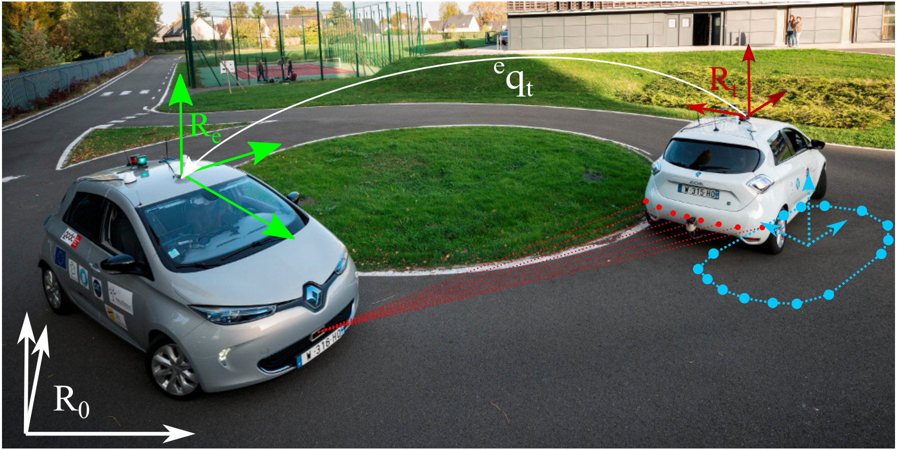
LiDAR based relative pose and covariance estimation for communicating vehicles exchanging a polygonal model of their shape

Elwan Héry, Philippe Xu and Philippe Bonnifait

Sorbonne Universités, Université de Technologie de Compiègne,
Heudiasyc UMR CNRS 7253

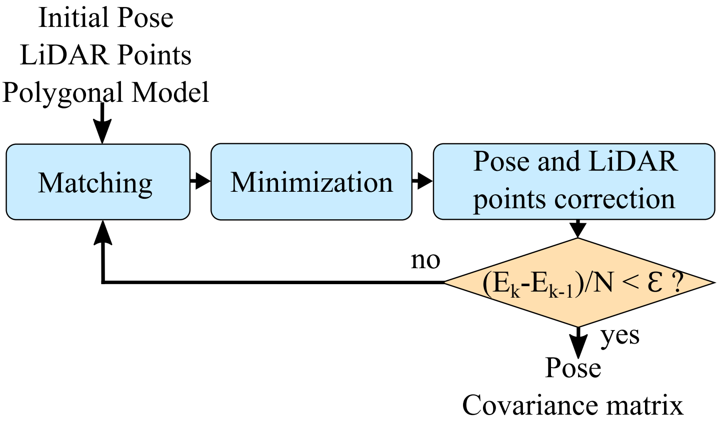
10th Workshop on Planning, Perception and Navigation for Intelligent vehicles, October 1st, 2018, Madrid, Spain

Problem statement



- Iterative optimization
  - Matching
  - Minimization
    - Minimization using polynomial roots
    - Minimization using pseudo-inverse matrix
    - Covariance matrix approximation
- Simulation Results
  - Scenarios
  - Errors and consistencies

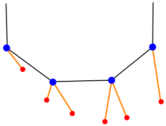
Iterative optimization



Matching

Matching

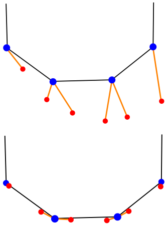
ICP
Point-to-point



Matching

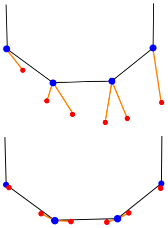
ICP

Point-to-point

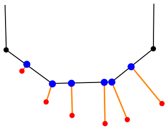


Matching

ICP
Point-to-point



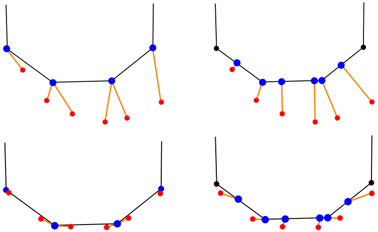
ICPP
Point-to-projection



Matching

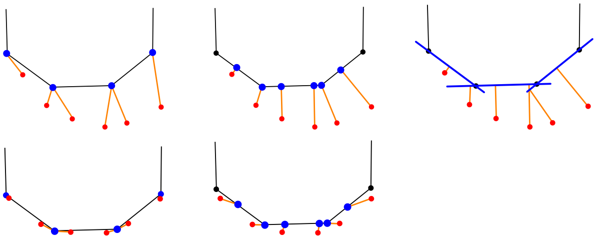
ICP
Point-to-point

ICPP
Point-to-projection



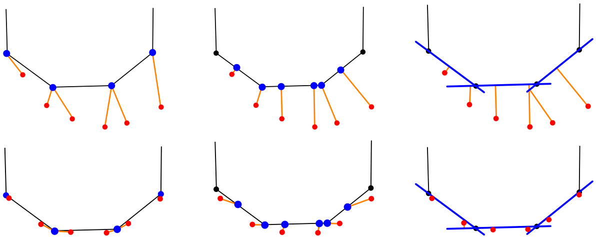
Matching

ICP Point-to-point	ICPP Point-to-projection	PLICP Point-to-line



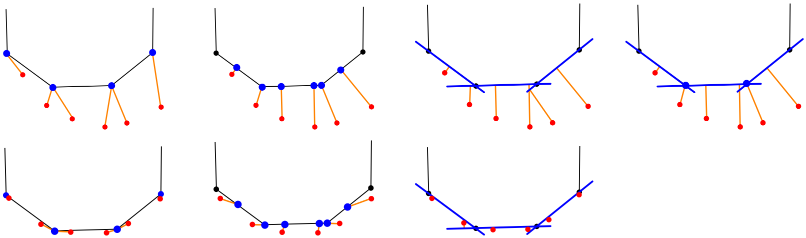
Matching

ICP	ICPP	PLICP
Point-to-point	Point-to-projection	Point-to-line



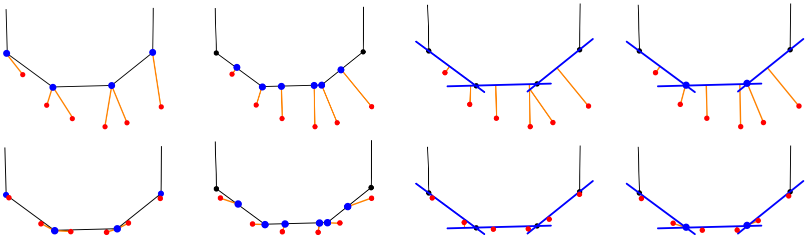
Matching

ICP	ICPP	PLICP	mixICP
Point-to-point	Point-to-projection	Point-to-line	Mix-matching



Matching

ICP	ICPP	PLICP	mixICP
Point-to-point	Point-to-projection	Point-to-line	Mix-matching



Minimization

Minimization problem:

$$\hat{q} = \arg\min_{q} E(q) = \arg\min_{q} \sum_{i=1}^{n} d(q; p_i, M)$$

Euclidean distance

$$d(q, p_i, M) = \|m_j - \Delta T p_i\|^2$$

Orthogonal distance

$$d(q, p_i, M) = ((m_j - \Delta T p_i) \cdot n_j)^2$$

Transformation:

$$\Delta T = \begin{bmatrix} \cos(\Delta\theta) & -\sin(\Delta\theta) & \Delta x \\ \sin(\Delta\theta) & \cos(\Delta\theta) & \Delta y \\ 0 & 0 & 1 \end{bmatrix}$$

Minimization using polynomial roots

With $q_{4D} = \left[x \; y \; \cos\left(\theta\right) \; \sin\left(\theta\right)\right]^T$

$$\begin{cases} \min_{q_{4D}} & E\left(q_{4D}\right) = q_{4D}^T A q_{4D} + b^T q_{4D} + c \\ \text{subject to} & q_{4D}^T W q_{4D} = 1 \end{cases}$$

A. Censi. An ICP variant using a point-to-line metric. In IEEE International Conference on Robotics and Automation, pages 19–25, May 2008.

Minimization using pseudo-inverse matrix

Using the 1st order small-angle approximation:

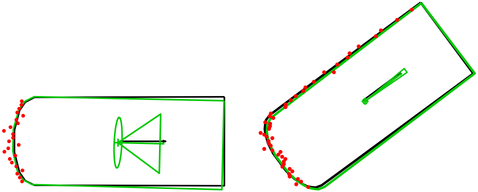
$$\min_{q} \|Aq - b\|^2$$

Then

$$\hat{q} = \text{pinv}(A) b$$

K.L. Low. Linear Least-Squares Optimization for Point-to-Plane ICP Surface Registration. Technical Report TR04-004, Department of Computer Science University of North Carolina at Chapel Hill, February 2004.

Covariance matrix approximation

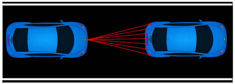


$$\widehat{\Sigma} = \frac{E(\hat{q})}{n-k} \left(\frac{\partial^2 E(\hat{q})}{\partial q^2} \right)^{-1}$$

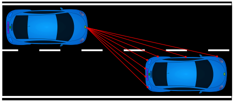
$E(q)$: cost function,
n: number of LiDAR Points
k: number of parameters (3 in 2D)

O. Bengtssons and A.J. Baerveldt. Robot localization based on scan-matching-estimating the covariance matrix for the IDC algorithm. Robotics and Autonomous Systems, 44(1):29–40, July 2003.

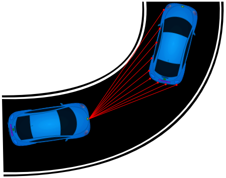
Scenarios



Straight lane

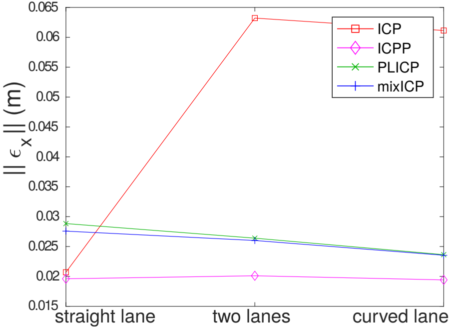


two lane



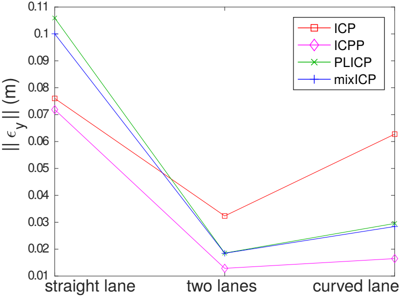
curved lane

Results

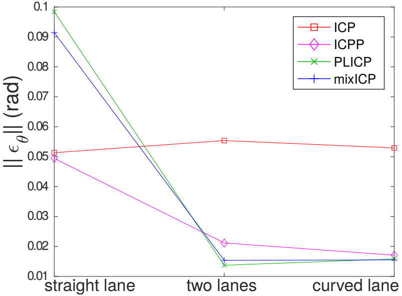


Longitudinal error

Results



Lateral error



Heading error

Errors and consistencies

Consistency test:

$$({}^e q_t - {}^e \hat{q}_t)^T \, {}^e\hat{\Sigma}_t^{-1} ({}^e q_t - {}^e \hat{q}_t) < \chi^2_{3,0.05}$$

		ICP	ICPP	PLICP	mixICP
Polynomial minimization	$\|\bar{\epsilon}\|$ (cm)	8.2	7.8	13.7	11.0
	consistency (%)	85.5	58.8	69.8	70.0
Pseudo-inverse minimization	$\|\bar{\epsilon}\|$ (cm)	8.2	7.8	11.5	10.8
	consistency (%)	93.5	83.9	91.6	89.8

The minimization using pseudo-inverse matrix with point-to-line matchings gives the best consistencies.

Conclusion

- The relative pose and covariance matrix estimation using an iterative minimization algorithm was tested with different matching and minimization methods.
- The geometry of the vehicle is well represented by the point-to-line matching. The approximation of the covariance matrix is then more consistent.
- The minimization using a pseudo-inverse matrix formulation is more accurate and consistent.
- When two sides of the vehicle are seen by the perception sensor, the estimated pose becomes more accurate.

Thank you for your attention!

LiDAR based relative pose and covariance estimation for communicating vehicles exchanging a polygonal model of their shape

Elwan Héry, Philippe Xu and Philippe Bonnifait

Sorbonne Universités, Université de Technologie de Compiègne,

Heudiasyc UMR CNRS 7253

10th Workshop on Planning, Perception and Navigation for Intelligent vehicles, October 1st, 2018, Madrid, Spain