



A Comprehensive Review of Indoor Localization Techniques for Autonomous Robots

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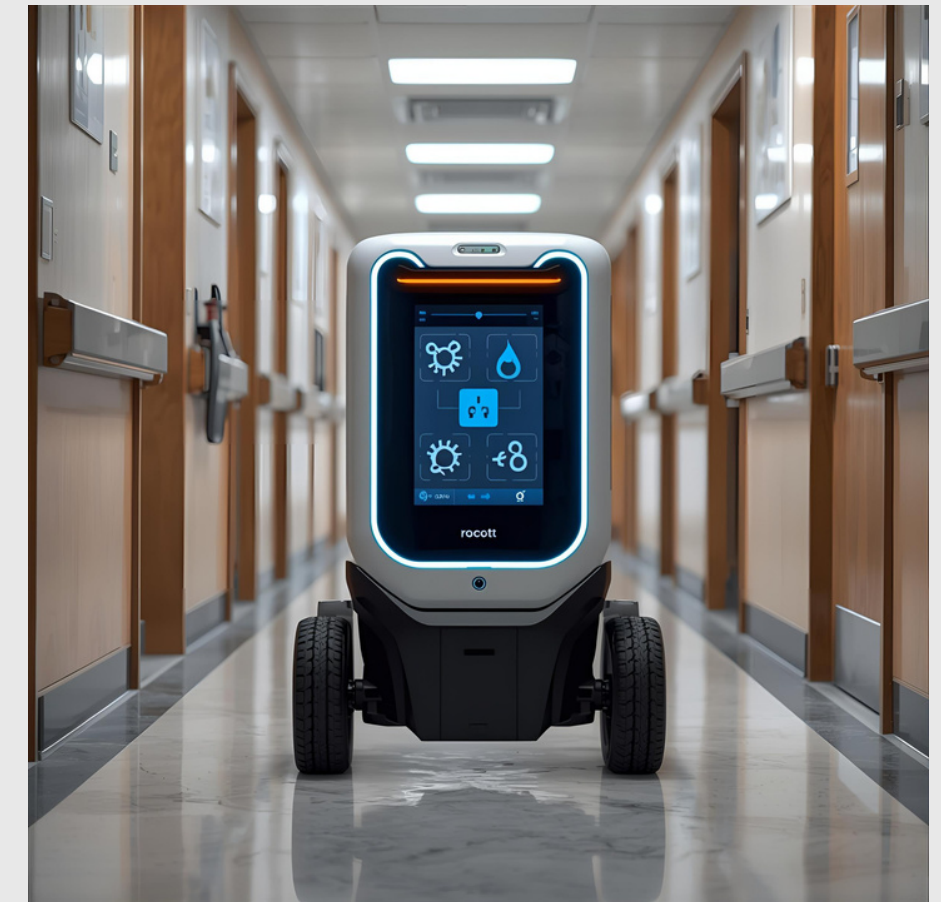
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Motivation

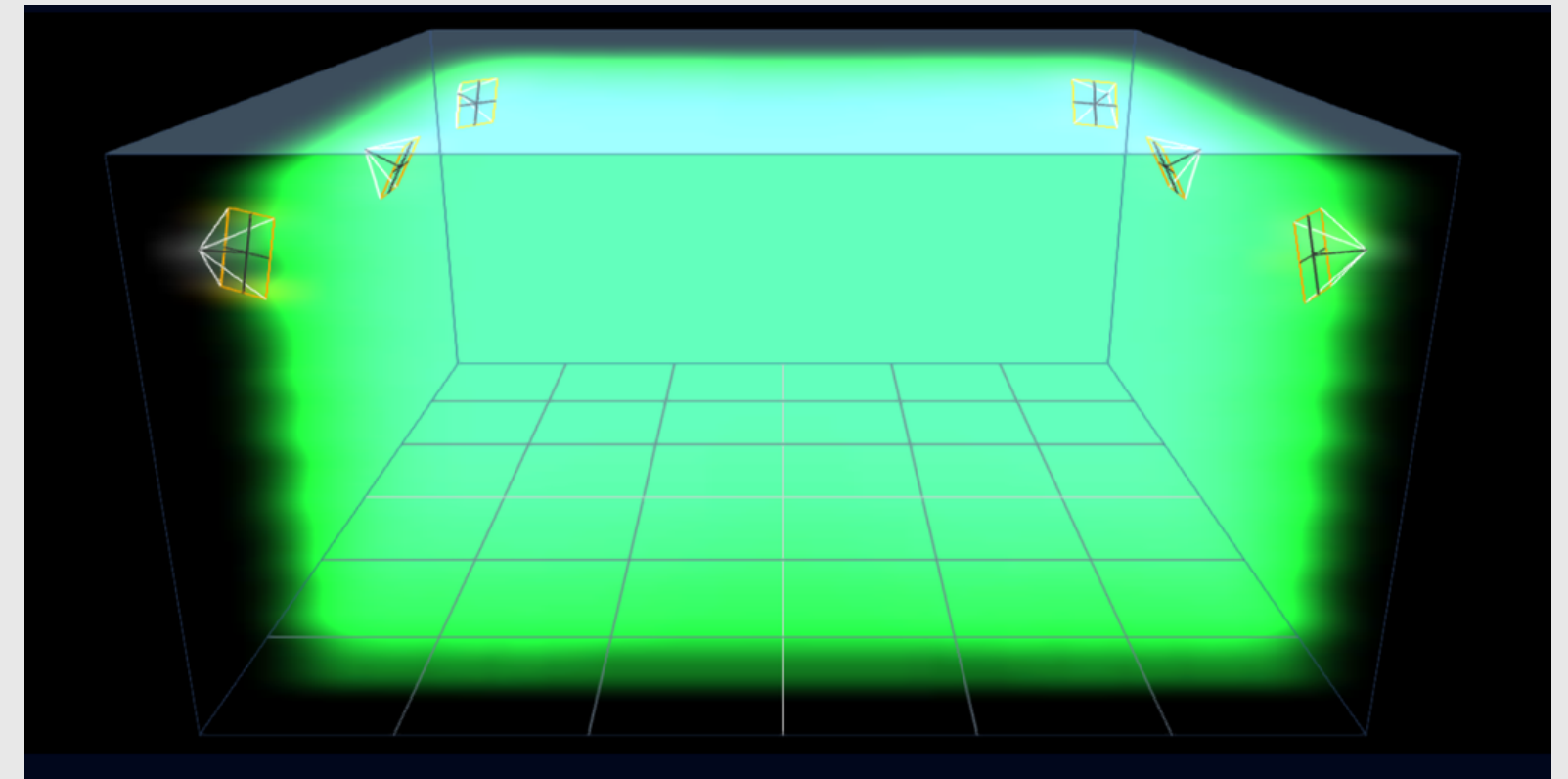
- **Increasingly use of robots indoors**
 - warehouses, hospitals, homes etc..
- **GPS is unreliable indoors**
 - need of alternatives
- **Trade-off:** Accuracy vs Cost vs Infrastructure
- **Robots must adapt in dynamic environments in real time**



Problem statement

Balancing accuracy, cost and scalability

- **High-precision systems** (eg: Vicon[1])
 - too costly
- **Affordable methods**
 - lack accuracy
- **Need:**
 - scalable
 - low-cost
 - real-time



Vicon Heat Map for tracking

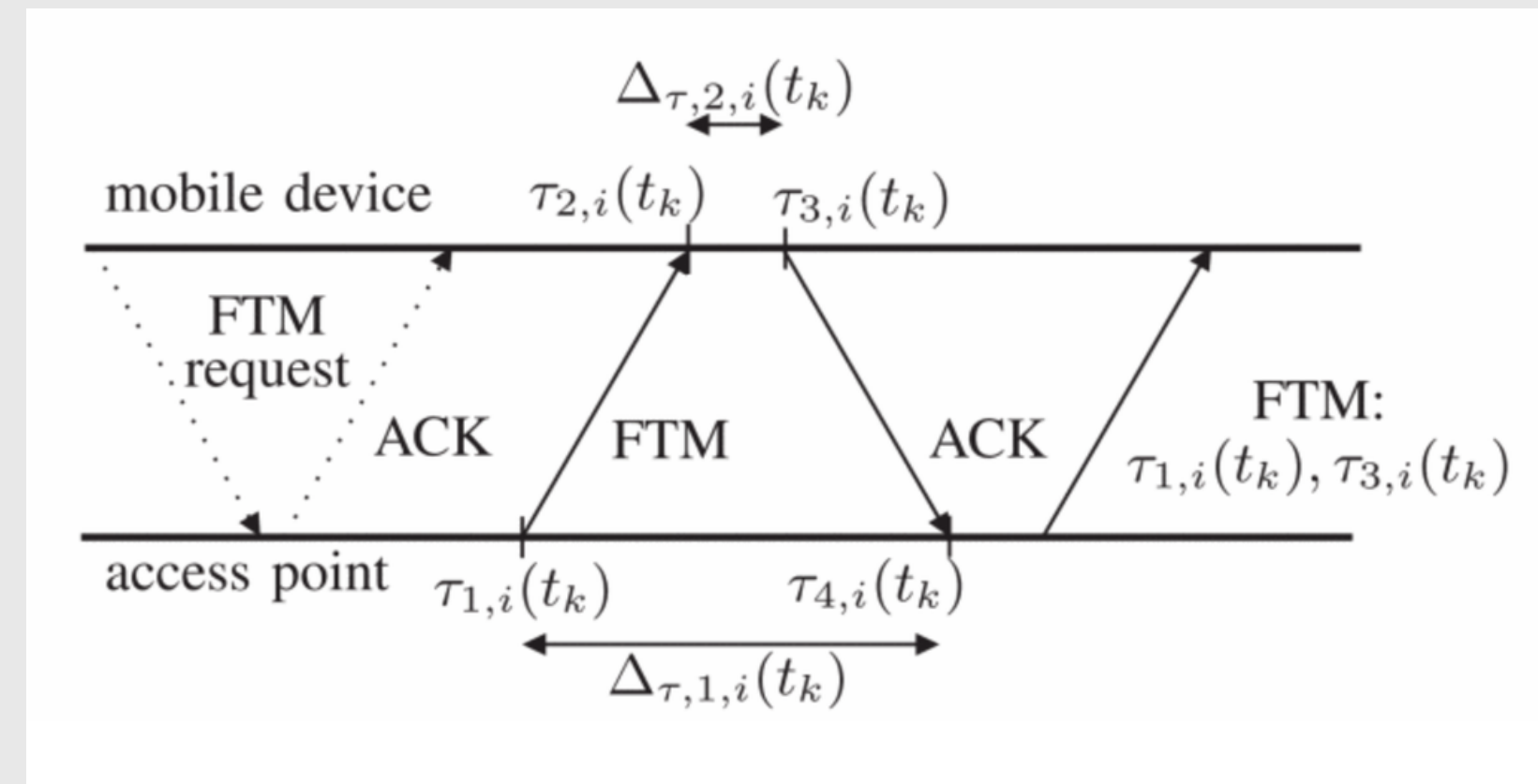
Overview of Techniques

- **Radio Frequency**
 - WiFi, UWB, BLE
- **IMU-based**
 - Dead Reckoning
- **Vision-based**
 - marker, marker-free, VLP
- **Sensor Fusion approaches**



Wi-Fi Approaches

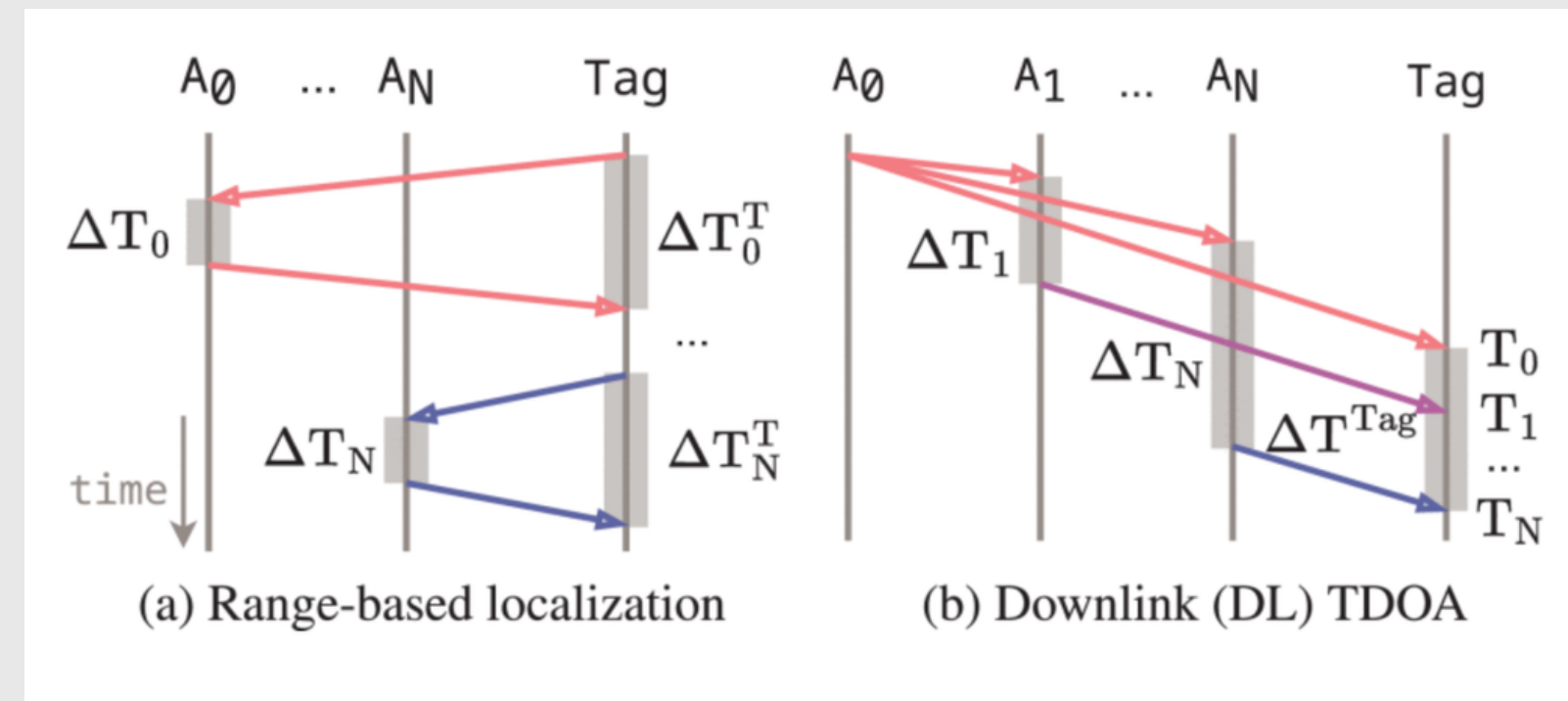
- Cheap, existing infrastructure
- Fingerprinting / RTT:
 - errors in meters
- UAV localization[2]:
 - <5% radio range error
- Limitations:
 - interference
 - multipath
 - low update rate



Overview of Wi-Fi FTM protocol

Ultra-Wideband (UWB)

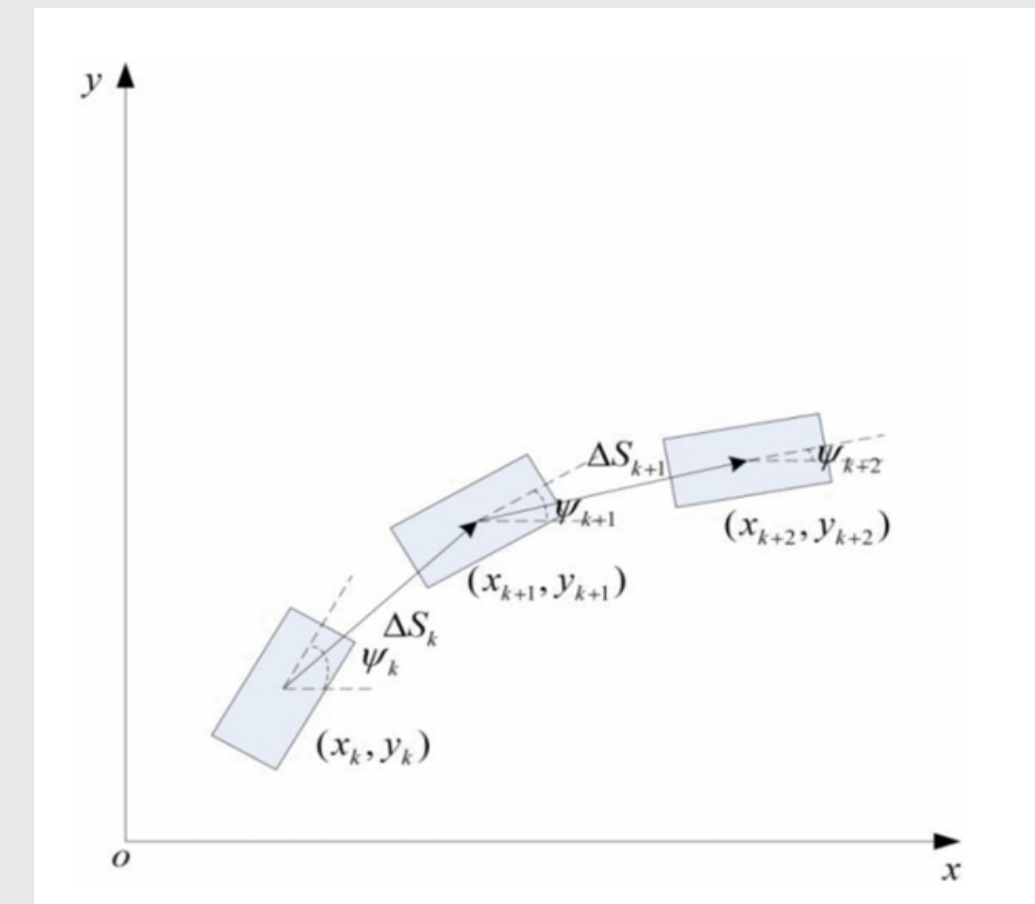
- **Accuracy ~20 cm**
 - **FlexTDOA**[3] reduces errors by 38%
- **High update rate (10–100 Hz)**
- **Scales for multi-robot use**
- **Limitations:**
 - cost
 - NLOS sensitivity
 - coverage area



Localization based on TWR or on DL TDOA[3]

IMU Dead-Reckoning

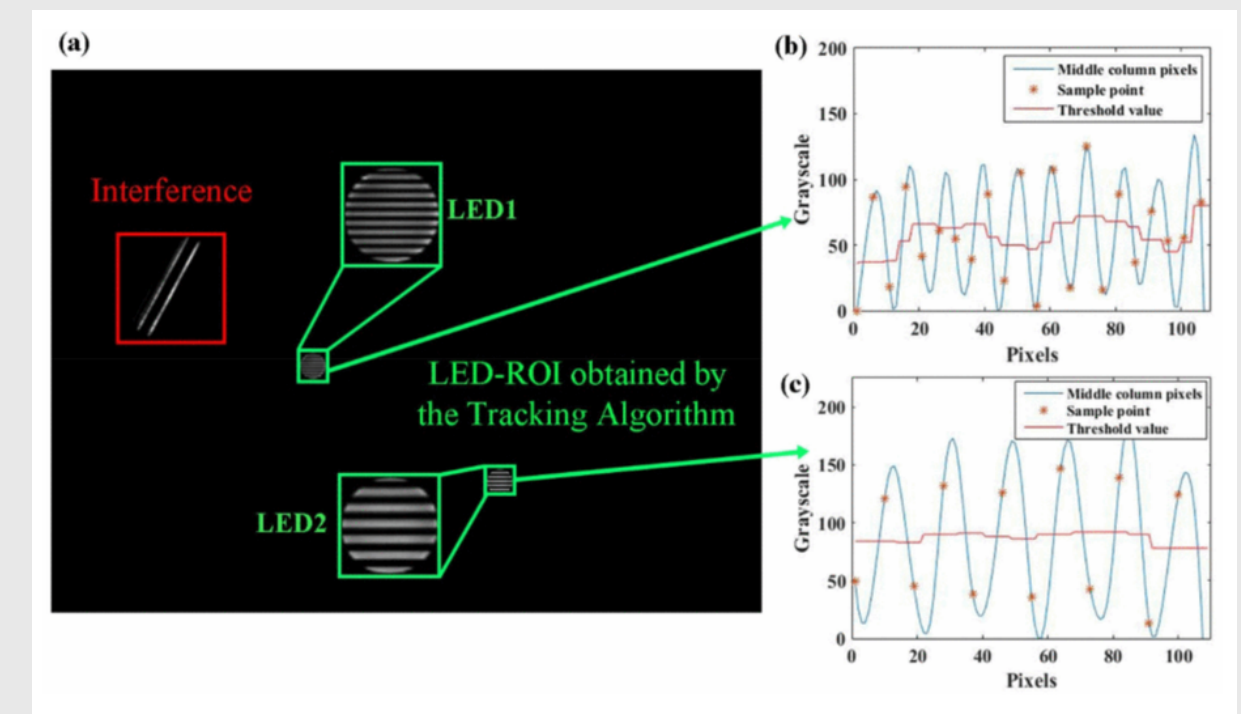
- Cheap, power-efficient, self-contained
- Provides high-frequency updates
- Limitations:
 - errors accumulate (drift)
 - needs correction
- Often fused with vision or RF for accuracy



Dead-reckoning principle in 2D plane

Vision-Based Methods

- **Cameras detect features or markers for localization**
- **Visible Light Positioning (VLP)[4]:**
 - Uses LED lights as reference points
 - Achieves centimeter-level accuracy (<1 cm)
 - Fast response (~ 12.5 Hz)
- **Challenges:**
 - requires line-of-sight
 - sensitive to lighting & occlusions
- **Medium computational demand (lightweight algorithms exist)**



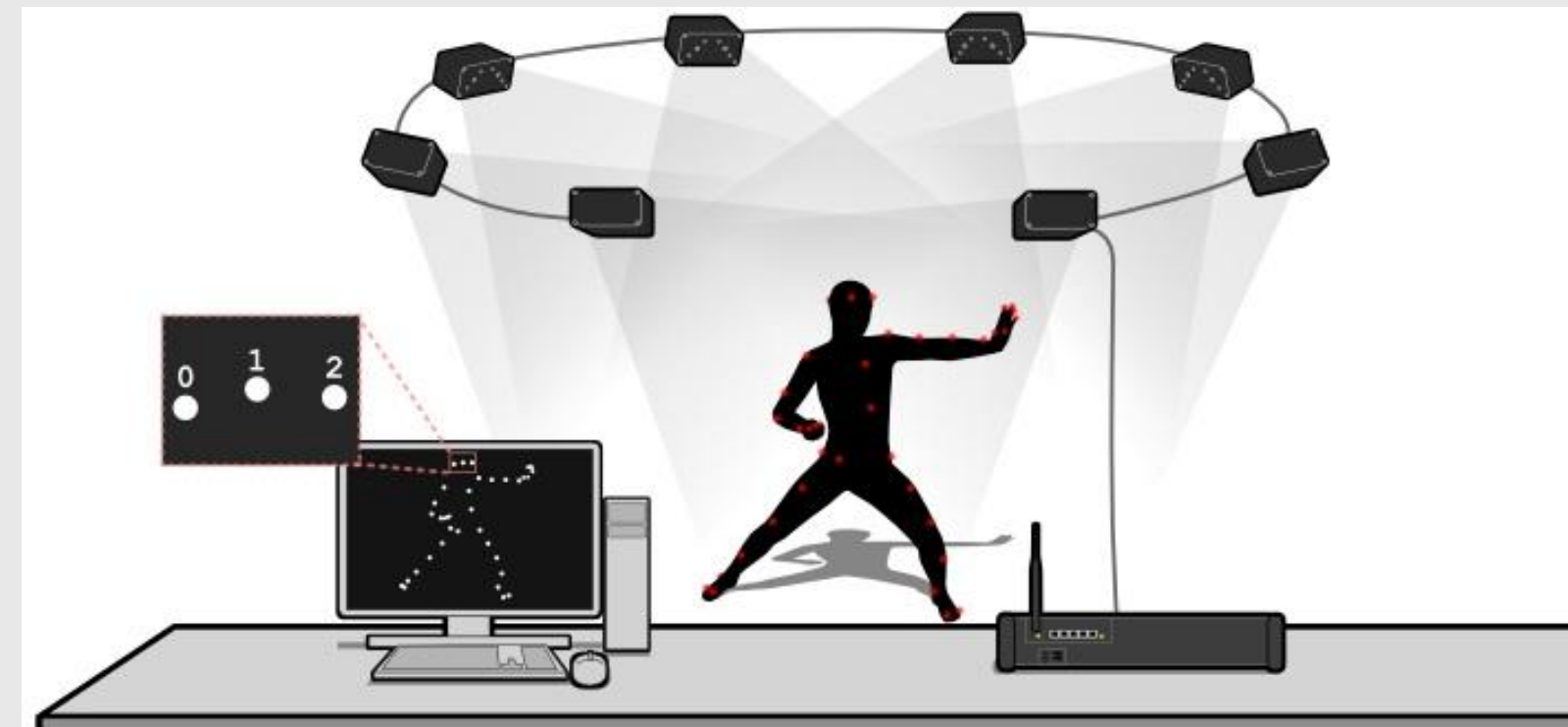
The original frame obtained by the camera; (b) and (c) Experimental grayscale value pattern and the applied LEXW scheme (red curve) for two LED-ROI. [13]

Sensor Fusion

- **Combines:**
 - **IMU** (fast)
 - **Vision** (global)
 - **RF** (anchors)
 - **Enables real-time corrections and long-term accuracy**
 - **Achieves decimeter–centimeter precision**
 - **Robust choice for indoor robotics**
-

Commercial Systems

- **Vicon:**
 - millimeter accuracy
 - expensive
 - research only
- **HTC Vive Tracker:**
 - sub-mm accuracy
 - cheaper
- **Trade-off:**
 - Vive limited to base-station setup



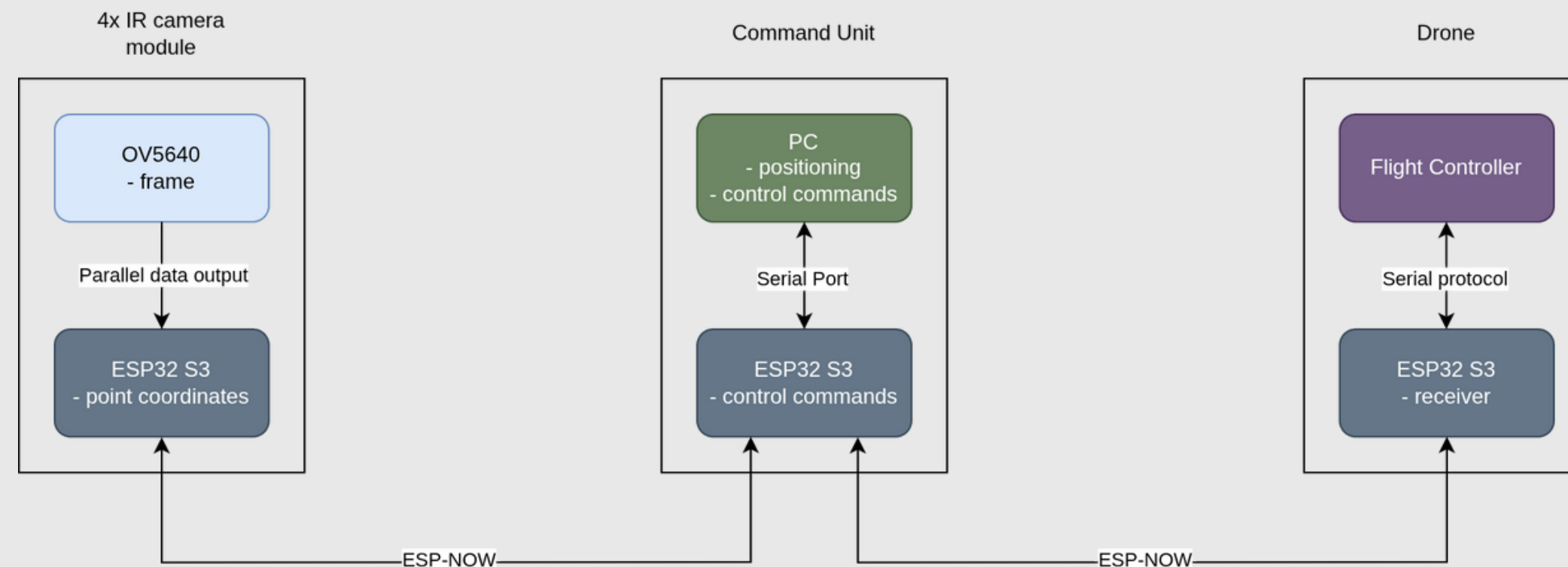
Vicon MoCap System

Comparative Analysis

Technique	WiFi-RTT	UWB	IMU	Computer Vision (VLP)	Vicon	Vive Tracker
Typical Accuracy	Errors on the order of meters; in UAV, <5% of the radio range error	20 cm mean error; FlexTDOA reduces errors up to 38% vs. classic approaches	Inadequate as standalone; decimeter-level accuracy on fusion	Centimeter-level (ROS-integrated VLP reported <1 cm)	Millimeter-level	Sub-millimeter level
Update Rate	1-5 HZ	10-100Hz	Real-time operation (fused)	0.08s processing time(12.5Hz)	Tens to hundreds of Hz	90Hz (real-time performance)
Infrastructure Requirements	Existing WiFi access points	Dedicated UWB anchors	None (self-contained sensors)	Requires cameras/ markers	Multiple high-speed IR cameras; reflective markers	Lighthouse base stations
Computational Cost	Low (not explicitly reported)	Higher computational demands	Very low cost and reduced power consumption	Medium (lightweight detection algorithms)	Complex software for data processing	Wireless; host computer required

Proposed Research Direction

- Vision-centric architecture with RF corrections
- Automatic calibration
- Affordable and scalable
- Target: precise localization for budget robots



System architecture

Conclusion

- Indoor localization is crucial for autonomous robots
- Each technique has trade-offs in accuracy, cost, infrastructure
- Sensor fusion is the most promising approach
- Future: lightweight, adaptive, vision-centric systems

