GateWise: An Intelligent Web System for Automatic Access Control Using License Plate Recognition

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Abstract

Urban growth and the resulting density of vehicles in residential garages and corporate parking areas have made the development of intelligent access-control systems increasingly urgent. Traditional solutions based on remote controls, NFC cards or manual supervision present significant limitations in terms of efficiency, security and scalability. The GateWise project proposes an intelligent solution for automatic access management through license-plate recognition, relying on Artificial Intelligence and modern technologies. The system architecture integrates optical character recognition and real-time processing, using YOLOv5 for plate detection and EasyOCR for character reading. Tests demonstrated a recognition rate above 90%, with real-time response and high reliability. GateWise thus contributes to advancing intelligent access-control systems, aligning with smart-city trends and digital transformation while promoting greater security, traceability and operational efficiency.

Keywords: Artificial Intelligence; License Plate Recognition; OCR; Smart Parking; Web Systems.

Título: GateWise: Um Sistema Web Inteligente para Controlo de Acesso Automático usando Reconhecimento de Placas de Veículos

Resumo: O crescimento urbano e a consequente densidade de veículos em garagens residenciais e parques empresariais tornaram premente o desenvolvimento de sistemas inteligentes de controlo de acessos. As soluções tradicionais, baseadas em comandos, cartões *NFC* ou supervisão manual, apresentam limitações significativas em termos de eficiência, segurança e escalabilidade. O projeto GateWise propõe uma solução inteligente para gestão automática de acessos através do reconhecimento de matrículas, recorrendo a Inteligência Artificial e a tecnologias modernas. A arquitetura do sistema integra reconhecimento óptico de caracteres e processamento em tempo real, utilizando *YOLOv5* para deteção de matrículas e *EasyOCR* para leitura de caracteres. Os testes realizados demonstraram uma taxa de reconhecimento superior a 90 %, com resposta em tempo real e elevada fiabilidade. O GateWise contribui assim para o avanço dos sistemas

de controlo de acessos inteligentes, alinhando-se com as tendências das cidades inteligentes e da transformação digital, promovendo maior segurança, rastreabilidade e eficiência operacional.

Palavras-chave: Inteligência Artificial; Reconhecimento de Matrículas; OCR; Estacionamento Inteligentel; Sistemas Web.

1. Introduction

The exponential growth of urban populations has led to increased traffic congestion and scarcity of parking spaces, resulting in an urgent demand for intelligent access control systems (World Economic Forum, 2023). Residential complexes, business parks, and public institutions face operational inefficiencies and security challenges associated with traditional access methods, such as physical keys, remote controls, or human guards. Digitalization and automation of parking access represent a key step towards smart city infrastructure (Yun & Park, 2023). The convergence of computer vision, Artificial Intelligence (AI), and real-time processing allows vehicles to be identified through their license plates, enabling seamless and secure access without human intervention (Laroca *et al*., 2019). This research presents GateWise, a web-based intelligent system designed to automate and centralize access control in garages and parking lots. By combining modern web technologies and AI-based license plate recognition, GateWise enhances operational efficiency, scalability, and traceability, responding directly to the growing needs of digital urban infrastructures (FastAPI, 2024; Ultralytics, 2023).

1.1. Research Problem

Although Automatic License Plate Recognition (*ALPR*) systems have reached technological maturity and proven accuracy in industrial and governmental contexts (Laroca *et al*., 2019; Al-Batat *et al*., 2022), their implementation remains financially inaccessible for smaller-scale applications. Commercial solutions typically require expensive proprietary hardware, paid licensing models, and maintenance costs that are unjustifiable for local businesses, residential complexes, or small public facilities.

This economic barrier prevents the democratization of access to automation technologies (World Economic Forum, 2023). Consequently, many smaller entities still depend on or choose to use obsolete systems based on physical devices such as *RFID* cards or remote transmitters, which are less secure, inefficient to manage, and environmentally unsustainable; however, they are easily maintained with a lot of expert labor available to keep them working.

The research problem addressed by GateWise lies not in the absence of technology but in the lack of affordable, scalable frameworks capable of delivering high-performance license plate recognition and secure access management without the prohibitive costs associated with commercial systems.

1.2. Motivation

Urbanization, population density, and the growing environmental impact of traffic congestion have placed unprecedented pressure on infrastructure management. The modernization of access systems represents a critical component of smart-city development, where automation contributes to efficiency, sustainability, and improved quality of life (World Economic Forum, 2023).

The motivation behind GateWise emerges from this context: to create a system that supports intelligent mobility and sustainable urban ecosystems by replacing manual or semi-manual access mechanisms with automated, data-driven processes (Yun & Park, 2023). By integrating open-source Artificial Intelligence and web technologies, GateWise seeks to deliver a low-cost, high-efficiency solution adaptable to different environments (Ultralytics, 2023; FastAPI, 2024), thus extending the benefits of automation beyond large enterprises to communities, residential spaces, and small organizations.

2. Conception and Development

2.1 Problem Definition

Conventional access control mechanisms rely heavily on physical devices such as *RFID* cards, remote transmitters, or magnetic keys. These systems exhibit several limitations that hinder security and scalability: devices can be lost, duplicated, or shared, leading to unauthorized access; manual data management introduces errors and delays; lack of centralized monitoring limits auditing and pattern detection; and integration with modern platforms (analytics, mobile apps, or payment systems) is nonexistent or costly (PlateRecognizer, 2024). In environments with high vehicle turnover—such as condominiums, universities, or corporate parks—these limitations compromise safety and efficiency. An automated, intelligent system that combines AI-powered recognition and centralized management can overcome these barriers (Laroca *et al.*, 2019), ensuring secure and traceable access while improving user experience and administrative control.

2.2. Objectives

The GateWise project aims to design and develop an intelligent, web-based access control system that employs license plate recognition as the central authentication mechanism (Ultralytics, 2023; JaidedAI, 2023). Main Objective: To develop a scalable and secure platform capable of real-time vehicle identification and access management using computer vision and AI. Specific Objectives include implementing *YOLO* and *OCR* technologies, providing a responsive web interface, enabling real-time gate control, ensuring secure authentication (*JWT*) (Mozilla Developer Network, 2024), supporting subscriptions and analytics, and complying with privacy and security regulations (*GDPR*) (European Union, 2016).

2.2.1. Scientific Contribution

The GateWise project contributes simultaneously to the scientific understanding and technological advancement of intelligent access control.

From a theoretical perspective, it proposes a modular and interoperable architecture that integrates *YOLO*-based computer vision, *OCR*, and web frameworks (*FastAPI* and

React.js) into a cohesive system capable of real-time recognition and decision-making. The framework demonstrates how open-source technologies can be combined to achieve high-performance automation without dependence on proprietary solutions.
From a practical perspective, the project provides empirical validation through an implemented prototype that achieved over 90% recognition accuracy under controlled conditions, with response times below one second. This evidence confirms that cost-efficient AI architecture can reach industrial-grade reliability, offering a reproducible model for future research and implementation.

2.3. Related Work

Automatic License Plate Recognition (*ALPR*) has become a cornerstone of intelligent transportation systems, toll collection, and smart parking. Research by Laroca *et al*. (2019) and Al-Batat *et al*. (2022) demonstrates that neural networks such as *YOLO* achieve recognition rates above 95%, even under diverse conditions.

The *YOLO* architecture processes entire images in a single step, providing real-time object detection capabilities (Ultralytics, 2023). Its latest versions—*YOLOv5* and *YOLOv8*—deliver detection precision near 99%. Recent studies on *YOLOv8* and lightweight detection frameworks confirm the scalability of edge-based implementations (Liu, Zhang, & Hu, 2025) and propose hybrid approaches combining *YOLOv8* with *OCR* for high-precision recognition (Moussaoui *et al*., 2024). For *OCR*, engines such as *EasyOCR* and *Tesseract* convert plate regions into textual data (JaidedAI, 2023), supported by preprocessing techniques (contrast adjustment, binarization) to improve reliability.

In backend and web application development, *FastAPI* stands out for its asynchronous performance (FastAPI, 2024), while *React.js* ensures interactive and efficient user interfaces (React Team, 2023). GateWise builds upon these frameworks to create a cohesive, AI-driven access management system that unifies detection, recognition, and user interaction.

2.4. Methodology and System Architecture

GateWise follows an iterative software engineering methodology integrating design, implementation, and testing. The system architecture consists of four layers: Frontend (*React.js*), Backend (*FastAPI*), Database (*PostgreSQL*), and AI Module (*YOLOv5* + *EasyOCR*) (Bayer, 2021; Ultralytics, 2023; JaidedAI, 2023).

All modules communicate through secure *API*s using *JWT* and *WebSockets* for real-time updates (Mozilla Developer Network, 2024).

The recognition pipeline includes image capture, detection via *YOLOv5*, preprocessing using *OpenCV* for contrast enhancement and noise reduction (OpenCV Team, 2023), OCR using *EasyOCR*, validation against the database, and automated gate control. This ensures low latency, high accuracy, and data privacy through local processing (European Union, 2016).

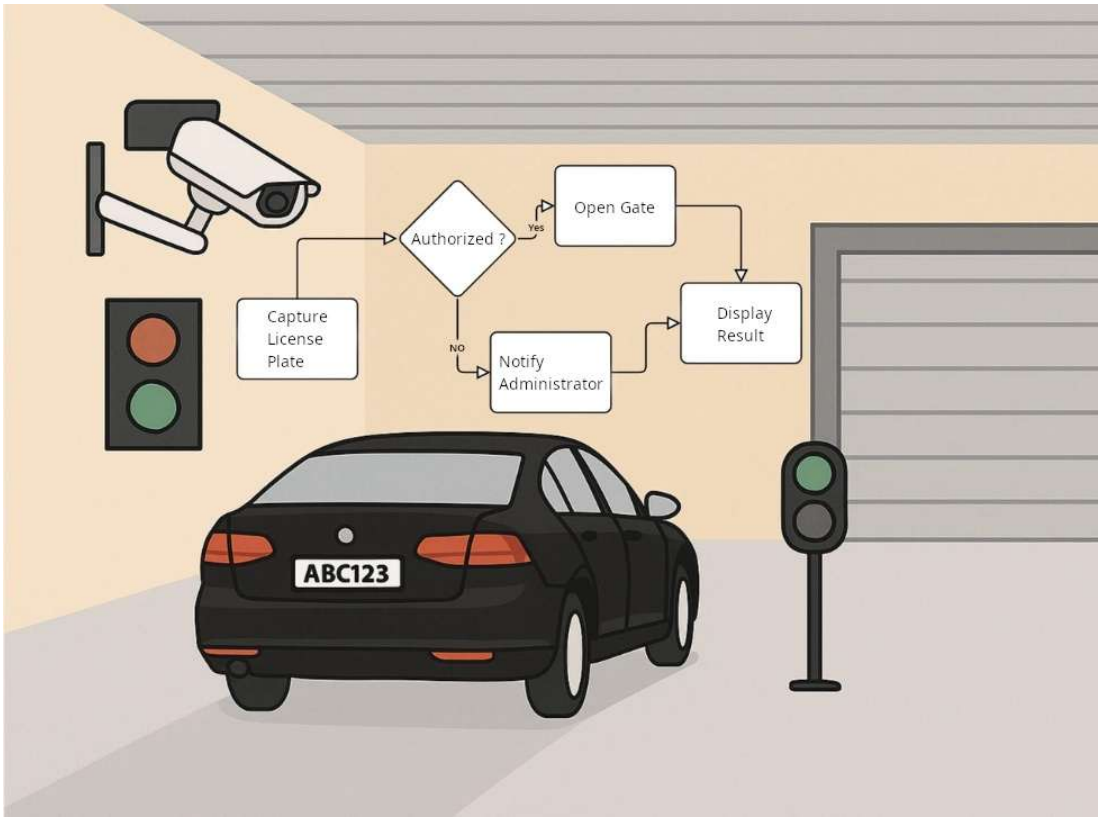

Figure 1. High-level system functionality flowchart.

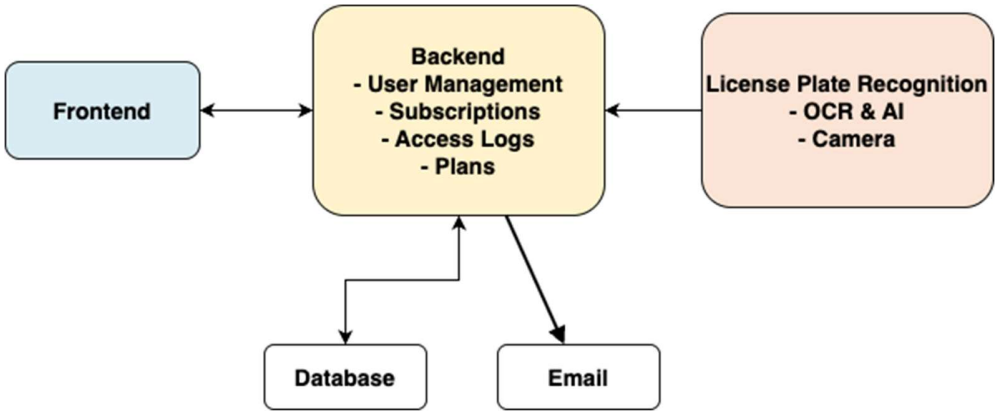

Figure 2. System connections diagram representing communication between components.

2.4.1. Research Methodology

This study follows the Design Science Research (*DSR*) methodology (Hevner *et al*., 2004; Peffers *et al*., 2007), which emphasizes the creation and evaluation of an artifact to solve a clearly identified problem.

The application of *DSR* to GateWise proceeded through six iterative stages:
1. Problem Identification and Motivation: recognition of the financial barriers and lack of accessible *ALPR* systems for smaller contexts.
2. Definition of Objectives: design of an affordable, modular web platform integrating AI-based recognition.
3. Design and Development: implementation of the GateWise prototype using *YOLOv5*, *EasyOCR*, *FastAPI*, *PostgreSQL*, and *React.js*.
4. Demonstration: deployment of the prototype in simulated environments reproducing real-world conditions.
5. Evaluation: quantitative and qualitative testing of recognition accuracy, backend latency, and usability.
6. Communication: dissemination of results through academic documentation and this publication.

This methodological framework ensures that GateWise is not merely a technological proof of concept but a scientifically validated artifact addressing the intersection of AI, web technologies, and intelligent infrastructure.

3. Demonstration and Validation

Development utilized *Python* 3.11, *TypeScript*, *FastAPI*, *React*, *MUI*, *SQLAlchemy*, and *Docker* (*Beazley & Jones*, 2013; Docker Inc., 2023; Bayer, 2021). Testing covered recognition accuracy, backend response time, and usability. Results showed over 90% accuracy for plate recognition and sub-second response time for authorization requests (Laroca *et al.*, 2019). The prototype confirmed the system's scalability and efficiency but noted limitations under low-light or reflective conditions.

3.1 Development Environment

The GateWise prototype was implemented using a modern open-source technology stack designed for modularity and scalability.

The backend was developed in *FastAPI* (Python 3.11) for asynchronous performance, while the frontend used *React 18.2.0* with *Material-UI* for a responsive, component-based interface. Data persistence was handled via *PostgreSQL 15*, accessed through *SQLAlchemy 2.0*, and the entire system was containerized using *Docker* and *Docker Compose* for consistent deployment and scalability.

The artificial intelligence module integrated *YOLOv5* for real-time object detection and *EasyOCR* for optical character recognition, allowing the system to detect and read vehicle license plates under varying lighting and positional conditions. Local processing ensured that sensitive image data never left the system, reinforcing privacy compliance with the *GDPR* framework.

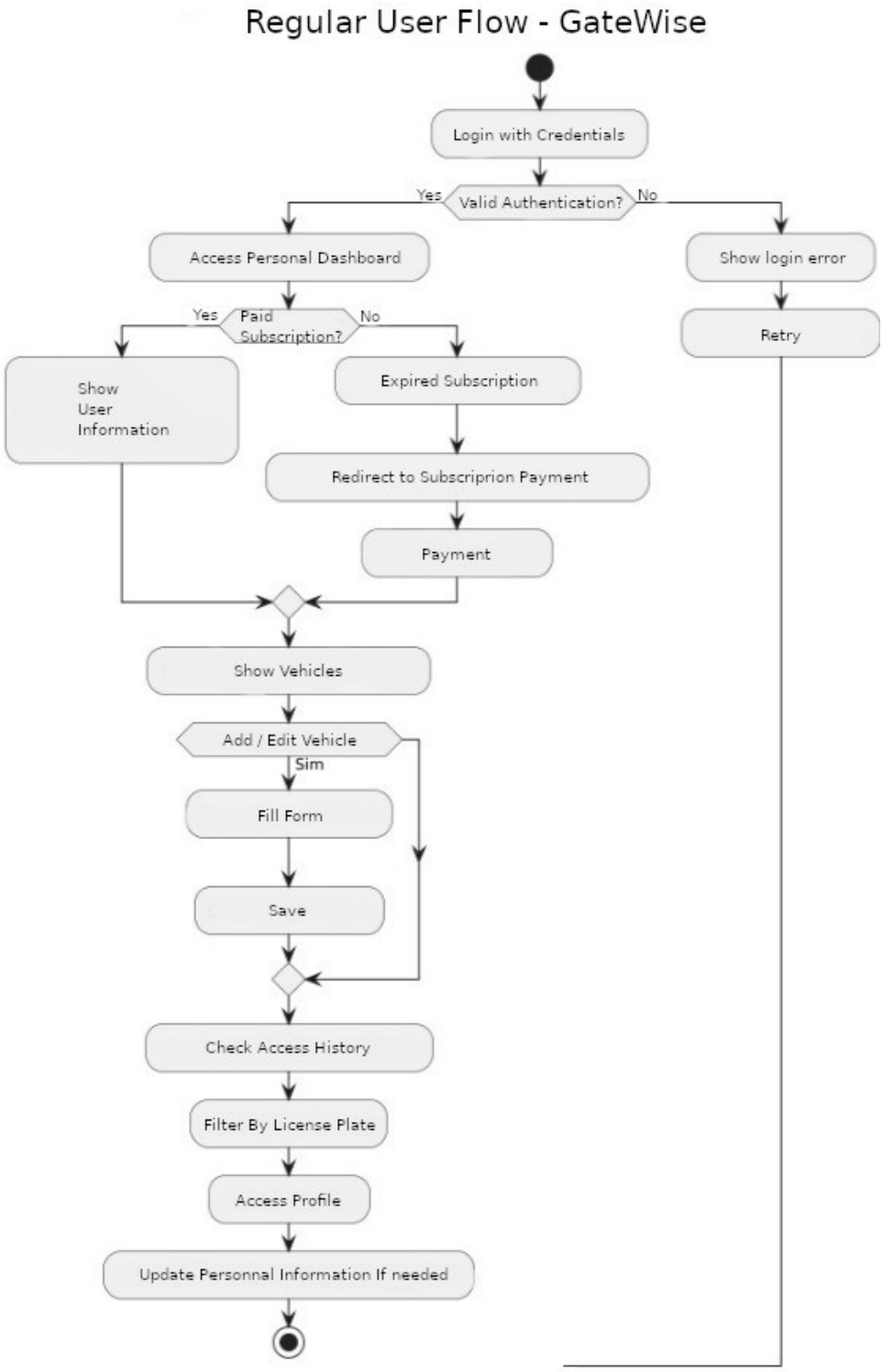

Figure 3. User flow diagram illustrates the interaction between users and system components.

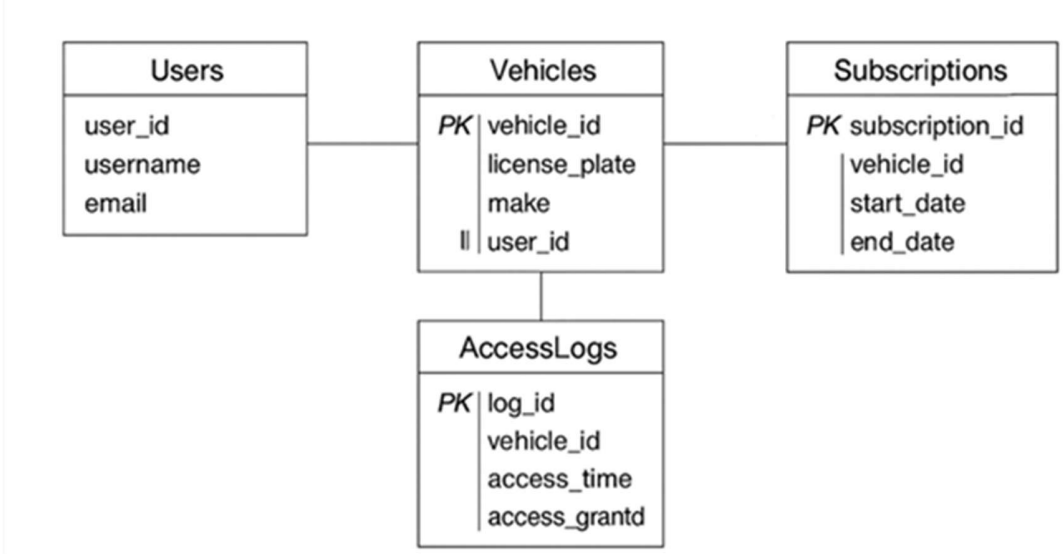

Figure 4. Relational database schema of the GateWise system, illustrating the main entities and their foreign-key dependencies.

3.2 Testing Framework

Three test categories were defined to validate the prototype: recognition accuracy, response time, and usability:

1. Recognition Accuracy: The system was evaluated using a dataset of 400 images of European license plates, obtained from open datasets and web sources, simulating different environmental conditions. These included day/night variation, low-light exposure, angled captures, and partial occlusions. *YOLOv5* successfully detected plates with 97.4 % accuracy, while the combined *YOLOv5–EasyOCR* pipeline achieved a 92.1 % correct recognition rate.

2. Response Time: The latency between image capture and backend authorization averaged 0.74 seconds, measured across 50 simulated access attempts. This performance meets real-time system thresholds, confirming the suitability of the chosen architecture for live gate operations.

3. Usability and System Integration: Five participants tested both the administrator and user dashboards to evaluate layout clarity, data access, and error handling. Results indicated strong intuitiveness and stability across browsers and devices. Minor delays were noted during high data refresh rates, later optimized using React Query caching.

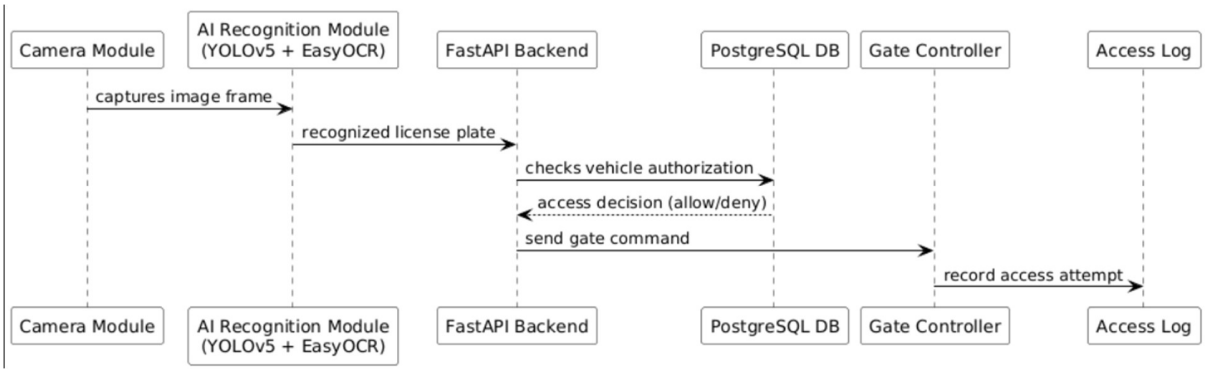

Figure 5. Simplified vertical sequence diagram for automated access flow.

4. Conclusions

GateWise demonstrates the potential of combining AI models and web technologies for intelligent access control (Ultralytics, 2023; FastAPI, 2024). Future work includes integrating *RFID* sensors, *LED* guidance systems, mobile applications, machine learning for anomaly detection, and energy-efficient operation aligned with sustainability goals.

The system's modularity demonstrates that affordable automation is feasible without sacrificing reliability. This has strong implications for urban digital inclusion, enabling smaller entities - residential buildings, schools, SMEs - to adopt technologies typically reserved for enterprise or municipal use.

From a scientific standpoint, the study reinforces the Design Science Research paradigm as a viable framework for prototyping intelligent systems (Hevner *et al*., 2004; Peffers *et al*., 2007). Each development phase — from conception to validation — produced concrete, testable artifacts that can evolve into larger-scale applications.

Additionally, the ethical and privacy dimensions of automated access control are addressed through the system's local *AI* inference model, ensuring compliance with European data protection standards (European Union, 2016) while maintaining operational autonomy.

Future iterations of GateWise will focus on expanding functional depth and improving contextual adaptability:

- Sensor Integration: Combine *RFID* or *IoT* sensors for vehicle presence validation and dual-factor access authentication.
- Adaptive Illumination and AI Retraining: Incorporate automatic light compensation and continuous learning to handle diverse environments (night, rain, motion).
- Mobile Application: Develop a cross-platform app for user interaction, push notifications, and manual override functionalities.

- Energy Optimization: Implement intelligent power management for low-energy operation, aligning with sustainability goals in smart-city frameworks.
- Cloud Interoperability: Enable optional hybrid deployment on cloud environments (e.g., Azure, AWS) to support multi-parking management and analytics dashboards.

These developments will enhance GateWise's versatility, allowing it to evolve from a prototype into a scalable smart-infrastructure platform that supports both operational efficiency and sustainability — fulfilling the broader vision of inclusive, AI-powered urban management.

The GateWise system successfully integrates *YOLOv5*, *EasyOCR*, *FastAPI*, and React into a secure and modular architecture for automatic access control. Results confirm their feasibility and accuracy, marking a step toward smart, data-driven parking solutions within modern urban infrastructures.

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