Analysis and Design of the Smart Park Entry Logistics Vehicle Management System

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Abstract: With the rapid development and widespread application of information technology, 5G, cloud computing, artificial intelligence, and the Internet of Things (IoT), the construction of "smart parks" has become a common trend in park development. To create a "smart security" park with core features of security, access control, and energy efficiency, addressing the challenges of difficult monitoring, lack of order, and dispersed timing in the delivery process of inbound logistics vehicles, this study proposes an Intelligent Entry Logistics Vehicle Management System based on IoT technology. This system integrates wireless communication technology, mobile terminal technology, GPS positioning, and vehicle management application services from the Smart Park Data Service Platform to efficiently monitor logistics vehicles within the park. Furthermore, the system focuses on intelligent parking space planning and allocation to provide comprehensive support, including optimizing the processes of vehicle entry and exit and parking. The design goal of this system is to enhance the security of inbound logistics vehicles within the park and provide more convenient parking and cargo handling services.

Keywords: Smart Park; Vehicle Management System; License Plate Recognition; Intelligent Guidance

1. Introduction

In the post-pandemic era, digital technology is pervading various industries, profoundly altering production and lifestyles. Industry 4.0 emphasizes digital manufacturing, which involves the digitization of production processes, including digital supply chain management [1]. China Manufacturing 2025 has also proposed the deep integration of informatization and industrialization, promoting the intelligent development of industrial parks [2]. In large industrial parks, which may involve multiple resident companies, the confidentiality of production materials, and significant production scales, the task of security management within the park is exceptionally demanding and complex [3]. Particularly, in the management of logistics vehicle passage within the park, enhancing passage efficiency and achieving intelligent passage become crucial aspects of smart park construction. Throughout the development of smart parks, through the interconnection of various systems, we can realize intelligent management of logistics vehicle entry and exit, intelligent parking guidance for logistics vehicles within the park, vehicle position visualization, vehicle anomaly warning, dynamic management, and monitoring.

2. Scenario Requirements and Objectives

2.1 Current Issues in Park Vehicle Management

With the continuous development of China's social economy and the improvement of manufacturing capabilities, an increasing number of industrial parks are being constructed. Meanwhile, the concept of "Made in China 2025," along with the continuous advancement of domestic manufacturing, has led to the expansion of production scale in industrial parks. As these industrial parks grow, issues related to security have gradually become more pronounced. One such issue is the supervision of logistics vehicles entering and exiting these parks [4].

Under traditional management methods, the coordination of vehicles from multiple companies and the distribution of production materials have led to ineffective control and supervision of logistics vehicles entering and leaving the parks. This situation increases the risk of unauthorized vehicles gaining access to the premises. Additionally, traditional industrial parks struggle to track the movements of logistics vehicles, potentially resulting in undetected issues or security incidents. Uninspected and uncontrolled vehicles might carry hazardous or illegal goods, further increasing the potential security risks.

Apart from the potential security hazards, traditional management methods also face challenges related to uneven parking space allocation. Traditional vehicle management systems typically lack parking space allocation functionality, requiring drivers to find available parking spots themselves. Some traditional systems use random allocation, guiding vehicles to any available parking spaces without considering factors like vehicle type, cargo loading/unloading requirements, or other considerations. This haphazard parking space allocation can lead to inconvenience and chaos, reducing efficiency in cargo handling. Unreasonable parking space allocation can also result in vehicle congestion within the park, leading to an increased risk of accidents such as scratches and collisions, thereby jeopardizing the safety of both personnel and vehicles.

With the development of smart parks, traditional methods for vehicle entry and parking management are no longer suitable for the evolving requirements of smart parks. Therefore, in-depth research into the relevant technologies of intelligent parking management systems is essential [5].

2.2 System Overall Objectives

The objective of the Smart Park Entry Logistics Vehicle Management System is to enhance the experience of vehicles entering the park, achieving a more intelligent and convenient process for entry, parking, and optimizing resource allocation within the park. This aims to improve parking efficiency, expedite cargo loading and unloading, and strengthen security management. In line with the system's overall objectives, we present an overview of the entire process for logistics vehicles entering the park, as illustrated in Figure 1 below.

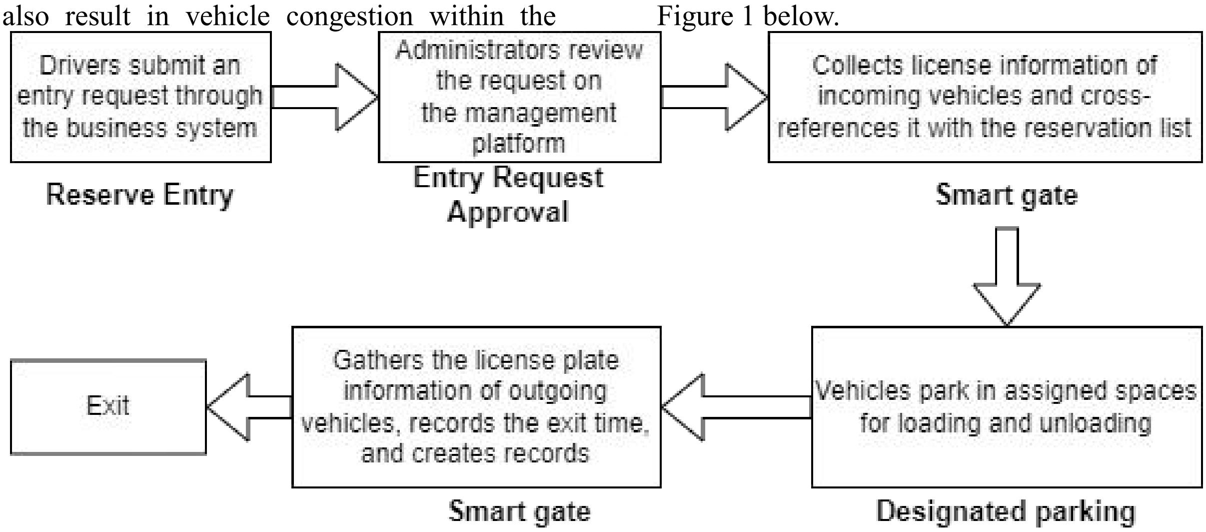

Figure 1. Streamlined Process for Logistics Vehicles Entering

According to the process shown in Figure 1, the vehicle entry into the park can be divided into the following 6 steps:

(1)Reserve entry: drivers initiate the process by submitting an entry request through the business system. This request typically includes details such as license plate information, entry time, and cargo specifics.

(2)Entry request approval: administrators review these entry requests on the management platform. They carefully assess the information provided and ensure it complies with the park's policies and schedules.

(3)License plate recognition: once the requests are approved, the system collects the license plate information of incoming vehicles. This data is cross-referenced with a reservation list, which contains pre-authorized vehicles and their details. Access is granted to those with matching records.

(4)Designated parking: authorized vehicles are then guided to specific parking spaces designated for loading and unloading purposes.

These spaces are strategically allocated to optimize the efficiency of cargo handling, ensuring a smooth operation.

(5)Exit data collection: when vehicles are ready to leave the park, the system gathers license plate information once again. This time, it records the exit time, creating an exit record for each vehicle. This information enhances monitoring and post-event analysis capabilities.

(6)Exit: following the successful collection and verification of data, vehicles are allowed to exit the park in an organized and secure manner.

This process aims to provide a structured and secure system for the entry and exit of logistics vehicles in the park, enhancing both security and operational efficiency.

3. Architecture of Smart Park Entry Logistics Vehicle Management System

The Smart Park Entry Logistics Vehicle Management System primarily consists of three layers: the Perception Layer, the Network Layer, and the Application Layer, as illustrated in Figure 2. The first layer is the Perception Layer, which includes data acquisition devices such as sensors, AI cameras, license plate recognition cameras, GPS terminals, and other data collection equipment. Data is efficiently collected through sensor networks and intelligent terminals before entering the gateway. The second layer is the Network Layer, built on top of existing mobile communication networks and the Internet infrastructure. It connects to mobile communication networks and the Internet via various access devices to perform functions like information storage, retrieval, and network management, enabling data communication between front-end devices and the management platform. The third layer is the Application Layer, which provides specific services to users through data analysis and processing. In this system, the Application Layer mainly offers services related to vehicle access management, park security monitoring, and vehicle parking guidance.

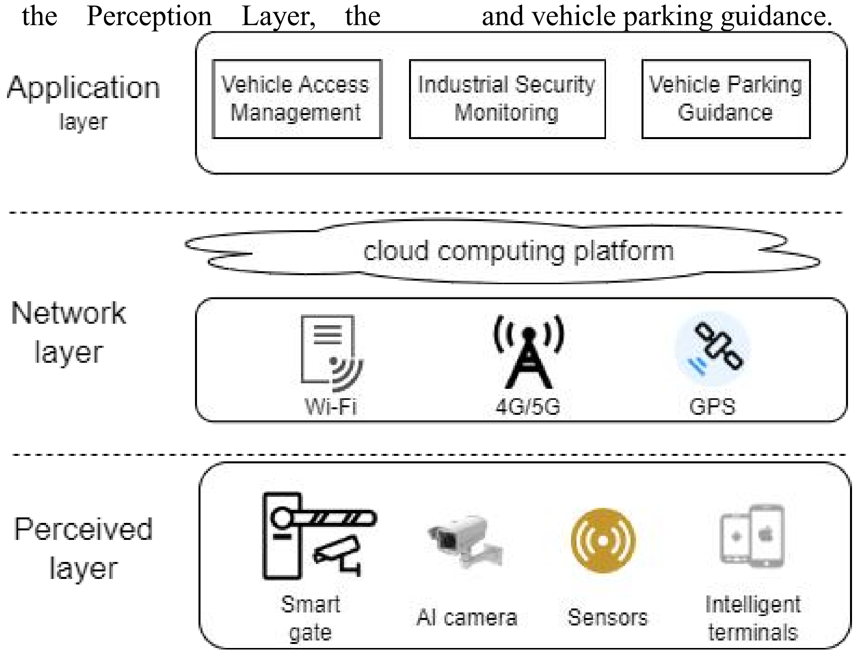

Figure 2. Architecture of Smart Park Entry Logistics Vehicle Management System

3.1 Front-End Sensing Devices

3.1.1 Smart gates

Smart gates play a vital role in the Smart Park Entry Logistics Vehicle Management System. Their primary responsibility is to effectively manage vehicle entries and exits, ensuring that only authorized vehicles can safely access and leave the park. Smart gates utilize advanced license plate recognition systems, providing high-speed and precise vehicle identification capabilities. Through license plate recognition technology, smart gates can instantaneously recognize and verify vehicles, ensuring strict control over vehicle movements within the park.

Furthermore, smart gates serve as essential record-keepers of all entries and exits. They meticulously record the entry and exit times of every vehicle, generating comprehensive access records. These records are invaluable for park management, as they offer robust data insights into parking facility usage. The park management team can analyze access records to understand the actual usage of parking areas, including peak periods, traffic volume statistics, and vehicle entry and exit frequency. These data support the development of effective strategies and enhance operational efficiency, ensuring intelligent and efficient vehicle management in the park.

3.1.2 AI cameras

In the Smart Park Entry Logistics Vehicle Management System, we employ cutting-edge AI camera technology to capture real-time imagery of the park's parking areas, enabling precise monitoring of park activities. This monitoring includes the surveillance of vehicles and personnel within the parking areas, aiming to enhance overall park security and promptly detect potential issues or unlawful activities. This intelligent monitoring system serves both as a preventive and protective measure, effectively maintaining park safety and order. Administrators can remotely access the management platform at any time to view real-time monitoring feeds, facilitating rapid responses to potential issues or incidents. Whether monitoring vehicle parking, the entry and exit processes, or tracking personnel activities within the park, this intelligent surveillance system provides comprehensive information.

Simultaneously, AI cameras offer parking space detection functionality, assisting incoming vehicles in locating suitable parking spaces quickly. This parking guidance system not only enhances vehicle parking efficiency but also reduces traffic congestion within the park. This intelligent solution provides a more convenient parking experience through real-time data and image analysis, effectively improving park operational efficiency.

3.2 Network Transmission

Network transmission consists of two primary components: wired and wireless transmission, which are used for the transfer and exchange of video and data. The park has established a network system that combines optical and wireless networks. Given the extensive area of the industrial park, there is a considerable distance between the on-site access switch and the data center's core switch. Laying optical cables would require extensive ground construction, resulting in a large-scale project that isn't conducive to the park's current upgrade and renovation. Therefore, a wireless solution is considered, involving the establishment of a connection between the on-site access switch and the router. This connection enables the transmission of video data to the backend server through 5G or Wi-Fi networks, achieving the goal of information exchange.

3.3 Data Center

A cloud-based data center has been established to centralize the data from all subsystems within the park, including the Entry and Logistics Vehicle Management System. The data center includes a range of service systems, such as data exchange service systems, data integration service systems, directory management service systems, and operation and maintenance management service systems. These systems not only facilitate internal data management but also provide information services to external stakeholders. The core of the cloud-based data center consists of two parts: distributed data storage and distributed computing. To adapt to the ever-changing environment, the BP neural network algorithm is employed to achieve system output and iterative evolution [6]. Equation (1) and (2) is the output of the neural network:

$$z_l = f\left(\sum_j v_{lj} y_j - \theta_j\right) = f(net_l) \tag{1}$$

Including:

$$net_l = \sum_j v_{lj} y_j - \theta_j \tag{2}$$

3.4 Application Platform

3.4.1 Vehicle entry and exit management service

The primary goal of the Vehicle Entry and Exit Management Service is to ensure the compliant entry and exit of vehicles within the park. By continuously monitoring and analyzing the data related to vehicle entry and exit, the system can identify potential security risks, such as unauthorized vehicles gaining access to the park. Additionally, this service provides essential information to management personnel, including parking lot utilization rates, traffic statistics, and security management alerts. This contributes to enhancing the security and management efficiency of vehicles entering and exiting the park. Including

3.4.2 Park security monitoring service

The Park Security Monitoring Service aims to comprehensively monitor the safety conditions within the park. Through devices such as intelligent gates and AI cameras, the system can capture and analyze various activities in the park in real-time. It can detect and alert to violations such as illegal parking, wrong-way driving, congestion, as well as provide early warnings regarding potential risks and anomalies. In this way, park management personnel can have better control and maintenance of the overall security of the park.

3.4.3 Vehicle parking guidance service

The primary objective of the Vehicle Parking Guidance Service is to optimize the parking experience for vehicles within the park. It provides real-time parking space information and guidance to users through intelligent terminals, such as mobile applications or GPS terminals. By considering the cargo information loaded onto the vehicles, it offers the closest available parking space to the loading and unloading platform, thereby increasing the efficiency of loading and unloading goods for logistics vehicles and reducing the waste of manpower and resources caused by long-distance loading and unloading. This intelligent guidance service reduces vehicle congestion within the park, enhances the efficiency of goods handling, and ensures the effective utilization of parking areas.

4. System Function Module Design

4.1 Vehicle Entry and Exit Management Module

The Vehicle Entry and Exit Management module play a crucial supervisory role at the entrance of the park, dedicated to monitoring all vehicles entering and exiting the park. The core components of this module include AI cameras and intelligent gate devices. Through these devices, the system can effectively capture the license plate information of vehicles entering and exiting the park, perform license plate recognition [7] and vehicle detection. The intelligent gates are responsible for controlling the opening and closing of the gate during this process.

When a driver plans to enter the park, they are required to submit an entry reservation request through the intelligent terminal system. In the request, the driver must provide details such as their license plate information, planned entry time, and information about the goods they are transporting. This submitted information initiates the subsequent approval process.

Administrators receive new entry reservation requests through the data management platform and proceed to review and verify them. During the approval process, administrators scrutinize various application details, including the driver's license plate number, entry time, and details about the transported goods. Based on this information, administrators decide whether to approve or reject the reservation.

Once the reservation request is approved by administrators, the relevant information is recorded in the database. This record includes the license plate number, entry time, and information about the transported goods, which will be used in the subsequent vehicle entry and exit processes.

The actual control of vehicle entry and exit from the park is achieved through license plate recognition technology. AI cameras capture the license plate information of the vehicles, which is then cross-referenced with the entry reservation information in the database. This step is crucial in confirming the eligibility of vehicles for entry. If all checks are successful, the system issues a release signal, allowing vehicles to enter or exit the park safely and promptly.

The specific process flowchart is illustrated in Figure 3 below:

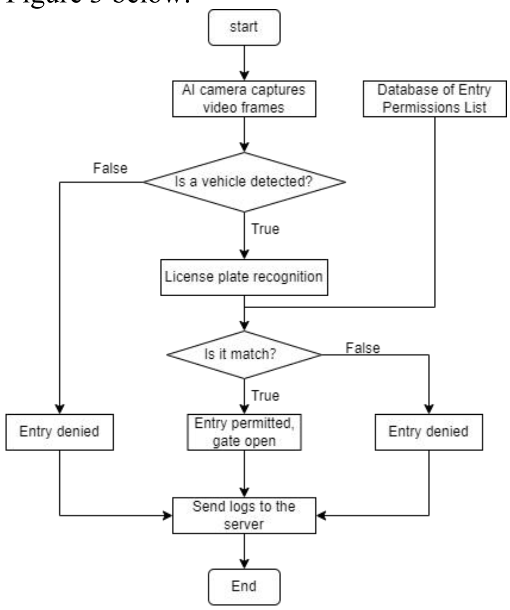

Figure 3. Process Flowchart of Vehicle Entry and Exit Management Module

License Plate Recognition (LPR) is a crucial component within the Vehicle Entry and Exit Management module, typically encompassing the following key steps:
(1)Image Capture: Initially, vehicle images or videos are captured using AI cameras. This usually occurs as vehicles pass through specific points, such as the entrance or exit of a parking lot.
(2)Image Preprocessing: The acquired images may contain various forms of noise or interference, such as lighting variations, blurriness, or obstructions. In the image preprocessing stage, the images are corrected, cropped, denoised, and enhanced to improve the accuracy of subsequent processing steps.
(3)Feature Extraction: During this step, the system detects specific features of the license plate, such as characters, borders, colors, and more. These features are used for plate identification and segmentation.
(4)Character Segmentation: Characters on license plates are typically connected, so they need to be separated for individual recognition. This often involves determining the spacing and relative positions between characters.
(5)Character Recognition: Each segmented character is fed into a character recognition engine, which is a machine learning model or deep learning neural network trained to map characters to their respective text. The character recognition engine generates textual information from the characters on the license plate.
(6)Post-processing: After character recognition, post-processing steps may be required to remove potential errors or correct inaccuracies in character recognition.
(7)Recognition Results: Finally, the text information from the license plate is extracted and typically presented in textual form for subsequent use or record-keeping.
These steps collectively enable the system to accurately recognize and record the license plate information of vehicles entering and exiting the area, contributing significantly to security and management processes.

4.2 Vehicle Positioning and Monitoring Module

Achieving precise monitoring and positioning of vehicles upon entry into the park is essential for effective management. Common methods for this purpose include Global Positioning System (GPS), Bei-Dou Satellite Navigation technology, and more. However, in a smart park environment, we can complement traditional navigation technologies by utilizing advanced visual positioning techniques [8], magnetic sensor positioning, and Wi-Fi positioning [9]. Table 1 shows a comparison of the advantages and disadvantages of these three technologies.
As shown in Table 1, visual positioning provides precise location accuracy in both indoor and outdoor environments and is well-suited for object recognition and tracking. Therefore, visual positioning technology was chosen for the design of this system. Visual positioning technology is built on a network of AI cameras strategically placed within the park. These cameras capture images of vehicles and transmit them to a backend server for processing. By using the captured image data, including license plate information and environmental context, along with precise location and angle data from the cameras, the system's algorithms can accurately determine the relative position of vehicles within the park, essentially providing real-time vehicle positioning.
This visual positioning technology offers several advantages. It is known for its precision and real-time capabilities, enabling park management to effortlessly monitor and pinpoint vehicle locations. This significantly enhances park security and management efficiency by providing a reliable and up-to-the-minute overview of all vehicle movements within the premises.

Table 1. A Comparison of the Advantages and Disadvantages of Technologies.

Features	Wi-Fi Positioning	Magnetic Sensor Positioning	Visual Positioning
Advantages	- Relies on existing Wi-Fi - Near real-time capability - Applicable in urban and indoor environments - Relatively low cost	- Unaffected by indoor or outdoor environments - Stable performance - Low cost	- High precision - Suitable for both indoor and outdoor environments - Multipurpose
Disadvantages	- Limited precision	- Limited coverage range	- High cost

	- Dependent on user device Wi-Fi support - Privacy concerns may exist	- Not suitable for outdoor environments - Low precision	- High computational complexity - Subject to lighting conditions

4.3 Vehicle Parking Guidance Module

The Vehicle Parking Guidance Module takes full advantage of the image information captured by the installed AI cameras. Through computer vision image processing, it provides a detailed overview of the parking lot's occupancy status, analyzing in real-time whether each parking space is occupied or vacant. This enables the timely illumination of indicators for vacant parking spaces, offering parking information for incoming vehicles. By integrating data from various AI cameras, real-time parking lot status reports are generated and stored in the database.

As logistics vehicles enter the park, the system combines the cargo information provided by the drivers in their applications with the current availability of parking spaces in the lot. It then employs shortest-path planning [10] to assist vehicles in determining the optimal route for loading and unloading cargo, thereby enhancing cargo handling efficiency. This function not only offers real-time navigation but also helps reduce labor costs and resource wastage, ensuring efficient cargo flow. This comprehensive parking guidance system contributes to more efficient and intelligent vehicle management within the park. The system layout for the parking guidance module is depicted in Figure 4.

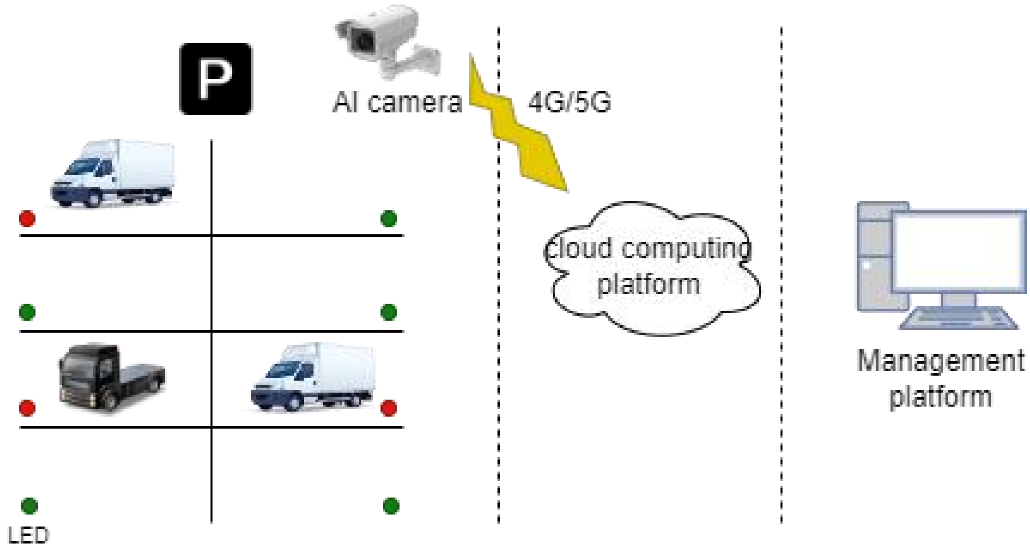

Figure 4. System Layout for the Parking Guidance Module

4.4 Vehicle Traffic Flow Statistics Module

The Vehicle Traffic Flow Statistics Module is utilized for monitoring and recording the activities of vehicles within the park. It records key data through log entries in the intelligent gates, such as entry and exit times, frequency of entries and exits, and the duration of vehicle stays. This data is used to generate statistical reports on the vehicle flow in and out of the park, including daily, weekly, and monthly traffic flow statistics. It provides valuable data analysis tools that enable management personnel to gain better insights into and optimize traffic flow within the park. Additionally, if the Vehicle Traffic Flow Statistics Module detects any abnormal conditions, such as the number of vehicles entering or exiting the park exceeding predefined thresholds, the system can trigger alerts to notify administrators.

5. Conclusion

This paper aimed to analyze the core technologies of the smart park logistics vehicle management system and create a comprehensive, intelligent smart park logistics vehicle management system. Within a smart park, the spatial movements of all elements, including people, vehicles, and goods, are accompanied by a significant exchange of information. Through sensors in the Internet of Things sensing layer and backend processing devices, this information is continuously monitored in real-time. The system provides real-time guidance for logistics vehicles, thus achieving intelligent management of vehicles within the park. This innovation holds the potential to enhance the operational efficiency and level of informatization across the entire logistics operation, contributing to an overall improvement in smart park management quality.

Acknowledgments

This work was supported in part by a grant from the youth academic project titled "Research on Data Services in Cloud-Smart Industrial Park Under the Purview of Artificial Intelligence." (project number: 2023HSQX045).

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