P²SLAM: Bearing-Based WiFi SLAM for Indoor Robots

UC San Diego JACOBS SCHOOL OF ENGINEERING

WCSNG Wireless Communications Sensing and Networking

ICRA 2022 IEEE International Conference on Robotics and Automation

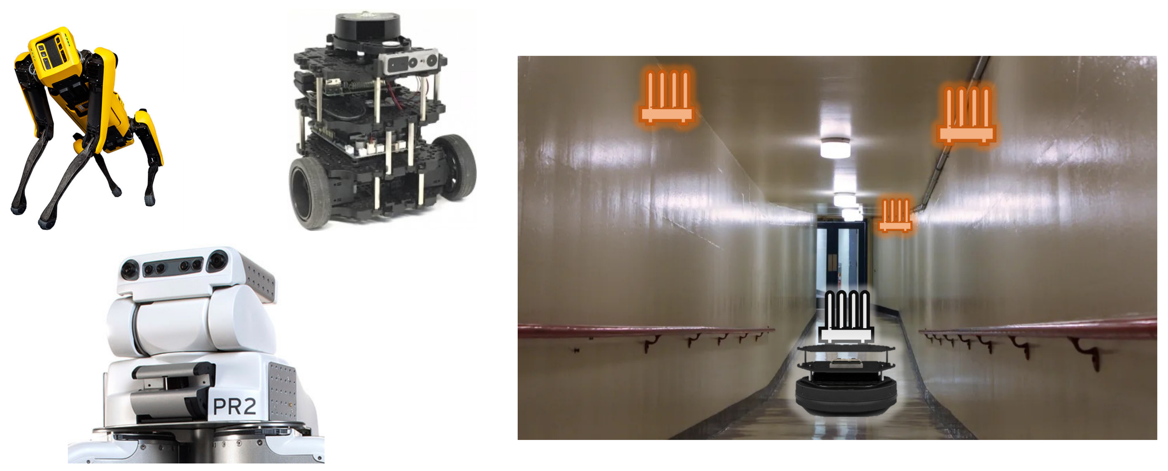
Aditya Arun, Roshan Ayyalasomayajula, William Hunter, Dinesh Bharadia

Electrical and Computer Engineering, UC San Diego

Contact: P.I. Dinesh B. (dineshb@ucsd.edu), Aditya A. (aarun@ucsd.edu)

Link to Website

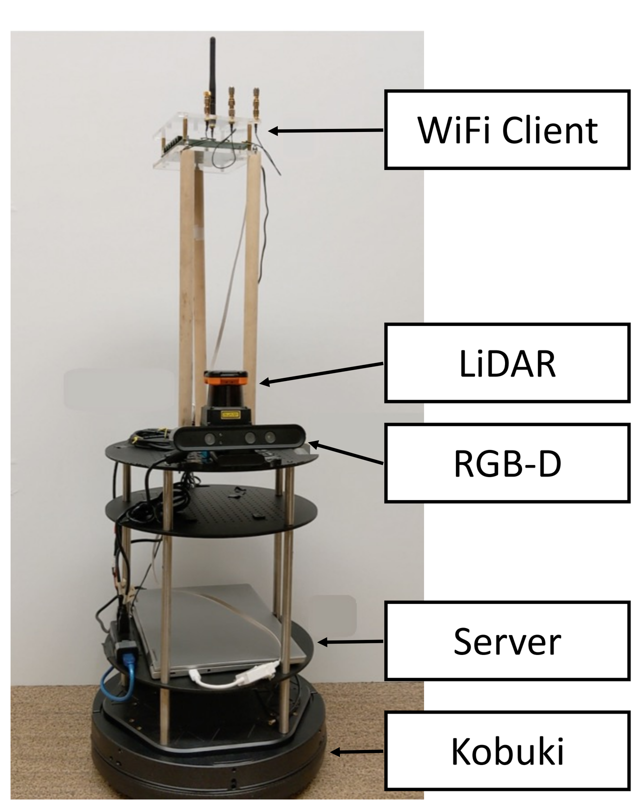
Motivation



- Visual sensors can fail in highly structured or dense environments, and under poor lighting conditions.
- All indoor robots have Wi-Fi devices on them for connectivity.
- Robots can exploit Wi-Fi devices' sensory capabilities to make SLAM systems more robust.

Images: https://www.bostondynamics.com/press-release-spot-commercial-launch

Implementation



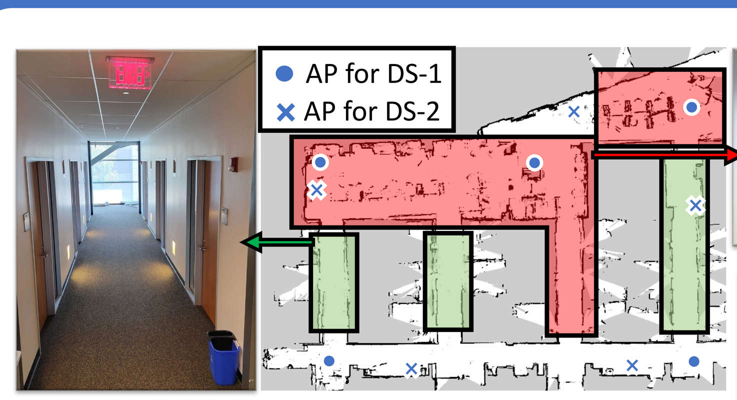
Robot
- Turtlebot 2 running ROS Melodic

Sensors
- Quantenna AP
- Hokuyo UTM-30LX LiDAR
- Intel D415 RGB-D Camera

Ground Truth
- Google Cartographer [1]

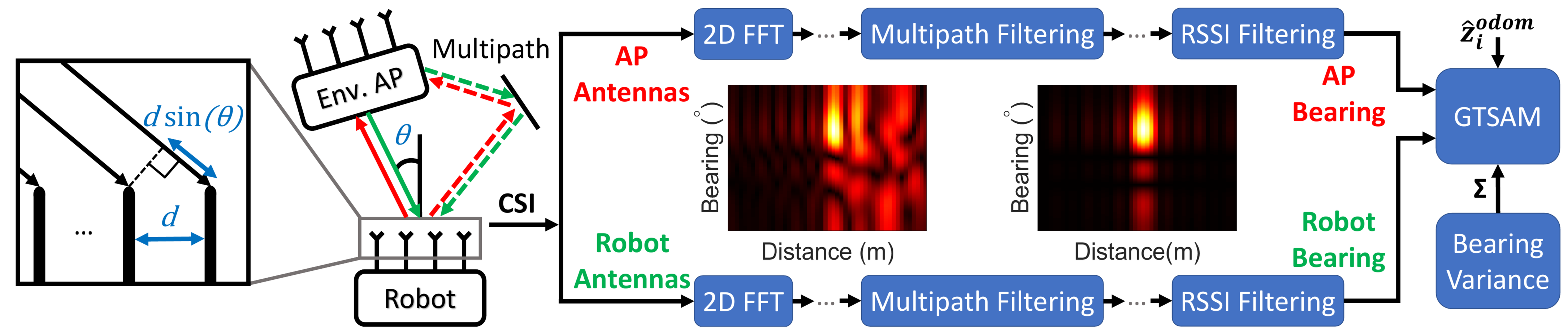
Backend
- GTSAM [3]

Benchmarking
- RTAB-Map [2]



Environment: Tested across diverse range of indoor environments, driving a total distance of over 1,225m.
Difficulty: Emulate realistic trajectories as commonly taken for package delivery or cleaning tasks.

Wi-Fi + Odometry Fusion

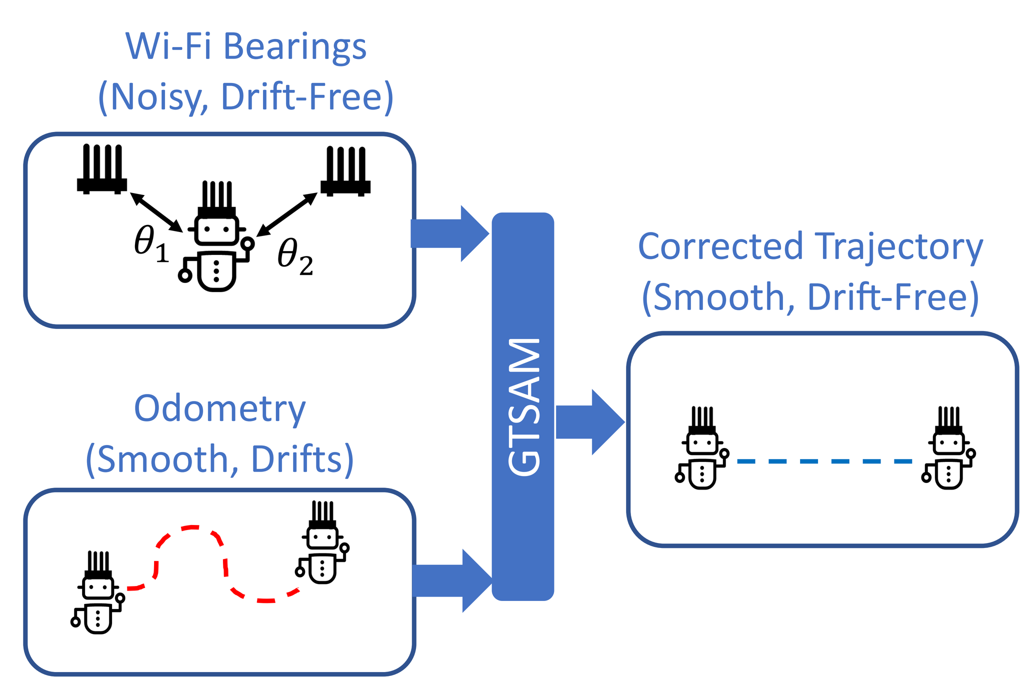


- Wi-Fi signal bearings estimated from a commercially available Wi-Fi card.
- CSI (Channel State Information) is used to estimate the signal's bearing (θ) using the 2D-FFT algorithm.
- We explore using these bearings for a SLAM application.

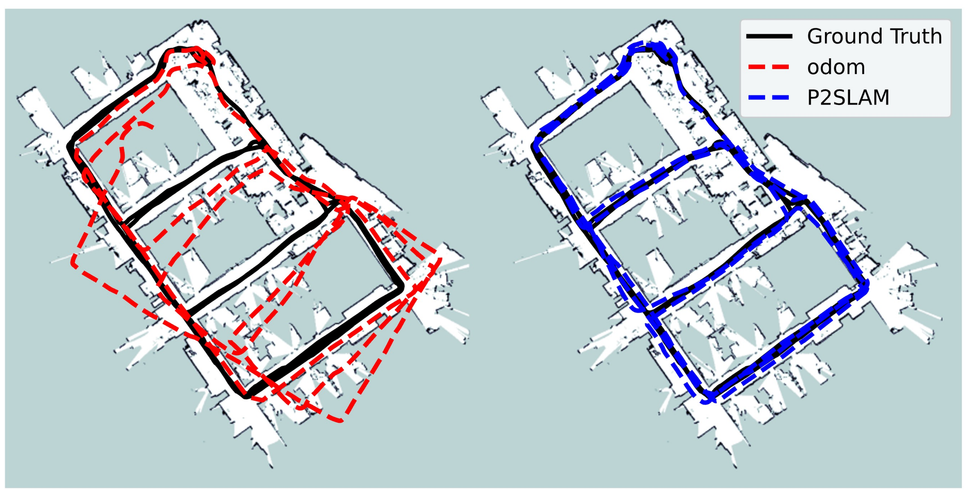
System Design

SLAM

The goal is to combine **Wi-Fi** sensor measurements with the Odometry measurements to compute the most likely trajectory.

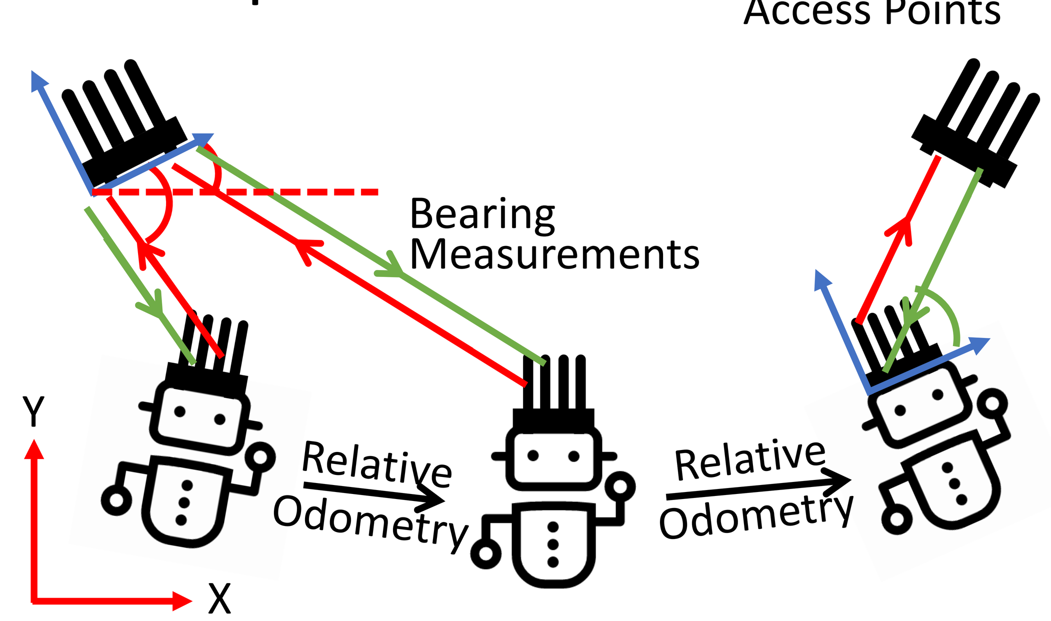


Estimated poses p before and after optimization.

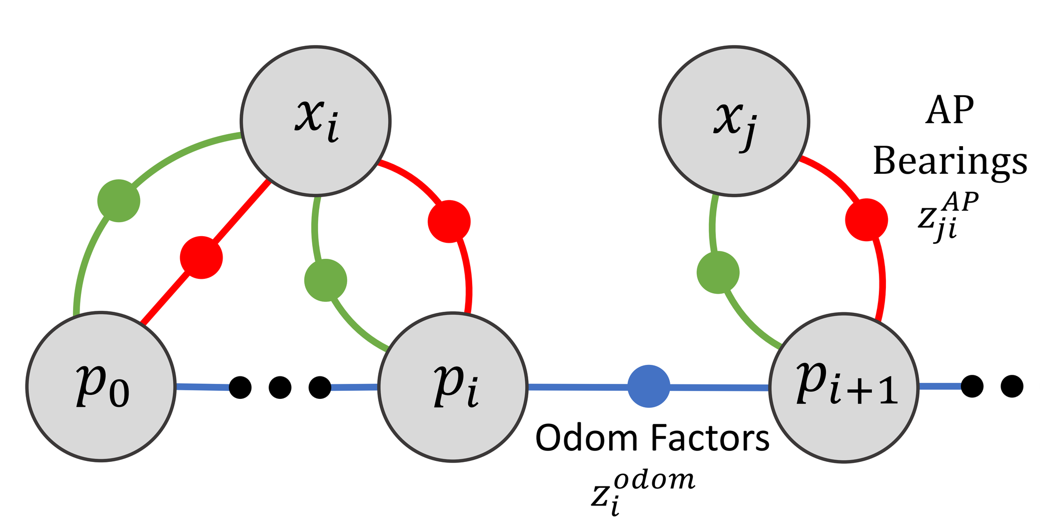


- P²SLAM corrects for odometry drifts without training or a-priori knowledge of the environment.
- P²SLAM is robust to sparse deployment of APs.

Factor Graphs



- Visualization of the real-world sensor measurements.
- Odometry is measured at the robot, and bearings are measured at the robot and the APs.



Factor Graph backend, supported by GTSAM[3]

$$\hat{z}_{ij}^{robot}(p_i, x_j) = R(-p_i^{\theta})\, atan2(x_j^x - p_i^x, x_j^y - p_i^y),\quad p_i, x_j \in SE(2)$$

Robot sided bearing measurement model, can be similarly extended for AP-sided bearings

Related Works

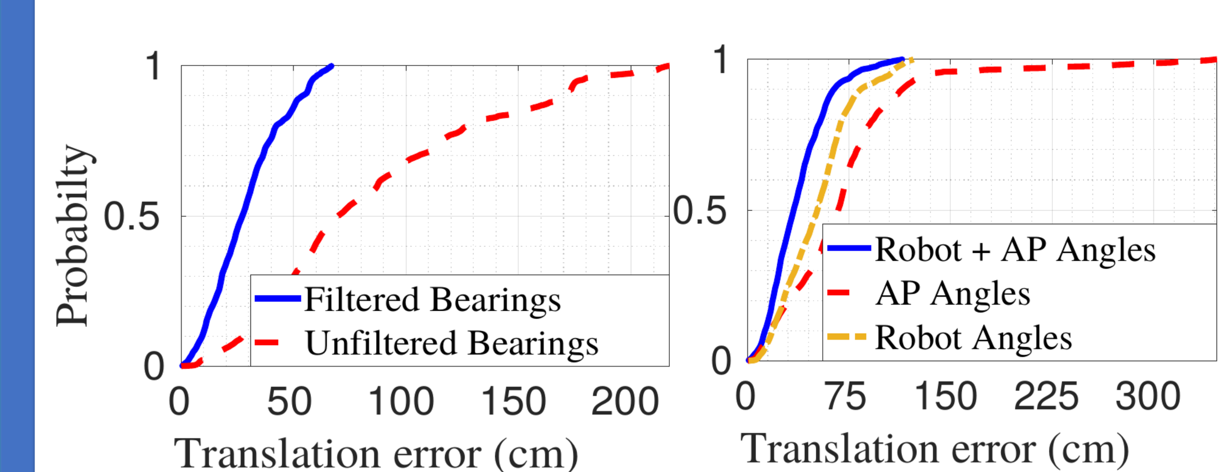
RSSI-based techniques [4, 5, 6]
- Signal strength (RSSI) as a proxy for distance to access point
- Con: Performs poorly in dynamic conditions
- Con: Highly correlated with environment conditions

CSI-based techniques
- Pro: Robust to environment, less affected by reflected paths
- Con: Do not fuse with odometry to provide robot pose [7]
- Con: Rely on dense deployment of WiFi backscatter tags [8]

Results

Algorithm	Env 1-Dataset 1		Env 1-Datset 2		Env 2-Dataset 3	
	Trans [cm]	Orient [°]	Trans [cm]	Orient [°]	Trans [cm]	Orient [°]
Dead-reckoning	180.6 (513.9)	8.64 (18.1)	378.6 (1156)	23.34 (37)	422 (1098)	16 (30.5)
RTAB-Map [2]	36.8 (165.7)	2.97 (10.83)	**38.5 (63.7)**	**0.74 (2.69)**	**61.5** (256)	2.2 (7.99)
P2SLAM	**26.9 (54.7)**	**1.28 (3.16)**	40.4 (76.9)	1.32 (3.7)	65.2 **(158)**	**1.65 (3.95)**

Localization: P²SLAM's trajectory estimates perform on par with RTAB-Map (2), a state-of-the-art SLAM system.



Ablation: (Left) Effect of RSSI filtering on localization performance. (Right) Benefits of two-way bearing measurements.

References

[1] W. Hess, D. Kohler, H. Rapp, and D. Andor, "Real-time loop closure in 2d lidar slam," in 2016 IEEE International Conference on Robotics and Automation (ICRA). IEEE, 2016, pp. 1271–1278.

[2] M. Labb́e and F. Michaud, "Rtab-map as an open-source lidar and visual simultaneous localization and mapping library for large-scale and long-term online operation," Journal of Field Robotics, vol. 36, no. 2, pp. 416–446, 2019.

[3] M. Kaess, H. Johannsson, R. Roberts, V. Ila, J. J. Leonard, and F. Dellaert, "isam2: Incremental smoothing and mapping using the bayes tree," The International Journal of Robotics Research, vol. 31, no. 2, pp. 216–235, 2012.

[4] Ferris, B., Fox, D., & Lawrence, N. D. (2007, January). Wifi-slam using gaussian process latent variable models. In *IJCAI* (Vol. 7, No. 1, pp. 2480-2485).

[5] Huang, J., Millman, D., Quigley, M., Stavens, D., Thrun, S., & Aggarwal, A. (2011, May). Efficient, generalized indoor wifi graphslam. In *2011 IEEE international conference on robotics and automation* (pp. 1038-1043). IEEE.

[6] A. M. Ladd, K. E. Bekris, A. Rudys, G. Marceau, L. E. Kavraki, and D. S. Wallach, "Robotics-Based Location Sensing using Wireless Ethernet," in *Proceedings of the Eight ACM International Conference on Mobile Computing and Networking (MOBICOM 2002)*, Atlanta, GE, 2002, pp. 227–238.

[7] Jadhav, N., Wang, W., Zhang, D., Khatib, O., Kumar, S., & Gil, S. (2020). WSR: A WiFi sensor for collaborative robotics. *arXiv preprint arXiv:2012.04174*.

[8] Zhang, S., Wang, W., Tang, S., Jin, S., & Jiang, T. (2020). Robot-assisted backscatter localization for IoT applications. *IEEE Transactions on Wireless Communications*, *19*(9), 5807-5818.