH Fast-ICP Tracker
- Two datasets
  - XYZ: small volume, motion along the axes
    - Volume of camera trajectory: 0.5m x 0.7m x 0.4m
    - Average camera speed: 0.25m/s
    - Good for debugging
  - Desk: motion across four desks, contains loops
    - Volume of camera trajectory: 2.4m x 1.3m x 0.7m
    - Average camera speed: 0.41m/s
    - Good for SLAM evaluation
- Evaluate camera trajectory (metric 1)

Preliminary evaluation results

Dataset: XYZ



Dataset: Desk



Conclusions

- Dataset for RGB-D SLAM
- Ground-truth camera poses
- Evaluation criteria
- Automatic evaluation tools

➡ Benchmark for RGB-D SLAM evaluation

We plan to publish a joint paper on the evaluation of RGBD-SLAM algorithms. Contact us if you are interested! (sturmju@in.tum.de)

Discussion

- Motion blur + rolling shutter effects due to fast camera motions
- ➡ Will record additional data with slower camera motion in July

- Any suggestions for the scenes?
- What do you need?

Thank you!