Towards GPS-denied inspection of electric towers with mini-UAVs

Pascal MORIN

ISIR – Sorbonne Université

Based on Ph.D. Work of **Carlos VINA** (now at BALYO Robotics)

Objectives

Develop **pose estimation** strategies for MAVs equipped with **2D LiDARs**.

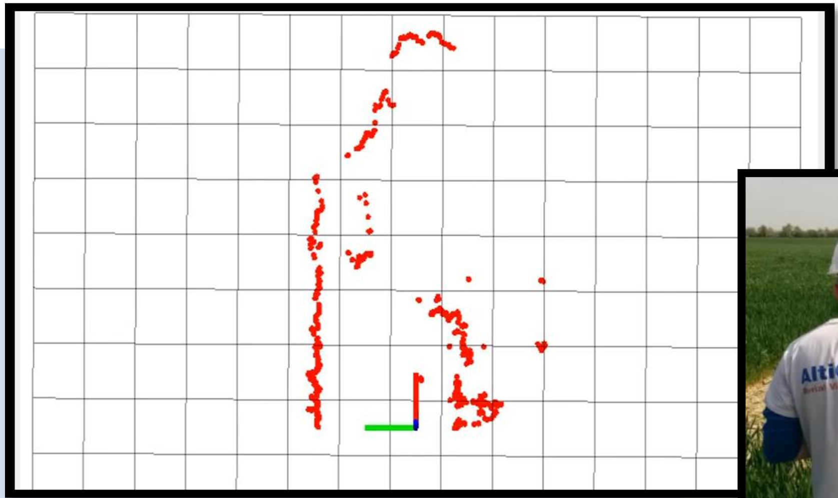
- Real-time and on-board.
- Coupled with commonly available sensors.
- For **electric towers** inspection.

Long term objective: automatic inspection

Complete sensor setup:

- 2D Hokuyo Lidar (UTM 30-LX)
- Inertial measurement unit (IMU): Accelerometer + gyrometer (+ barometer)
- Height sensor**:** Laser altimeter.

Characteristics of the laser range measurements



The scans capture a cross-section of the tower.

- Very discontinuous.
- Can change drastically between scans.
- Limited overlap between 2 scans

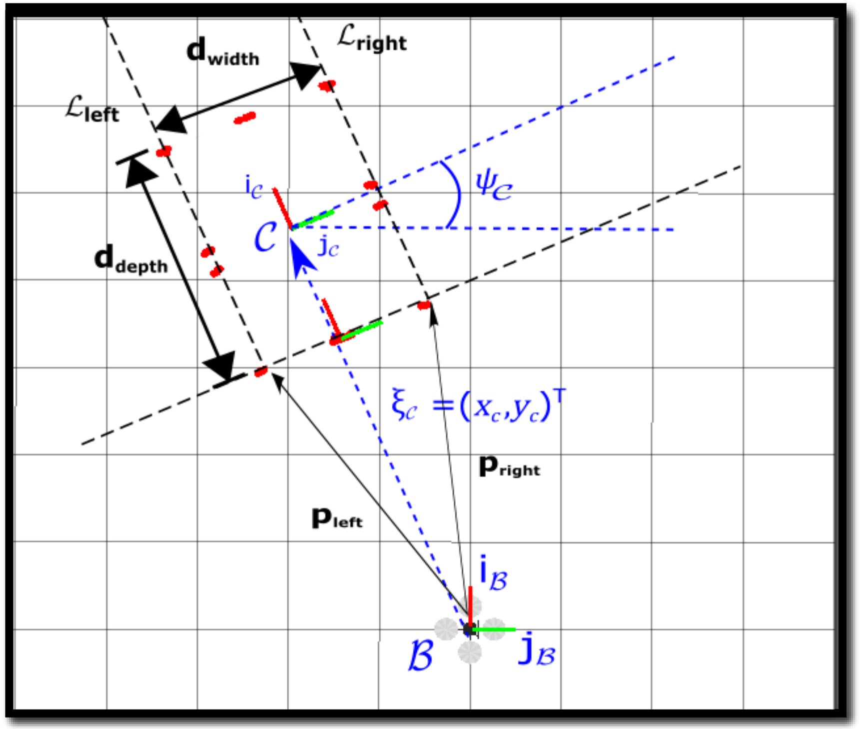
Aligning pairs of 2D laser scans isn't appropriate.

- Distinguishable from surrounding objects.

Proposal

- Focus on the cross-section's geometry. Rectangular (for small inclinations)

Feature-based approach: Overview



Procedure:

2D LiDAR → Scan segmentation →

Geometric fitting

Extract notable features

- **Front corners**
- **Lines:** $c + n_x x + n_y y = 0$

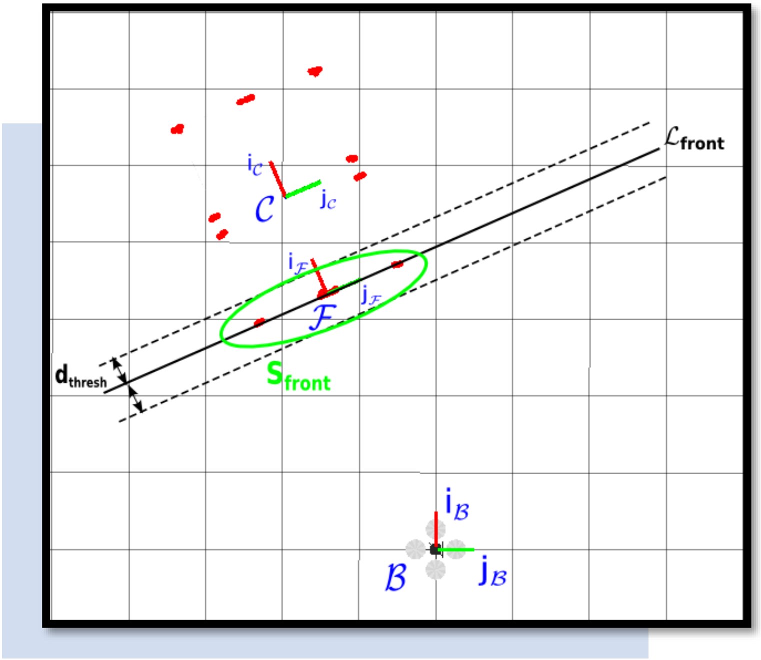
↑

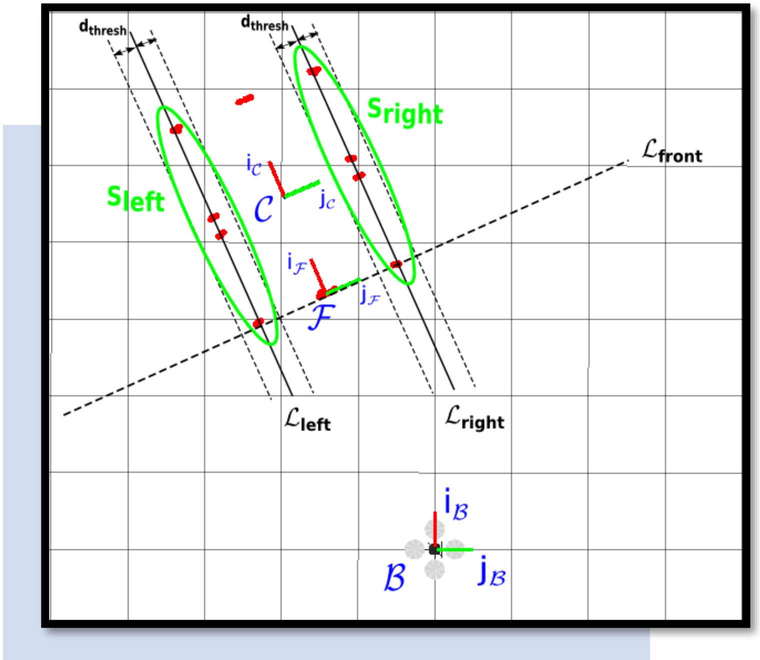
Estimate unknown dimensions

↑

Determine $\{x_c, y_c, \psi_c\}$

Feature-based approach: Scan segmentation





Front side → **Lateral sides**

- RANSAC (**Fischler,1981**)
- d_{thresh}, ψ_{max}

Output S_{front}, S_{right}, S_{left}

Feature-based approach: Geometric fitting

Rectangular cross-section:

$$\begin{aligned} \mathcal{L}_{\text{front}}: \quad & c_F + n_x x_F + n_y y_F = 0, \\ \mathcal{L}_{\text{left}}: \quad & c_L - n_y x_L + n_x y_L = 0, \\ \mathcal{L}_{\text{right}}: \quad & c_R - n_y x_R + n_x y_R = 0, \\ & n_x^2 + n_y^2 = 1. \end{aligned}$$

Problem Calculate the parameters that best fit $\mathbf{S}_{\mathbf{front}}$, $\mathbf{S}_{\mathbf{left}}$ and $\mathbf{S}_{\mathbf{right}}$

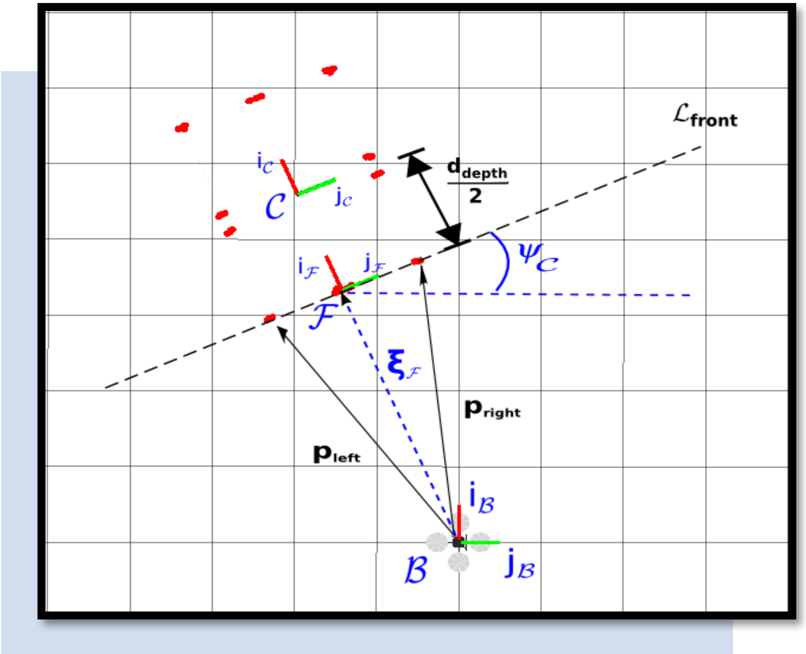
$$\min \|\boldsymbol{\rho}\|^2 \quad \text{subject to} \quad \begin{pmatrix} 1 & 0 & 0 & x_{F,1} & y_{F,1} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 1 & 0 & 0 & x_{F,N_F} & y_{F,N_F} \\ 0 & 1 & 0 & y_{L,1} & -x_{L,1} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 1 & 0 & y_{L,N_L} & -x_{L,N_L} \\ 0 & 0 & 1 & y_{R,1} & -x_{R,1} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 1 & y_{R,N_R} & -x_{R,N_R} \end{pmatrix} \begin{pmatrix} c_F \\ c_L \\ c_R \\ n_x \\ n_y \end{pmatrix} = \boldsymbol{\rho} \quad \text{and } n_x^2 + n_y^2 = 1$$

Constrained least squares (**Gander, 2004**)

Feature-based approach: Position and orientation

From geometric fitting:

- **Calculate front corners**
- $\xi_F = \frac{p_{right} + p_{left}}{2}$
- **Determine depth and width.**



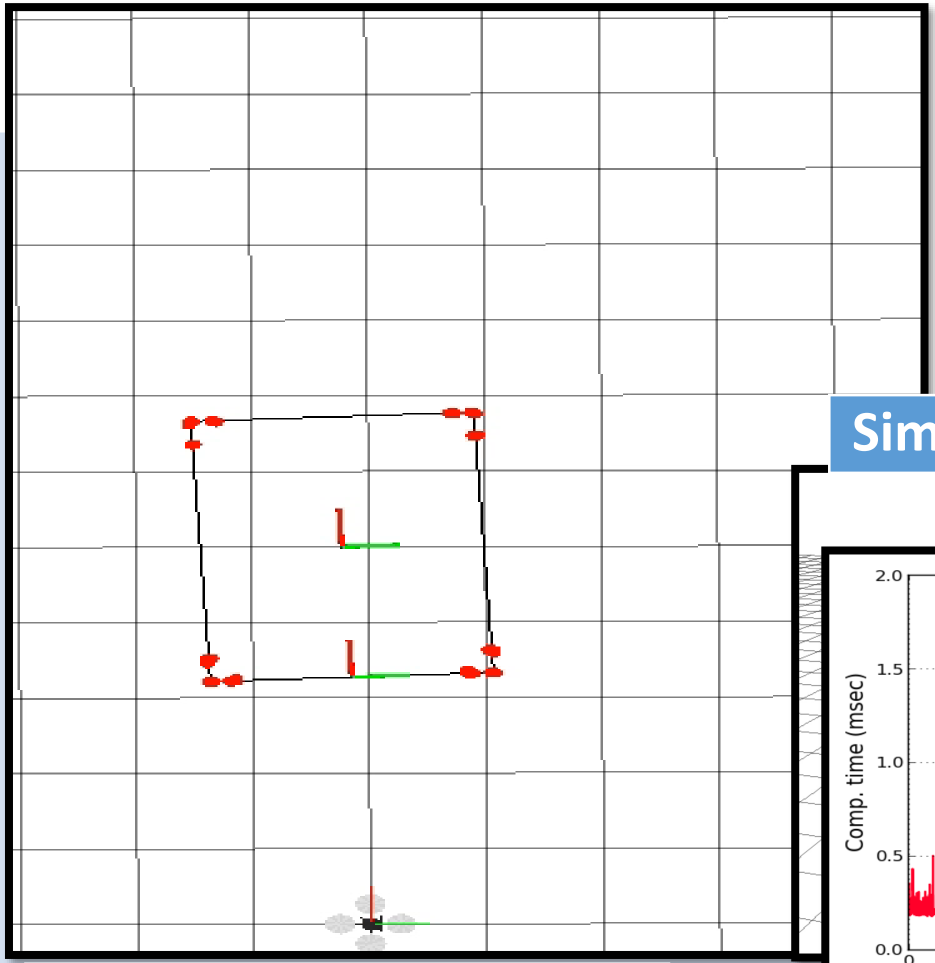
Output

- **Calculate the orientation:** $\psi_c = \text{atan2}(n_y, n_x)$
- **Calculate the position:** $\xi_C = \xi_F + \frac{depth}{2}\begin{pmatrix}\cos\psi_c \\ \sin\psi_c\end{pmatrix}$

- Filter with first-order low-pass filters.

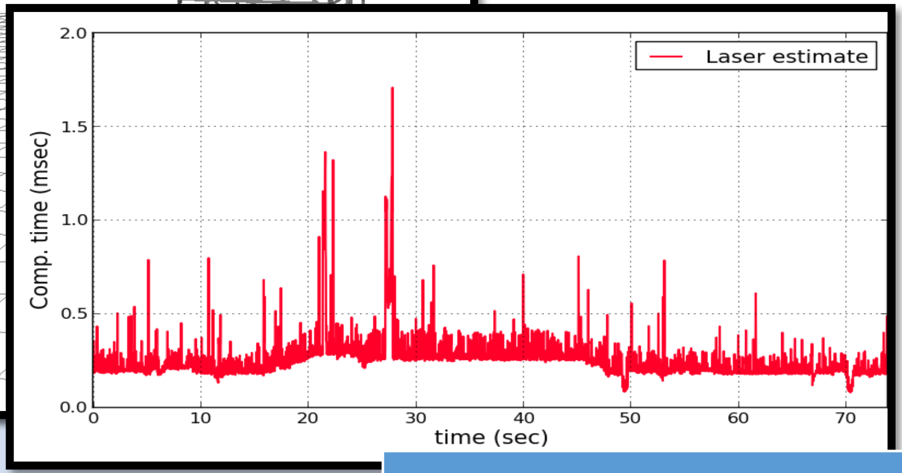
Simulation results: Flight in front of the tower

- **Gazebo** simulator (**Koenig, 2004**)
- Hector quadrotor stack from **ROS**. (**Meyer, 2012**)
- Intel 3.4 GHz Quad-Core processor and 8 GB of RAM



Tracked cross-section

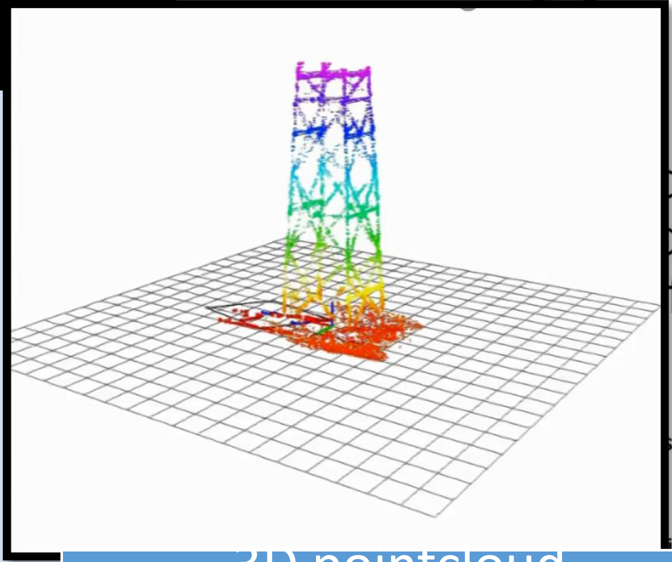
Simulation setup



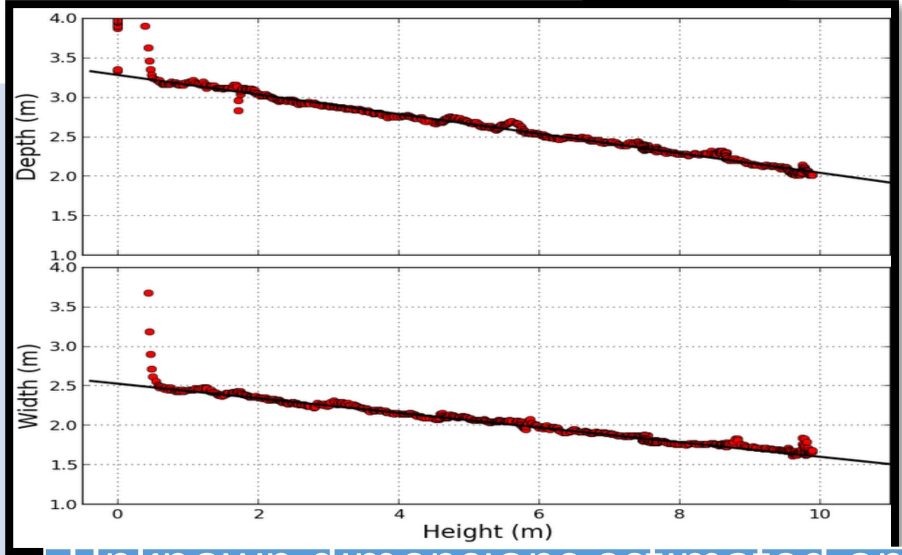
Computation time

Experimental results

- Hokuyo UTM-30LX.
- MPU6000.
- SF10/A LightWare Optoelectronics.



3D pointcloud reconstruction

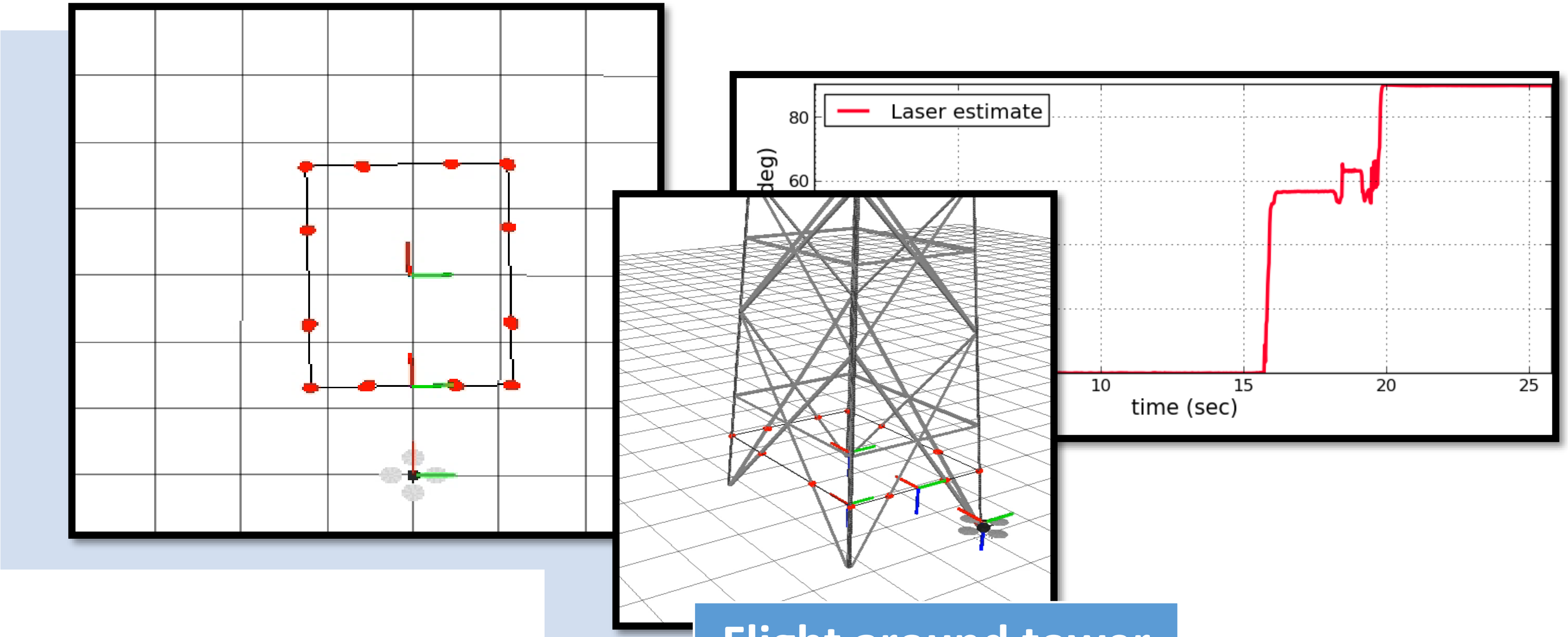


Unknown dimensions estimated on-flight

Limitations

- Rectangular cross-section assumption is valid for low inclinations.

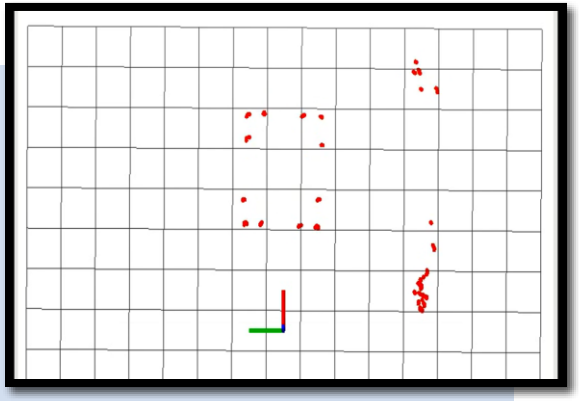
- Based on tracking the closest line.
  - Flight limited to one side of the tower.

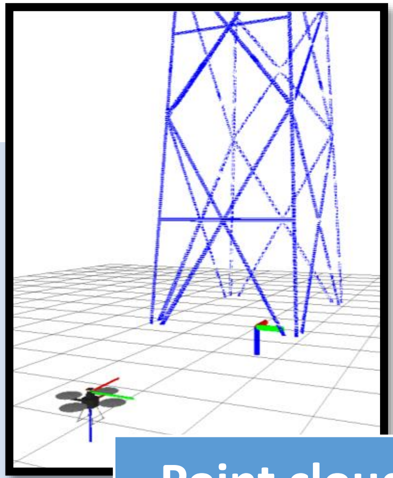


Flight around tower

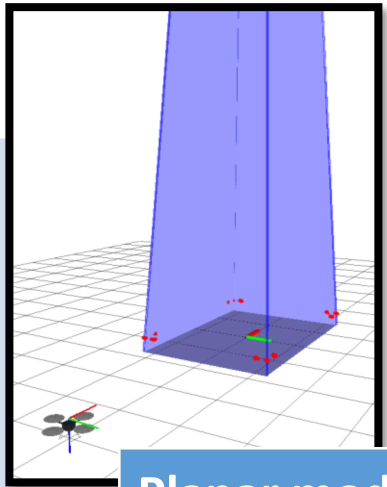
Model-based approach: Overview

From the previous method:





Point cloud



Planar model

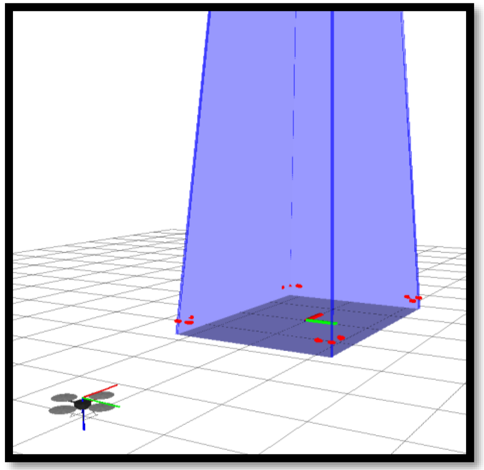
Proposal

- Adapt classic scan registration techniques (ICP)
- Using tower model as a **reference.**
- With the aid of on-board sensors.

Adapting the ICP algorithm: Planar model

$\mathcal{P}$: Current 2D scan (in B)
$\mathcal{T}_0$: Initial rigid body transformation from B to I.

- $\{x_0, y_0, z_0, \phi_0, \theta_0, \psi_0\}$



For each iteration *k*

$\mathcal{P}' \leftarrow \mathcal{T}_k(\mathcal{P})$

↓

Matching

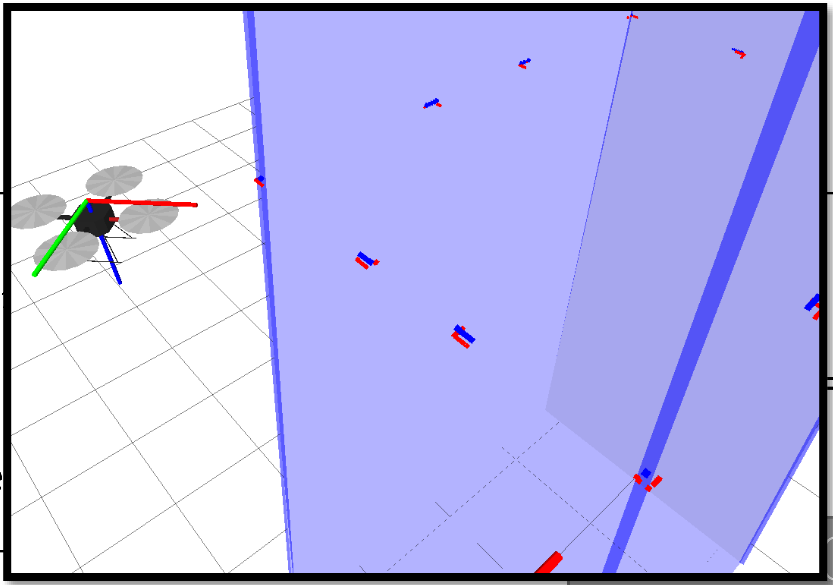
↓ $\mathcal{M}$

Minimization

↓

$\mathcal{T}_{k+1} \leftarrow \mathcal{T}_{min} \cdot \mathcal{T}_k$

- Projection-based matching **(Rusinkiewicz, 2001).**



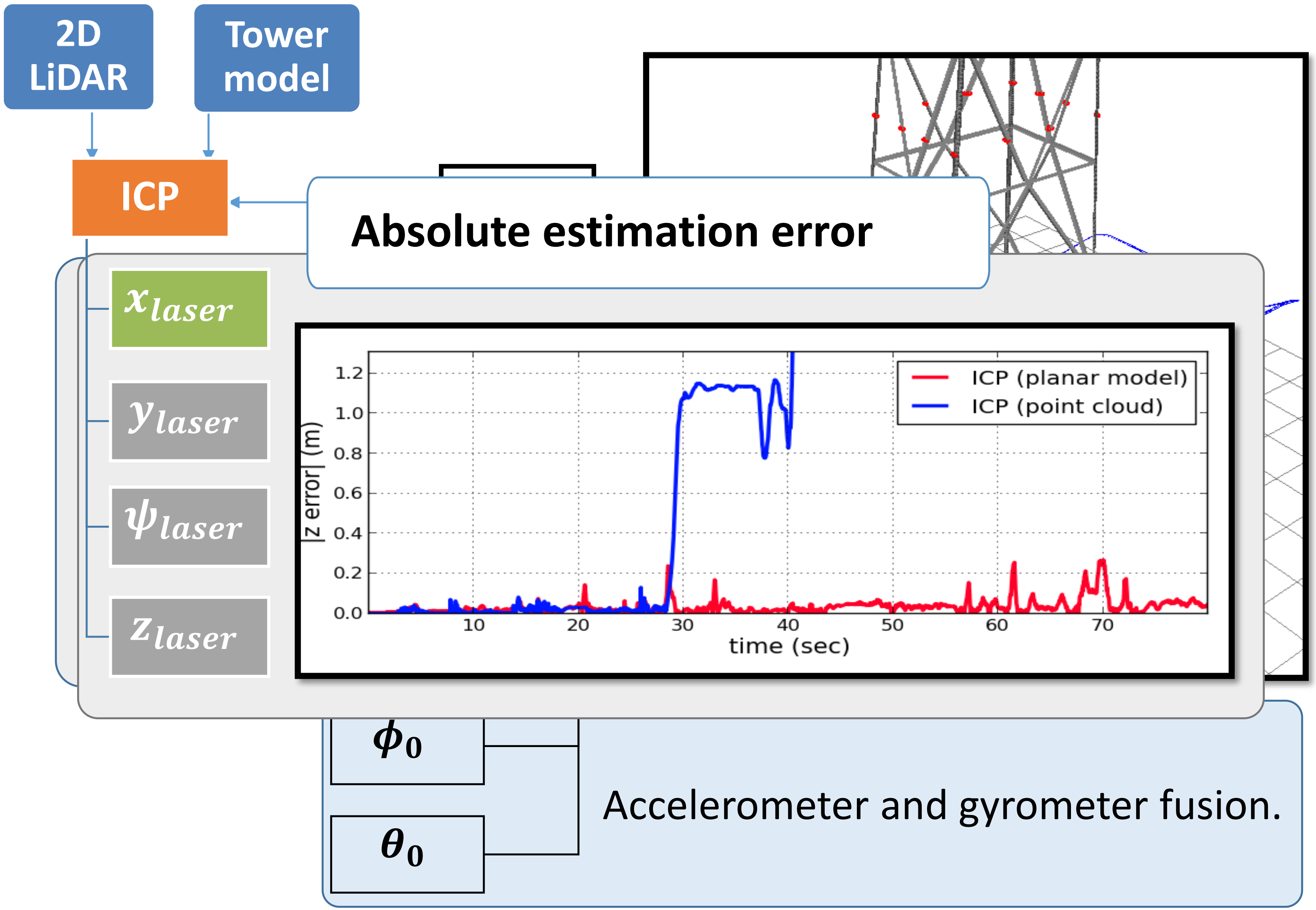
$\mathcal{T}_{mi}$

= (0,0)

- Le

(x, y, z, ψ)

Simulation results: Laser odometry



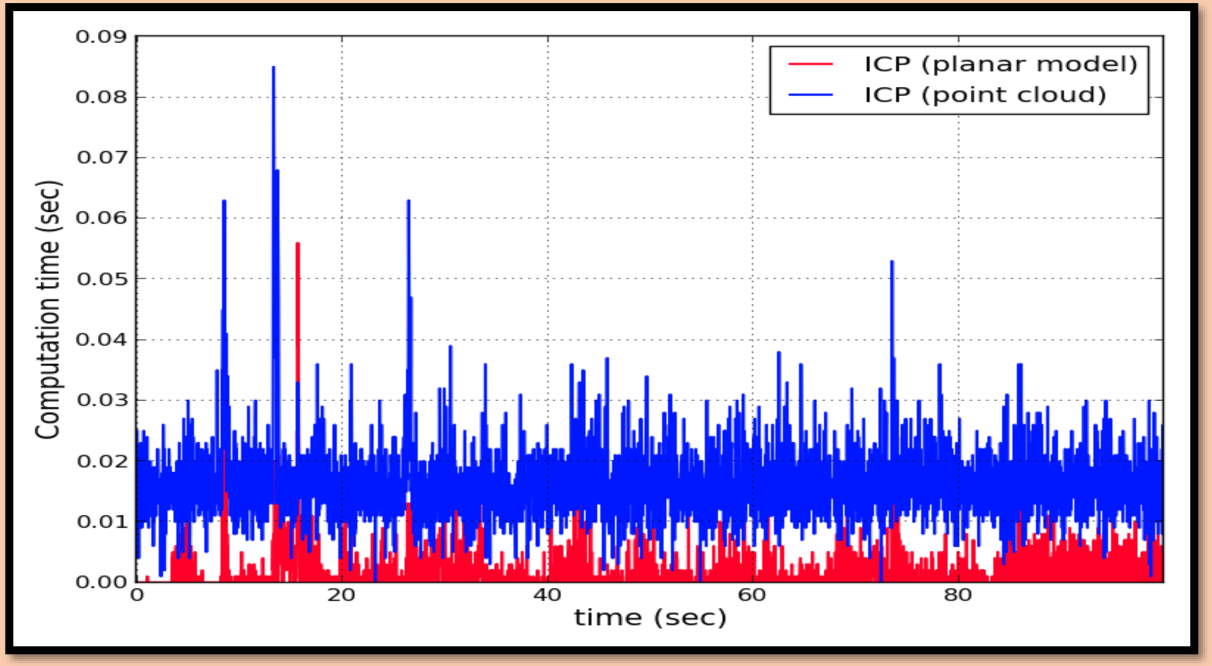
Simulation results: Laser odometry

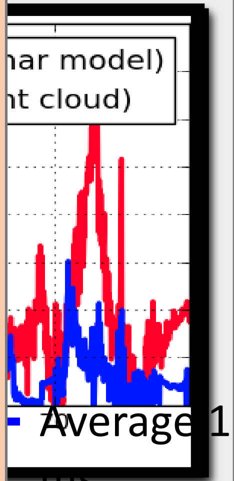
2D LiDAR

Tower model

ICP

Computation time





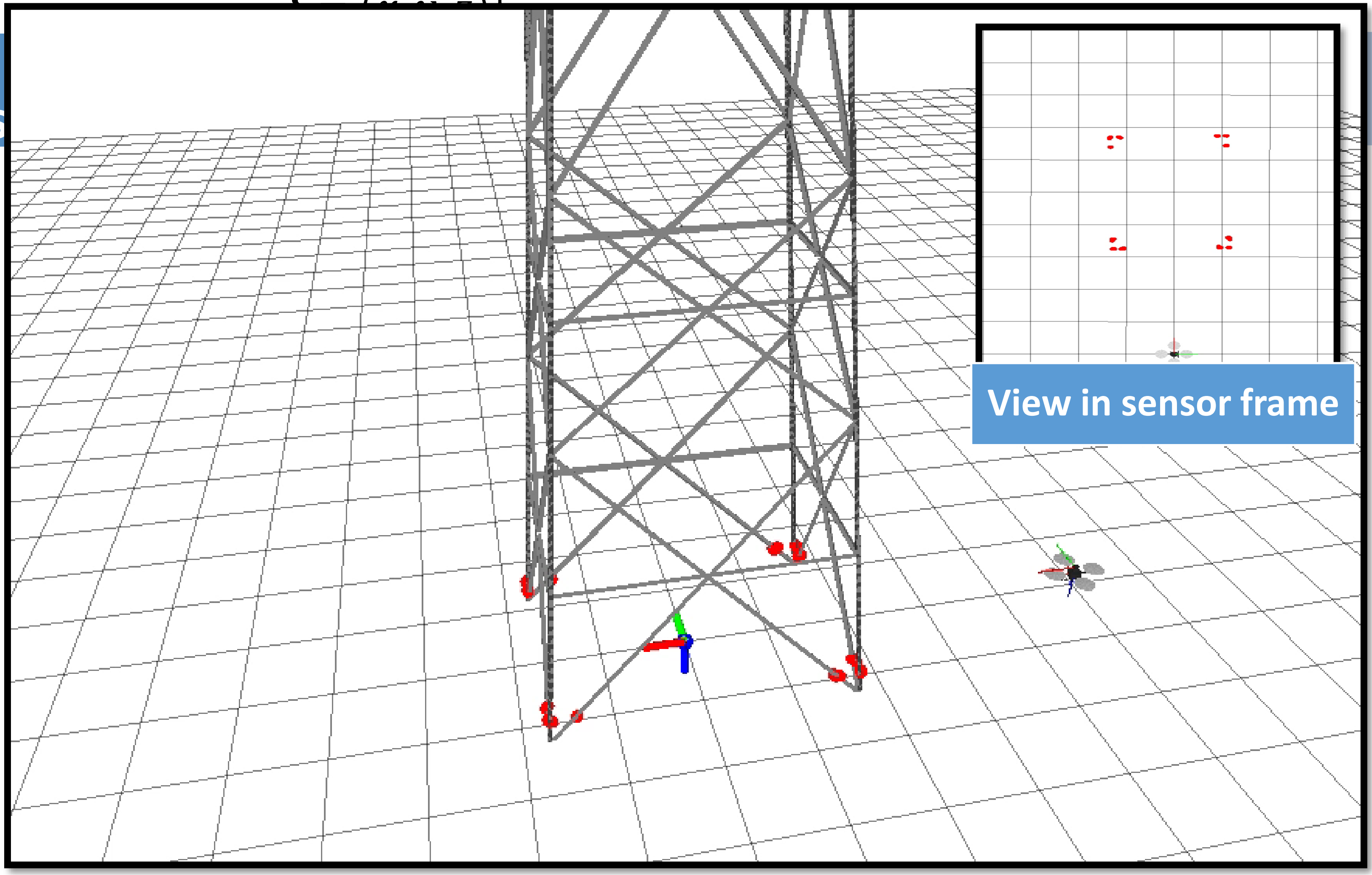
Average 16 ms

Average 1.4 ms

eter fusion.

$\boldsymbol{\theta}_0$

Simulation results: Position control



Conclusions

- 2D Lidars provide useful information for MAVs localization w.r.t. electric towers
- and also allow for acceptable 3D reconstruction
- but fusion with IMU data is fundamental in this context
- **Access to infrastructures is fundamental to progress in this field**

For more information:

C. Viña and P. Morin, *MAV local pose estimation with a 2D laser scanner: A case study for electric tower inspection*. International Journal of Micro Air Vehicles, 2018.