Robot Navigation in Unknown Environments: Towards Topographical SLAM

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Introduction

- *The ability of a robot to deterimne its own location relative to the world around it, also known as "navigation", is a crucial component of autonomous robotic exploration.*
- *There are many ways a robot can perform navigation, and each have their advantages and disadvantages in terms of performance and cost.*
- *This research focuses on navigation methodologies that exploit topographical change, changes in heights, to realize robot navigation in previously unexplored enviroments.*

Navigation and SLAM

- Navigation is the process of estimating robot states, such as position and orientation, that are not necessarily directly measured using sensors. Navigation is needed for both path planning and control of autonomous robotic systems.
- **S**imultaneous **L**ocalization **A**nd **M**apping (SLAM) is a specific kind of navigation where a map of the environment is estimated and the robot localizes itself within this estimated map.
- Navigation and, in particular, SLAM enable robot deployment in unknown, never before seen, environments.

Figure: Examples of the applications of SLAM.

Why are navigation and SLAM challenging?

Robots perceive their world through sensors. Though sensors may be accurate, their measurements always contain at least a small amount of noise, meaning their precision varies.

Ideal Sensor

$$\underbrace{\mathbf{y}}_{\text{perfect sensor reading}} = \underbrace{\mathbf{x}}_{\text{perfect tracked state}}$$

Real Sensor

$$\underbrace{\mathbf{y}}_{\text{imperfect sensor reading}} = \mathbf{x} + \underbrace{\mathbf{w}}_{\text{noise}}$$

Sensor noise causes navigation error if not properly accounted for.

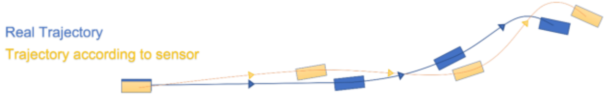

Figure: Representation of the error between real and estimated trajectories.

Therefore, properly accounting for sensor noise, and other uncertainties, is critical in any navigation or SLAM algorithm.

Objective

- A common solution to navigation in unknown environments is employing expensive and computationally heavy computer vision systems.
- The objective of the research is to investigate SLAM methodologies that used cheaper, readily accessible, sensors that leverage different feature of the environement, such as changes in topography.
- In theory, SLAM could be done using only simple sensors such as an *Inertial Measurement Unit* (IMU) and a height sensor to map uneven terrain, which is the starting point of this research.

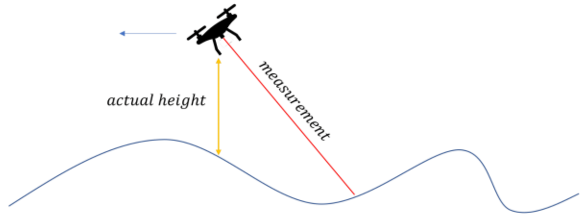

Figure: Representation of the topography-based SLAM problem.

Methods

- ***Kalman Filter*** (KF): The KF is the best, unbiased, linear estimator [1] of state at a certain time based on combined sensor inputs.
- ***Batch Least Squares Optimization*** (BLSO): Finding the most likely set of states that correspond to our sensor readings.

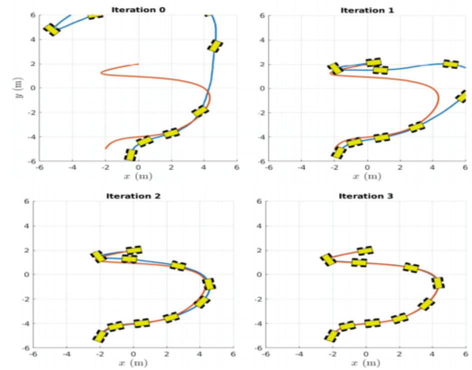

Figure: Batch least squares optimization [2].

- Derivation of state estimators done from **first principles**.
- Validation done on both **simulated and testing use, real datasets**.

Results

- Successful application of KF and BLSO methods has been completed on both linear and nonlinear systems.
- Efficiency of estimation methods has been compared.

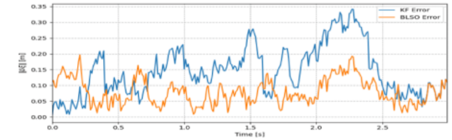

Figure: Comparison of **estimation error** of Kalman filter and BLSO methods for simulated 2D case.

- Simulations show that it is feasible to perform topography-based localization using only an IMU and a laser rangefinder by scanning a ceiling with a known profile.

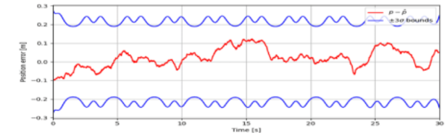

Figure: **Estimation error and** $\pm 3\sigma$ **bounds** of localization using topography sensing.

Future Work

- Extend topography-based navigation to topography-based SLAM.
- Simulate and validate a collaborative approach to topographical SLAM using UWB transceivers for inter-agent communication.

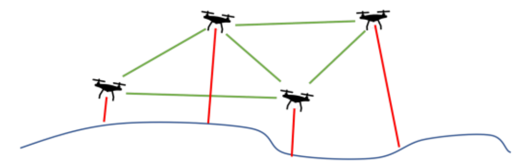

Figure: Collaborative Topographical SLAM.

Acknowledgements

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References

[1] J. Farell, *Aided Navigation: GPS With High Rate Sensors*, McGraw Hill, 2008, pp. 189.
[2] C. C. Cossette and J. R. Forbes, *Batch State Estimation — All Available Data for Estimation —*, McGill University, 2021.