COLLEGE OF ENGINEERING AND COMPUTER SCIENCE
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"RSSI-based Passive Localization in Complex Outdoor Environments Using Wi-Fi Probe Requests"

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ABSTRACT OF DISSERTATION
RSSI-based Passive Localization in Complex Outdoor Environments Using Wi-Fi Probe Requests

Capturing pedestrian mobility patterns with high fidelity provides a foundation for data-driven decision-making in support of city planning, emergency response, and more. Due to scalability requirements and the sensitive nature of studying pedestrian movements in public spaces, the methods involved must be passive, low-cost, and privacy-centric. Pedestrian localization based on Received Signal Strength Indicator (RSSI) measurements from Wi-Fi probe requests is a promising approach. Probe requests are spontaneously emitted by Wi-Fi-enabled devices, are readily captured by off-the-shelf components, and offer the potential for anonymous RSSI measurement. Given the ubiquity of Wi-Fi-enabled devices carried by pedestrians (e.g., smartphones), RSSI-based passive localization in outdoor environments holds promise for mobility monitoring at scale. To this end, we developed the Mobility Intelligence System (MobIntel), comprising inexpensive sensor hardware to collect RSSI data, a cloud backend for data collection and storage, and web-based visualization tools. The system is deployed along Clematis Street in the heart of downtown West Palm Beach, FL, and over the past three years, over 50 sensors have been installed.

Our research first confirms that RSSI-based passive localization is feasible in a controlled outdoor environment (i.e., no obstructions and little signal interference), achieving ≤ 4 m localization error in more than 90% of the cases. When significant time-varying signal fluctuations are introduced as a result of long-term deployment, performance can be maintained with an overhaul of the problem formulation and an updated localization model. However, when the outdoor environment is fully uncontrolled (e.g., along Clematis Street), the performance decreases to ≤ 4 m error in fewer than 70% of the cases. However, the drop in performance may be addressed through improved sensor maintenance, additional data collection, and appropriate domain knowledge.

This dissertation presents the following contributions:

1. We design and build a robust Wi-Fi probe request sensor that uploads data via a 4G/LTE network, possesses self-diagnostic mechanisms, allows remote control, and supports over-the-air software updates.

2. We systematically explore methods to conduct RSSI-based passive localization in a controlled environment with minimal signal fluctuations. We determine that methods based on traditional fingerprinting and support vector machines achieve the best performance, with ≤ 4 m error in more than 90% of the cases.
3. We observe significant performance degradation after RSSI temporal fluctuations are introduced and show that the performance can be restored by reformulating the localization problem, using a new multi-stage model, and discarding data of poor quality (approximately 30%).
4. We collect an RSSI dataset for localization purposes on Clematis Street. We present the dataset, describe the challenges of using it, and make it publicly available.
5. We introduce a final localization model for real-world deployment. It can achieve ≤ 4 m error in approximately 70% of the cases with roughly 20% of the data discarded. We investigate possible causes that impair the performance and propose potential improvements.

In summary, with the development of MobIntel and the confirmation that Wi-Fi RSSI-based passive localization is feasible in complex outdoor environments, our research has taken the next steps toward monitoring pedestrian mobility patterns in a passive, low-cost, and privacy-centric manner.

BIOGRAPHICAL SKETCH

Born in Shanghai, China
B.S. Biological Sciences, Peking University, Beijing, China, 2012
M.S. Forensic Science, Florida International University, Miami, Florida, 2015
M.S. Exercise Science, Florida Atlantic University, Boca Raton, Florida, 2017
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CONCERNING PERIOD OF PREPARATION
& QUALIFYING EXAMINATION

Time in Preparation: 2019 - 2023

Qualifying Examination Passed: Fall 2021

Published Papers:

- S. Mazokha, **F. Bao**, J. Zhai, and J. O. Hallstrom, "MobIntel: Sensing and analytics infrastructure for urban mobility intelligence," Pervasive and Mobile Computing, vol. 77, p. 101475, Oct. 2021.
- S. Mazokha, **F. Bao**, G. Sklivanitis and J. O. Hallstrom, "Urban-scale Testbed Infrastructure for Data-driven Wireless Research," 2021 IEEE 4th 5G World Forum (5GWF), Montreal, QC, Canada, 2021, pp. 517-522, doi: 10.1109/5GWF52925.2021.00097.
- **F. Bao**, S. Mazokha, and J. O. Hallstrom, "Mobintel: Passive outdoor localization via rssi and machine learning," in 2021 17th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob), 2021, pp. 247–252.
- **F. Bao**, S. Mazokha, and J. O. Hallstrom, "Mobility Intelligence: Machine Learning Methods for Received Signal Strength Indicator-based Passive Outdoor Localization," Advances in Science, Technology and Engineering Systems Journal, vol. 7, no. 6, pp. 269–282, Dec. 2022.
- **F. Bao**, S. Mazokha, and J. O. Hallstrom, "Addressing RSSI Fluctuation in Wi-Fi-based, Passive Outdoor Localization," IEEE Internet of Things, **In Submission**
- **F. Bao**, S. Mazokha, and J. O. Hallstrom, "RSSI-based Passive Localization in the Wild, at Streetscape Scales," **To Be Submitted**