Simultaneous Localization and Mapping for Aerial Vehicles

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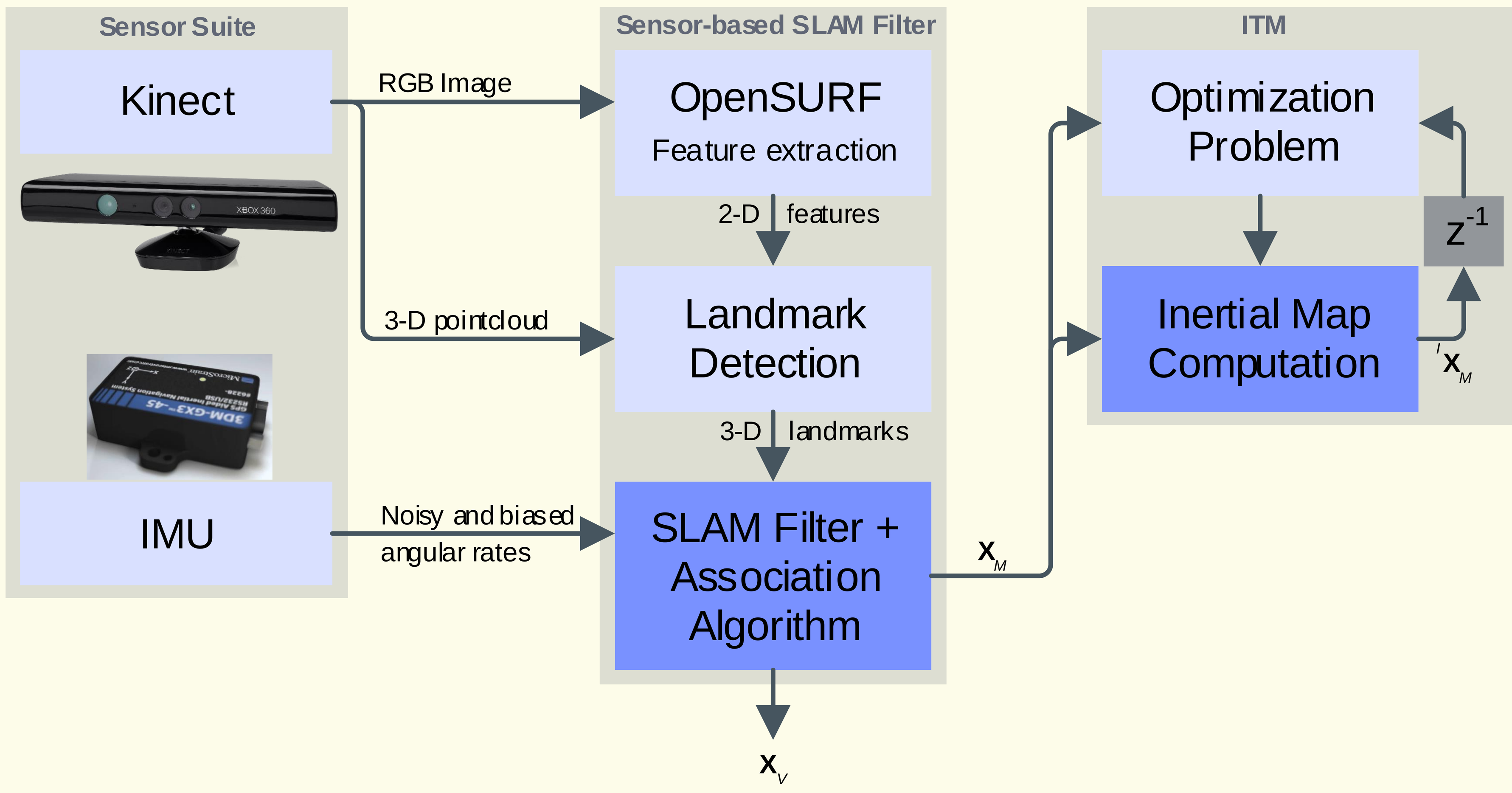
Objective

Navigate an AV in a new environment with no a priori info:

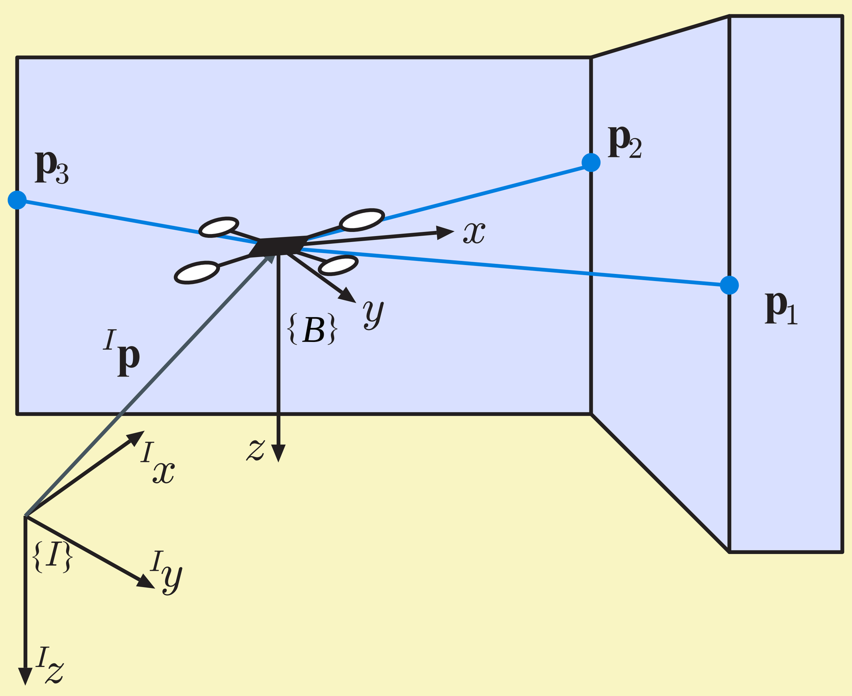
- Obtain a detailed map of the environment.
- Maintain an accurate estimate of the location of the vehicle.

Idea Design a two-part algorithm:

- **Sensor-based** SLAM filter
  - Filter in the space of sensors – no attitude representation
- **Inertial** Trajectory and Map Estimation
  - Obtain the pose of the vehicle



1. Sensor-based SLAM filter



Biased angular measurements

$$\boldsymbol{\omega}_m(t) = \boldsymbol{\omega}(t) + \mathbf{b}_\omega$$

Landmark Kinematics

$$\dot{\mathbf{p}}_i(t) = -\mathbf{S}\left[\boldsymbol{\omega}_m(t)\right]\mathbf{p}_i(t) - \mathbf{v}(t) - \mathbf{S}\left[\mathbf{p}_i(t)\right]\mathbf{b}_\omega$$

System state:

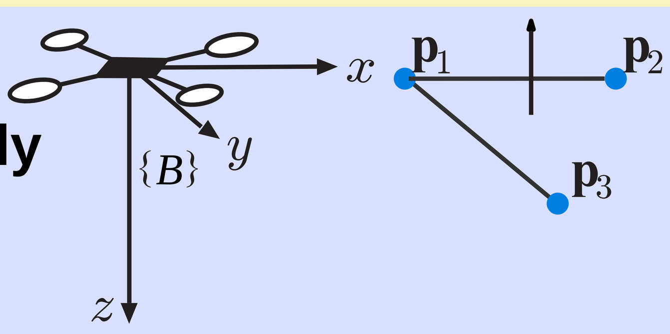
$$\mathbf{x} = \begin{bmatrix}\mathbf{v}(t) & \mathbf{b}_\omega(t) & \{\mathbf{p}_i(t)\}\end{bmatrix}$$

- From the landmark kinematics and assuming deterministically constant body-fixed velocity and measurement bias results a system with **nonlinear** dynamics: cross terms

Idea:

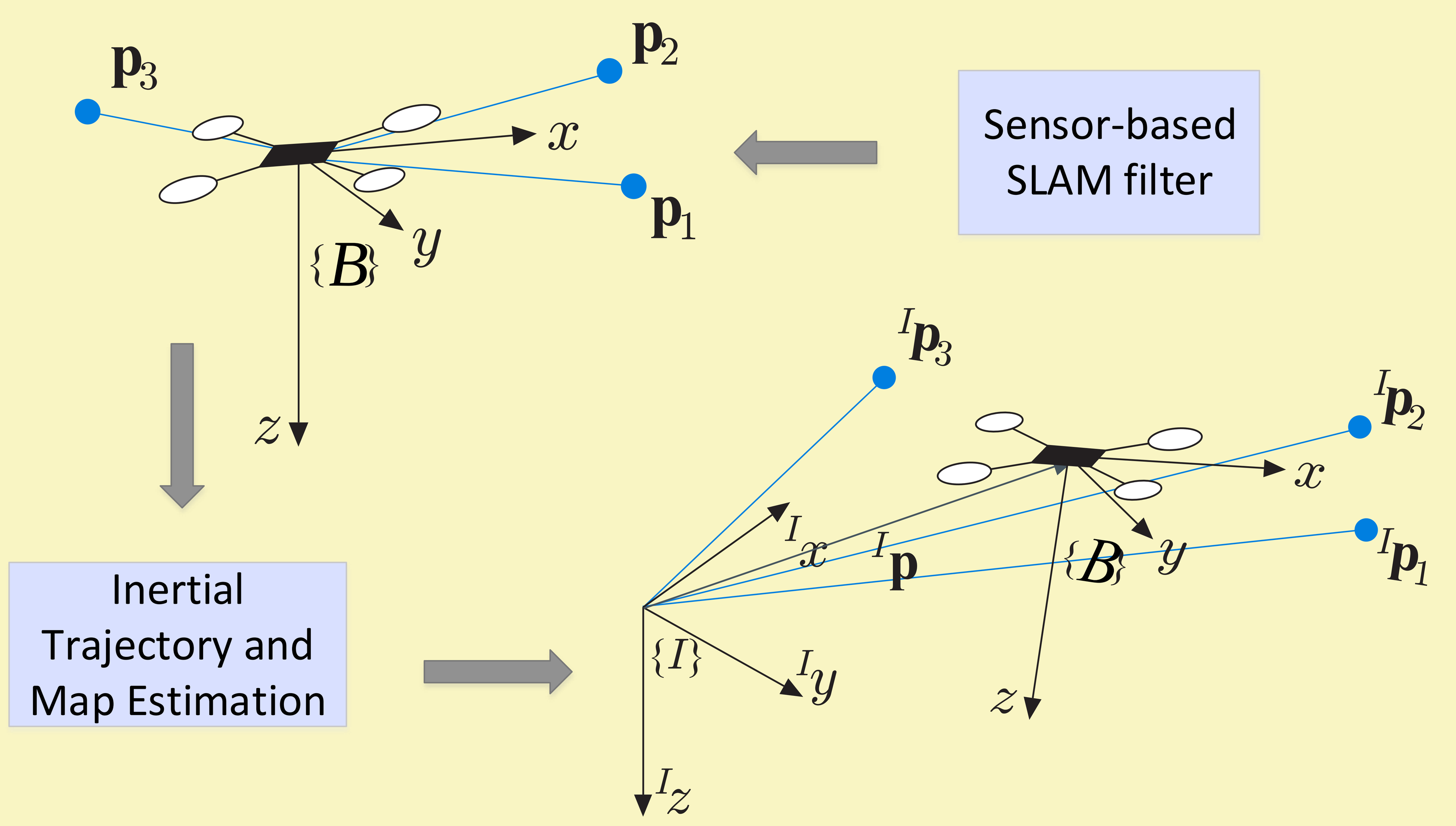
- Visible landmarks are outputs → system dynamics discarding non-visible landmarks is LTV for observability.
- Linear theory applies → **LTV Kalman filter** is designed.

Results:



- LTV system is **uniformly completely observable**
- The designed Kalman filter has **globally asymptotically stable** (GAS) error dynamics

2. Inertial Trajectory and Map Estimation



- The **sensor-based SLAM filter** does **not** provide information regarding the **pose of the vehicle** in an inertial setting.
- The only **a priori** knowledge is that of the **initial pose** and the **landmark map in the body-fixed** frame for all time.
- Idea – optimization problem with **closed form** solution:

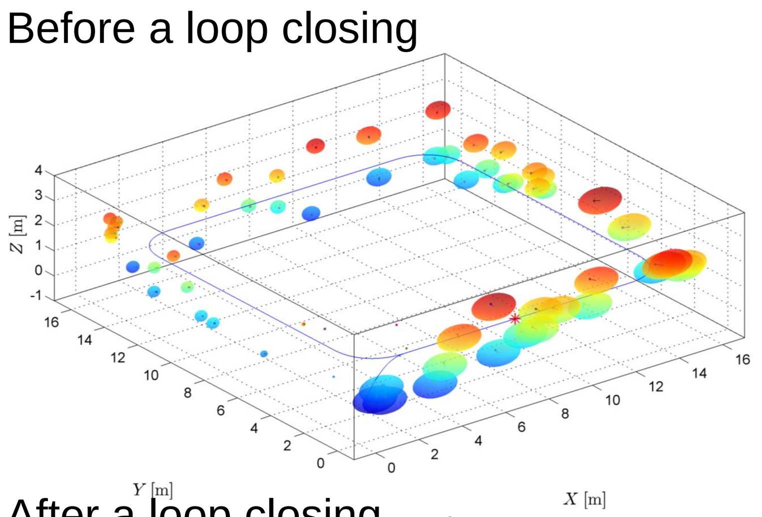
$$\left(\mathbf{R}_k^*, {}^I\mathbf{p}_k^*\right) = \arg \min_{\substack{\hat{\mathbf{R}}_k \in SO(3) \\ {}^I\hat{\mathbf{p}}_k \in \mathbb{R}^3}} \sum_{i=1}^{N_T} \sigma_{i_k}^{-2} \left\| {}^I\hat{\mathbf{p}}_{i_{k-1}} - \hat{\mathbf{R}}_k \hat{\mathbf{p}}_{i_k} - {}^I\hat{\mathbf{p}}_k \right\|^2$$

- Inertial map updated using the computed optimal pose.
- Approximate **uncertainty description** for the optimal estimates derived using perturbation theory was obtained.

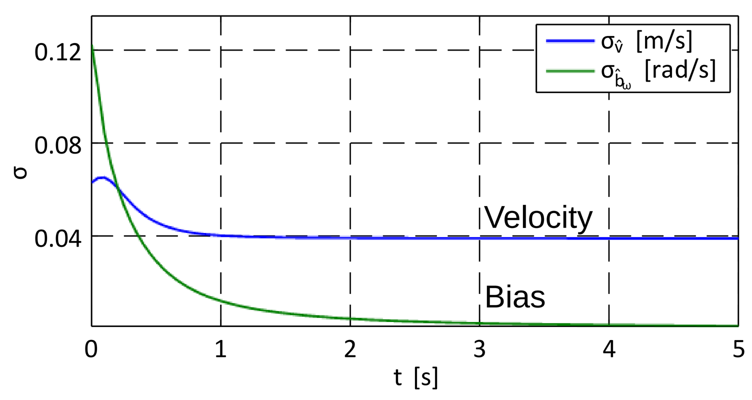
3. Results

Simulation

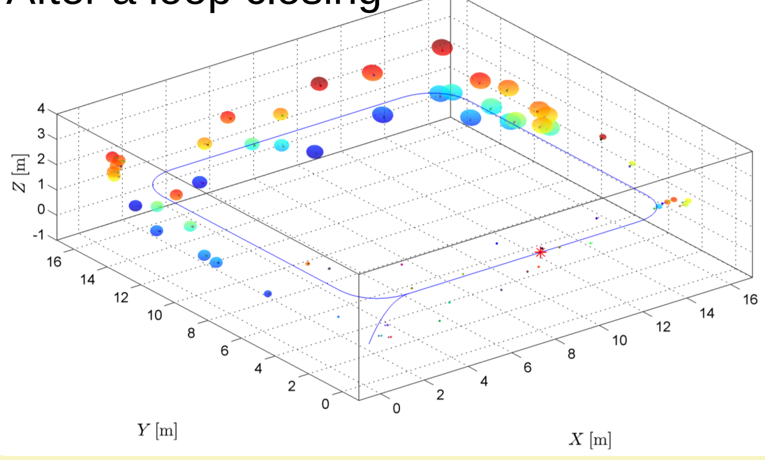
Before a loop closing

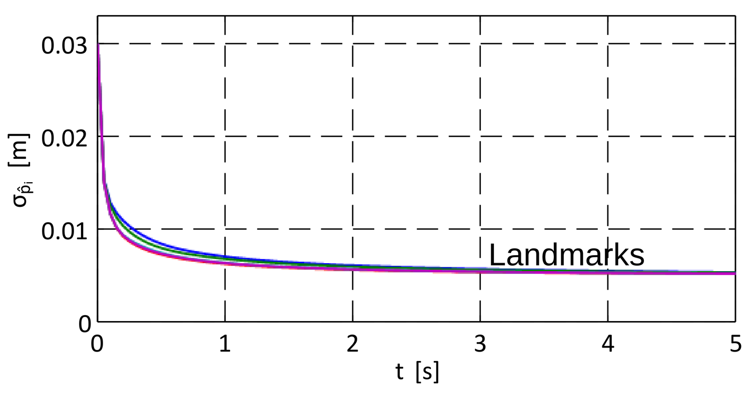


Convergence



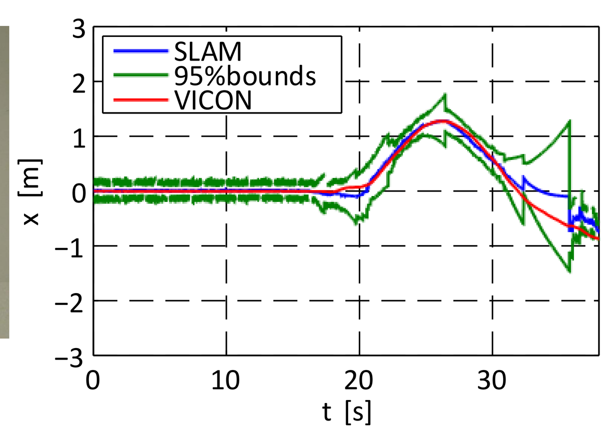
After a loop closing

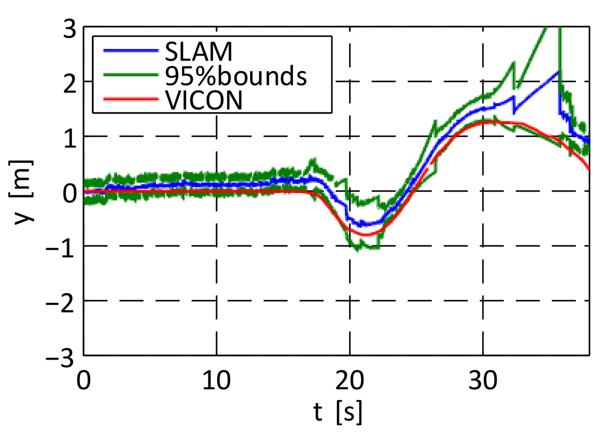




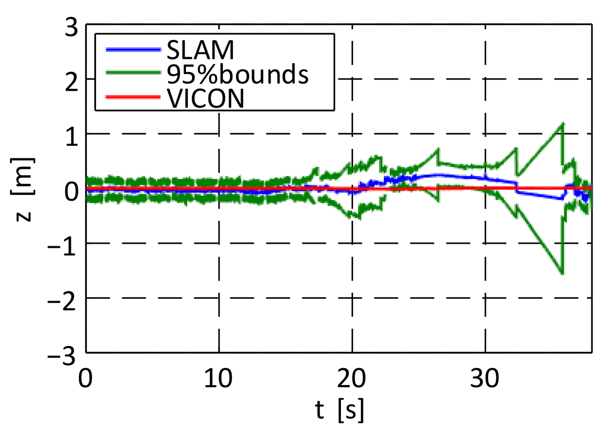
Preliminary Experiments

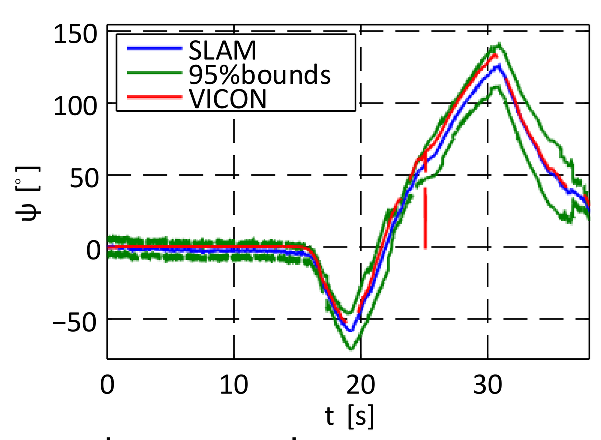
The vehicle





Technical difficulties with the equipment impaired the experiments, although the obtained results hint at the good performance of the algorithm.





Note: Futher and more complete experiments on the way.

P. Lourenço, B. Guerreiro, P. Batista, P. Oliveira, and C. Silvestre, ***"Preliminary Results on Globally Asymptotically Stable Simultaneous Localization and Mapping in 3-D",*** Proceedings of the 2013 American Control Conference, Washington, D.C., USA, June 2013, pp. 3093-3098.

P. Lourenço, B. Guerreiro, P. Batista, P. Oliveira, and C. Silvestre, ***"3-D Inertial Trajectory and Map Online Estimation: Building on a GAS Sensor-based SLAM filter",*** Proceedings of the 2013 European Control Conference, Zurich, Switzerland, July 2013, pp. tba.