

FSM: Correspondenceless scan-matching of panoramic 2D range scans

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ΑΡΙΣΤΟΤΕΛΕΙΟ
ΠΑΝΕΠΙΣΤΗΜΙΟ
ΘΕΣΣΑΛΟΝΙΚΗΣ

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- Leads to increased accuracy & robustness in the face of sensor noise, and fewer parameters needed to be set

Why dispense with correspondences?

Euclidean Space | S_{ref}, S_{sens}

Correspondences' space

Figure: Matching with correspondences in ideal conditions. Sensor noise: $\mathcal{N}(0, 0)$ [m,m²]. Final estimation errors: 0.0023 m, 0.006 rad. Adapted from <https://nbviewer.org/github/niosus/notebooks/blob/master/icp.ipynb>, courtesy of Igor Bogoslavskyi

Why dispense with correspondences?

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Figure: Matching with correspondences in real conditions. Sensor noise: $\mathcal{N}(0, 0.10^2)$ [m,m²]. Final estimation errors: 0.035 m, 0.011 rad. Adapted from <https://nbviewer.org/github/niosus/notebooks/blob/master/icp.ipynb>, courtesy of Igor Bogoslavskyi

Why dispense with correspondences?

Euclidean Space | S_{ref}, S_{sens}

Correspondences' space

Figure: Matching with correspondences in real conditions, with outliers/void correspondences. Sensor noise: $\mathcal{N}(0, 0.10^2)$ [m, m^2]. Adapted from <https://nbviewer.org/github/niosus/notebooks/blob/master/icp.ipynb>, courtesy of Igor Bogoslavskyi

Why dispense with correspondences?

Ultimately:

- Due to sensor noise (higher as sensor cost decreases)
- Void (and false) correspondences' rejection is based on offline- and user-set parameters

More details:

Filotheou, A. et al. "Passive Global Localisation of Mobile Robot via 2D Fourier-Mellin Invariant Matching". In *Journal of Intelligent & Robotic Systems* 104 (2022). <https://doi.org/10.1007/s10846-021-01535-7>

Why dispense with correspondences?

Figure: Matching without correspondences in real conditions, with outliers/void correspondences. Sensor noise: $\mathcal{N}(0, 0.10^2)$ [m,m²]. Final estimation errors: 0.018 m, 0.0008 rad

The Fourier Scan Matcher (FSM)

- Operates on panoramic scans ($\text{FOV} = 2\pi \text{ rad}$)
- Does not deal in correspondences between inputs
- Requires minimal (if any) tuning

The Fourier Scan Matcher (FSM)

Operating principle:
Scan-to-map-scan matching

- \mathcal{S}_{ref} projected to 2D plane \Rightarrow map M
- $\mathcal{S}_{\text{sens}}$ matched against scans derived within M (so-called *map-scans* \mathcal{S}^M)

Correspondenceless solution to orientation estimation

- Via 1D Phase-only Matched Filtering (error $\leq \frac{\text{angle increment}}{2}$)

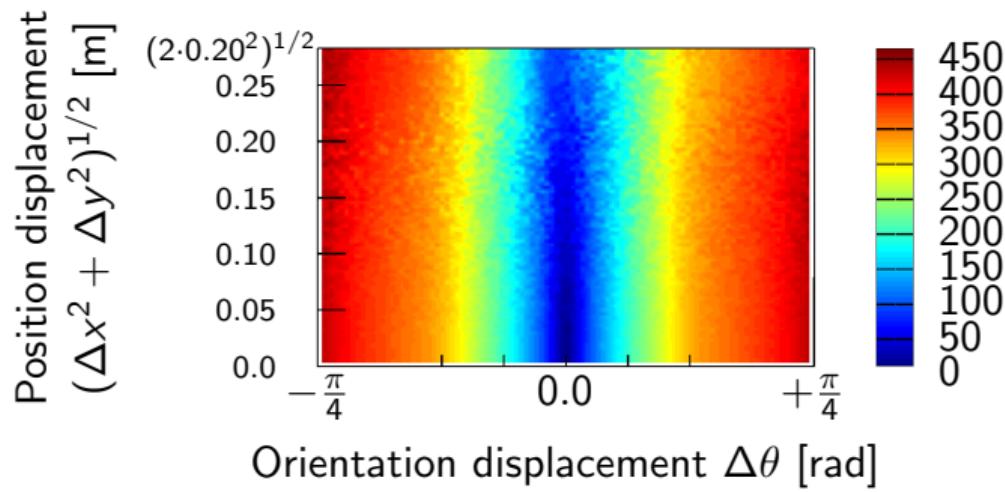
Correspondenceless solution to orientation estimation

- Via 1D Phase-only Matched Filtering + angular oversampling (error $\leq \frac{\text{angle increment}}{2^{1+\nu}}$)

Correspondenceless solution to orientation estimation

Final orientation estimate \Leftarrow Rehearse translation estimation for 2^ν pose estimates $\hat{\mathbf{p}}_i$,
 $i = 0, 1, \dots, 2^\nu - 1$, and rank values of *Cumulative Absolute Error per Ray*:

$$\text{CAER}(\mathcal{S}_{\text{sens}}(\mathbf{p}), \mathcal{S}^M(\hat{\mathbf{p}}_i)) = \frac{1}{N_s} \sum_{n=0}^{N_s-1} \left| \mathcal{S}_{\text{sens}}(n)|_{\mathbf{p}} - \mathcal{S}^M(n)|_{\hat{\mathbf{p}}_i} \right|$$



Correspondenceless solution to translation estimation

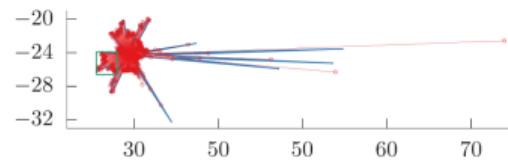
- Continuous space solution; feedback of DFT difference between $\mathcal{S}_{\text{sens}}$ and scans \mathcal{S}^M

More details:

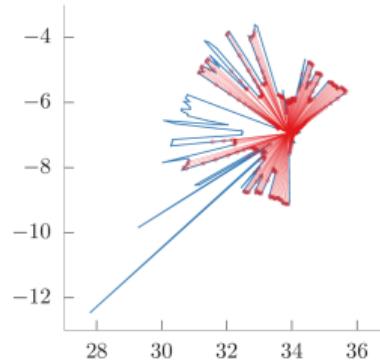
Filotheou, A. "Correspondenceless scan-to-map-scan matching of homoriented 2D scans for mobile robot localisation".
In *Robotics and Autonomous Systems* 149 (2022). <https://doi.org/10.1016/j.robot.2021.103957>

FSM alignment progress and properties

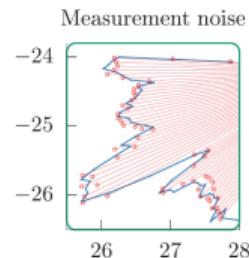
FSM alignment progress and properties



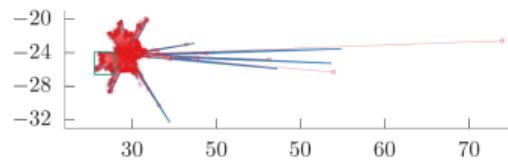
$$\begin{aligned}\Delta x &= -0.00085 \text{ m} \\ \Delta y &= 0.00337 \text{ m} \\ \Delta\theta &= -0.00346 \text{ rad}\end{aligned}$$



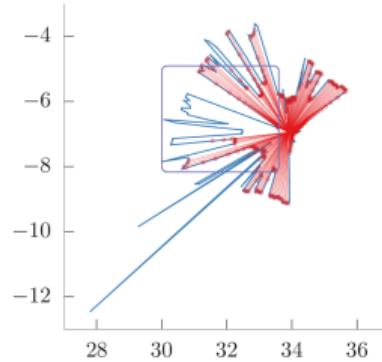
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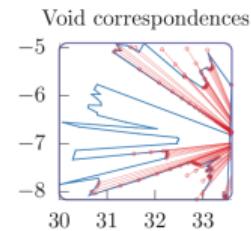
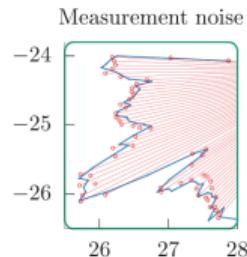
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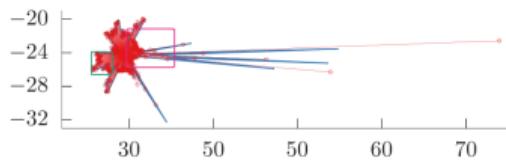
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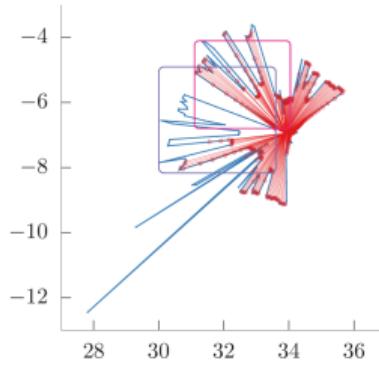
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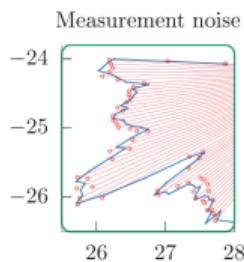
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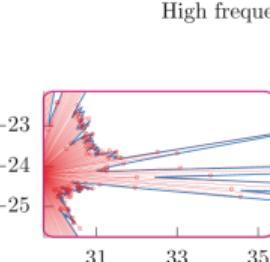
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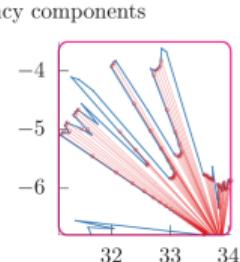
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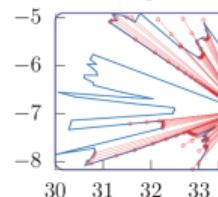
Measurement noise



High frequency components



Void correspondences



Laser odometry comparison

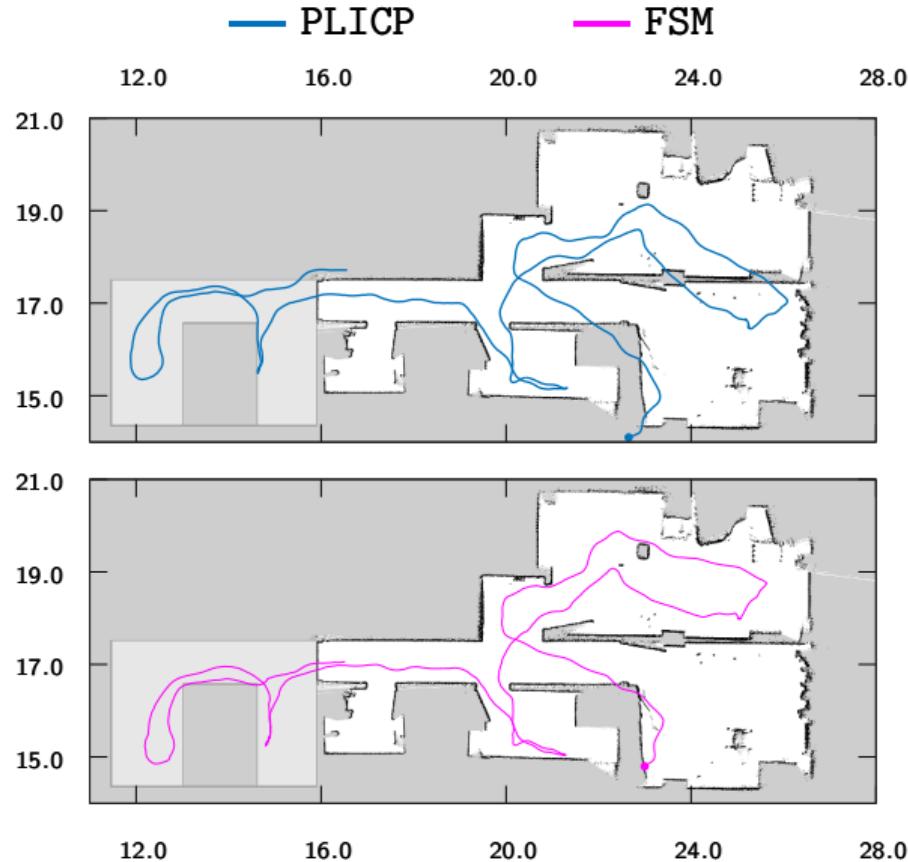
Sensor: YDLIDAR TG30

Range d [mm]	Mean error [mm]
50-5000	$\leq \pm 60$
5000-20000	$\leq \pm 40$
20000-30000	$\leq \pm 100$

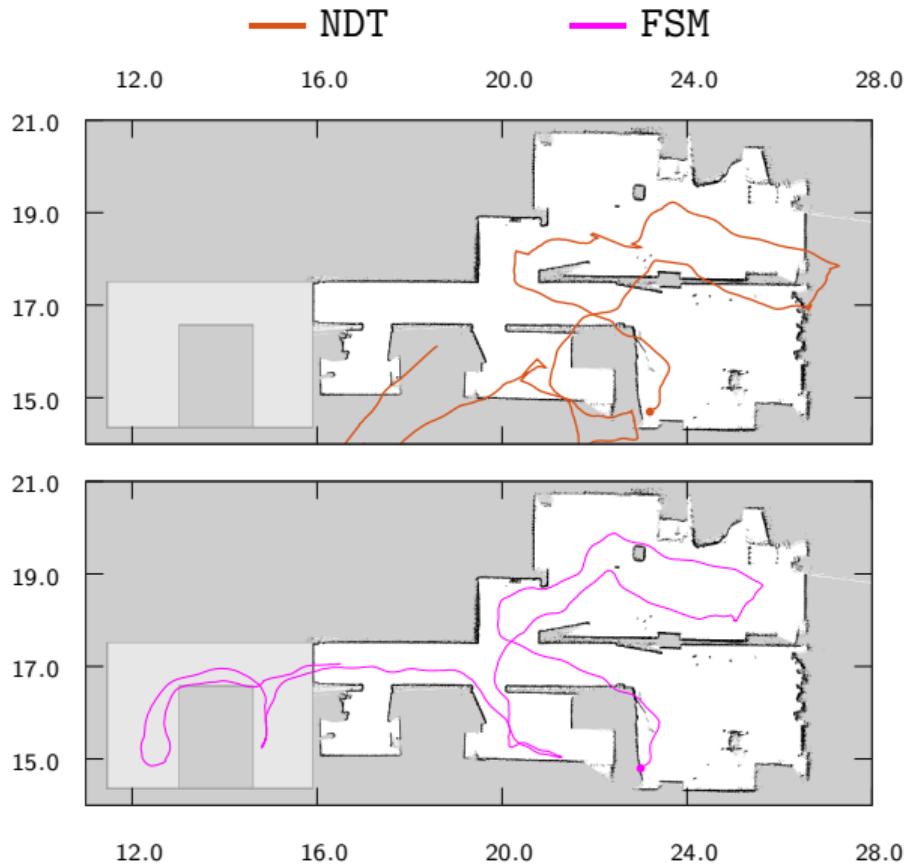
Table: Sensor noise properties (knowledge of distribution N/A). Source:

[www.ydlidar.com/Public/upload/files/2022-06-21/YDLIDAR%20TG30%20Data%20Sheet%20V1.4\(211230\).pdf](http://www.ydlidar.com/Public/upload/files/2022-06-21/YDLIDAR%20TG30%20Data%20Sheet%20V1.4(211230).pdf)

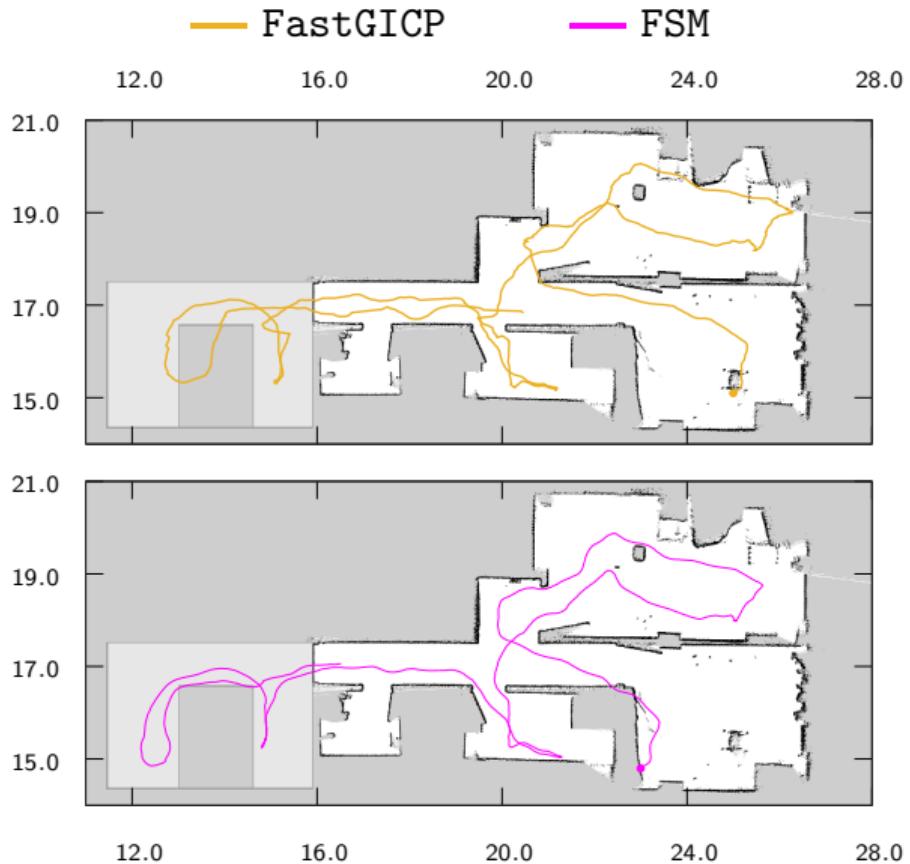
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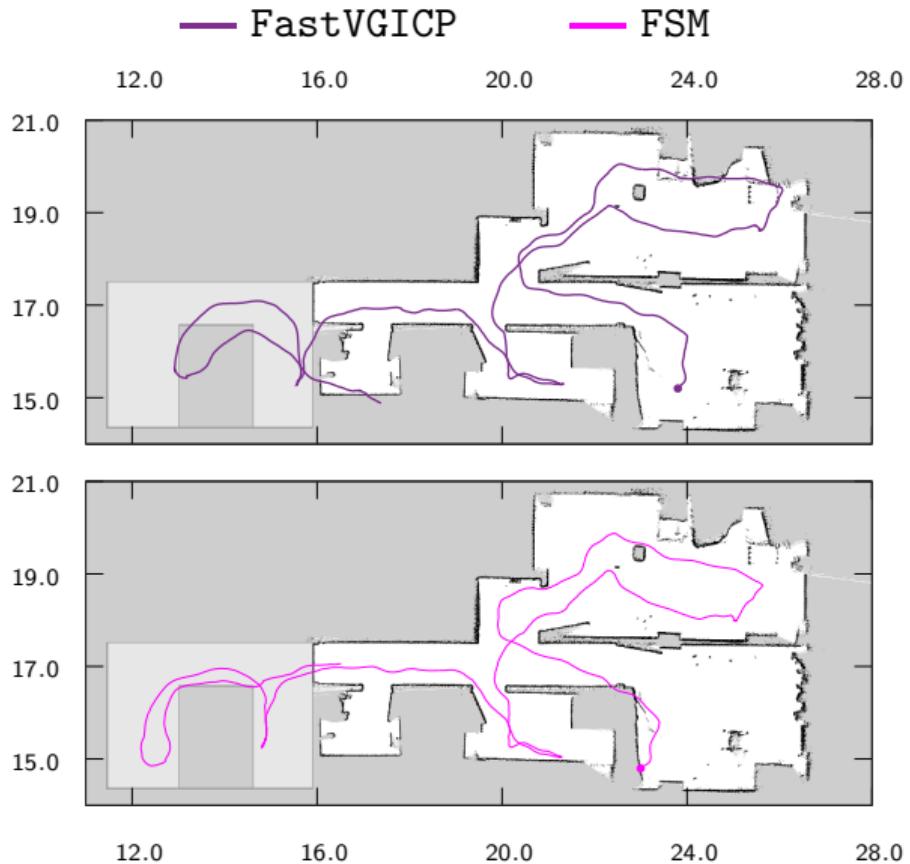
Laser odometry comparison



Laser odometry comparison



Laser odometry comparison



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Thank you for your attention

- Presentation available at https://github.com/li9i/fsm_presentation_iros22
- Code available at www.github.com/li9i/fsm