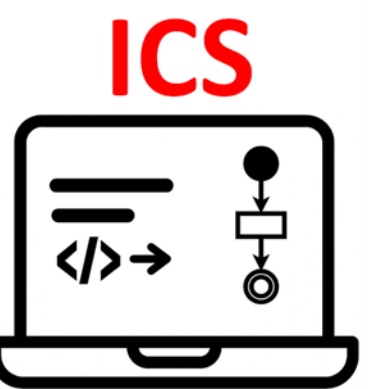


Tawaf Navigator: An Accessible, Beacon Guided Crowd Balancing System for AlMasjid AlHaram

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Introduction & Problem

Context:

- Tawaf handles over 37 million pilgrim journeys annually.
- High density and mutli-level circulation create safety risks.

Problem Statement:

- Current signage is static and cannot adapt to real-time crowds.
- Elderly pilgrims struggle with long walking distances.

Solution:

- A BLE-based navigation system using age-weighted routing to balance crowds.

Constraints & Specifications

Constraints:

1. Limited Bluetooth beacon range and accuracy.
2. Vast beacon testing area.
3. Need to acquire map of a building to test system.
4. Navigation system must be implemented as an application instead of a website for Bluetooth support.

Specifications:

1. Beacons will emit signals every 250 milliseconds.
2. Shortest path algorithm should take no longer than 500 milliseconds
3. App must support at least Android 10+.
4. The app must fully load within 15 seconds on flagship devices.
5. Beacons should be placed every 10 to 20 meters for optimal accuracy.

Integrated Specifications:

1. User's position must update within 2 seconds of movement.
2. API Response Time: Backend APIs must respond within <3 seconds.

Prototype Design

System Architecture:

- **Hardware:** Custom ESP32 Beacons.
- **Localization:** On-device RSSI trilateration using BLE advertising.

Key Design Features:

- **Age-Aware Routing:** Reserves shorter loops for elderly and disabled.
- **Operational Visibility:** Admin console allows workers to manage closures and view level usage.

Conclusion

- BLE trilateration effectively supports Tawaf-specific guidance.
- Load-balancing policies successfully reserve shorter path for elderly pilgrims while maintaining throughput.
- The system offers a low-cost, scalable solution for mass crowd management.

