SLAM-based Integrity Monitoring for Multi-Sensors and Multi-Receivers

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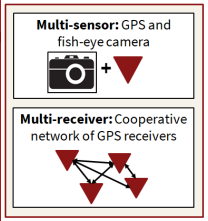
Introduction

- **Integrity** denotes a measure of confidence in the correctness of position estimated by the navigation system
  - Error bound of estimated position is **Protection Level (PL)**
- In **urban environments, measurement redundancy** plays a key role in Integrity Monitoring (IM)
- **Challenges of GPS-only integrity** in urban canyons
  - Tall buildings and thick foliage cause satellite blockage, multipath effects and satellite broadcast anomalies
- **Our solution:** Leverage urban infrastructure to introduce additional redundancy by aiding GPS receiver with sensors that include
  - Visual feature-rich surroundings using camera
  - Cooperative inter-vehicle interactions via ranging

Objectives

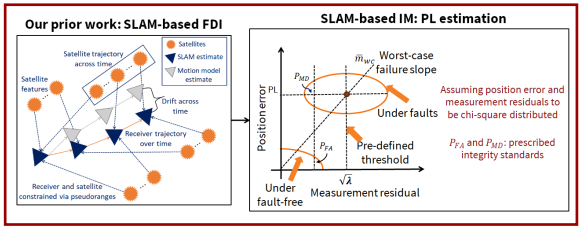
Develop an **aided-GPS IM algorithm** for urban areas, which

- Provides a flexible platform for easy scalability across varied sensors;
- Accounts for multiple measurement faults in different sensors, not just GPS
- Computes the PL of estimated position



Our Prior Work: SLAM-based FDI [1]

- **Simultaneous Localization and Mapping (SLAM)**-based Fault Detection and Isolation (FDI) using GPS-only receiver
  - Simultaneously localizes receiver and landmarks, i.e., satellites
  - Performs **graph optimization** via GPS measurements, motion dynamics of receiver and GPS satellites
- Flexible platform that easily incorporates varied sensors by including sensor features as additional landmarks in the graph
- Requires no prior assumption regarding the distribution of states

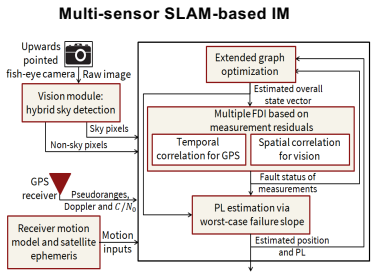


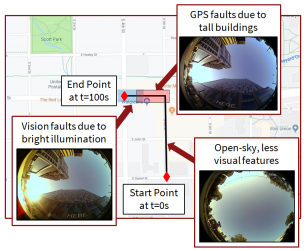
SLAM-based IM: PL Estimation

- PL is derived as **linear function** of the **worst-case failure slope of Graph-SLAM**
  - Failure slope is ratio between the position error and measurement residual
- Worst-case failure slope equals **maximum eigenvalue** of the failure slope formulation [2]
- Depends on fault status of measurements but is independent of absolute fault magnitude

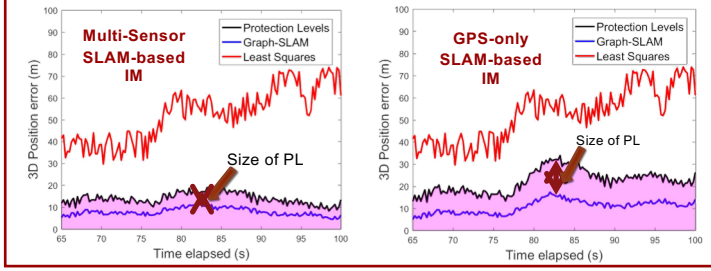
Multi-Sensor SLAM-based IM [3]

- Incorporating pixel intensities from **fish-eye camera** as additional constraints in graph optimization localize key image pixels, receiver and GPS satellites
- In multiple FDI, each measurement assigned binary fault status, i.e., reliable or unreliable
  - Temporal analysis of GPS measurement residuals
  - Analysis of spatial correlation across pixel intensity residuals





Real-world experiments for 100 s in semi-urban area of Champaign, IL experiencing both GPS and vision faults

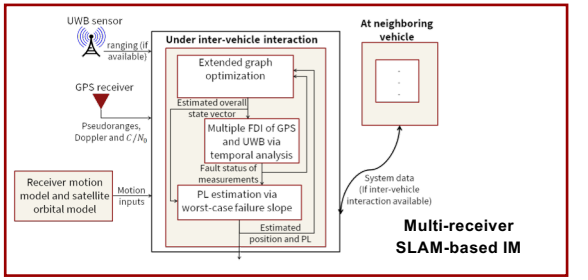


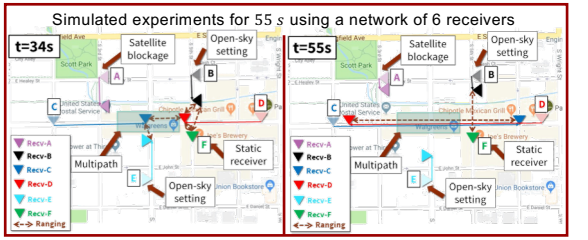
Statistics (m)	SLAM-based IM		Least Squares
	GPS-only	Multi-Sensor	
Position Error	16.2	**8.8**	52.44
Size of PL	10.5	**6.5**	--

Achieved tighter PL via multi-sensor SLAM-based IM as compared to GPS-only SLAM-based IM

Multi-Receiver SLAM-based IM [4]

- **Distributed** approach to Graph-SLAM that additionally utilizes **Ultra-Wide Band (UWB)** ranging across a network of vehicles
- At each vehicle, simultaneously localization of GPS satellites, itself and interacting vehicles





Receivers	Position Error (m)		Size of PL (m)	
	Multiple	Single	Multiple	Single
A (satellite blockage)	**7.0**	8.4	**5.2**	6.0
B (Open-sky)	**5.9**	7.1	**4.3**	5.8
C (Multipath)	**9.1**	12.5	**5.4**	8.4
D (Multipath)	**7.1**	11.6	**4.6**	9.7
E (Open-sky)	**2.4**	3.7	**1.8**	2.1

Lower position errors and tighter PL via multi-receiver SLAM-based IM

Conclusions

- Estimated PL in urban areas using SLAM-based IM via
  - Multi-sensor setup that utilizes GPS and fish-eye camera
  - Multi-receiver that include a cooperative network of vehicles
- Using real-world and simulated experiments, demonstrated higher position accuracy and associated tighter PL

References

[1] S. Bhamidipati, G. X. Gao, "Multiple GPS Fault Detection and Isolation Using a Graph-SLAM Framework," ION GNSS+, Miami, FL, Sept- 2018, pp. 2672-2681

[2] M. Joerger, F. C. Chan, and B. Pervan, "Solution separation versus residual-based RAIM," NAVIGATION: Journal of the Institute of Navigation, vol. 61, no. 4, pp. 273–291, 2014

References

[3] S. Bhamidipati, G. X. Gao, "SLAM-based Integrity Monitoring Using GPS and Fish-eye Camera," ION GNSS+, Miami, FL, Sept 2019, pp. 4116-4129

[4] S. Bhamidipati, G. X. Gao, "Distributed Cooperative SLAM-based Integrity Monitoring Via a Network of Receivers," ION GNSS+, Miami, FL, Sept 2019, pp. 2023-2034

Acknowledgements and Contact

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