UNIVERSITY OF SOUTH CAROLINA

CSCE274 Robotic Applications and Design

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State Estimation

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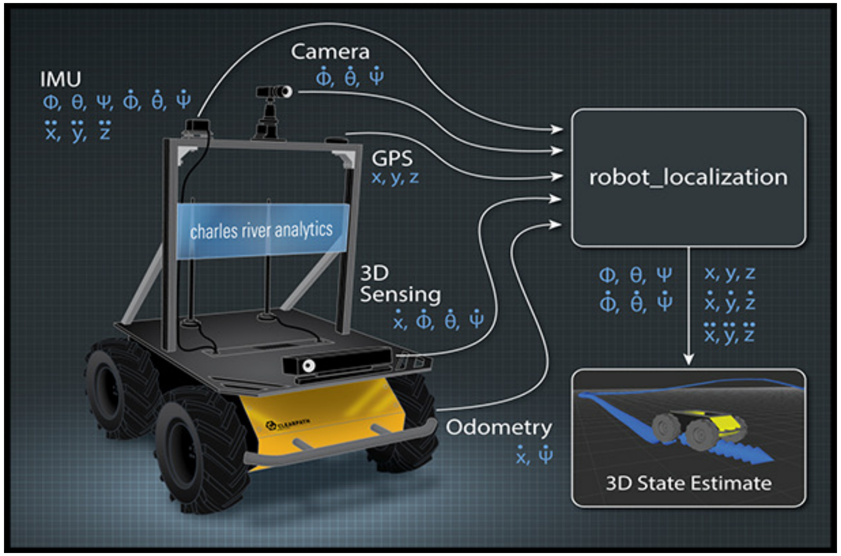
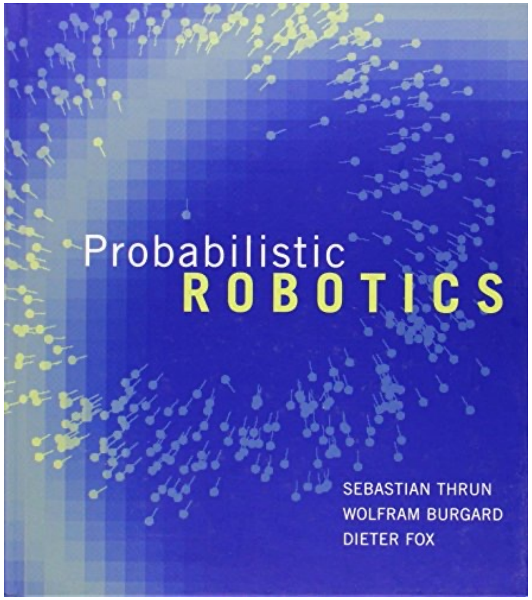
State Estimation

- *State estimation* is the problem of estimating the set of quantities that if known fully describe the robot's motion over time



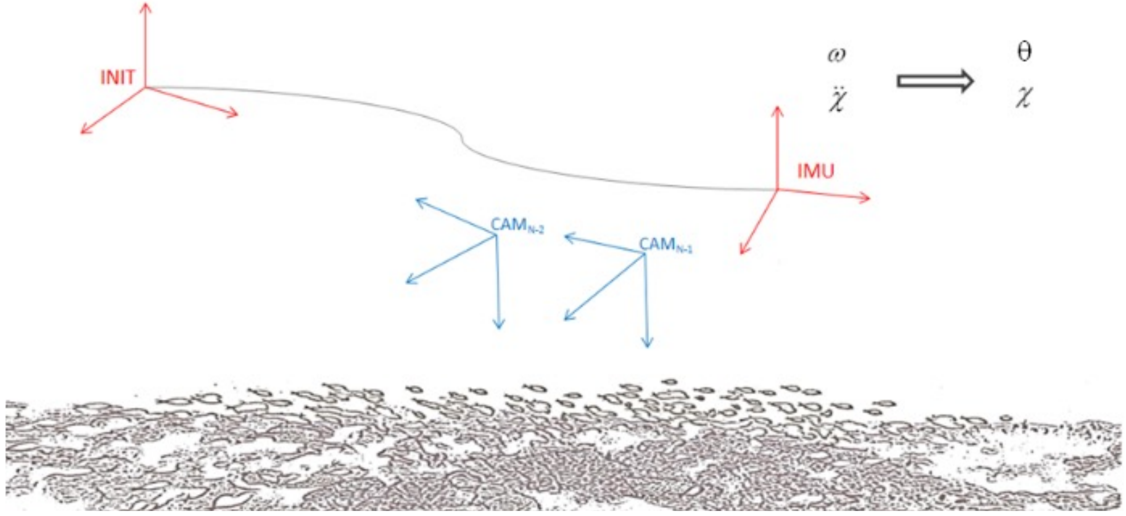
Source: cra.com



Source: probabilistic-robotics.org

Localization

- Localization problem answers to the question "where am I?"
- Given an environment map and some sensor data, return pose estimate of the robot

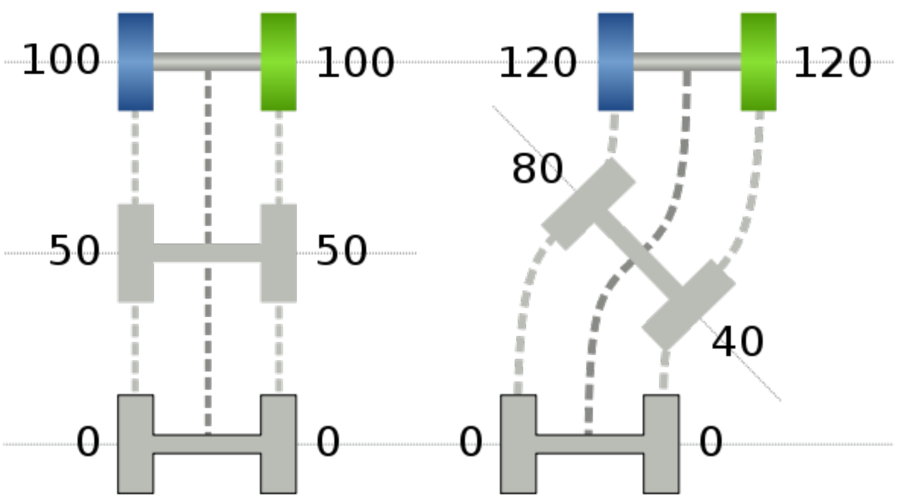


Global localization

- If a robot doesn't know its initial pose, it has to solve the *global localization* problem

Dead reckoning

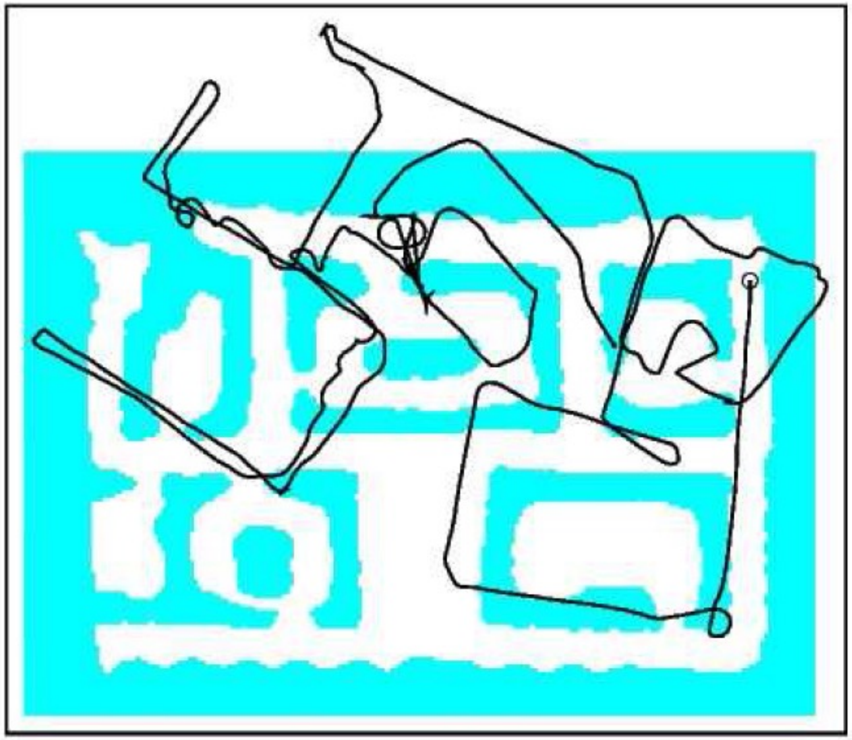
- A simple method is to use *odometry* to track robot's pose based on measured wheel rotations
- This process is also called *dead reckoning*



Source: wikimedia.org

Odometry error

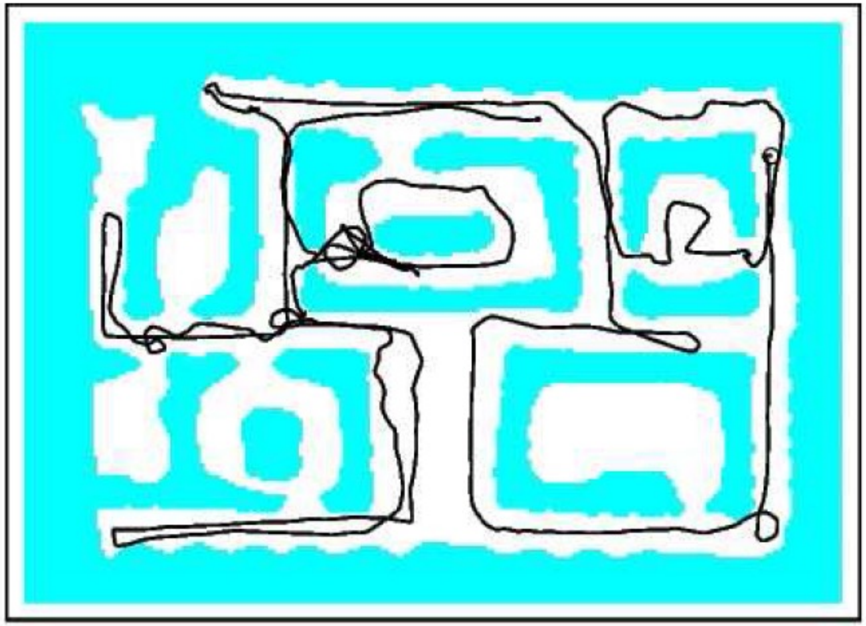
- However, *odometry* tends to drift



Source: [Thrun et al., 2005, MIT Press]

Trajectory correction

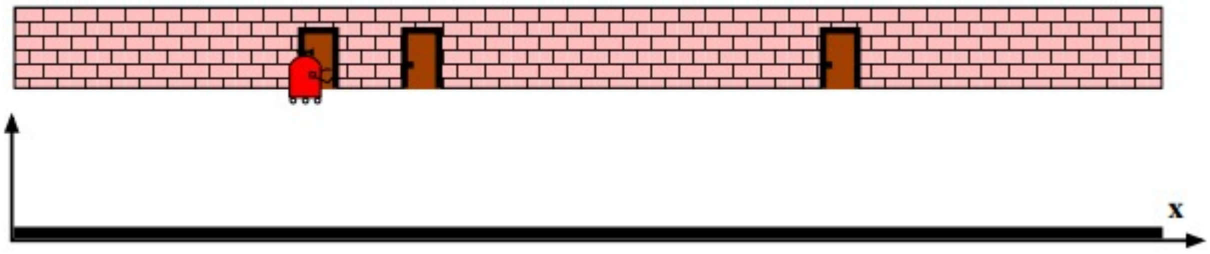
- Using sonar data to match with occupancy grid maps correct the trajectory



Source: [Thrun et al., 2005, MIT Press]

Probabilistic localization

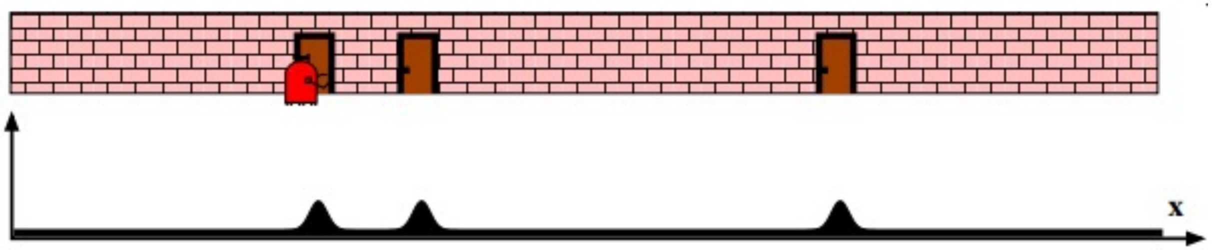
- To account for noise and errors, probabilistic approaches can be used to model the *belief* on its pose
- E.g., global localization on a line, for a robot that is able to detect doors
  - Initially uniform probability because the robot doesn't know where it started from



Source: [Thrun et al., 2005, MIT Press]

Probabilistic localization

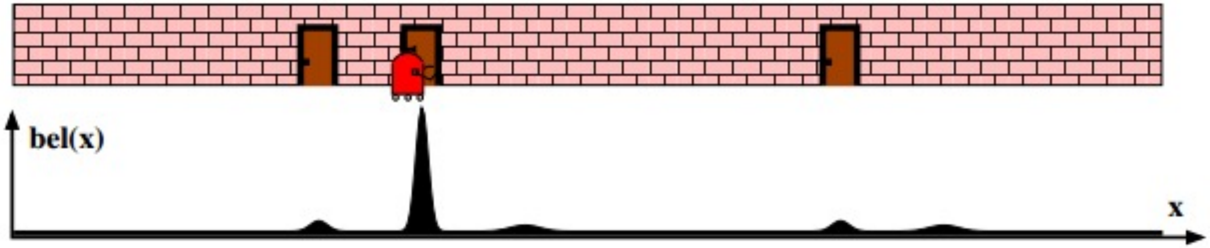
- As the robot sense that there is a door, its belief changes, and peaks are corresponding to where doors are



Source: [Thrun et al., 2005, MIT Press]

Localization

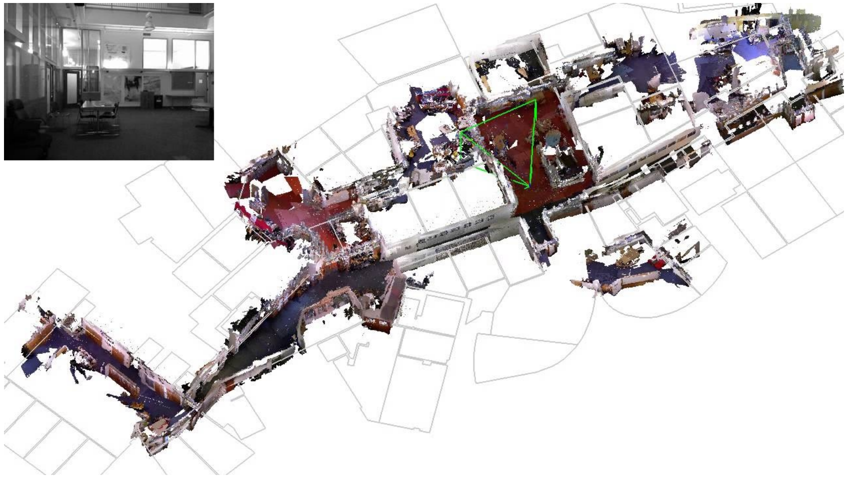
- The robot moves, and discovers another door, thus the maximum peak is on the second door



Source: [Thrun et al., 2005, MIT Press]

Mapping

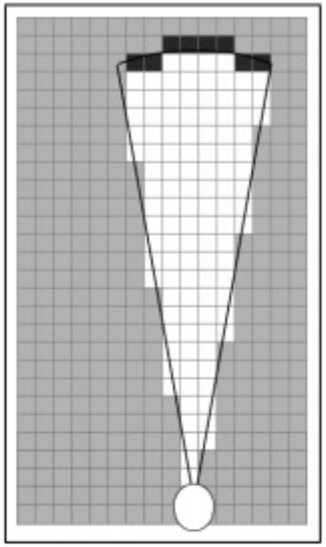
- Mapping problem tries to answer to the question "What the world looks like?"
- Given the pose of the robot and sensor data, reconstruct the world



Source: http://people.csail.mit.edu/hordurj/

Occupancy grid mapping

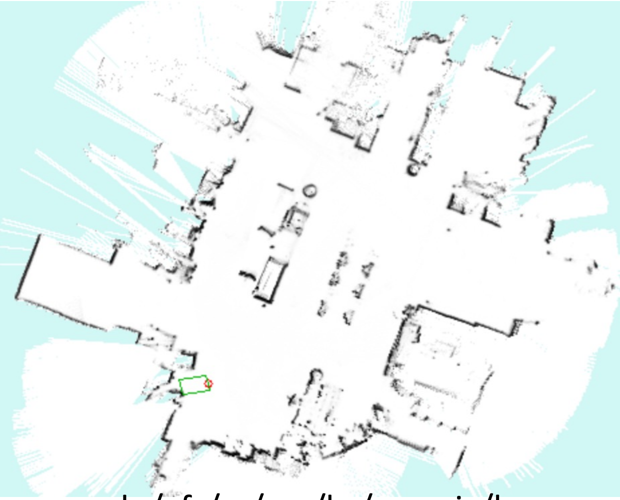
- Given the pose of the robot and a sensor model, it is possible to determine free space and obstacles
- e.g., robot with laser sensor



Source: [Thrun et al., 2005, MIT Press]

Simultaneous Localization and Mapping

- Localization and Mapping together form the problem of SLAM
- Problem much more complex because the robot has to keep track of the hypotheses of both pose and world



Source: cs.cmu.edu/afs/cs/usr/br/mosaic/homepage.html

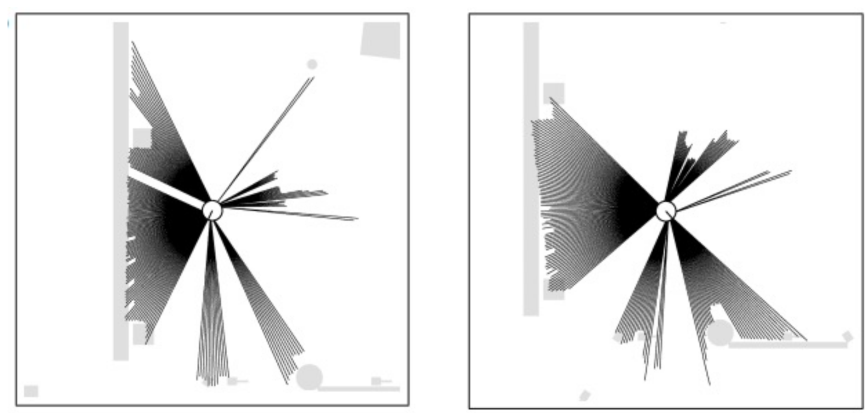
Sensors for state estimation

- Different sensors can be used for state estimation
  - Distance to obstacles: scan matching

Source: parallax.com

Source: hokuyo-aut.jp

Robot equipped with laser sensor in two different poses

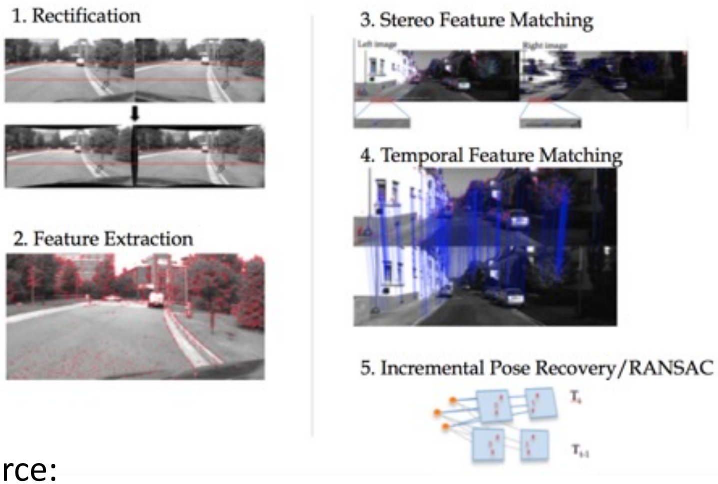


Source: [Thrun et al., 2005, MIT Press]

Sensors for state estimation

- Different sensors can be used for state estimation
  - Cameras that provides visual odometry and visual SLAM, namely using images to recover robot poses

Source: ids-imaging.com

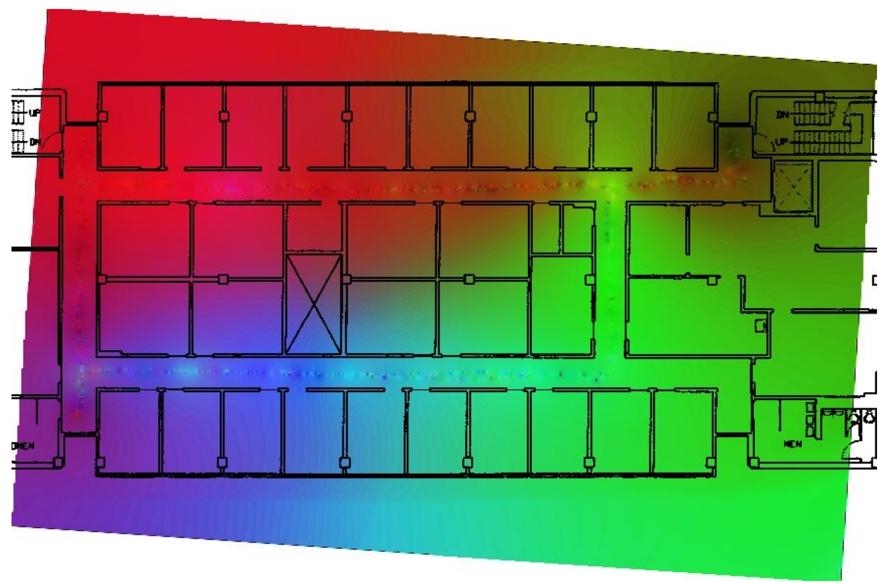


Source: cc.gatech.edu/~dellaert/FrankDellaert/Frank_Dellaert/Entries/2014/6/28_Visual_SLAM_Tutorial_at_CVPR.html

Sensors for state estimation

- Different sensors can be used for state estimation
  - WiFi
    - WiFi signal strength can be used as a cue for localizing robot

WiFi signal-strength map of a floor



Source: robotics.usc.edu/~ahoward/projects_wifi.php

Main state estimation processes

- Sensor data processing
- Sensor data fusion is the process of combining information from different sensors to provide a robust and complete description of the state
- *Data association* is the process of associating uncertain measurements to known tracks
- *Registration* associates sets of data into a common coordinate system
- *Loop closure detection* is the process for finding a previously visited place
- *Global optimization* improves the state estimate considering part of or the whole trajectory according to new observations

Comparative analysis

- In

  A. Quattrini Li, A. Coskun, S. M. Doherty, S. Ghasemlou, A. S. Jagtap, M. Modasshir, S. Rahman, A. Singh, M. Xanthidis, J. M. O'Kane, and I. Rekleitis
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  an experimental comparison of several Visual SLAM packages was performed

Datasets used

- Datasets collected with robots in the lab to have datasets that capture different scenarios and challenges

Comparison dataset

- Husky

A. Quattrini Li, A. Coskun, S. M. Doherty, S. Ghasemlou, A. S. Jagtap, M. Modasshir, S. Rahman, A. Singh, M. Xanthidis, J. M. O'Kane, and I. Rekleitis "*Experimental Comparison of Open Source Vision-Based State Estimation Algorithms*"
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Comparison dataset

- Parrot ARDrone

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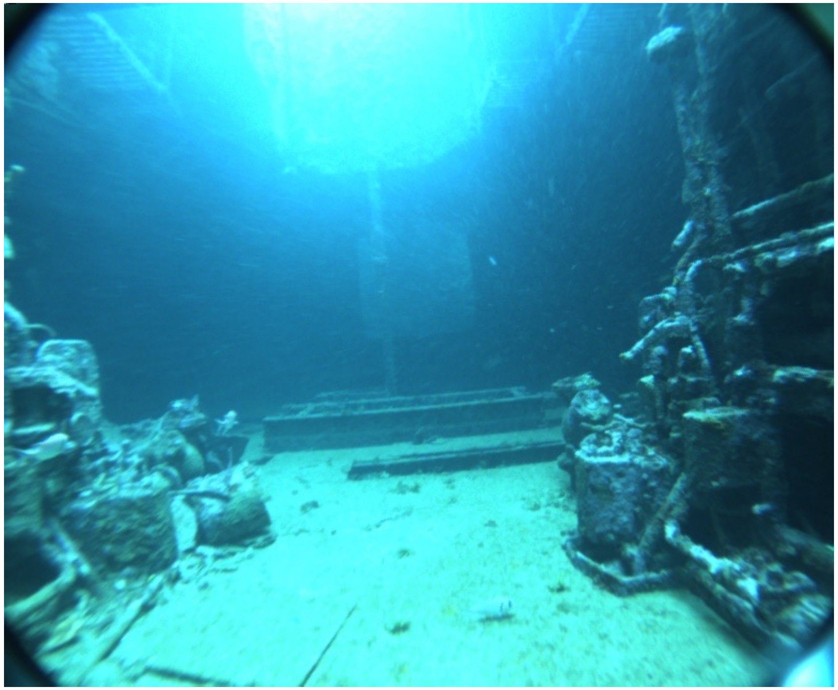
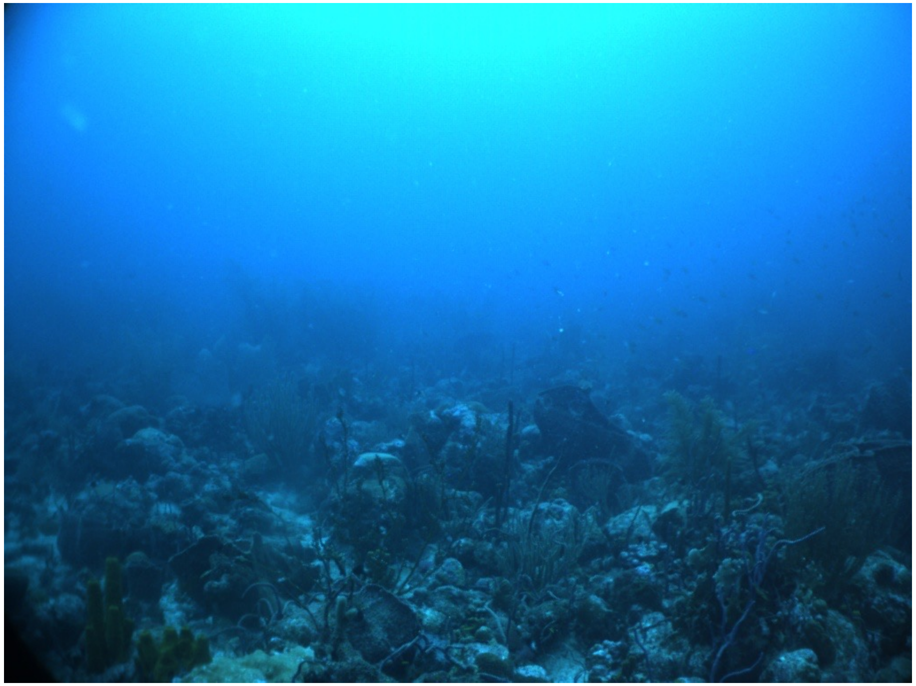
Comparison dataset

- Aqua





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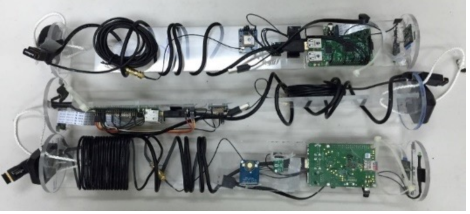

Comparison dataset

- Drifter

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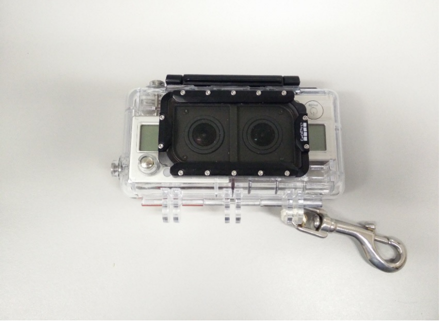

Comparison dataset

- Gopro Hero 3+

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Results

- Crossvalidation, namely test over dataset provided together with packages
- Results are generally good

Package-Dataset		[3]	[13]	[17]	[24]	[9]	[8]	[2]	[29]
MonoSLAM	[3]							N/A	N/A
libVISO	[13]							N/A	N/A
PTAM	[17]							N/A	N/A
ORB-SLAM	[24]							N/A	N/A
SVO	[9]							N/A	N/A
LSD-SLAM	[8]		N/A					N/A	N/A
RatSLAM	[2]								N/A
ColMap	[29]								

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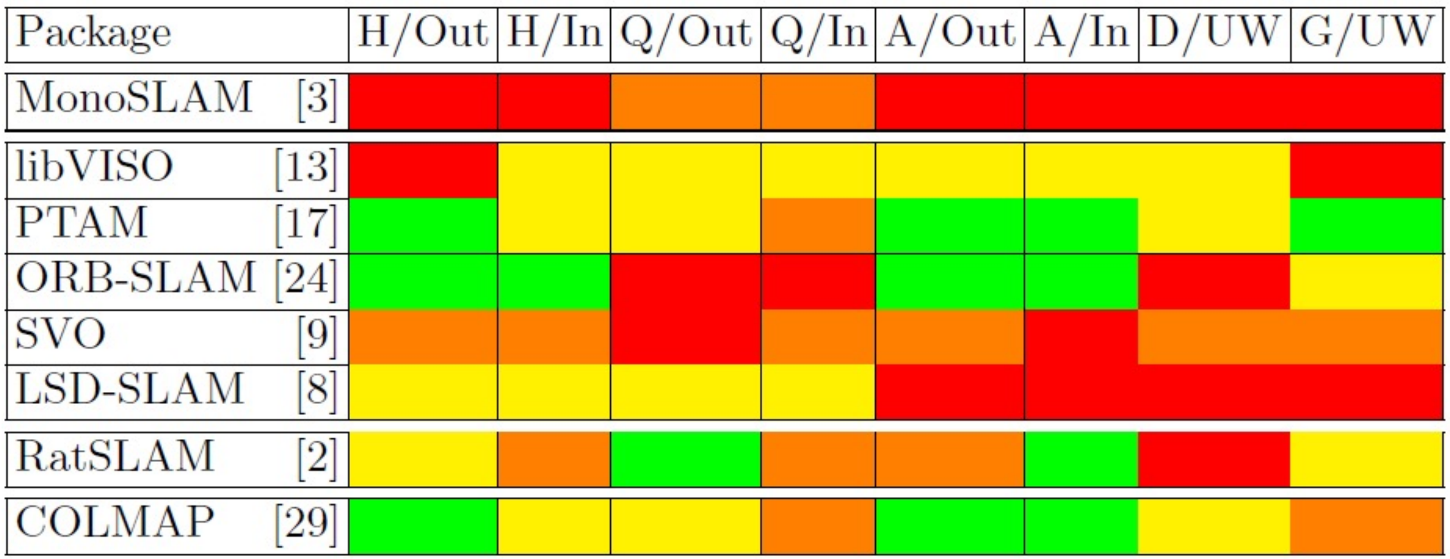
Results

- Results on our datasets are less good because of the “non-optimality” of our datasets for the methods



A. *Quattrini Li*, A. Coskun, S. M. Doherty, S. Ghasemlou, A. S. Jagtap, M. Modasshir, S. Rahman, A. Singh, M. Xanthidis, J. M. O'Kane, and I. Rekleitis
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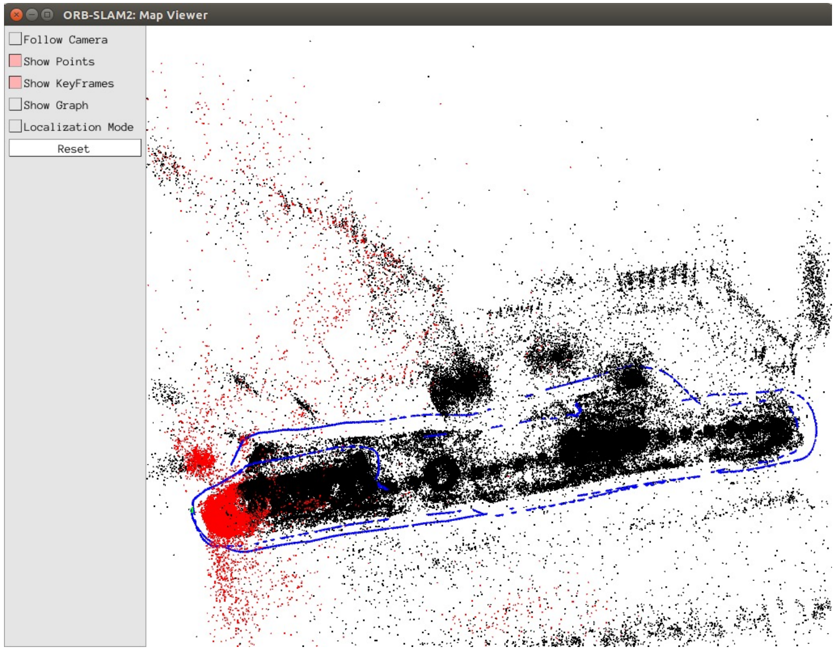
Results

- Example of results from our dataset
  - ORB-SLAM: real-time method



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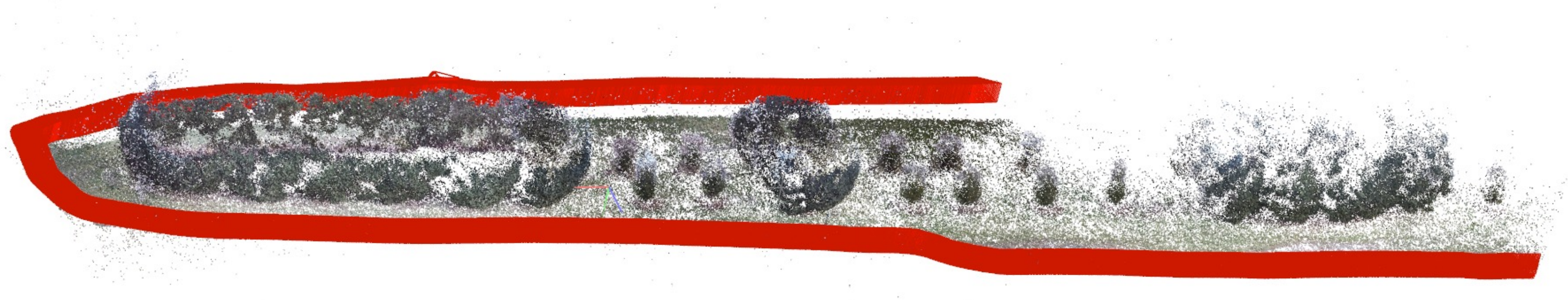
Results

- Example of results from our dataset
  - COLMAP: global method



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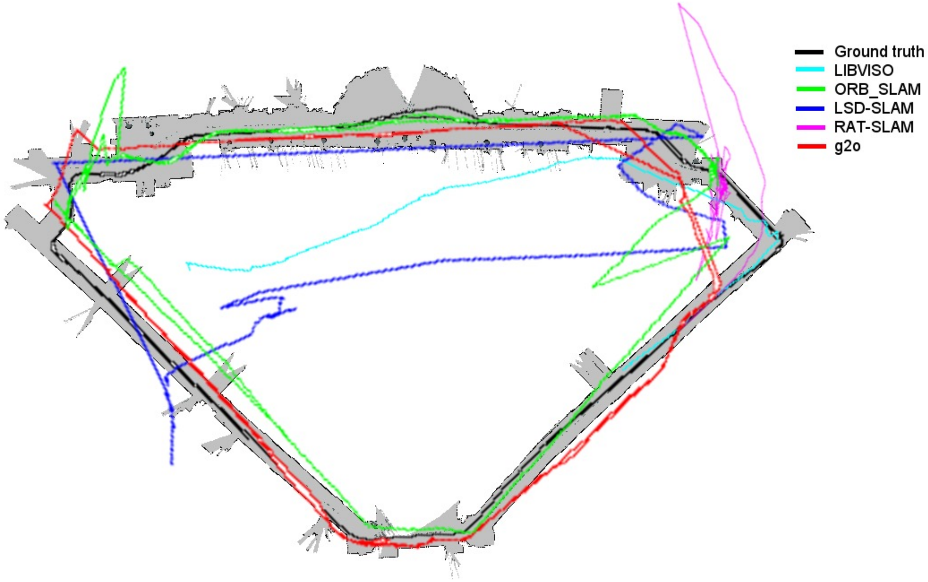
Results

- Trajectory in Swearingen from different visual SLAM methods compared to the trajectory from a laser-based SLAM method



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Results

- Quantitative results showing errors over 400m long trajectory

Package-Dataset		H/Out$_1$			H/Out$_2$			H/In		
		Er m	TL %	Mem MB	Er m	TL %	Mem MB	Er m	TL %	Mem MB
MonoSLAM	[3]		95.7%	73		90.6%	5171		97.3%	102
libVISO	[13]		9.5%	155		3.0%	130	67.8	8.3%	165
PTAM	[17]	33.4	7.6%	1543	24.0	15.9%	718	23.4	3.5%	437
ORB-SLAM	[24]	12.0	33.9%	5537	11.2	6.5%	2089	10.1	0.0%	4222
SVO	[9]		18.8%	904		64.9%	244		63.5%	261
LSD-SLAM	[8]	38.8	0.1%	2728	27.6	12.0%	1376	15.1	78.6%	1067
RatSLAM	[2]		N/A	402		N/A	444		N/A	333
ColMap	[29]	23.7	N/A	N/A	9.2	N/A	N/A	29.6	N/A	N/A
g^2o	[19]	12.0	N/A	N/A	11.2	N/A	N/A	10.1	N/A	N/A

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