Battery-free Real-time Localization of Autonomous Robot Swarms Using UWB

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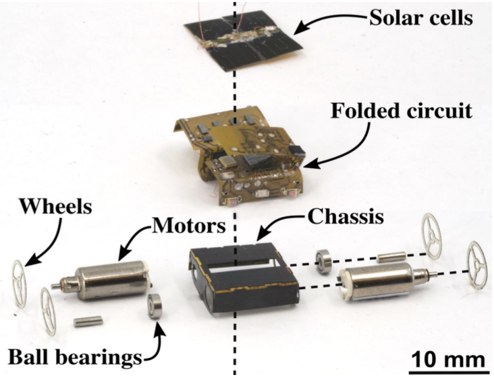
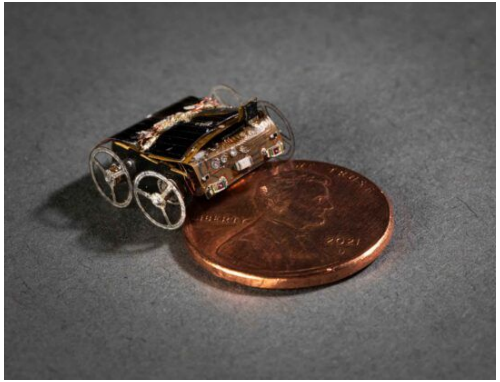
Problem Statement

How can small-scale, battery-free, autonomous robots achieve precise, energy-efficient localization and communication?

Problem Breakdown

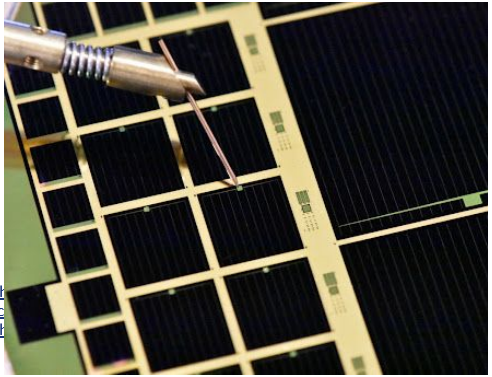


Battery-free[2]

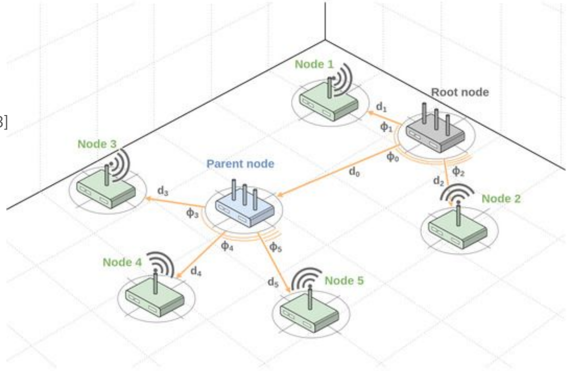


Localization[4]

Small-scale[1]



Autonomous[3]



Source [1]: https://www.geekwire.com/2023/univ-of-washington-research
Source [2]: http://mldevices.com/index.php/news/67-microlink-devices-ac
Source [3]: https://www.geekwire.com/2023/univ-of-washington-research
Source [4]: https://www.mdpi.com/1424-8220/24/12/3925

Communication Background

Technology	Accuracy	Range	Power Consumption	Cost	Use Cases
UWB	~10-30 cm	10-100 meters	Moderate (High during Tx)	Higher	Precise localization, industrial automation
BLE	~1-5 meters	100-200 meters	Low	Low	Asset tracking, indoor navigation
Wi-Fi	~5-15 meters	100-300 meters	High	Moderate	Large-area tracking, location-based services
Zigbee	~5-10 meters	50-100 meters (mesh)	Low	Low	Mesh-based, low-power tracking
RFID	~1 meter (passive)	1-10 meters (active)	Very low (passive)	Very low	Inventory tracking, proximity-based detection

Motivation

Applications of Mobile Sensing Robots

Agricultural Monitoring (Smart Farms)

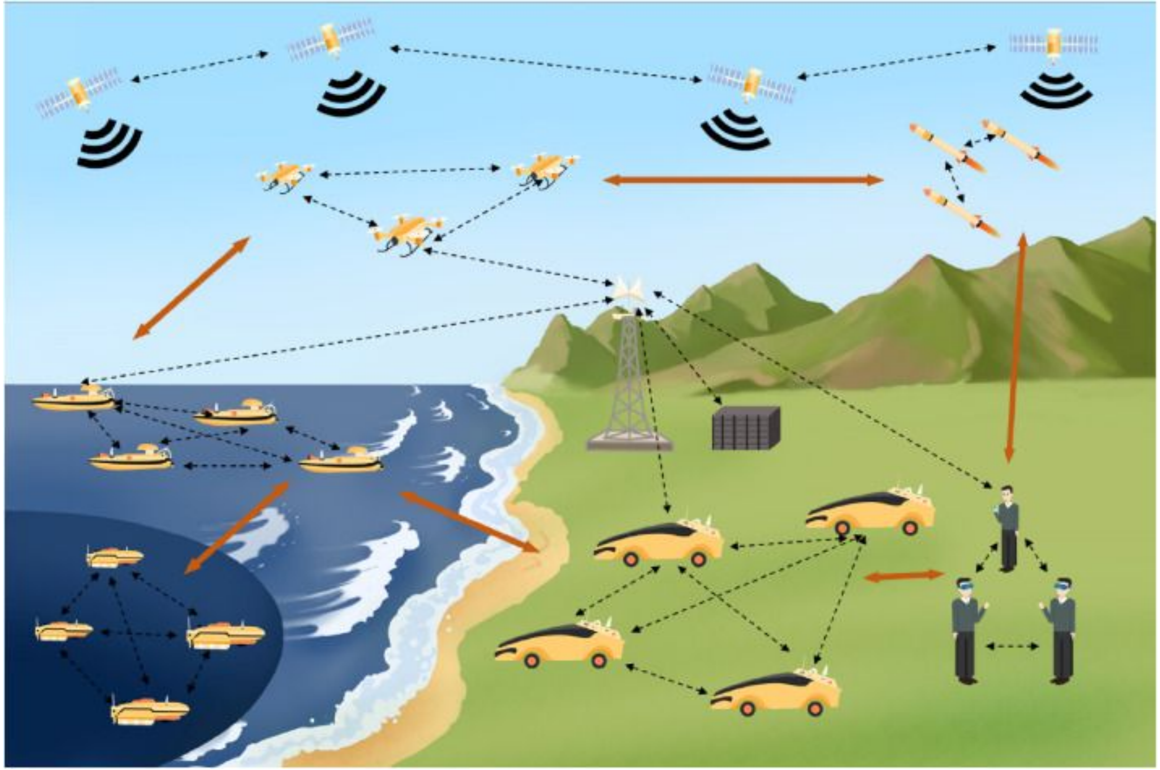
Hazardous Environmental Sensing

Industrial Infrastructure Inspection

Seed Planting and Tracking (Outdoor)

Image Credit: Mark Stone/University of Washington & Desaseni

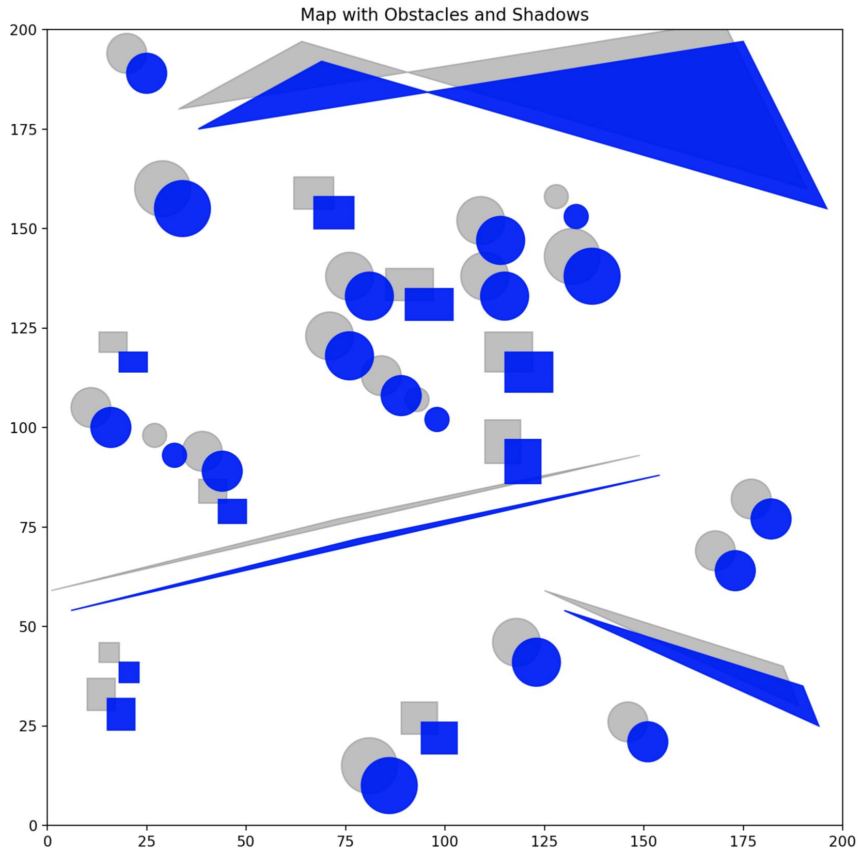
What does this all mean?



Source [1]: https://www.sciencedirect.com/science/article/pii/S2214914723001368

Expected Results

Simulation



Map with Obstacles and Shadows
200
175
150
125
100
75
50
25
0
0
25
50
75
100
125
150
175
200

Expected Results

Area of Investigation	Key Results / Metrics
Localization Accuracy	- Avg. error (cm) across swarm sizes and anchor densities
Power Consumption	- Power per robot (μW) and efficiency of duty-cycling
Localization Range	- Max distance with accurate localization
Anchor Node Optimization	- Min. number of anchors for reliable localization
Path Planning Efficiency	- Area covered (%) vs. energy usage per robot
Duty Cycling (UWB + BLE)	- Efficiency of UWB duty-cycling + BLE coordination
Dynamic Leader Selection	- Impact of dynamic leader selection on energy use and coverage
Environmental Factors	- Effect of light, obstacles on localization and energy

Expected Conclusions

Benchmarks

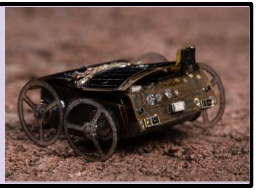
Table.1. System and Performance Comparison

	Mapping Accuracy	Battery free	Weight	Total Power	Computing Power	Reference
This work	<30cm	Yes	<2g(?)	<1mW(?)	<1mW(?)	
1	<30cm	No	46g	8.96W	960mW	[1]
2	8-12cm	No	35.68g	10W	200mW	[2]
3	10-15cm	No	34.8g	5-10W	240mW	[3]
4	8-10cm	No	44g	5-10W	350mW	[4]
5	2.14cm	No	>2kg	100W	30W	[5]

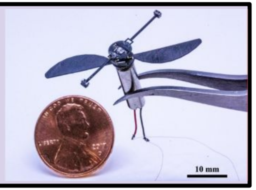
Future Work

Origami Microfliers. Wind dispersed sensors

MilliMobiles. Intermittent ground locomotion



Autonomous Aerial Microrobots. Collaboration



References

[1] Niculescu, Vlad, et al. "Ultra-Lightweight Collaborative Mapping for Robot Swarms." *arXiv preprint arXiv:2407.03136* (2024).

[2] McGuire, K. N., et al. "Minimal navigation solution for a swarm of tiny flying robots to explore an unknown environment." *Science Robotics* 4.35 (2019): eaaw9710.

[3] Friess, Carl, et al. "Fully Onboard SLAM for Distributed Mapping with a Swarm of Nano-Drones." *IEEE Internet of Things Journal* (2024).

[4] Niculescu, Vlad, et al. "NanoSLAM: Enabling fully onboard slam for tiny robots." *IEEE Internet of Things Journal* (2023).

[5] Shen, Hongming, et al. "PGO-LIOM: Tightly coupled LiDAR-inertial odometry and mapping via parallel and gradient-free optimization." *IEEE Transactions on Industrial Electronics* 70.11 (2022): 11453-11463.