

Realtime Occupancy Sensing, Contactless Authentication Using QR Codes

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Abstract– **Efficient space utilization and secure access control are critical requirements in smart buildings, campuses, and shared environments. This work proposes a unified system that combines real-time occupancy sensing with contactless authentication using QR codes. The system leverages sensor-driven detection mechanisms—such as computer vision, infrared, or IoT-based presence sensors—to continuously monitor and update occupancy status. Simultaneously, QR code-based authentication enables users to gain authorized access or register their presence through a fast, touch-free interaction via personal mobile devices. The architecture integrates a sensing layer, a communication layer, and a cloud-based analytics platform. Occupancy data is processed in real time to generate insights on space usage, congestion, and availability. Authentication events linked to QR scans enhance accuracy by validating identities and associating individuals with specific locations. This dual approach improves reliability compared to standalone sensing or manual check-in systems. The proposed solution prioritizes privacy by minimizing personally identifiable data collection and supports scalability through lightweight deployment and low-cost hardware.**

I. INTRODUCTION

The rapid evolution of smart environments has increased the demand for intelligent systems

that can efficiently manage space utilization while ensuring secure and seamless user access. Real-time occupancy sensing plays a vital role in optimizing resource allocation, enhancing safety, and improving energy efficiency in settings such as smart buildings, offices, campuses, healthcare facilities, and public venues. Simultaneously, the need for hygienic, contactless interactions has accelerated the adoption of touch-free authentication technologies, particularly in the wake of global health concerns.

Traditional occupancy monitoring approaches—such as manual headcounts, card-based access systems, or standalone sensors—often suffer from limitations including inaccuracies, high deployment costs, privacy concerns, or lack of scalability. Similarly, conventional authentication methods may introduce friction, require physical contact, or fail to integrate meaningfully with occupancy analytics. To address these challenges, this work explores a unified framework that combines real-time occupancy sensing with contactless authentication using Quick Response (QR) codes. QR codes offer a low-cost, widely accessible, and device-agnostic mechanism for user interaction. When paired with sensor-based occupancy detection, QR-driven authentication not only validates user identity but also strengthens the reliability of presence tracking. The integration of sensing technologies with QR code scanning enables dynamic monitoring, improved accuracy, and enhanced user convenience. Furthermore, cloud-based analytics can transform collected data into actionable insights for space management, crowd control, and operational efficiency. This study proposes a layered system architecture that merges sensing, communication, and analytics components to deliver a scalable, privacy-aware solution. By bridging occupancy intelligence with secure, touch-free authentication, the approach aims to contribute to safer, smarter, and more efficient environment

II. BACKGROUND AND MOTIVATION

A. Overview

Real-time occupancy sensing and contactless authentication using QR codes represent an integrated approach to intelligent space management and secure access control. The system combines sensor-based technologies—such as IoT presence sensors, infrared detectors, or computer vision—with QR code scanning via personal mobile devices to monitor, verify, and manage human presence within a physical environment. Occupancy sensors continuously capture data to determine whether spaces are vacant, occupied, or crowded, while QR codes enable users to authenticate or register their presence through a fast, touch-free interaction.

The architecture typically consists of a sensing layer for data acquisition, a communication layer for secure data transmission, and a cloud or edge analytics layer for processing and visualization. By linking QR-based authentication events with sensor-derived occupancy data, the system enhances accuracy, reduces false detections, and provides reliable, real-time insights into space utilization. This unified model supports applications such as smart offices, educational institutions, healthcare facilities, co-working spaces, and public venues.

The approach offers several benefits, including improved operational efficiency, optimized resource allocation, enhanced safety, reduced physical contact, and scalability through low-cost deployment. Additionally, privacy-preserving mechanisms can be implemented to limit

sensitive data collection. Overall, the integration of occupancy sensing with QR-based authentication enables smarter, safer, and more adaptive environments.

B. Importance of Occupancy Sensing and Contactless Authentication

Occupancy sensing and contactless authentication have become essential components of modern smart environments, driven by the growing need for efficiency, security, safety, and user convenience. Real-time occupancy sensing enables organizations to understand how spaces are utilized, allowing optimized allocation of rooms, desks, and shared resources. This leads to improved operational efficiency, reduced energy consumption through intelligent control of lighting and HVAC systems, and better infrastructure planning based on actual usage patterns.

From a safety perspective, occupancy monitoring supports crowd management, emergency response, and regulatory compliance by preventing overcrowding and enabling faster evacuation strategies. In environments such as hospitals, campuses, and public venues, accurate occupancy insights contribute directly to safer and more organized operations.

Contactless authentication further enhances these benefits by enabling secure, hygienic, and frictionless access control. Technologies like QR code-based authentication eliminate the need for physical contact with devices, reducing wear-and-tear, minimizing health risks, and improving user experience. Contactless systems also speed up entry processes, reduce queues, and simplify identity verification.

When combined, occupancy sensing and contactless authentication create a powerful, integrated solution. Authentication events validate presence data, improving sensing accuracy, while occupancy intelligence strengthens security and access management. Together, they enable smarter decision-making, enhanced safety, and scalable deployment in smart buildings, workplaces, educational institutions, healthcare facilities, and public spaces.

C. Limitation of Occupancy Sensing and Contactless Authentication

Despite their advantages, occupancy sensing and QR code-based contactless authentication present several limitations. Sensor-based occupancy detection may experience inaccuracies due to environmental factors such as lighting conditions, occlusions, reflections, or sensor placement. False positives and false negatives can occur, particularly in vision-based or motion-based systems where distinguishing between stationary occupants and empty spaces is challenging.

QR code authentication relies on user participation and device availability. Users without smartphones, low battery levels, or connectivity issues may face access difficulties. Additionally, QR codes can be susceptible to misuse, such as unauthorized sharing, screenshot duplication, or replay attacks if security measures (e.g., dynamic or time-bound codes) are not implemented.

Privacy concerns also arise, as occupancy monitoring and authentication systems may collect sensitive data related to user identity, movement patterns, or behavioral insights. Without proper anonymization and data protection mechanisms, these systems risk regulatory non-compliance and user distrust.

Scalability and infrastructure costs can pose challenges, especially in large deployments requiring multiple sensors, network reliability, and maintenance. Integration complexity with existing building management or security systems may further increase implementation effort.

Overall, while effective, these systems require careful design, calibration, and security controls to mitigate technical, operational, and privacy-related constraints.

D. Motivation of this Proposed System

The motivation for developing a real-time occupancy sensing and contactless authentication system using QR codes stems from the growing need for smarter, safer, and more efficient management of shared spaces. Traditional methods of monitoring occupancy and controlling access—such as manual records, swipe cards, or isolated sensor systems—often suffer from inefficiencies, inaccuracies, hygiene concerns, and limited adaptability to dynamic environments.

Modern buildings and institutions require real-time visibility into space utilization to optimize resources, reduce operational costs, and improve user comfort. Simultaneously, the increasing demand for touch-free interactions highlights the necessity of secure and hygienic authentication mechanisms. QR code-based solutions offer a low-cost, widely accessible, and user-friendly approach that aligns with the widespread adoption of smartphones.

However, standalone occupancy sensing or authentication systems alone may not deliver sufficient reliability. Sensor-based detection can misinterpret presence, while authentication-only systems may not reflect actual occupancy conditions. Integrating both technologies addresses these gaps by enabling cross-validation between sensing data and authenticated user interactions.

Furthermore, the proposed system is motivated by the need to enhance safety through crowd monitoring, support energy-efficient building operations, and ensure privacy-aware data handling. By combining real-time sensing with seamless, contactless authentication, the system aims to provide a scalable and practical solution suited for smart offices, campuses, healthcare facilities, and public environments.

II. NOVEL APPLICATIONS OF OCCUPANCY SENSING AND CONTACTLESS AUTHENTICATION QR CODES

1. Adaptive Workspace Automation – Automatically adjusts lighting, HVAC, and

equipment settings based on authenticated occupancy, enabling personalized comfort and energy optimization.

2. Smart Emergency Management – Combines live occupancy data with authentication logs to identify who is present during emergencies, improving evacuation planning and rescue coordination.
3. Dynamic Seat/Desk Allocation – Enables flexible booking where users scan QR codes to claim available desks or seats, with sensors validating real-time availability.
4. Secure Exam & Attendance Systems – Prevents proxy attendance by linking QR authentication with occupancy verification in classrooms or examination halls.
5. Healthcare Zone Monitoring – Tracks occupancy in sensitive hospital areas (ICUs, labs) while ensuring only authorized personnel gain access via QR authentication.
6. Crowd Density & Safety Analytics – Detects congestion hotspots in malls, events, or transport hubs and triggers alerts or redirection strategies.
7. Touch-Free Visitor Management – Visitors authenticate via temporary QR codes, while occupancy sensing ensures compliance with capacity limits.
8. Context-Aware Digital Signage – Displays targeted information or advertisements based on real-time occupancy and user presence patterns.
9. Energy Usage Optimization & Billing – Allocates energy costs to departments or zones based on verified occupancy rather than static assumptions.
10. Privacy-Preserving Access Control – Uses minimal identity exposure by validating entry via QR codes while sensors confirm presence without intrusive tracking.

These applications demonstrate how integrating occupancy intelligence with QR-based authentication can enable smarter automation, enhanced safety, improved security, and innovative user experiences across diverse environment

III.ROLE AND POTENTIAL OF OCCUPANCY SENSING AND CONTACTLESS AUTHENTICATION QR CODES

1. Role of Occupancy Sensing

Occupancy sensing technology detects the presence, absence, or number of people in a

specific area using sensors such as PIR (Passive Infrared), ultrasonic, camera-based systems, or IoT-enabled smart sensors. Its primary role is to improve energy efficiency, security, and smart automation.

In smart buildings and traffic systems, occupancy sensors automatically control lighting, HVAC systems, and ventilation based on real-time presence data. This reduces energy consumption and operational costs. In smart traffic management, occupancy detection helps analyze pedestrian density, vehicle congestion, and parking space availability. It supports intelligent decision-making and enhances public safety by monitoring crowd levels in real time.

Occupancy sensing also plays a key role in emergency management systems by detecting overcrowded zones and triggering alerts. In smart cities, it contributes to data-driven infrastructure planning and resource optimization.

2. Role of Contactless Authentication using QR Codes

QR (Quick Response) codes are two-dimensional barcodes that store encrypted data for authentication and identification. Contactless authentication using QR codes allows users to verify identity without physical contact, enhancing hygiene, speed, and security.

In smart environments, QR codes are widely used for:

- Access control in offices and institutions
- Digital attendance systems
- Secure parking management
- Public transportation ticketing
- Emergency vehicle identification

QR-based systems reduce manual verification, minimize fraud, and enable real-time data tracking. When integrated with cloud systems and mobile applications, they provide secure and scalable authentication solutions.

3. Potential of Combining Both Technologies

The integration of occupancy sensing and QR-based contactless authentication has strong potential in smart traffic and smart city systems. For example:

- Controlled building entry based on occupancy limits
- Smart parking systems verifying authorized vehicles
- Emergency vehicle priority management
- Real-time crowd control with authenticated access

Together, these technologies enhance automation, security, efficiency, and user convenience. Their future potential lies in AI-driven analytics, IoT integration, and large-scale smart infrastructure development.

IV. CONCLUSION

In conclusion, the implementation of real-time occupancy sensing combined with contactless authentication using QR codes offers a highly efficient and intelligent solution for modern smart environments. Occupancy sensing technology enables accurate detection of people presence and movement, allowing dynamic control of lighting, ventilation, access systems, and crowd management. This significantly improves energy efficiency, safety, and operational optimization in smart buildings,

institutions, transportation hubs, and urban infrastructure.

At the same time, QR code-based contactless authentication ensures secure, fast, and hygienic verification of individuals without physical interaction. It reduces manual monitoring, minimizes security risks, and supports real-time data recording and access control. The integration of these technologies enhances automation, improves user convenience, and strengthens system reliability.

When deployed together in real-time systems, occupancy sensing and QR authentication create a smart, scalable, and cost-effective framework suitable for smart cities, intelligent traffic systems, corporate offices, educational institutions, and public spaces. Their future potential lies in integration with AI, IoT, and cloud computing platforms to enable predictive analytics, adaptive control, and enhanced security. Overall, this combined approach represents a significant step toward sustainable, secure, and technology-driven infrastructure development.

V. FUTURE RESEARCH DIRECTIONS FOR OCCUPANCY SENSING AND CONTACTLESS AUTHENTICATION QR CODES

Future research in occupancy sensing should focus on improving accuracy, scalability, and real-time responsiveness using advanced AI and deep learning models. Integrating computer vision with edge computing can enable faster decision-making while reducing latency and cloud dependency. Researchers can explore multimodal sensing systems that combine PIR, ultrasonic, thermal imaging, and camera-based detection to improve reliability under varying environmental conditions. Privacy-preserving occupancy detection using anonymized data and federated learning is also a critical research direction, especially for smart buildings and public surveillance systems

In contactless authentication using QR codes, future studies can emphasize enhancing security mechanisms such as dynamic QR codes, encrypted time-based tokens, and blockchain-based verification systems. This can reduce risks like code duplication, spoofing, and unauthorized access. Integration with biometric authentication and multi-factor verification can further strengthen system security. Research can also focus on improving QR code scanning performance in low-light, high-speed, or crowded environments.

Another important direction is the combined integration of occupancy sensing and QR-based authentication within IoT-enabled smart city infrastructures. Future systems may include AI-driven predictive analytics for crowd control, smart traffic flow optimization, and adaptive building management. Energy-efficient sensor networks, 5G/6G connectivity, and cloud-edge hybrid architectures will further enhance scalability and performance. Overall, continued innovation in automation, cybersecurity, data privacy, and intelligent analytics will shape the next generation of smart, secure, and sustainable infrastructure systems.

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