Hospital Indoor Localization & Behavior Analysis

USE CASE – V2.

1. Medical Environments

1.1 Patient-Related

- **Activity Tracking**
  - Movement between room → corridor → public areas
  - Analysis of speed, activity frequency, and dwell points
- **Risk Event Detection**
  - Fall detection
  - Alerts when patients enter restricted zones (ICU or isolation rooms…)

1.2 Staff

- Rounding path monitoring / identifying
- Workload & crowded areas detection
- Process optimization

1.3 Medical Equipment

- **Real-Time Asset Tracking**
  - Wheelchairs
  - beds…
- **Usage Pattern Analysis**
  - Usage frequency
  - Movement cycles

2. Constraints in Hospital Environments

2.1 Radio Environment Instability

- Surveyed literature emphasizes that indoor environments (especially hospitals) cause high variability in wireless signals due to obstacles and dynamic conditions.
  Source: A Survey on Indoor Positioning Systems for IoT-Based Applications
- Frequent movement of beds, metallic equipment, human crowds, and door opening/closing causes multipath, fading, and severe RSSI fluctuations.

2.2 Interference from Medical Devices

- Imaging devices and electronic medical equipment generate electromagnetic emissions that may interfere with localization technologies.

2.3 Privacy and Ethical Limitations

- Sensors must comply with medical privacy standards.
- Wearable-based solutions for patients may require consent and approval.

2.4 Deployment & Operational Constraints

- Hospitals often avoid major infrastructure changes.
- low-maintenance and low-cost solutions.
- Multiple technologies (Wi-Fi, BLE, IR, ultrasound) coexist (increasing system management complexity).

3. Existing Localization Solutions (in Hospitals)

Wi-Fi RSSI-Based Localization	◆ RSSI value. ◆ Simple, widely available due to existing Access Points. ◆ Typical accuracy: 2–4 meters in real indoor conditions. ◆ High interference, limited accuracy.
RSSI Fingerprinting Systems	◆ Offline fingerprint database + online matching. ◆ Achieves sub-meter accuracy (≈ 60 cm under ideal conditions). ◆ Highly sensitive to environmental changes. ◆ Labor-intensive to maintain.
Bluetooth Low Energy (BLE)	◆ RSSI beacon sequences (requires beacon deployment) ◆ Low deployment cost, low power consumption. ◆ Works well for room-level or corridor-level localization ◆ Sensitive to environmental dynamics.
Ultra-Wideband (UWB)	◆ Uses ToF / TDoA measurements ◆ Provides high accuracy (cm-level). ◆ High cost & infrastructure requirements
IMU-Based Behavioral Monitoring	◆ IMU accelerometers/gyroscopes → fall detection ◆ Requires wearable devices

4. Sensors and Methods Used in Hospital Localization

4.1 Sensors

Wi-Fi RSSI	Uses existing APs; supports fingerprinting or signal-model methods	RSSI values	Good for coarse localization; affected by multipath	high interference, limited accuracy.
BLE	Low cost; RSSI-based	RSSI beacon sequences	Suitable for basic tracking and geofencing	requires beacon deployment; sensitive to environment.
UWB	ToF/TDoA; cm-level accuracy	Ranging distance / XYZ position	Best for asset tracking and precise zones	expensive; requires approval; deployment complexity.
IMU	Acceleration/gyro for behavior inference	3-axis acceleration	Useful for fall detection & motion analysis	wearable required; patient consent needed
RFID	Electromagnetic field activates tags and returns ID at short range.	Tag ID	Good for tracking equipment presence and movement.	not suitable for human

4.2 Methods

POSITIONING TECHNIQUE COMPARISONS

Technique	Technology	Accuracy	Computation	Latency	Synchronization	Implementation
ToA	UWB	A few to tens of centimeters	Medium	Hard Realtime	Yes	LoS is required
TDoA	UWB	A few to tens of centimeters	Medium	Hard Realtime	Yes	Larger bandwidth and easier than ToA
RTT	UWB	A few centimeters	Medium	Hard Realtime	No	Higher delay in UWB
PoA	RFID	Tens of centimeter to a few meters	High	Soft Realtime	Yes	LoS is required for high accuracy, use as supplementary method
RSSI	BLE	Tens of centimeters to a few meters	Low	Hard Realtime	No	Prone to multi-path, environmental noise, inexpensive but labor intensive in wide areas
CSI	WiFi	Tens of centimeters with several APs	Medium	Hard Realtime	No	Labor-intensive site survey calibration
PSRP - PSRQ	Cellular	A few meters	High	Soft Realtime	No	Need Cellular
AoA	BLE 5.1	A few meters to tens of centimeter	High	Soft Realtime	No	Fewer nodes is required, not accurate in long distance and NLoS and few practical use cases

- **Distance & Angle-Based Approaches**
  - **ToA / TDoA**: Used in UWB; requires synchronization.

- **AoA**: Supported by BLE 5.1 antenna arrays; higher deployment cost.

- **RSSI Fingerprinting**
  - Widely used in hospitals: easy to deploy
  - Common algorithms include KNN, SVM, probabilistic models, and deep learning.
- **CSI-Based Localization**
  - Provides richer channel information
  - Improving stability and accuracy.
- **Tracking & Filtering Methods**
  - Kalman Filter, Particle Filter for smoothing trajectories.
  - Widely used in real-time tracking systems: noise robustness.
- **Multi-Sensor Fusion**
  - Combining Wi-Fi + BLE + IMU or UWB ….
  - Improves robustness in dynamic hospital environments.
  - Multipath, occlusions, and varying conditions…