Journal of World Architecture, 2025, Volume 9, Issue 6
https://ojs.bbwpublisher.com/index.php/JWA
Online ISSN: 2208-3499
Print ISSN: 2208-3480

Discussion on the Design of Intelligent Gate Systems for Airport Self-Service Security Inspection

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Abstract: This paper focuses on the intelligent gate system in airport self-service security inspection, outlining the evolution of airport security technology from traditional manual methods to intelligent solutions. It analyzes the current research status and development trajectory of intelligent gate systems, discusses key design elements in both technical and non-technical aspects, and addresses challenges such as balancing security speed and accuracy, technical compatibility, data security, and privacy protection, while proposing corresponding solutions.

Keywords: Airport self-service security inspection; Intelligent gate system; Identity recognition technology; Security detection technology; User experience design

Online publication: December 31, 2025

1. Introduction

With the booming development of the aviation industry, airport passenger traffic continues to rise, and the shortcomings of traditional manual security inspection in terms of efficiency and accuracy are increasingly evident, making it difficult to meet the operational needs of modern airports. Against this backdrop, the intelligent gate system has emerged as the core component of self-service security inspection. It integrates multiple functions such as identity recognition and security detection, serving as an important milestone in the evolution of airport security technology toward automation and intelligence.

2. Related overview

2.1. Development history of airport security inspection technology

The development of airport security inspection technology has undergone a profound transformation from traditional manual inspection to intelligent inspection. In the early stages, airport security primarily relied on manual operations, involving manual checks of passengers' identities, luggage, and personal safety. This method could basically meet demands when passenger traffic was low. However, with the rapid growth of the aviation industry, airport passenger volumes have increased year by year, gradually exposing issues such as low efficiency and insufficient accuracy in traditional manual inspection. This is particularly pronounced during holidays or peak periods, where slow inspection speeds severely impact passenger travel experiences [1].

To address these challenges, security technology has gradually evolved toward automation and intelligence. In recent years, with the cross-integration of information technology, self-service security verification systems have emerged and are gradually becoming a major trend in airport security. Self-service security systems incorporate advanced technologies such as measurement and control and artificial intelligence, not only significantly improving inspection efficiency but also enhancing accuracy and reliability. As the core component of self-service security, the intelligent gate system integrates functions like identity recognition and security detection, providing more efficient and convenient solutions for airport security and marking a new stage in the development of airport security technology.

2.2. Current research status of intelligent gate systems

Domestic and international scholars have achieved certain results in the research on intelligent gate systems in the field of airport security. From the perspective of technical implementation, existing research mainly focuses on the application of identity recognition and security detection technologies. For example, facial recognition technology is widely used in intelligent gate systems to achieve rapid verification of passenger identities, thereby improving throughput efficiency. Additionally, millimeter-wave detection and X-ray detection technologies are used for personal and luggage security checks, respectively, ensuring security while minimizing interference to passengers. In terms of application effects, studies show that intelligent gate systems can significantly enhance overall airport security efficiency, reduce labor costs, and provide passengers with a more convenient travel experience. However, existing research still has some shortcomings. Some studies overly focus on the application of single technologies while neglecting the synergistic effects of multiple technologies; research on the adaptability of intelligent gate systems in actual complex environments is relatively scarce, especially their performance under high passenger traffic and diverse scenarios, which requires further validation [2]. Furthermore, studies on user experience design and maintainability of intelligent gate systems are relatively weak, which imposes certain limitations on their promotion in practical applications.

2.2.1. Early automatic gate stage

Early automatic gates, as channel management devices, were initially applied in airport scenarios mainly for personnel access control. Their core function was to achieve standardized management of pedestrian entry and exit through mechanical or simple electronic controls. However, this stage of automatic gates had significant functional limitations, particularly in security verification. For instance, these devices could only implement basic restrictions on passersby through simple physical barriers, without effectively verifying passenger identities or linking with security equipment for comprehensive safety checks. Additionally, early automatic gates often lacked intelligent features, making it difficult to adapt to the complex and variable passenger flow demands at airports, resulting in low throughput efficiency and susceptibility to tailgating phenomena. Although these devices alleviated some manual management pressure to a certain extent, their single-function positioning could not meet the dual requirements of modern airports for security and efficiency, thereby driving the development of subsequent technology integration and intelligent upgrades.

2.2.2. Technology integration development stage

With the rapid development of identity recognition and security detection technologies, intelligent gate systems have gradually transformed from single access control devices into comprehensive security platforms integrating multiple functions. In this stage, technologies such as facial recognition, document recognition, and millimeter-wave detection were introduced into gate systems, significantly enhancing security functions and efficiency. For example, the application of facial recognition allows passengers to pass through gates quickly via non-contact verification, while combining it with ID document recognition effectively prevents impersonation. Furthermore, the introduction of millimeter-wave detection provides a more precise solution for personal security checks, enabling preliminary screening of prohibited items without infringing on passenger privacy [3]. This integration of technologies not only optimizes the security process but also significantly improves throughput efficiency and reduces passenger queuing time. It is worth noting that the technology integration process in this stage was not without challenges, with compatibility issues between different technologies and system integration complexity being the main hurdles.

2.2.3. Intelligent upgrade stage

Currently, intelligent gate systems are leveraging cutting-edge technologies such as artificial intelligence and big data to achieve higher levels of intelligent upgrades, further enhancing security efficiency and service quality. The introduction of artificial intelligence enables intelligent analysis of security data, such as modeling historical security data through machine learning algorithms to predict potential threats and take preemptive measures. Additionally, big data-based applications allow the system to dynamically adjust access strategies based on real-time passenger flow, optimizing the overall process. For instance, in a real-world case at a certain airport, the intelligent gate system, combined with big data, successfully achieved precise diversion of peak-hour passenger flows, significantly shortening passenger wait times [4]. At the same time, intelligent upgrades are also reflected in improvements to user experience, such as intelligent voice guidance and visual interfaces that help passengers complete security operations more conveniently. It is worth noting that intelligent upgrades not only enhance the system's functionality but also strengthen its adaptability, enabling it to flexibly respond to future changes in security demands.

3. Key design elements of intelligent gate systems: Technical aspects

3.1. Identity recognition technology

Facial recognition technology serves as the core identity verification method in intelligent gate systems. By extracting facial features from passengers and comparing them with stored information in the database, it achieves rapid and accurate identity confirmation. Its application principle is primarily based on computer vision and pattern recognition technologies, completing the identity verification process through steps such as facial image acquisition, preprocessing, feature extraction, and matching. In practical applications, this technology significantly improves passenger throughput efficiency, reduces the need for manual intervention, and effectively prevents the misuse of others' ID documents (**Figure 1**). However, facial recognition technology still faces certain limitations in complex airport environments, such as reduced accuracy under poor lighting conditions or significant changes in passenger facial angles. Additionally, facial occlusions (e.g., masks, hats) pose challenges to recognition effectiveness. To overcome these issues, researchers have proposed multimodal fusion recognition methods that combine infrared imaging or other biometric recognition technologies to improve the system's robustness and adaptability.

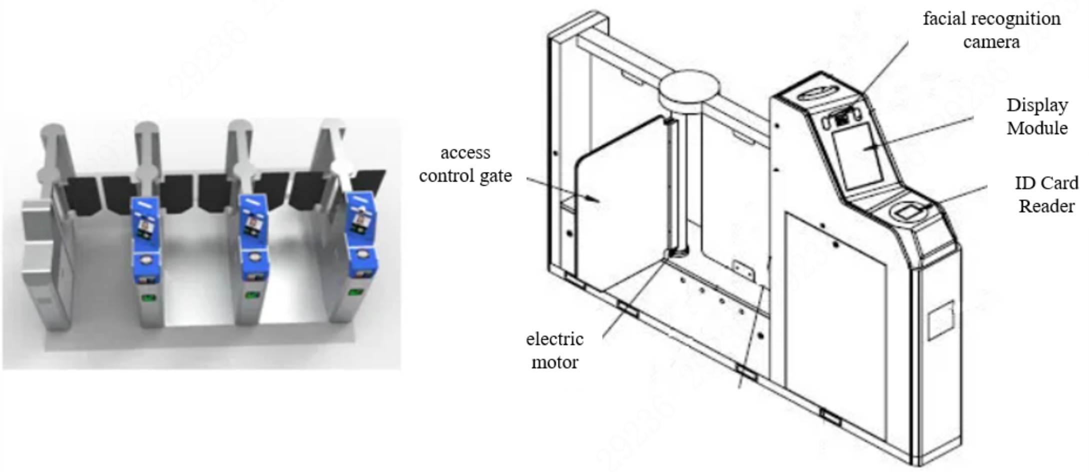

Figure 1. Intelligent gate machine image.

3.2. Security detection technology

Millimeter-wave detection technology, as a non-invasive personal security method, has been widely applied in airport intelligent gate systems in recent years. Its working principle involves scanning the human body with electromagnetic waves in the millimeter-wave frequency band and generating imaging results of the body surface and concealed items by analyzing reflected signals [5]. Compared to traditional metal detectors, millimeter-wave detection offers significant advantages, such as being harmless to the human body, providing clear imaging, and detecting non-metallic prohibited items, making it an important tool for enhancing security efficiency and safety. However, this technology also presents some technical challenges in practical applications, such as limited penetration of millimeter-wave signals, which may be affected by clothing materials or environmental humidity. Additionally, interpreting imaging results requires experienced security personnel, placing high demands on operators' expertise. To further improve detection accuracy, researchers are exploring the integration of deep learning algorithms into millimeter-wave image analysis to achieve automated prohibited item recognition and classification [6]. X-ray detection technology is a core technology in luggage security, emitting X-rays and receiving attenuated signals after penetration to generate images of internal items, thereby determining the presence of prohibited items. This technology plays a crucial role in airport intelligent gate systems, with its efficiency and reliability widely recognized.

3.3. Gate control technology

The intrusion detection function of intelligent security systems relies on mechatronics technology, integrating sensors and signal processing technologies. Infrared sensors detect human infrared radiation, while door/window sensors sense openings and closings; their combination determines intrusions. Multi-sensor fusion technology comprehensively analyzes data to reduce false alarms and improve reliability. Technical implementation must address signal acquisition, data processing, and alarm triggering. Sensors require high sensitivity and low noise;

data undergoes filtering and pattern recognition for noise reduction and feature extraction, then triggers alarms based on preset thresholds and rules [7]. Some systems incorporate machine learning to optimize performance, providing security for homes. The alarm linkage mechanism is a key part of mechatronics design, achieving rapid response and protection through multi-device coordination after intrusion detection. Upon detecting an intrusion, the system links acoustic-optical alarms, cameras, smart door locks, etc., such as activating alarms, recording footage with cameras and uploading to the cloud, and automatically locking doors.

3.4. Key design elements of intelligent gate systems: Non-technical aspects

3.4.1. User experience design

The operational convenience of intelligent gate systems is a core element in enhancing passenger usage experience. In airport self-service security scenarios, passengers often face time pressure and psychological stress, making it essential to simplify processes and provide intuitive guidance. The system must feature highly user-friendly interaction interfaces, using graphical prompts and textual instructions to guide passengers through identity verification and access operations. For example, high-resolution displays can show facial recognition areas and shooting requirements in real-time, helping passengers quickly adjust their positions and postures to improve recognition efficiency. It also supports seamless switching between multiple verification methods such as ID scanning, facial recognition, and QR code validation to meet diverse passenger needs. Additionally, voice-assisted functions can be provided for elderly or less tech-savvy groups, progressively guiding them through the process to enhance universality and inclusivity [8]. Optimizing operational convenience significantly shortens passenger passage times, reduces failure rates due to improper operations, and improves overall security efficiency and satisfaction.

3.4.2. Maintainability and scalability design

The maintainability design of intelligent gate systems is key to ensuring their long-term stable operation. Since airport security equipment must run 24/7 uninterrupted, faults directly impact efficiency and passenger experience. Modular design becomes an important means to enhance maintainability by dividing core functions into independent modules such as identity recognition, security detection, and control, connected via standardized interfaces for easy later maintenance and troubleshooting. For instance, if a module fails, maintenance personnel can quickly restore functionality by replacing a spare module without disassembling the entire system, greatly reducing maintenance costs and time [9]. At the same time, the system is equipped with comprehensive fault detection and diagnosis mechanisms that monitor operating status in real-time, promptly identify potential issues, and generate detailed fault logs to provide precise positioning information for maintenance personnel. This not only improves system reliability but also extends equipment lifespan, saving operational costs for airports.

5. Challenges and solutions in intelligent gate system design

5.1. Balancing security speed and accuracy

In airport self-service security, improving speed often comes at the cost of reduced accuracy, which is a core challenge in intelligent gate system design. Rapid passenger growth requires efficient throughput to minimize queuing and enhance overall efficiency, while the core goal of security is to ensure accurate detection results. However, fast passage may prevent detection equipment from fully capturing and analyzing data, increasing the probability of missed detections or false alarms. For example, in millimeter-wave body scanning, excessively fast passenger speeds may prevent clear body imaging, affecting prohibited item recognition accuracy; similarly, high-speed X-ray luggage detection may suffer from insufficient image resolution, making small items hard to identify.

5.2. Technical compatibility issues

Intelligent gate system design requires integrating multiple identity recognition and security detection technologies, with compatibility between them being a major challenge in development. Devices and software platforms from different vendors vary in data formats and communication protocols, easily causing data interaction barriers during system integration. For instance, output formats for facial and iris recognition differ, making seamless docking difficult; differences in image processing algorithms between millimeter-wave and X-ray detection can affect subsequent data fusion and analysis [10]. To solve this, standardized interfaces and unified data formats are key. Establishing industry-wide technical standards to regulate communication protocols enables efficient data transmission and sharing. For example, the multi-sensor anti-tailgating technology proposed achieves collaborative data processing from depth sensors, thermal imaging sensors, and RGB cameras through standardized interfaces, enhancing system performance.

5.3. Data security and privacy protection issues

When processing passenger identity information and security data, intelligent gate systems face severe challenges in data security and privacy protection. Leakage of sensitive personal information such as facial features and iris data can severely infringe on privacy; unencrypted large volumes of security images and data may be stolen or tampered with, threatening airport operational safety. Moreover, interconnections with other airport service systems increase data breach risks. To counter these, encryption technologies and access control mechanisms are widely applied. For example, using Advanced Encryption Standard (AES) to encrypt passenger personal information ensures secure storage and transmission; implementing strict access controls limits access to authorized personnel only, reducing internal misuse risks. Additionally, anonymization techniques protect privacy by removing personal identifiers during data analysis, converting raw data into anonymous datasets, thereby reducing privacy infringement while ensuring data usability and comprehensively enhancing the system's data security and privacy protection levels.

6. Conclusion

Intelligent gate systems play a crucial role in airport self-service security inspection. Their development has progressed from early automatic gates through technology integration to intelligent upgrades, continuously adapting to new airport security demands. At the technical level, effective integration of identity recognition, security detection, and gate control technologies forms the foundation for efficient system operation; at the non-technical level, good user experience design, along with maintainability and scalability, ensures practicality and long-term development. Although system design faces challenges such as balancing speed and accuracy, technical compatibility, and data security with privacy protection, measures like algorithm improvements, standardized interfaces, and encryption technologies have addressed these to a certain extent.

Disclosure statement

The authors declare no conflict of interest.

References

[1] Hao D, Wang J, Li B, 2023, Design of Intelligent Gate System for Airport Self-Service Security Inspection. Electronics Making, 31(19): 86–89.

[2] Huang X, 2017, Discussion on Airport Self-Service Security Verification System Solutions. Intelligent Buildings and Smart Cities, 2017(12): 39–42.

[3] Chen S, Li B, Jin C, 2022, Simulation and Optimization of Airport Passenger Intelligent Security System. Wireless Interconnection Technology, 19(18): 29–31.

[4] Xu M, 2020, Exploration and Analysis of Conflicts between Intelligent Security Inspection and Traditional Modes. Science and Technology Innovation and Application, 2020(19): 70–71.

[5] Wang J, Li K, Liu R, et al., 2020, Discussion on Intelligent Security System for Airport Passenger Carry-On Luggage. Consumer Electronics, 2020(2): 46–47.

[6] Wang C, 2023, Research on Advantages, Disadvantages, and Implementation Paths of Intelligent Airport Security Modes. Research Results and Dissemination, 2023(1): 1923–1926.

[7] Ye N, 2021, Research on Intelligent Luggage Security System Based on IoT and AI Technologies. Wireless Interconnection Technology, 18(4): 16–17.

[8] Zeng X, Tang Y, Yao Z, 2018, Research on Intelligent Security System for Airport Passenger Carry-On Luggage. Science and Technology Innovation and Productivity, 2018(4): 46–48.

[9] Li Q, 2019, Analysis of the Application of Intelligent Security Technology in Airport Luggage Handling Systems. China New Technologies and New Products, 2019(21): 14–15.

[10] Zhu X, Jin C, Jia Y, et al., 2020, Research on Luggage Tracking System Based on RFID Technology. Electronics Making, 28(20): 19–20.