

QR-MAPS: A QR CODE-DRIVEN INDOOR NAVIGATION SYSTEM WITH STATIC MAP DESIGN

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Abstract: The widespread adoption of smartphones has significantly advanced location-based services, primarily through GPS technology. However, accurate indoor positioning remains challenging due to GPS unavailability and the high deployment cost of existing infrastructure-based solutions. This paper presents QR-Maps, an efficient and low-cost indoor navigation system for smartphones. The proposed approach utilizes strategically placed QR codes, where each QR code represents a unique node containing location information. Indoor maps are manually designed using Scalable Vector Graphics (SVG), enabling lightweight rendering and precise node mapping. Upon scanning a QR code, the user's current position is identified on the SVG map, and the shortest path to a selected destination is computed using Dijkstra's algorithm. The system does not rely on wireless technologies such as Wi-Fi or Bluetooth, making it easy to deploy and maintain. Experimental results demonstrate that the proposed solution provides accurate indoor localization and efficient route computation while significantly reducing implementation cost.

Index Terms: Indoor navigation, QR code localization, SVG maps, Dijkstra's algorithm, smartphone navigation, infrastructure-free positioning, graph-based routing.

I. INTRODUCTION

The increasing use of smartphones has driven the growth of location-based services, particularly navigation applications. While the Global Positioning System (GPS) provides accurate outdoor positioning, its performance is significantly degraded in indoor environments due to signal attenuation and multipath effects. Consequently, indoor navigation remains a challenging research problem.

Existing indoor localization solutions are largely hardware-based, including Wi-Fi fingerprinting, Bluetooth Low Energy (BLE) beacons, Radio Frequency Identification (RFID), and Ultra-Wideband (UWB). Wi-Fi fingerprinting requires extensive site surveys and frequent recalibration, while BLE beacon systems depend on additional hardware installation and maintenance. RFID and UWB technologies provide higher accuracy but incur increased deployment cost and system complexity. Vision-based and inertial sensor-based approaches introduce computational overhead and cumulative errors. These limitations motivate the need for low-cost, infrastructure-free indoor navigation systems.

Quick Response (QR) codes offer a simple and cost-effective alternative for indoor localization. QR codes are inexpensive, require no power, and can be easily scanned using smartphone cameras. By associating each QR code with a known indoor location, accurate user positioning can be achieved at discrete points without reliance on wireless signals.

This paper proposes QR-Maps, an indoor navigation system based on QR-code localization and manually designed indoor maps. The indoor environment is represented using Scalable Vector Graphics (SVG), enabling lightweight rendering, precise node placement, and easy map updates. Each QR code corresponds to a node on the SVG map and stores location-related information.

After scanning a QR code, the user's current position is identified, and the shortest path to a selected destination is computed using Dijkstra's algorithm. The indoor layout is modeled as a weighted graph, where nodes represent QR-coded locations and edges represent walkable paths.

To enhance navigation continuity, the system supports time-distance-based position updates. Following QR-based localization, the user's approximate movement is estimated using elapsed time and average human walking speed, allowing position updates between QR scan points.

The proposed system reduces deployment cost, avoids additional hardware, and provides an efficient and scalable indoor navigation solution suitable for various indoor environments.

II. BACKGROUND

Indoor navigation has become an increasingly important research area due to the inability of satellite-based positioning systems, such as GPS, to operate reliably in enclosed environments. While GPS provides highly accurate localization in outdoor spaces, its signals suffer from severe attenuation, multipath propagation, and non-line-of-sight conditions indoors. Thick walls, ceilings, and other structural obstacles weaken satellite signals, leading to poor localization accuracy or complete signal loss.

A significant portion of research in indoor localization has focused on hardware-based approaches that rely on wireless signals or specialized devices. Wi-Fi fingerprinting is one of the most widely adopted techniques, where the Received Signal Strength Indicator (RSSI) from multiple Wi-Fi access points is collected at predefined locations to create a signal database or "fingerprint map." During operation, a user's device measures real-time RSSI values and compares them with the database to estimate location. While this method can achieve reasonable accuracy in controlled environments, it requires extensive site surveys, frequent recalibration, and is highly sensitive to dynamic indoor conditions.

Bluetooth Low Energy (BLE) beacon-based systems offer another hardware-centric approach. BLE beacons are small, battery-powered transmitters that periodically broadcast signals detectable by smartphones. These systems are attractive due to their low power consumption and ease of deployment. However, BLE solutions require additional infrastructure installation, periodic maintenance, and calibration to maintain accuracy in large or complex environments.

Other technologies explored for indoor localization include Radio Frequency Identification (RFID) and Ultra-Wideband (UWB) systems. RFID-based localization relies on tags placed at known locations and readers to detect tag proximity. UWB systems provide sub-meter accuracy and low-latency positioning, making them suitable for robotics or industrial tracking. However, UWB hardware is expensive, requires tight synchronization, and is difficult to deploy at scale.

Vision-based and inertial sensor-based methods have also been investigated. Vision-based systems can offer highly detailed localization but introduce substantial computational overhead and privacy concerns. Inertial measurement unit (IMU) sensors exploit accelerometers, gyroscopes, and magnetometers to estimate movement, but suffer from cumulative drift errors over time.

To address the limitations of hardware-heavy methods, QR-code-based localization has emerged as a promising alternative. QR codes are inexpensive to produce, require no power source, and can be easily decoded using standard smartphone cameras. By strategically placing QR codes at known indoor locations, users can obtain precise positional information at discrete points. Unlike wireless signal-based methods, QR codes are unaffected by multipath interference or environmental changes.

Indoor navigation systems also depend heavily on accurate environment modeling. Graph-based representations are commonly used, where nodes represent locations of interest and edges represent walkable paths. These graph structures enable the application of shortest-path algorithms, such as Dijkstra's algorithm or A* search, for efficient route computation. Additionally, Scalable Vector Graphics (SVG) and other lightweight map formats enable precise representation of indoor layouts, efficient rendering on mobile devices, and flexible updates.

Emerging trends in indoor navigation emphasize hybrid localization frameworks that combine multiple sensor modalities to compensate for the limitations of individual systems. For example, integrating inertial sensors with QR-code checkpoints can correct cumulative drift errors, while machine learning techniques have been applied to adapt fingerprint databases in real time.

These foundational concepts provide the basis for the proposed QR-Maps system, which synergistically integrates QR-code-based localization, SVG-based indoor mapping, graph-based modeling, and shortest-path computation.

III. SYSTEM DESCRIPTION

The QR-Maps system is a comprehensive indoor navigation framework designed to provide accurate, low-cost, and infrastructure-independent positioning and routing in complex indoor environments. The system integrates four key modules: QR-code-based localization, SVG-based indoor map representation, graph-based environment modeling, and route computation with dynamic guidance.

A. QR-Code-Based Localization

The localization module serves as the primary mechanism for determining the user's position. QR codes are placed at carefully selected reference points within the indoor environment, such as corridor intersections, room entrances, elevators, or emergency exits. Each QR code encodes a unique identifier and optionally additional metadata, such as coordinates in a local reference frame, floor level, accessibility attributes, or semantic information (e.g., "Conference Room A").

QR-code detection and decoding is performed using the smartphone camera and an integrated computer vision library. To improve accuracy under varied lighting conditions and partial occlusion, the system employs preprocessing techniques including adaptive thresholding to normalize lighting and enhance contrast, perspective correction for angled scanning, and error correction handling using Reed-Solomon decoding, which allows decoding even if up to 30% of the QR code is damaged or obscured.

Once decoded, the QR-code information is mapped to a node in the indoor graph model, establishing the initial user position. To support continuous navigation, the system maintains a location buffer of previously scanned QR codes, which helps estimate user movement direction and predict the next node before scanning occurs.

B. SVG-Based Indoor Map Representation

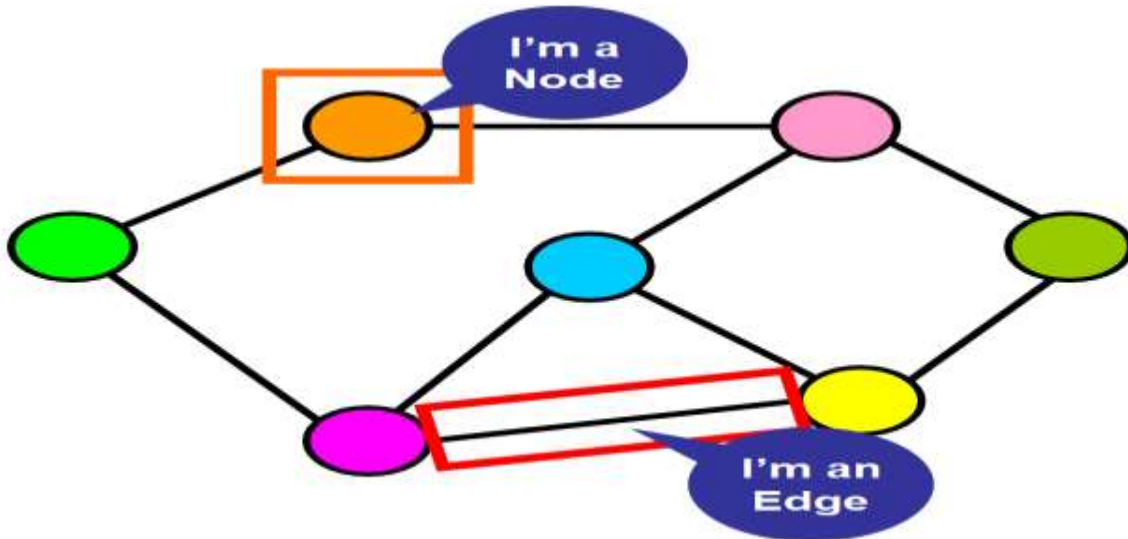
The indoor environment is represented using Scalable Vector Graphics (SVG), which provides a high-fidelity, resolution-independent map of the building layout. SVG maps encode architectural elements such as walls, doors, corridors, stairs, and rooms using geometric primitives. Key advantages of SVG include precision of exact coordinates for accurate spatial calculations, scalability for zoom and pan on mobile devices without loss of resolution, dynamic updates for easy layout modifications, and metadata integration enabling semantic-aware routing.

During initialization, the SVG map is parsed to extract the navigable space, QR-code locations, and connectivity information. Geometric data from the SVG is transformed into graph nodes and edges, with each edge annotated with attributes such as distance, traversal cost, and accessibility.

C. Graph-Based Environment Modeling

The indoor environment is modeled as a weighted undirected graph $G = (V, E)$, where V denotes the set of nodes corresponding to QR-code positions and key landmarks, and E denotes the set of edges representing walkable connections between nodes. Each edge is assigned a weight reflecting traversal cost, typically Euclidean distance derived from SVG coordinates.

Additional technical considerations include hierarchical graph modeling for multi-floor buildings with inter-floor edges at staircases or elevators, dynamic edge weighting to respond to temporary obstructions or crowd density, adjacency list representation for efficient shortest-path computation, and preprocessing techniques such as graph pruning and landmark precomputation to accelerate real-time path computation on mobile devices.



D. Route Computation and Shortest-Path Algorithms

The route computation module computes the optimal path between the current user location and the desired destination. QR-Maps primarily employs Dijkstra's algorithm, suitable for graphs with non-negative edge weights, to guarantee the shortest path. For performance optimization in large graphs, the system optionally uses A* search with a Euclidean or Manhattan distance heuristic to reduce the search space.

Key implementation details include node mapping from QR-code scans to graph nodes, destination specification by the user, dynamic recalculation when the user deviates from the computed path, and cost function extensions to incorporate parameters such as avoiding stairs for accessibility or minimizing travel time during peak congestion.

E. Navigation Guidance

Once the shortest path is computed, QR-Maps generates step-by-step navigation instructions. Visual guidance highlights the computed path on the SVG map with directional arrows, color-coded edges, and node indicators. Textual guidance provides turn-by-turn instructions displayed on the mobile interface. Real-time updates through continuous monitoring of QR-code scans allow the system to dynamically update the route if deviations occur.

Additional features include estimated time of arrival (ETA) based on average walking speed, floor-level indicators for multi-story navigation, and proximity alerts for nearby points of interest or hazards.

F. System Architecture and Workflow

The operational workflow of QR-Maps proceeds as follows: (1) Initialization – the user launches the application and the SVG map is loaded and parsed; (2) Localization – the user scans the nearest QR code and the decoded data identifies the current node; (3) Graph Mapping – the SVG map is translated into a graph representation with QR-code nodes, edges, and weights; (4) Path Planning – the shortest-path algorithm computes an optimal route from the current node to the destination; (5) Navigation Guidance – visual and textual directions are displayed, continuously updating in response to QR-code scans; (6) Completion – the user reaches the destination and traversal data may be logged for analytics.

S. No.	Parameter	Description	Observed Result	Remarks
1	Localization Accuracy	Accuracy of detecting user position using QR code scanning	100% at scan points	No signal interference; exact position obtained at each QR checkpoint
2	Path Computation Time	Time required to compute shortest path using Dijkstra/A* algorithm	< 10 ms	Very fast computation suitable for real-time navigation
3	Map Rendering Performance	Smoothness of SVG map during zoom and pan operations	~60 FPS	Provides smooth and responsive user experience
4	System Latency	Time between QR scan and path update	50–100 ms	Minimal delay ensures real-time updates
5	Cost Efficiency	Cost required for deployment compared to traditional systems	Very Low	No hardware required; only printed QR codes
6	Scalability	Ability to support larger indoor environments	High	Easily scalable by adding more nodes and QR codes
7	Usability	Ease of use for general users	High	Simple UI with search and navigation features
8	Dependency on Network	Requirement of internet connectivity	Low	Works offline after initial load
9	Error Rate	Chances of incorrect navigation	Very Low	Only depends on correct QR placement
10	Maintenance Effort	Effort required to maintain the system	Minimal	Only QR codes and map updates needed

Table: Results Analysis of QR-Maps System

IV. DESIGN CONSIDERATIONS

The QR-Maps system is designed to provide accurate, scalable, and low-cost indoor navigation while maintaining usability and robustness. The main design considerations include:

A. Accuracy and Precision

- Strategic placement of QR codes at intersections, corridors, and entrances ensures frequent location updates.
- QR codes encode coordinates and metadata, supporting precise mapping to the graph model.
- High error-correction QR codes improve reliability under partial occlusion or wear.

B. Scalability and Extensibility

- Graph-based modeling allows easy addition of new nodes and paths.
- Hierarchical multi-floor graphs support modular and incremental updates.
- SVG maps enable flexible modification of building layouts without reconfiguring the system.

C. Computational Efficiency

- Adjacency lists and optimized shortest-path algorithms (Dijkstra or A*) ensure real-time path computation on mobile devices.
- Incremental path updates reduce unnecessary computation when users deviate from the route.

D. Usability and Accessibility

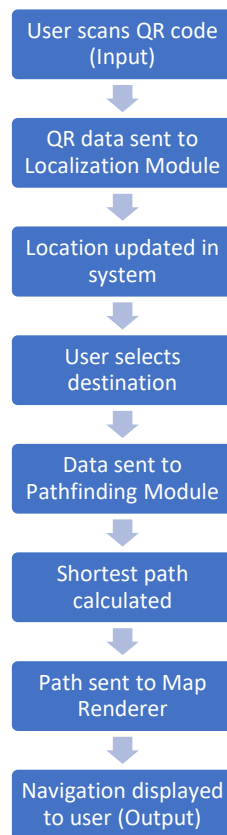
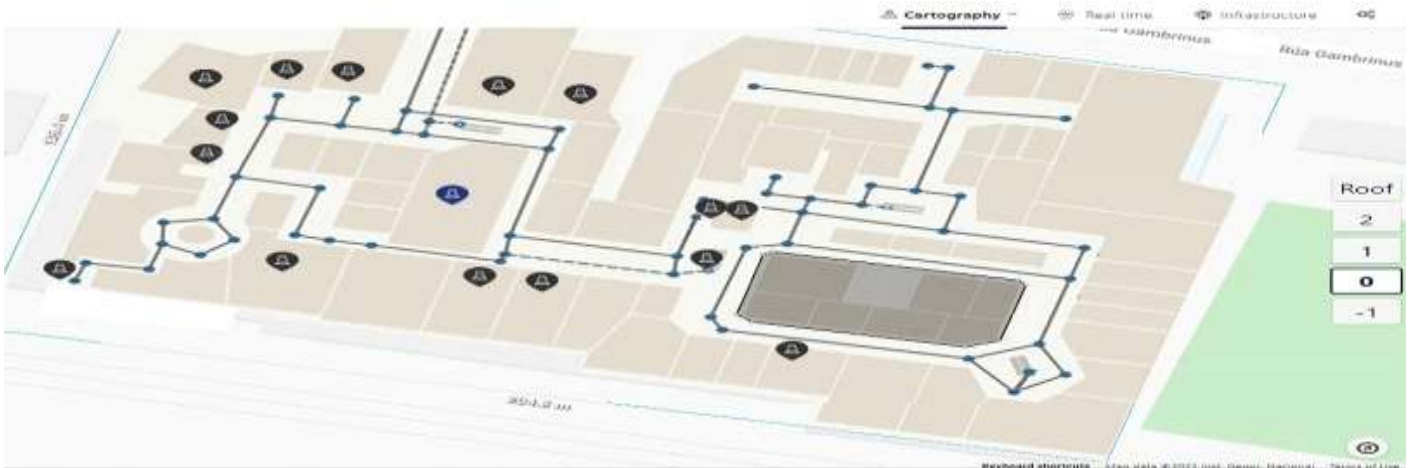
- Visual and textual guidance provides clear turn-by-turn navigation.
- Paths can be optimized for accessibility, avoiding stairs or narrow corridors.
- Error recovery through QR-code rescan allows seamless rerouting.

E. Robustness and Reliability

- Dynamic edge weighting and node updates accommodate temporary obstacles or layout changes.
- QR codes are designed for durability and resilience to environmental factors.

F. Cost and Maintenance

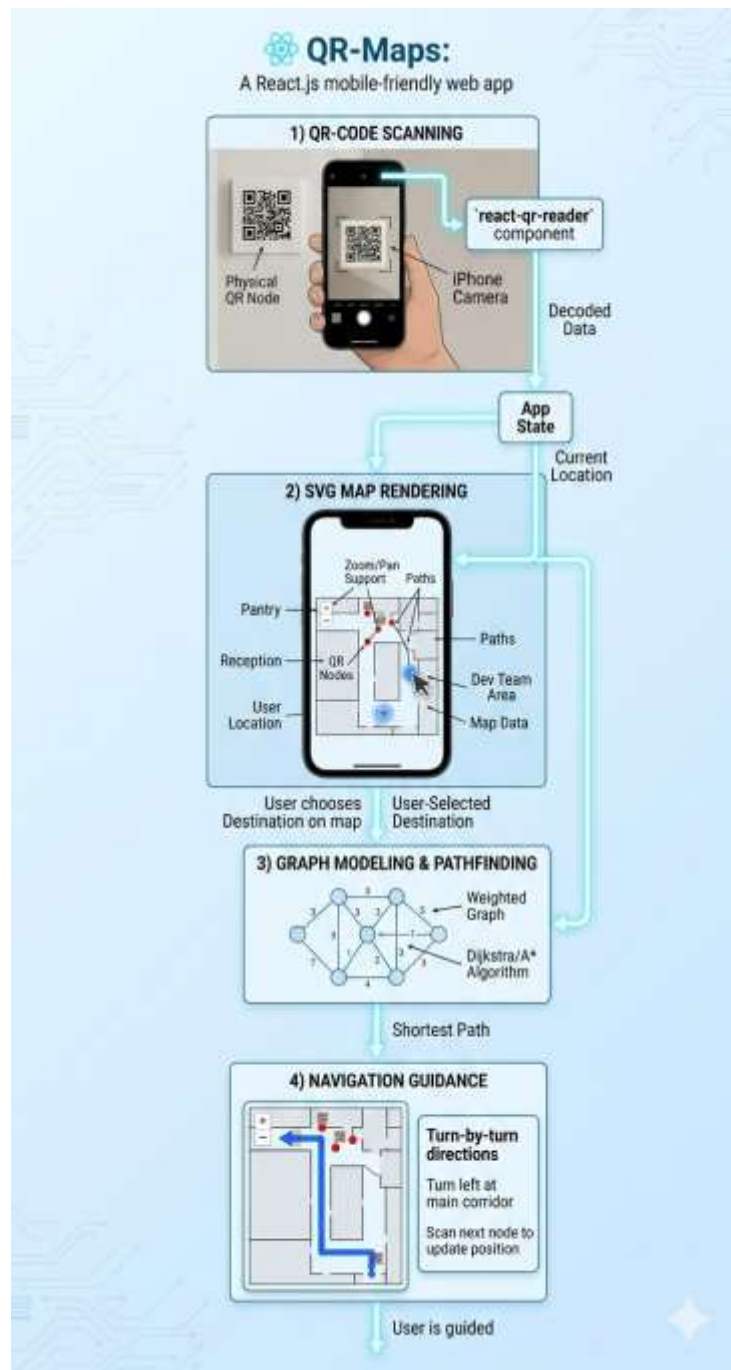
- Low-cost QR codes require no power or extensive infrastructure.
- Minimal calibration or maintenance is needed compared to RF-based systems.
- This design ensures that QR-Maps is accurate, efficient, user-friendly, and cost-effective, making it suitable for complex indoor environments such as airports, malls, hospitals, and educational campuses.



V. IMPLEMENTATION

QR-Maps is implemented as a React.js mobile-friendly web app, combining QR-code scanning, SVG map rendering, graph-based pathfinding, and navigation guidance.

- 1) **QR-Code Scanning:** Uses react-qr-reader to decode QR codes, updating the user's location in state.
- 2) **SVG Map Rendering:** Displays floor plans, QR nodes, and paths interactively with zoom/pan support.
- 3) **Graph Modeling & Pathfinding:** Converts the map into a weighted graph; computes shortest path using Dijkstra or A*.
- 4) **Navigation Guidance:** Highlights routes on the map and provides turn-by-turn directions.



VI. CONCLUSIONS

This paper presented QR-Maps, a tool for indoor navigation using QR codes and local SVG maps, without relying on external wireless technologies. The system identifies the user's current position by scanning nearby QR codes and displays the corresponding section of the SVG map locally. Users can view points of interest and receive step-by-step guidance to reach their destination entirely offline.

As future work, we plan to integrate smartphone compasses to provide directional guidance and accelerometers to estimate walking distances, enhancing navigation accuracy and user experience.

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