My path in the land of Robotics and Control

Alexandros Filotheou

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Timeline

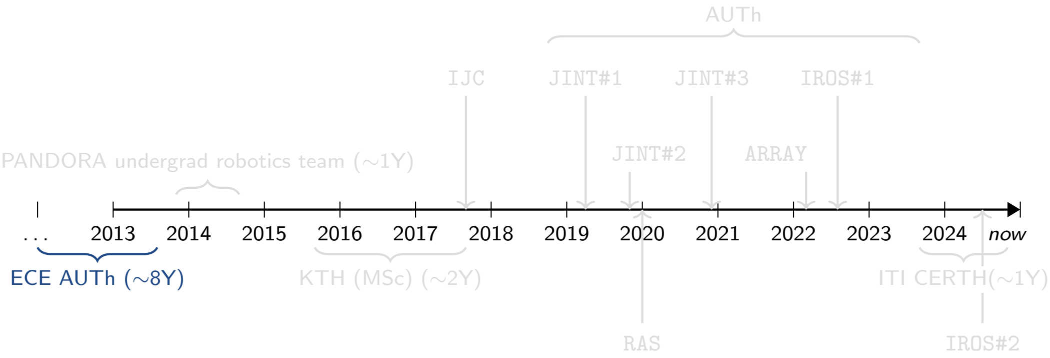

Figure: Institution

Timeline

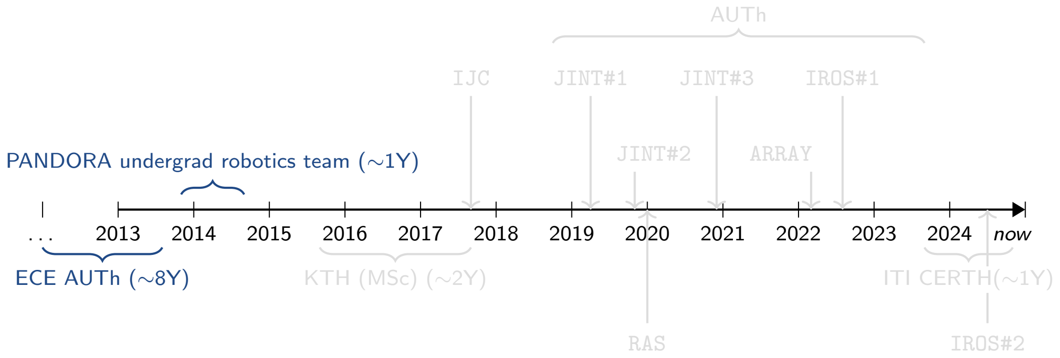

Figure: Insitution

Program for the Advancement of Non Directed Operating Robotic Agents (PANDORA; 2013-14)

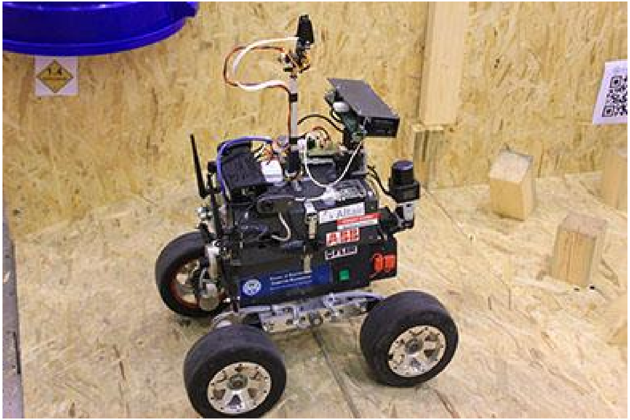

Figure: The PANDORA 2014 robot

PANDORA (2013-14)

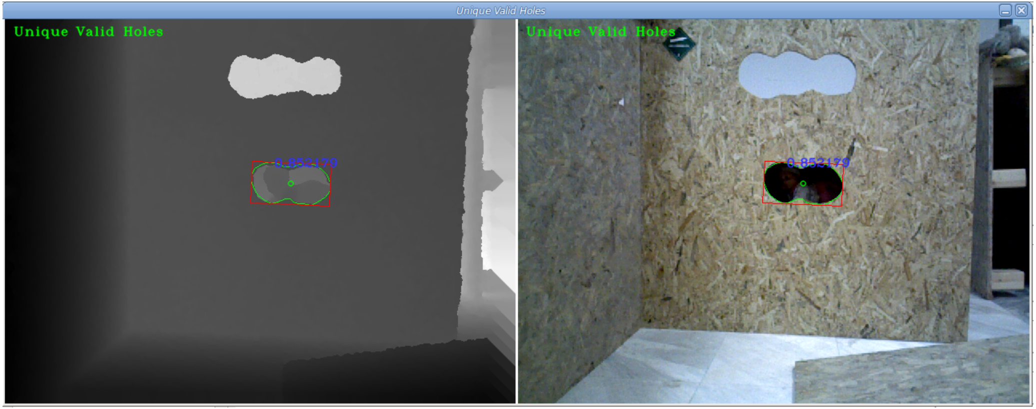

Figure: Although the wall has two holes, only the one closer to the ground is valid: the one above it is a through-hole (i.e. it cannot contain possible victims)

PANDORA (2013-14)

- 2nd place in autonomy class at 2015 RoboCup Rescue, Hefei China

Timeline

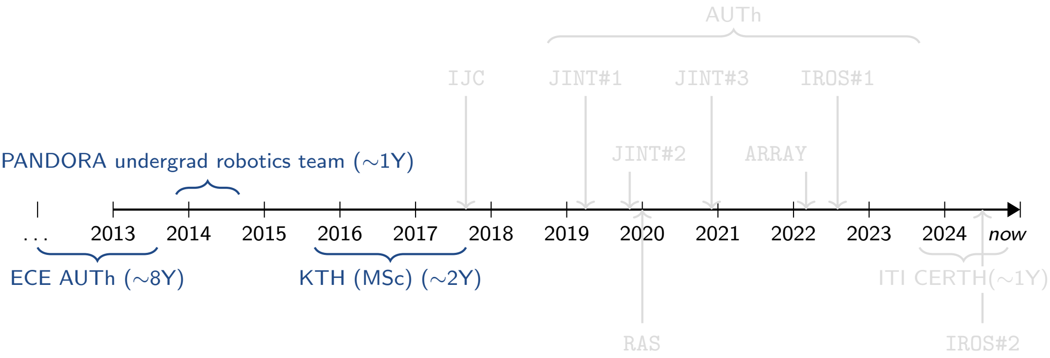

Figure: Insitution

Systems, Control, and Robotics MSc program, KTH (2015-17)

- ~~Robotics~~ $\rightarrow$ Control

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- ROS experience $\Rightarrow$ handy in pre-degree Automatic Control project

pre-degree Automatic Control project

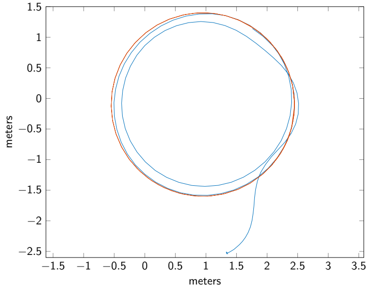


Figure: Reference trajectory (red) and trajectory of the vehicle (blue), in the transient phase

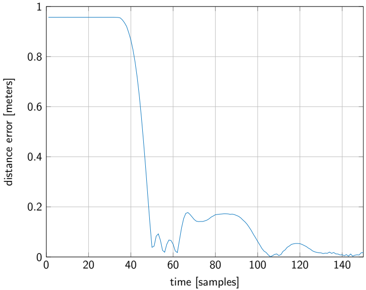


Figure: The discrepancy in distance between the trajectory of the vehicle and the reference trajectory in the transient phase, in meters

Systems, Control, and Robotics MSc program, KTH (2015-17)

- ~~Robotics~~ $\rightarrow$ Control
- ROS experience $\Rightarrow$ handy in pre-degree Automatic Control project
- Thesis: "Robust Decentralized Control of Cooperative Multi-robot Systems: An Inter-constraint Receding Horizon Approach"

Thesis: “Robust Decentralized Control of Cooperative Multi-robot Systems: An Inter-constraint Receding Horizon Approach”

Objective: Make N agents navigate and stabilise themselves while

- avoiding environment obstacles
- keeping minimum and maximum distances with each other

under state disturbances (bounded and additive)

Result (no disturbances)

Equilibrium close-up

Timeline

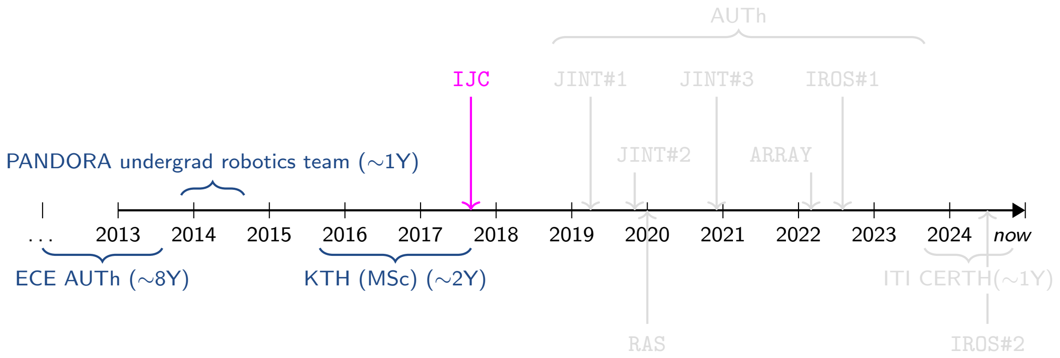
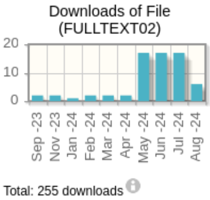
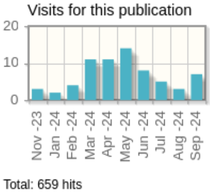


Figure: Insitution; Publication

Alexandros Filotheou, Alexandros Nikou, and Dimos V. Dimarogonas. "Robust decentralised navigation of multi-agent systems with collision avoidance and connectivity maintenance using model predictive controllers. *International Journal of Control*

Achievements

- Degree obtained
- 



- TITLE — CITED BY

  Robust decentralised navigation of multi-agent systems with collision avoidance and connectivity maintenance using model predictive controllers — 40
  A Filotheou, A Nikou, DV Dimarogonas
  International Journal of Control 93 (6), 1470-1484

Timeline

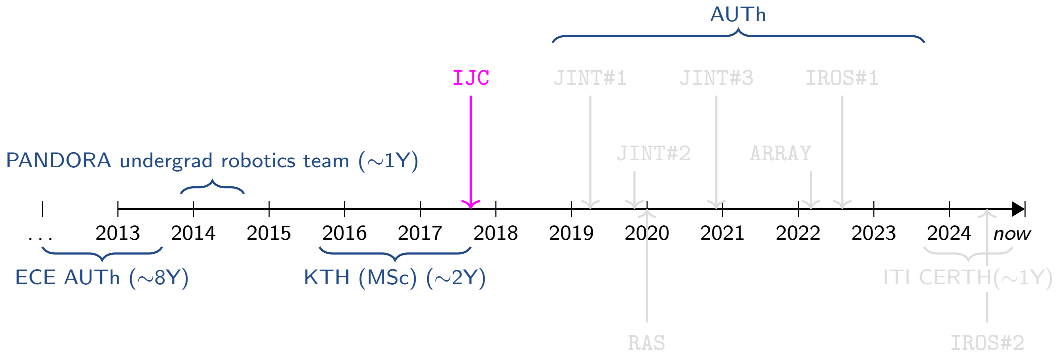


Figure: Insitution; Publication

Project RELIEF (start)

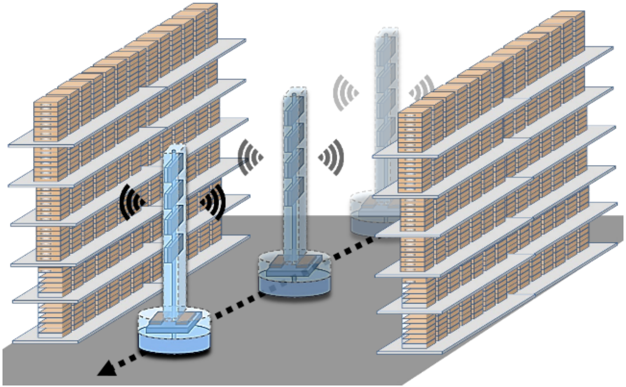


Figure: A robot equipped with RFID antennas and readers autonomously navigates a warehouse filled with RFID-tagged products and simultaneously determines pose estimates of itself and the products

Project RELIEF (finish)

Figure: Left: RELIEF's heavyweight autonomous ground vehicle at the Beyond Expo 2021 and a collection of RFID-tagged typical supermarket products. Right: the robot's reconstructed map of the products in physical space

Timeline

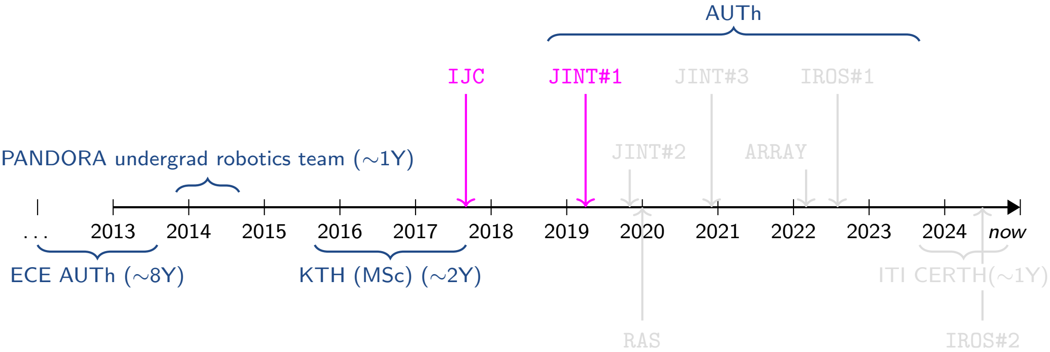


Figure: Insitution; Publication

Alexandros Filotheou, Emmanouil Tsardoulias, Antonis Dimitriou, Andreas Symeonidis, and Loukas Petrou. "Quantitative and Qualitative Evaluation of ROS-Enabled Local and Global Planners in 2D Static Environments". *Journal of Intelligent & Robotic Systems*

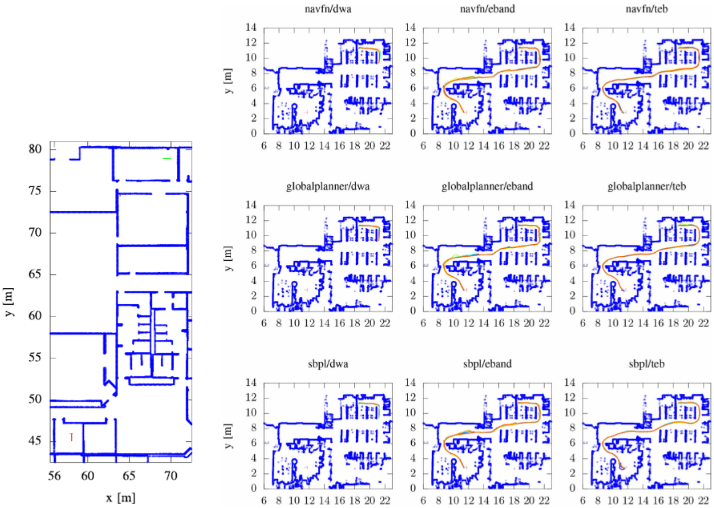
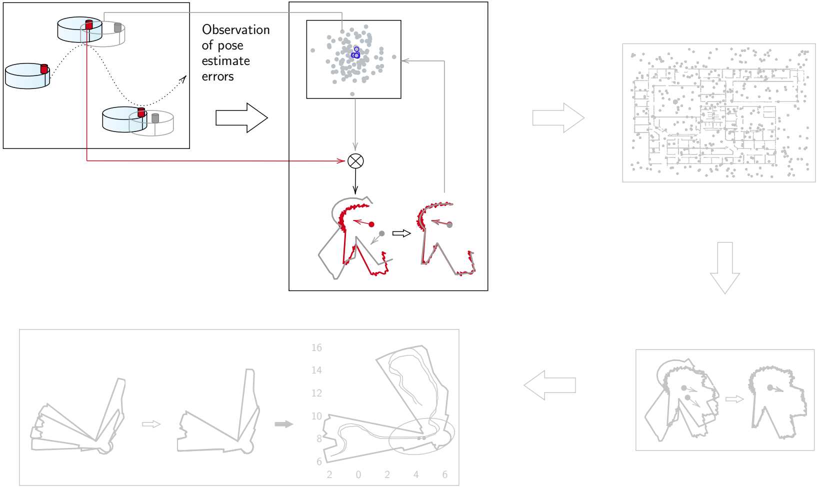


Figure: Evaluation environments. Left: Willowgarage in Gazebo. Right: CSAL AUTh


Observation
of pose
estimate
errors
16
14
12
10
8
6
2
0
2
4
6

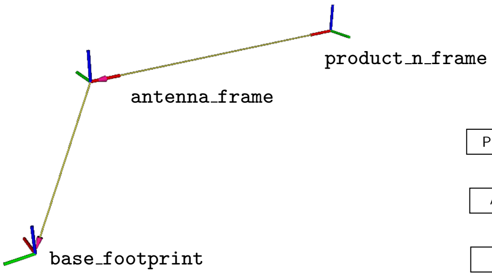


Figure: Robot, antenna, random product frames

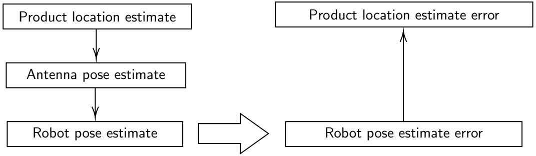


Figure: Product location error depends on robot pose error

Ideas

- Pose selection

Ideas

- Pose selection
- Scan–to–map-scan matching (backbone of my PhD)

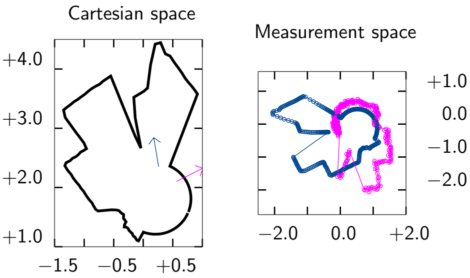


Figure: Left: Unknown LIDAR pose $\boldsymbol{p}(x, y, \theta)$ and estimate $\hat{\boldsymbol{p}}(\hat{x}, \hat{y}, \hat{\theta})$. Right: Real $\mathcal{S}_R(\boldsymbol{p})$ and virtual $\mathcal{S}_V(\hat{\boldsymbol{p}})$ scans, in the local coordinate frame of each sensor

Ideas

- Pose selection
- Scan–to–map-scan matching (backbone of my PhD)
- Feedback of scan–to–map-scan matched pose estimate into particle filter

Experimental evaluation (Gazebo)

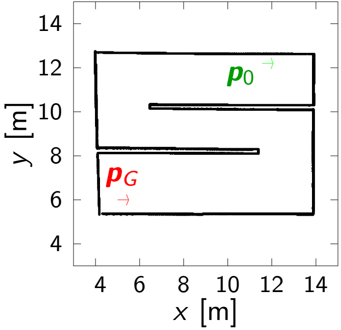


Figure: Map of environment CORRIDOR, $\boldsymbol{M}_C$

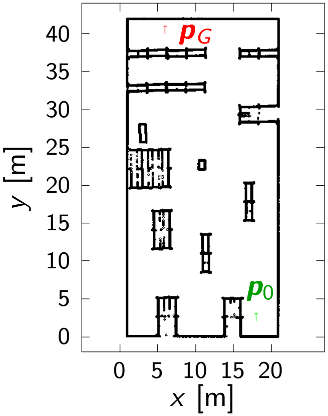


Figure: Map of environment WAREHOUSE, $\boldsymbol{M}_W$

$N = 100\times$ $\boldsymbol{p}_0 \rightarrow \boldsymbol{p}_G$

lidar:

$\lambda = 260^\circ$

$N_s = 640$ rays

$W_R \sim \mathcal{N}(0, \sigma_R^2 = 0.01^2)$ [m, m^2]

pf:

$200 \leq |\mathcal{P}| \leq 500$

Timeline

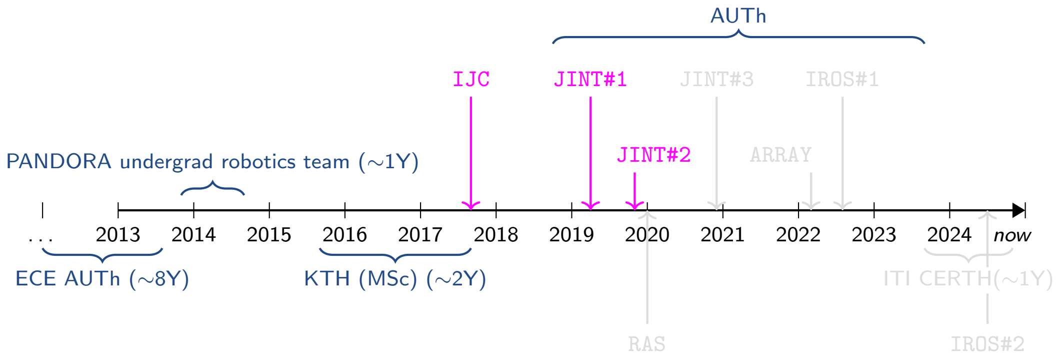


Figure: Insitution; Publication

Alexandros Filotheou, Emmanouil Tsardoulias, Antonis Dimitriou, Andreas Symeonidis, and Loukas Petrou. "Pose Selection and Feedback Methods in Tandem Combinations of Particle Filters with Scan-Matching for 2D Mobile Robot Localisation". *Journal of Intelligent & Robotic Systems*

In the meantime ...

Goran Vasiljevi, Damjan Mikli, Ivica Draganjac, Zdenko Kovai, Paolo Lista, "High-accuracy vehicle localization for autonomous warehousing", *Robotics and Computer-Integrated Manufacturing*

Idea: given $\hat{\theta} = \theta \Rightarrow$ control the location estimate via Fourier Transform

Turns out that we can prove via Lyapunov analysis (KTH thesis skill handy) that:

- the true position of the sensor can be recovered with arbitrary precision when the physical sensor reports faultless measurements and there is no discrepancy between the environment and its map
- when either is affected by disturbance, the location estimate is bound in a neighbourhood of the true location, whose radius is proportional to the affecting disturbance

Timeline

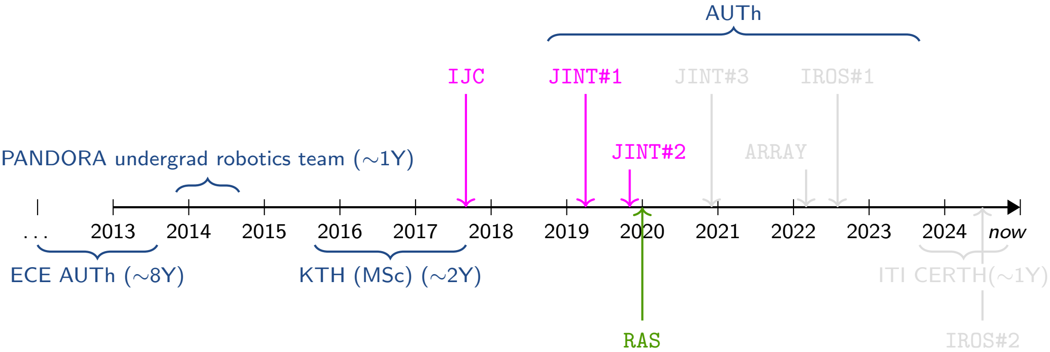
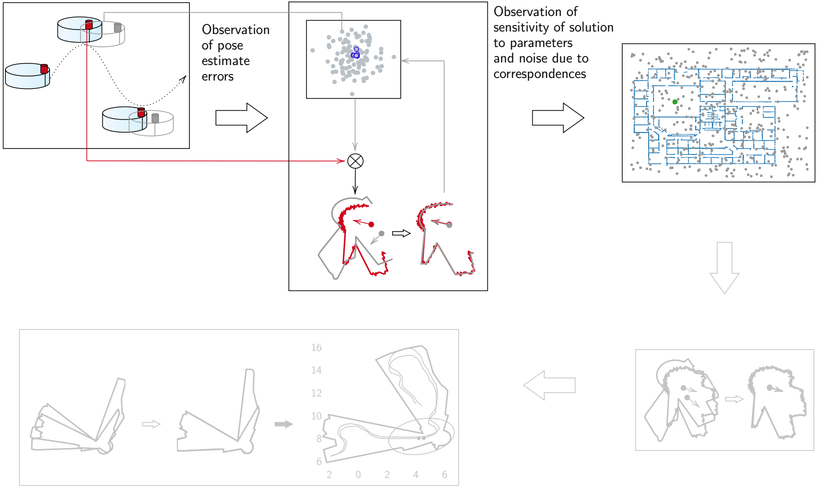


Figure: Insitution; Multi-author publication; Single-author publication

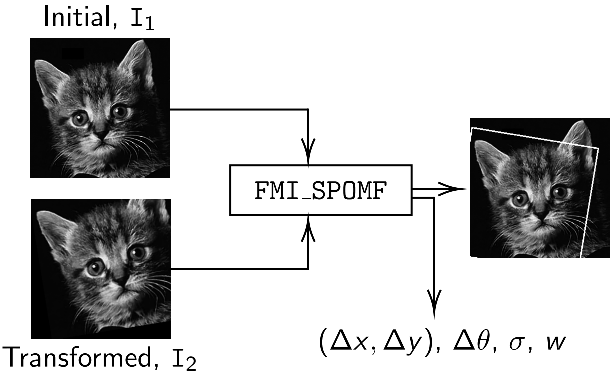
Alexandros Filotheou. "Correspondenceless scan-to-map-scan matching of homoriented 2D scans for mobile robot localisation". *Robotics and Autonomous Systems*

Proposal to do PhD


Observation of pose estimate errors
Observation of sensitivity of solution to parameters and noise due to correspondences
16
14
12
10
8
6
2
0
2
4
6

Global localisation experiments: simulation and real

`FMI_SPOMF` [1]: Fourier-Mellin Invariant (descriptor using) Symmetric Phase-Only Matched Filtering



$$Q(u, v) = \frac{\mathcal{F}\{\mathtt{I}_1\}^\star \,.\!^*\, \mathcal{F}\{\mathtt{I}_2\}}{|\mathcal{F}\{\mathtt{I}_1\}| \cdot |\mathcal{F}\{\mathtt{I}_2\}|}$$

$$q(\theta, \lambda) = \mathcal{F}^{-1}\{Q\}$$

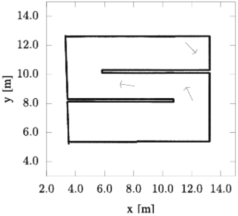
$$\Delta\theta = \arg\max_{\theta} q$$

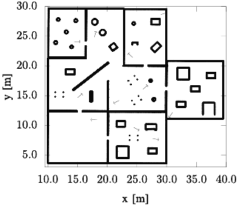
$$\sigma = \exp \arg\max_{\lambda} q$$

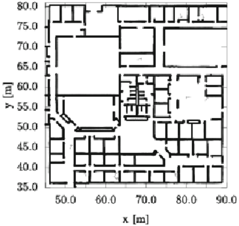
$$w = \max q$$

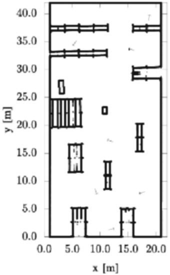
[1] Qin-Sheng Chen, M. Defrise and F. Deconinck, "Symmetric phase-only matched filtering of Fourier-Mellin transforms for image registration and recognition," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 1994

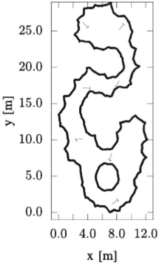
Global localisation experiments: simulation and real

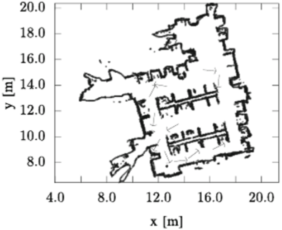












Timeline

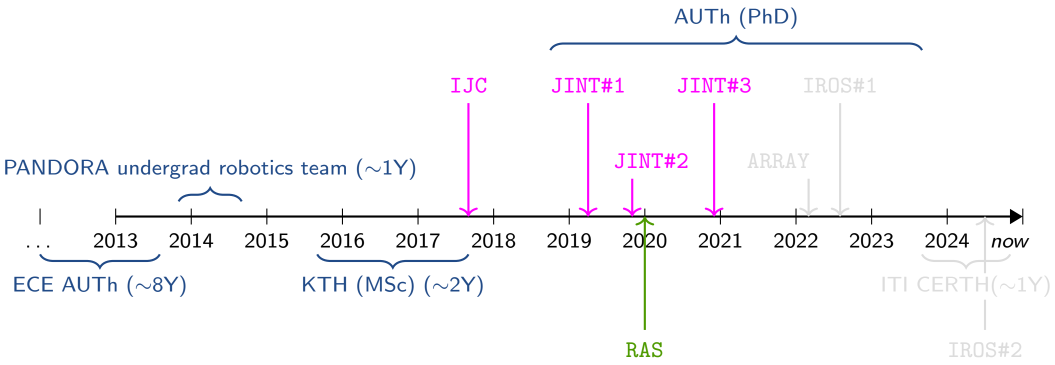
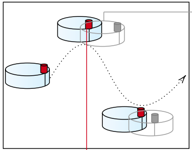


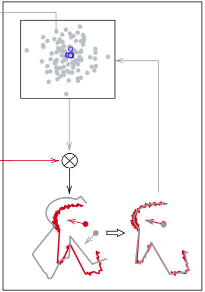
Figure: Insitution; Multi-author publication; Single-author publication

Alexandros Filotheou, Anastasios Tzitzis, Emmanouil Tsardoulias, Antonis Dimitriou, Andreas Symeonidis, George Sergiadis, and Loukas Petrou. "Passive Global Localisation of Mobile Robot via 2D Fourier-Mellin Invariant Matching". *Journal of Intelligent & Robotic Systems*

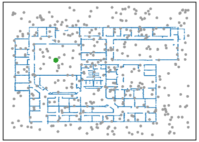
Scan–to–map-scan matching without correspondences



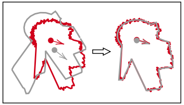
Observation of pose estimate errors

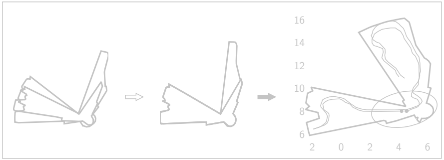


Observation of sensitivity of solution to parameters and noise due to correspondences



Solutions executable in real time





Scan–to–map-scan matching without correspondences

Contributions:

- A trilogy of real-time correspondenceless scan–to–map-scan matching methods for 2D panoramic LIDARs
- First ever correspondenceless methods
  $\Rightarrow$ more robust to
  - sensor and map noise
  - radial and angular distance between measurement poses

  than state of the art
  $\Rightarrow$ fewer parameters to tune / make sense of
- The CAER metric (more later on)

Scan–to–map-scan matching without correspondences

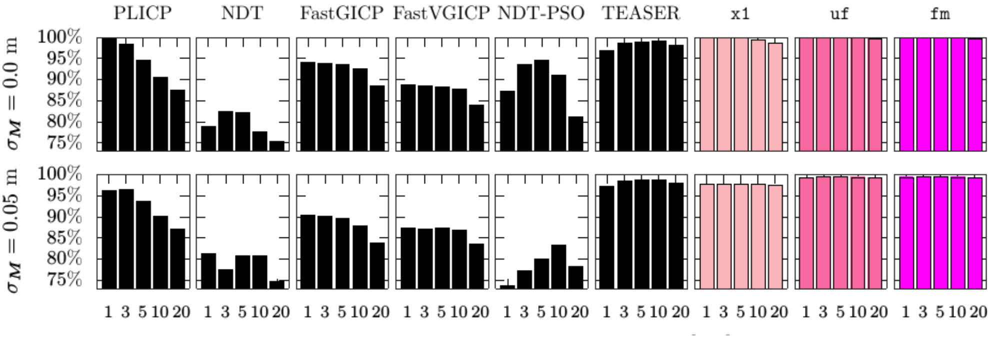


Figure: Of 100 pose estimates on which sm2 was applied: how many ended up with decreased pose error? x-axis is sd of sensor noise [cm]

Timeline

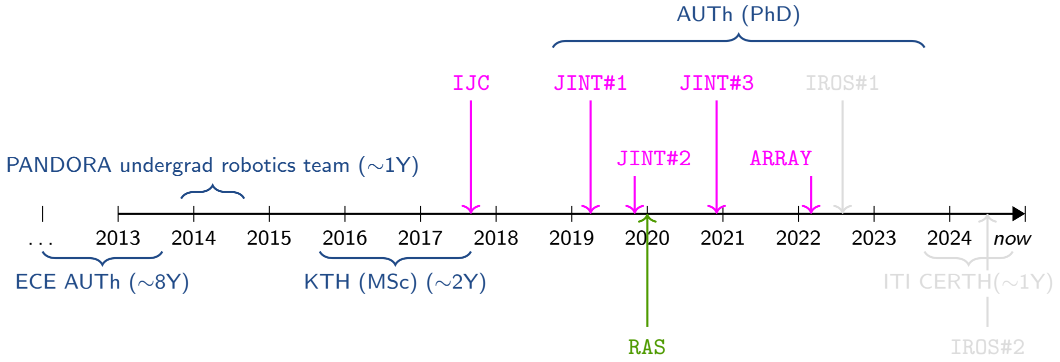
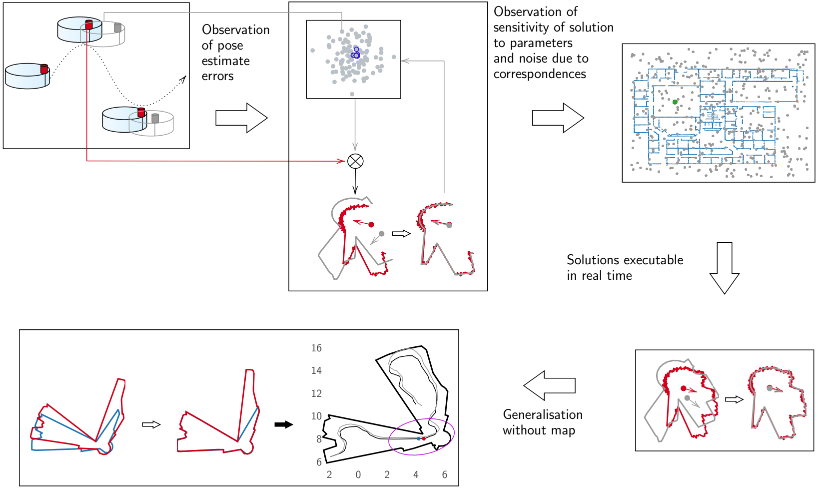


Figure: Insitution; Multi-author publication; Single-author publication

Alexandros Filotheou, Andreas L. Symeonidis, Georgios D. Sergiadis, and Antonis G. Dimitriou. "Correspondenceless scan-to-map-scan matching of 2D panoramic range scans". *Array*

Scan matching without correspondences



Scan matching without correspondences

Contributions:

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  $\Rightarrow$ more robust to
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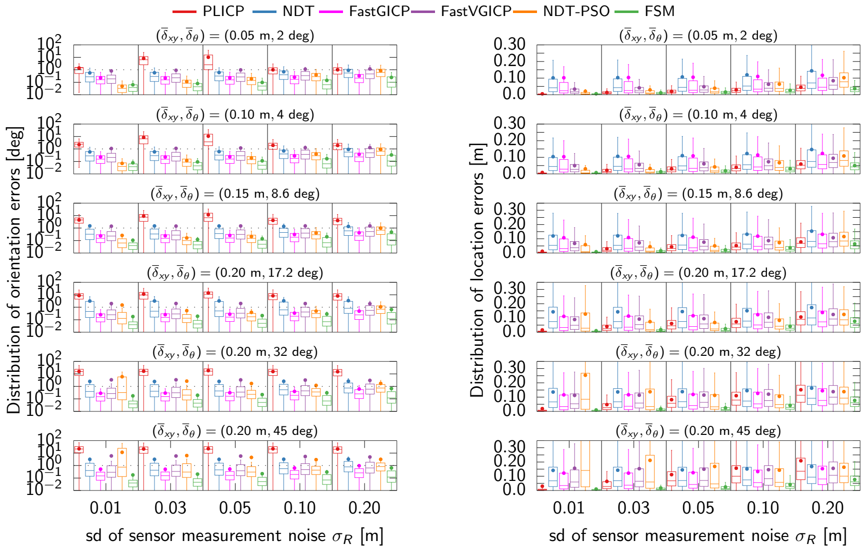


Figure: Distributions of orientation and position errors across a range of maximal positional and orientational displacements, for progressively larger sensor measurement noise levels sd. Each box represents the statistics of each method for $E = 10$ iterations over $\sum |D_k| \approx 45{\cdot}10^3$ random scan pairs for each configuration, where $k = 1, \dots, 5$ is the dataset index. Dots signify mean errors. FSM's errors are largely independent of the initial displacement of scans for a given level of sensor noise

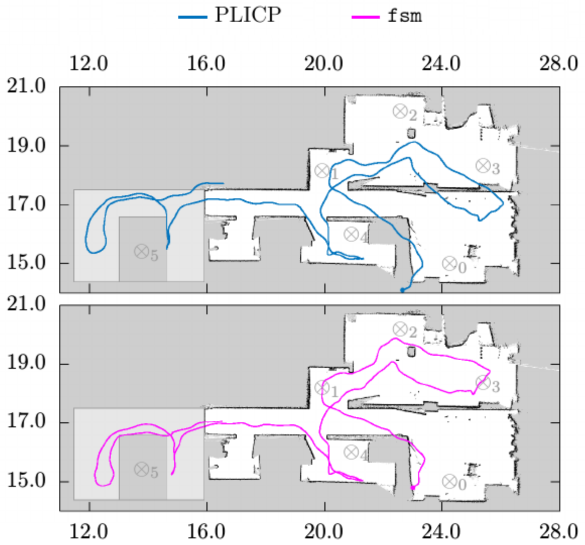


Figure: Lidar odometry in real conditions. Sensor is YDLIDAR TG30

Timeline

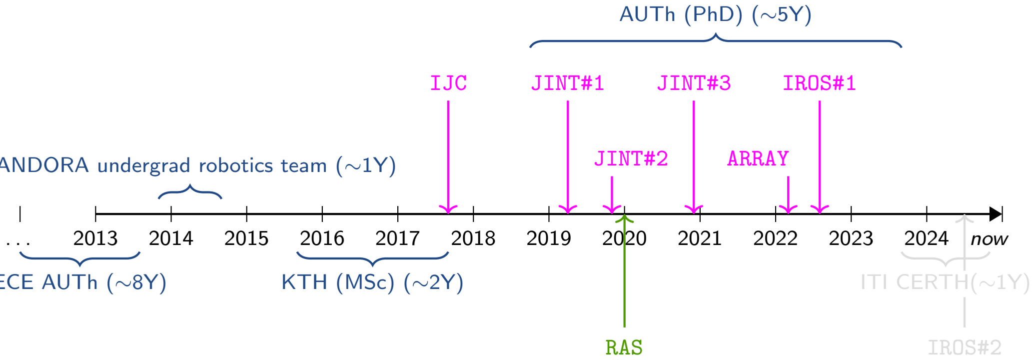


Figure: Insitution; Multi-author publication; Single-author publication

Alexandros Filotheou, Georgios D. Sergiadis, and Antonis G. Dimitriou. "FSM: Correspondence- less scan-matching of panoramic 2D range scans". *2022 IEEE/RSJ International Conference on Intelligent Robots and Systems* (IROS). Code: `https://github.com/li9i/fsm-lo`

Timeline

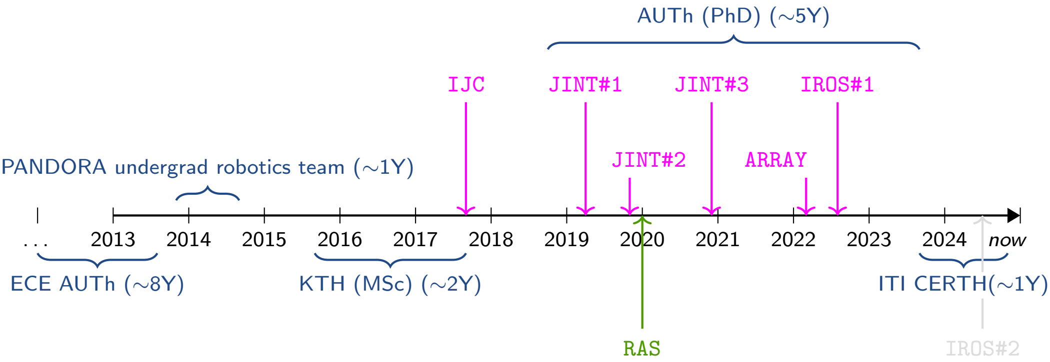
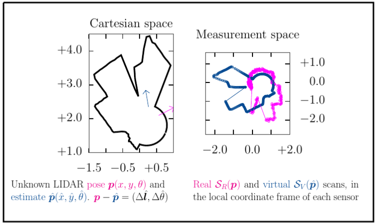


Figure: Insitution; Multi-author publication; Single-author publication

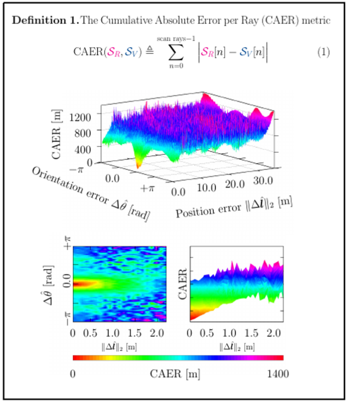
Current work

- ROS 2
- Task Planning with Behavior Trees
- Integration - DevOps (`ros1_bridge`, `zenoh`, `Docker`)

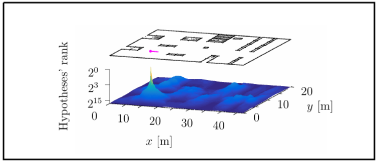
Cumulative Absolute Error per Ray (CAER) - Based Global Localisation

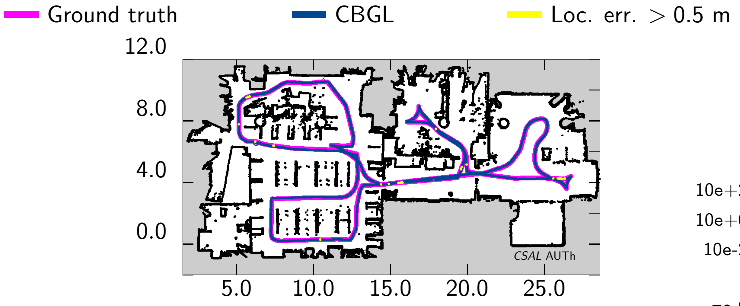


x10^N

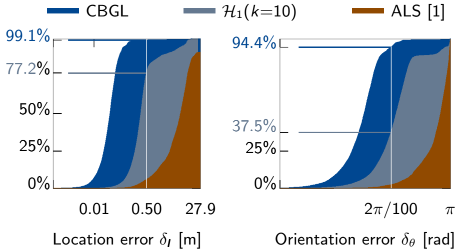


Rank

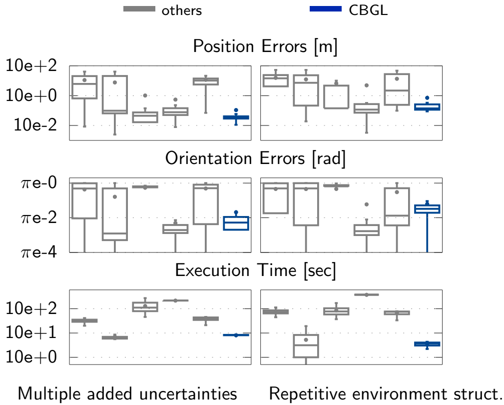




Ground truth
CBGL
Loc. err. > 0.5 m
12.0
8.0
4.0
0.0
5.0
10.0
15.0
20.0
25.0
CSAL AUTh



CBGL
$\mathcal{H}_1(k=10)$
ALS [1]
99.1%
77.2%
50%
25%
0%
0.01
0.50
27.9
Location error δ_l [m]
94.4%
37.5%
25%
0%
$2\pi/100$
π
Orientation error δ_θ [rad]



others
CBGL
Position Errors [m]
10e+2
10e+0
10e-2
Orientation Errors [rad]
πe-0
πe-2
πe-4
Execution Time [sec]
10e+2
10e+1
10e+0
Multiple added uncertainties
Repetitive environment struct.

Timeline

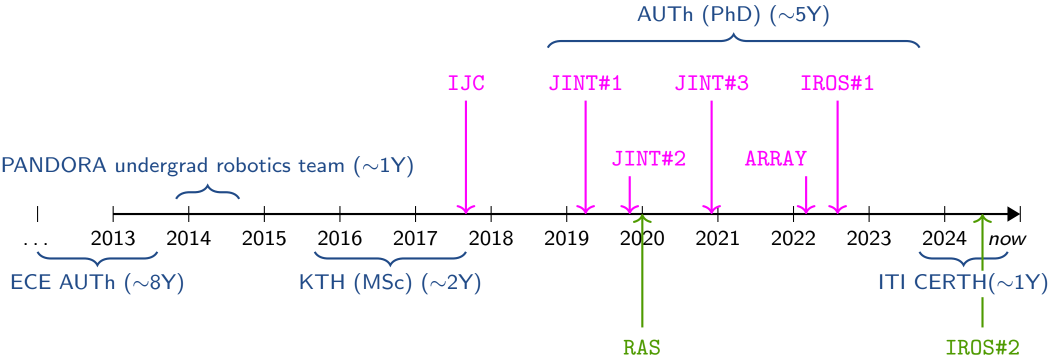


Figure: Insitution; Multi-author publication; Single-author publication

Alexandros Filotheou. "CBGL: Fast Monte Carlo Passive Global Localisation of 2D LIDAR Sensor". *Accepted in 2024 IEEE/RSJ International Conference on Intelligent Robots and Systems* (IROS). Code: `https://github.com/li9i/cbgl`