A Globally Exponentially Stable filter for Bearing-Only Simultaneous Localization and Mapping in 3-D

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Objective

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

- Obtain a detailed three-dimensional map of the environment measuring bearings to landmarks
- Maintain an accurate estimate of the location of the vehicle

Design a BO-SLAM filter with global exponentially stable error dynamics

Major issues

Nonlinearity

- SLAM is an inherently nonlinear problem due to the necessity of converting relative measurements into global estimates.

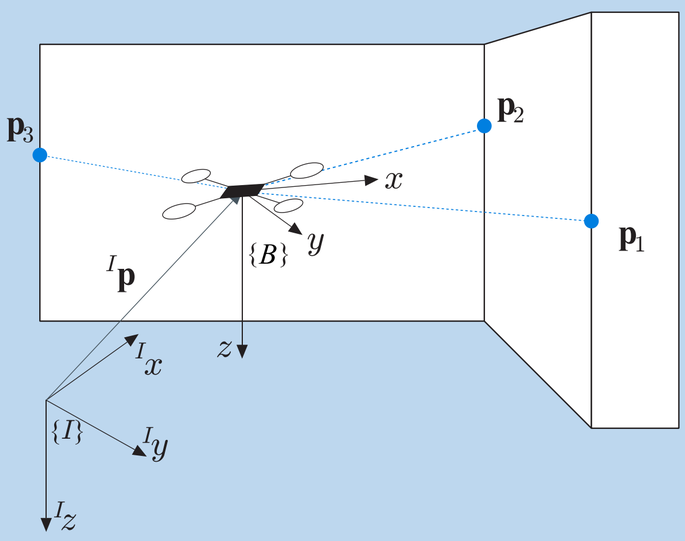
Partial observability / Landmark initialization

- One measurement is not enough to disambiguate a landmark providing only a (semi) straight line as an estimate

Idea

- **Sensor-based** formulation to eliminate the pose estimate from the filter
- **Output transformation** followed by **state augmentation** to obtain a **LTV-like** system
- Solve **initialization problem** by designing a filter with **global convergence** and **stability** guarantees

① Sensor-based BO-SLAM filter

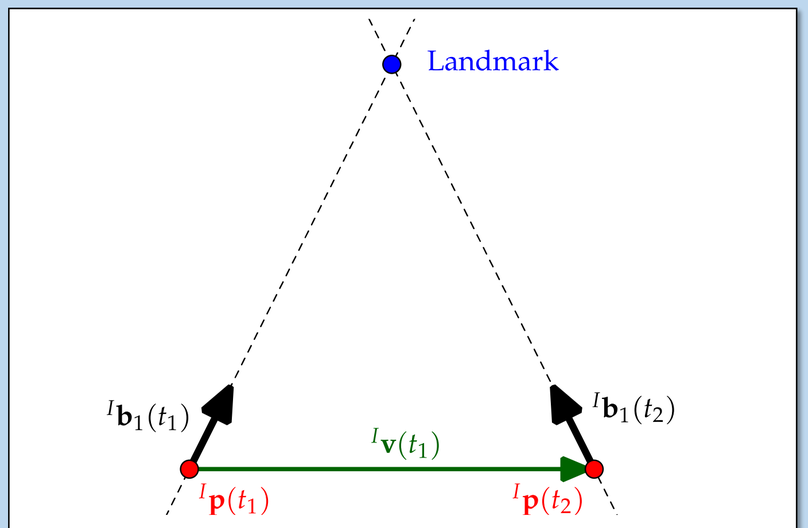


Mission scenario:

- Natural (vision) or artificial **landmarks** (acoustic/electromagnetic beacons)
- The vehicle measures **bearings** to beacons
- The **linear** and **angular velocities** are available

System design:

- Sensor-based **landmark kinematics**
- **Bearing** measurements
- Result: system with **nonlinear** output



IDEA

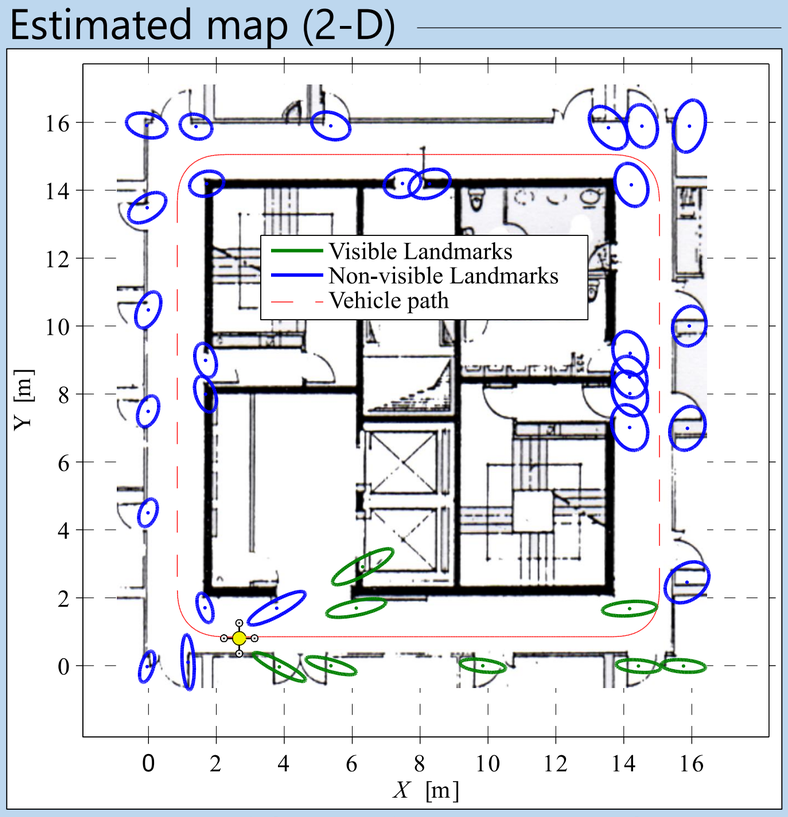
- Output **transformation** and state **augmentation** → **linear** ouput, **nonlinear** dynamics depending on the ratio landmark/range
- This ratio is the bearing, a known output→ system dynamics discarding non-visible landmarks is **LTV** for observability
- Linear theory applies → **Kalman filter** is designed for an LTV system

Results:

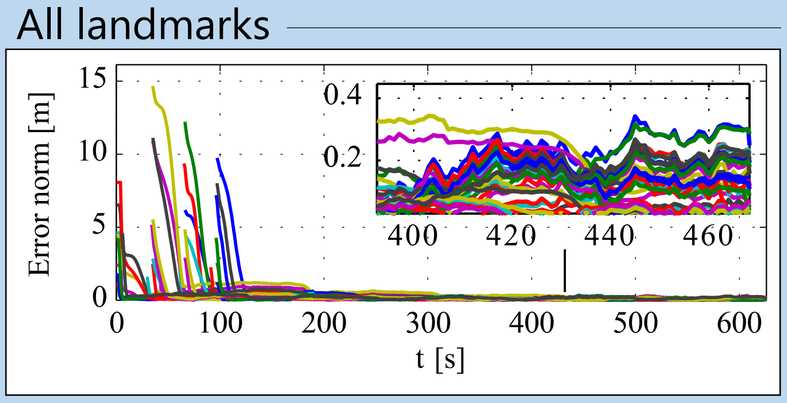
- LTV system is **uniformly completely observable**
- The designed Kalman filter has **globally exponentially stable** (GES) error dynamics

② Simulation results

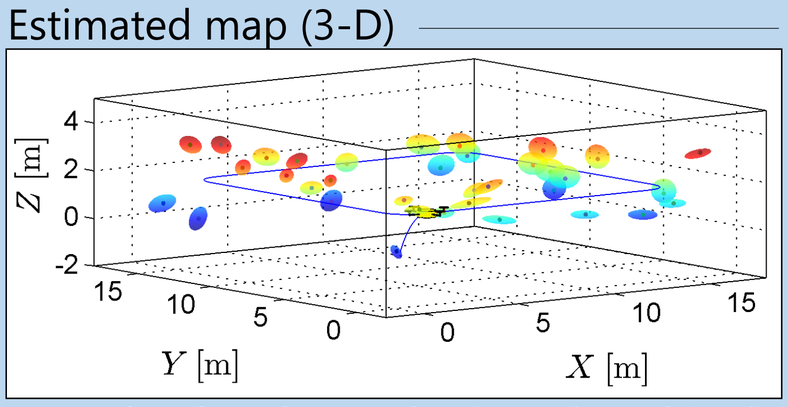
Estimated map (2-D)



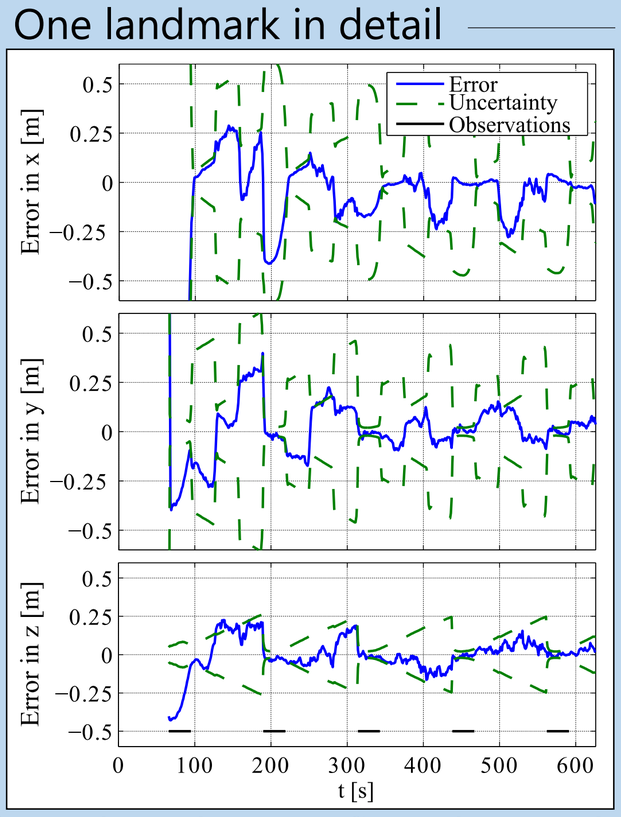
All landmarks



Estimated map (3-D)



One landmark in detail



- In contrast with previous approaches to BO-SLAM, landmarks can be introduced in the filter when they are first observed, no triangulation or SoG is needed.
- Results confirm fast convergence of the estimation error for a trajectory respecting observability conditions (movement in a direction different from the direction to each landmark).

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