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RESEARCH AND DESIGN OF INTELLIGENT PARKING MANAGEMENT SYSTEM BASED ON THE YOLO ALGORITHM

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Abstract. Given the difficulty in managing parking lots and inefficient utilization of parking spaces at university and college campuses, this paper designs an intelligent campus parking management system with functions such as license plate recognition (LPR), online parking space reservations, campus parking navigation, and mobile app payment through the parking space detection technology based on You Only Look Once (YOLO) algorithm, Internet of Things (IoT) technology, and cloud platform technology. This system obtains information relating to license plates, parking spaces, etc. from sensing nodes with the IoT technology and transmits the collected information through NB-IoT technology to a cloud platform for storage and management to facilitate information exchange between hardware and software. This paper describes the architecture of the intelligent parking management system, parking space detection technology based on the YOLOv4 algorithm, and hardware and software design of the system. The paper proposes an effective solution to parking problems facing colleges and universities. The paper concludes that the intelligent campus parking management system based on the YOLOv4 algorithm can prevent the haphazard parking of vehicles and traffic congestion at open campuses and therefore has important value for application and popularization.

Key words: YOLO algorithm; IoT technology; Cloud platform technology; Parking management system

1. Introduction. Universities and colleges with open campuses are facing many parking problems such as difficulty in parking vehicles and managing parking spaces, inefficient utilization of parking spaces, and ineliminable haphazard parking. All these would result in an inconvenience to teaching activities and daily management on campus[1]. As the existing parking management systems are often less information-based and usually require manual processing, parking management becomes rather inefficient. This paper proposes a solution that allows for a combination of ZigBee technology and a backbone communication network in a certain area with the help of 4G-based Narrowband Internet of Things (NB-IoT) gateway technology. The solution is aimed at resolving poor network coverage in indoor or underground locations, supporting ultra-low power hardware devices, and maintaining an extended standby time[2]. The technical solution to an intelligent campus parking management system also combines YOLOv4 algorithm-based parking space detection technology with the IoT technology to help drivers find vacant parking spaces more easily with the information provided. The solution also supports LPR, parking space reservation, parking navigation, and online payment to improve the efficiency of campus parking management[3-5].

2. Architectural Design of Intelligent Parking Management System. The building of an intelligent parking lot is critical to solving parking problems in universities and colleges. With NB-IoT as the core network, the intelligent parking management system is designed for parking lots on the open campuses of these schools. The parking management system uses CN18DX chips, which is a NB-IoT+GPRS dual-mode M2M modules equipped with the NB-IoT function and supports various interactions through embedded development, mobile app development, software and hardware design, and cloud data queries. The system has an overall platform architecture with an ecological parking cloud as the top layer, intelligent parking lots as the middle layer, and LPR modules and users as the bottom layer. At the top layer is an ecological cloud server for parking on campus, which is connected to ZigBee network nodes distributed across the campus via a China Mobile core network for data exchange. ZigBee is a low-power wireless mesh network standard targeted at battery-powered devices

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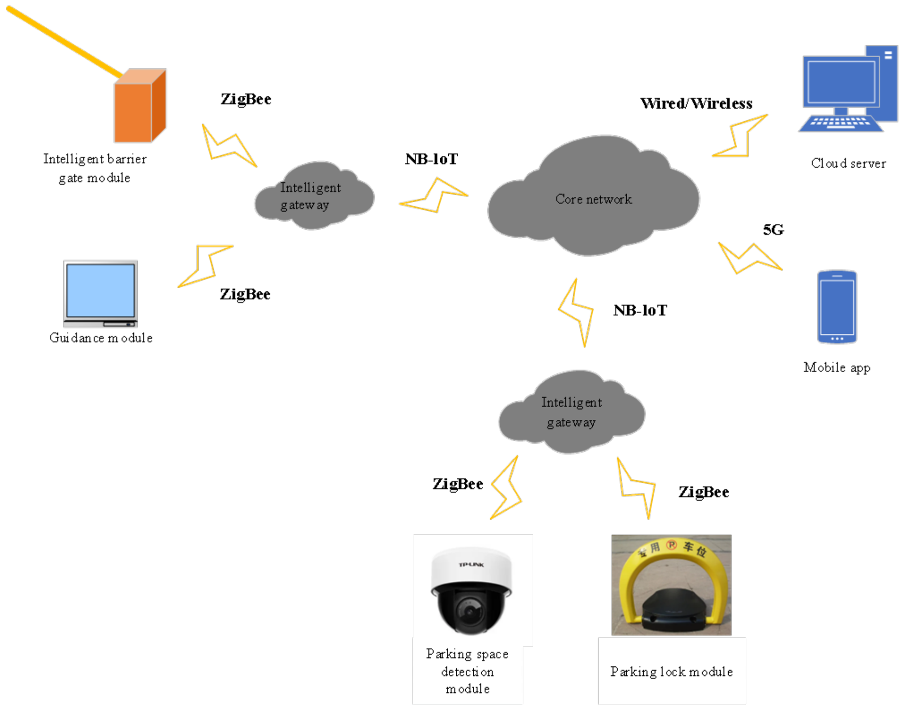

Fig. 2.1: Network topology diagram of an intelligent parking management system

in wireless control and monitoring applications. These ZigBee nodes are mainly distributed at the parking space detection modules of a parking lot, barrier gates for entry and exit lanes at school gates, entrances to above-ground and underground parking lots, and parking locks in each parking space. The system also includes a dedicated mobile app. The ecological parking cloud manages all parking space information through a cloud server. This allows a user to obtain parking space information via the mobile app in real time to choose a vacant parking space. The cloud server will guide the user through intelligent parking services on their mobile phone based on their needs. During the process, the cloud server will issue instructions and tasks to the devices of the local parking lot ecosystem to ensure smooth delivery of the parking services. The mobile app allows a user to view parking space information across the campus in real time and use functions such as parking space query and reservation, payments, and parking lock control. Figure 2.1 shows the network topology diagram of an intelligent campus parking management system.

3. Parking Space Detection Technology Based on YOLO Algorithm. Currently, there are two conventional parking space detection methods. The first one uses sensors for detection. Commonly used sensors mainly include coils, ultrasonic range finders, infrared sensors, and geomagnetic sensors[6]. The other method uses computer vision. Specifically, surveillance cameras that have been widely deployed in parking lots will detect parking spaces by collecting surveillance video. Although algorithms for parking space detection based on sensors have already become mature, finding a low-cost alternative to sensors has become a consensus in the industry due to their high installation costs and difficulty in maintenance.

Using cameras for parking space detection based on computer vision has a great application prospect, which will help popularize intelligent parking lots. On the one hand, this method makes the best of surveillance devices that have been widely installed in parking lots and allows one camera to monitor multiple parking spaces simultaneously, thereby saving upfront costs[7]. On the other hand, there is no need to make major changes for cameras to collect statistical information about parking spaces thanks to target detection algorithms as the cameras will capture video and transmit it to a processing center, which facilitates maintenance in the future.

As artificial intelligence (AI) technologies are cropping up and a series of algorithms for target detection

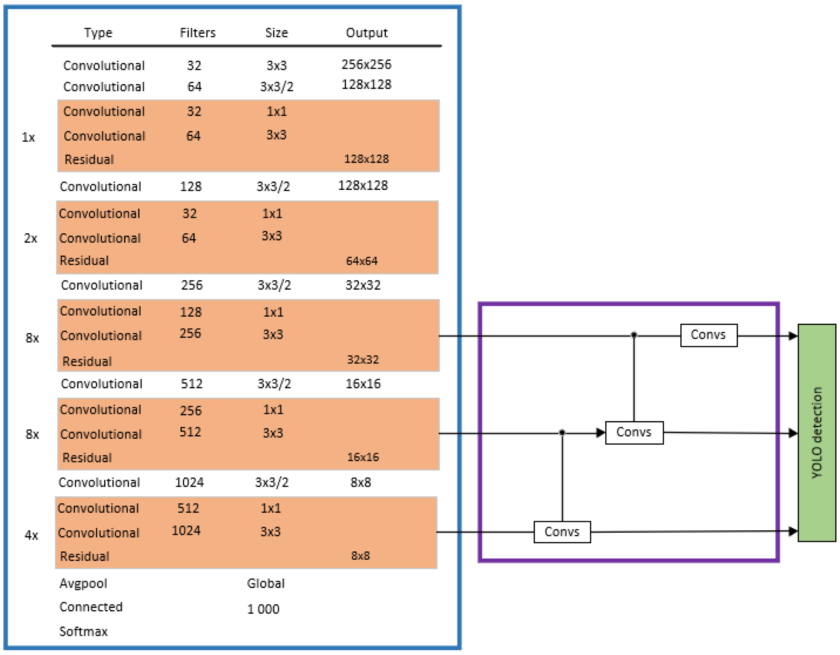

Fig. 3.1: YOLOv4 structure diagram

have emerged, this paper selects YOLOv4, a lightweight, high-precision target detection algorithm for real-time parking space detection.

The YOLO series[8-11] of algorithms are end-to-end target detection algorithms. These algorithms adopt the one-stage strategy to convert a target classification and positioning problem directly into a regression problem, thereby improving their detection speed. YOLOv4 is one of the algorithms with excellent accuracy and speed in the current target detection field as it improves activation functions and loss functions for the backbone feature extraction network of YOLOv3.

This paper mainly deals with the task of identifying vehicles in the fixed positions of a parking lot and transmitting relevant license plate information to the system terminal, which requires high real-time performance and accuracy from the algorithm. Using the YOLO v4 algorithm for detection can better fulfill the task but come with a slow target detection problem as found during its development. To solve this problem, this paper proposes to improve the performance of the YOLO v4 feature extraction network with the convolutional block attention module (CBAM)[12]. By assigning higher weight coefficients to areas of interest such as target areas, the proposed method can improve the feature expression ability of the model and speed up target detection.

The CBAM is a classic method in the field of channel attention and spatial attention. For a given feature map, CBAM can sequentially generate attention information in both channel and spatial dimensions and multiply the two sets of feature map information with the original input feature map for adaptive feature correction to produce the final feature map. In this paper, a lightweight CBAM is embedded into the output of features of three different scales from YOLOv4 to more accurately extract features of interest and weaken or even discard other features, thereby improving detection accuracy. The structure diagram of YOLOv4 is shown in Figure 3.1.

The BCAM consists of two attention modules: the channel attention module and the spatial attention module. The schematic diagrams of the two modules are shown in Figure 3.2 and Figure 3.3, respectively. In the channel attention module, each channel of a feature map is considered as a feature detector. With combined use of max pooling and average pooling, the spatial dimension of the feature map is compressed to generate two different spatial context information, the average pooling feature F^c_{avg} and the max pooling feature $F^c_{\max}$.

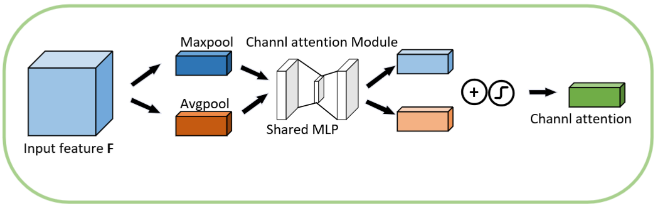

Fig. 3.2: Schematic diagram of the channel attention module

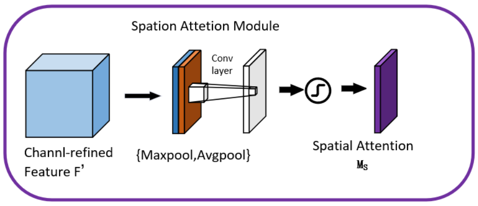

Fig. 3.3: Schematic diagram of the spatial attention module

The feature is then sent to a shared multilayer perceptron (MLP) network to produce the final one-dimensional channel attention feature map $M_c \in R^{C\times 1\times 1}$.

The spatial attention module focuses on the positional relationships within the feature map space. To calculate the spatial attention, a feature needs to be average pooled and max-pooled in the channel dimension first and the generated feature maps should be spliced together, followed by a convolutional layer to generate the final two-dimensional spatial attention feature map $M_s(F) \in R^{1\times H\times W}$. The software architecture of the intelligent parking management system offers several advantages. The utilization of the YOLOv4 algorithm for real-time parking space detection enhances the system's accuracy and speed in identifying vehicles in fixed positions within a parking lot. Additionally, the integration of the CBAM)with the YOLOv4 feature extraction network improves the model's feature expression ability, leading to enhanced target detection performance.

Figure 3.4 shows the overall design process of the parking space detection technology based on the YOLO algorithm proposed in this paper, and Figure 3.5 shows the effects brought by LPR.

4. System Hardware Design. The hardware of the system is mainly designed to include three parts: a parking space detection module, an intelligent barrier gate module, and intelligent shared parking locks.

4.1. Design of Parking Space Detection Module. As the basis of the entire ecological parking cloud, the parking space detection module senses parking spaces in a parking lot as well as their status and distribution through cameras and reasonably allocates and guides a driver to a designated parking space based on their needs[13]. The module is mainly composed of a microcontroller unit (MCU) module, a field-programmable gate array (FPGA) module, a camera module, a ZigBee wireless module, and a power management module. Figure 4.1 shows the block diagram of the module.

The MCU module uses the 32-bit low-power large-capacity chip STM32F103V8T6 based on an ARMCortex-M3 core as its microprocessor. STM32F103V8T6 is a 100-pin chip package with up to 51 multi-functional, bidirectional input and output ports, all of which can be mapped to 16 external interrupts[14]. The STM32 microprocessor works at a frequency of up to 72MHz and is built in with 256KB of flash memory and 48KB of SRAM. It has two 12-bit analog-to-digital converters (ADCs), 11 timers, and 13 on-chip communication interfaces. Its supply voltage is 2V–5V. When the camera module captures a vehicle entering a parking space, the FPGA runs the YOLO algorithm for license plate recognition and sends the recognized license plate number to the STM32 through serial ports. The communication module of the parking space detection module uses

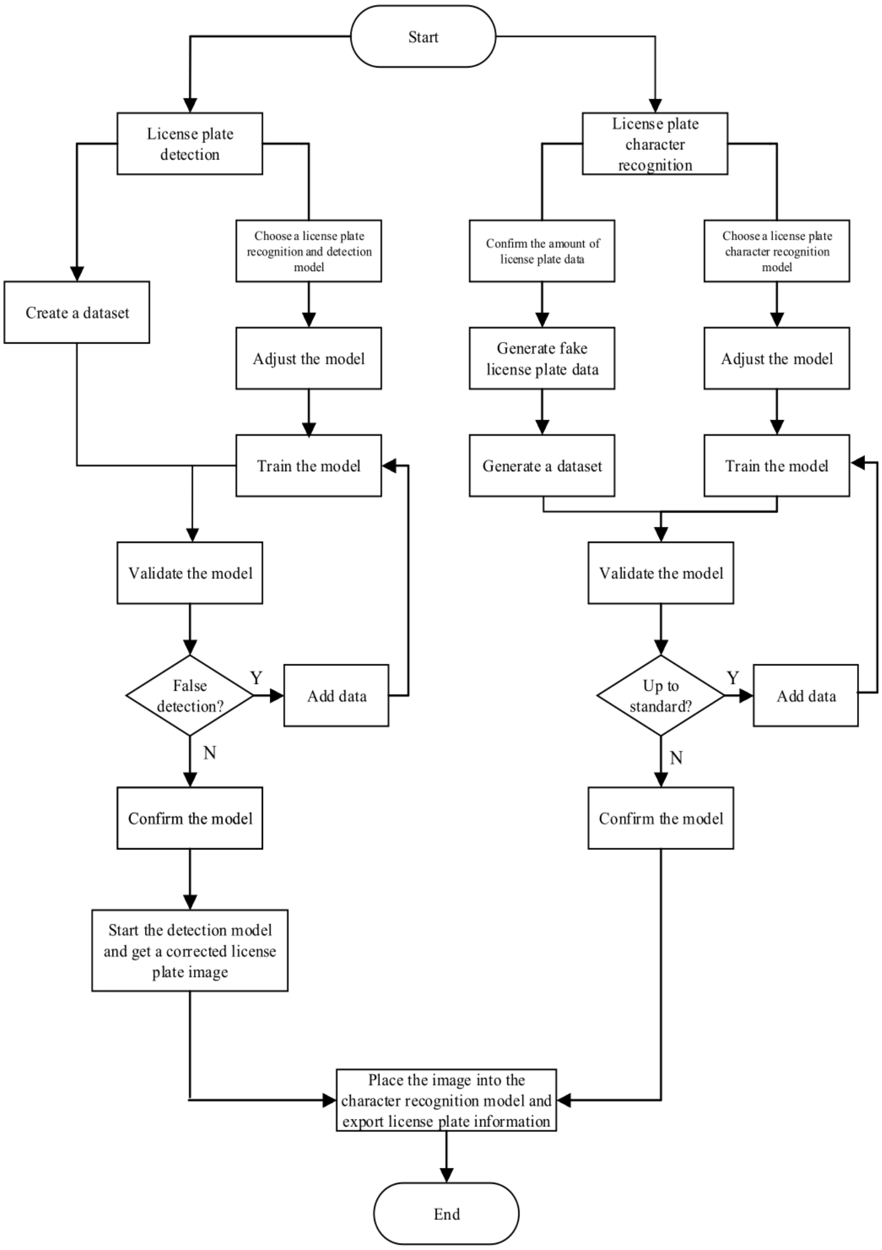

Fig. 3.4: Overall design flow chart of the parking space detection technology based on the YOLO algorithm

the ZigBee module with the CC2530 chip produced by TI as the core. CC2530 is a true system-on-chip (SoC) solution for IEEE 802.15.4, Zigbee, and RF4CE applications. It enables robust network nodes to be built with very low total bill-of-material costs. Its maximum transmission rate can reach 250Kbps and its supply voltage ranges from 3.4V to 4.2V. The system adopts the ZigBee wireless communication method, with low power consumption and strong performance, thereby greatly reducing the difficulty and costs of installation and maintenance. The entire parking space detection module adopts 5V DC power supply.

Fig. 3.5: Effects brought by LPR

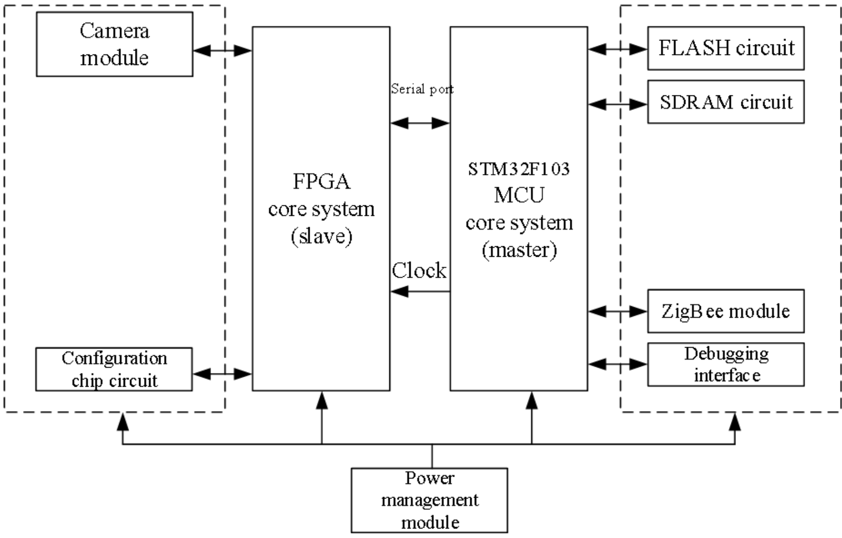

Fig. 4.1: Hardware block diagram of the parking space detection module

4.2. Intelligent Barrier Gate Module Design. The intelligent barrier gate module includes a license plate video recognition module, an electrical beam control module, a ZigBee wireless module, and an AC power supply. The license plate video recognition module is composed of an embedded ARM system and supports a light-emitting diode (LED) display. The Cortex-A8 processor is an application processor implementing the ARMv7 architecture and featuring Thumb-2 technology for enhanced performance and code density and reduced power consumption. The system operates at a voltage of 220V AC with a license plate recognition rate of more than 99.7% and a recognition speed of less than 500ms. The beam control unit uses a 250W motor, which can limit the lifting and lowering speed to less than 2s. The block diagram of the intelligent barrier gate module is shown in Figure 4.2.

4.3. Design of Intelligent Shared Parking Lock. Intelligent shared parking locks are designed for VIP customers and customers who reserve parking spaces. The locks can be lifted or lowered remotely and support

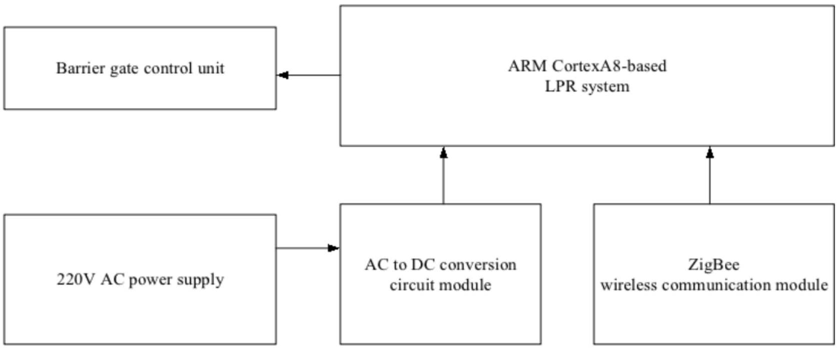

Fig. 4.2: Hardware block diagram of the intelligent barrier gate module

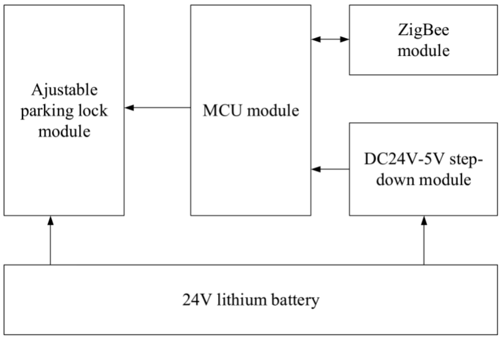

Fig. 4.3: Hardware block diagram of an intelligent parking lock

the uploading of ZigBee data. They are connected to the management platform via a ZigBee-NB-IoT gateway. Users may reserve parking spaces and unlock parking locks or perform other operations on their mobile app. The intelligent shared parking lock design uses STM32F103V8T6 as the core control module of the MCU to lift or lower parking locks and the NB-IoT communication module for data communications. The parking lock unit powered by a lithium battery supports the task wake-up function and maintains a low-power standby state with very low power consumption. The lithium battery has a capacity of 24V 20A/h and can work continuously for more than 2 years. Figure 4.3 shows the hardware block diagram of the lock.

5. System Hardware Design. Built on existing intelligent parking system solutions and based on the overall needs of campus parking, the system is designed to have the following major functions: cloud data query service, parking space map management, barrier gate system access, and mobile app functions.

5.1. Design of Cloud Data Query Service Function. As the operation center of the entire intelligent parking system, the cloud server is responsible for the timing and data scheduling of all workflows, data updates, storage and backup, updates on outdoor parking space indicator data, parking space management, payment services, vehicle query and positioning, navigation and positioning within a parking lot, and app services during parking to ensure the normal use of the intelligent parking lot service platform. The schematic diagram of the cloud data query service function is shown in Figure 5.1. On the hardware side, the design of the parking space detection module includes components such as the STM32F103 MCU core system, FPGA core system, camera module, ZigBee wireless module, and power management module. This hardware setup allows for efficient sensing of parking spaces in a parking lot, allocation of parking spaces based on driver needs, and seamless communication between different modules . The use of ZigBee wireless communication in the hardware architecture reduces installation and maintenance costs while ensuring strong performance and low

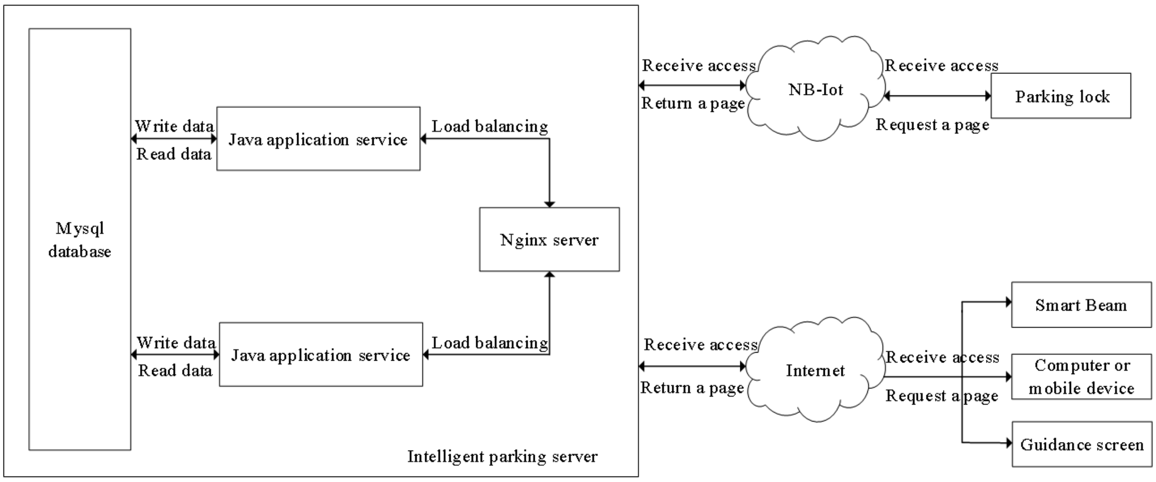

Fig. 5.1: Schematic diagram of the cloud data query service function

power consumption.

5.2. Design of Parking Space Map Management Function. Data about campus map models, locations of parking spaces, and paths are prepared through campus map data creation and navigation implementation, and offline data is generated and deployed on mobile devices. SuperMap IMoblie is used to design and develop a mobile navigation and positioning system. Relying on the network environment deployed on campus, positioning and navigation functions are made available through the mobile app[15-16]. This function allows for the management of information about all parking spaces under and above the ground, such as viewing the availability of parking spaces, checking and updating campus maps, using GPS navigation based on parking lot maps, and manually modifying parking space information (such as setting VIP parking spaces) by administrators. These functions enable administrators to manage campus parking spaces more efficiently and conveniently.

5.3. Design of the Access Control Function of the Barrier Gate System. The information provided by the barrier gate system mainly includes license plate numbers, parking duration, and parking fees. The system can receive from the cloud such information as if and when parking fees are paid. The cloud management interface can include operations that allow the barrier gate system to access the cloud URL and authentication information[17]. If wireless nodes of a barrier gate and license plate video recognition systems are deployed at the entrances and exits of a campus, vehicle information obtained at an entrance will be uploaded to the cloud server for identification and filing. Meanwhile, the timing function will be enabled for the calculation of fees and the barrier gate be open to allow the vehicle in. At an exit, a vehicle will be checked for its identification and may be allowed to leave based on its identification and payment information[18]. The intelligent barrier gate system can free security guards from performing lots of repetitive statistical work related to vehicles, improve their productivity and reduce possible mistakes. It can also speed up vehicle flows and relieve congestion at campus entrances and exits.

5.4. Mobile App Design. The mobile app is developed mainly with Android programming languages mainly for the Android system under the Vue framework[19]. The app can be registered on its mobile client and by WeChat users, making user registration easy even for people who visit campus for business purposes and removing the need for traditional onsite registration[20]. Relevant personnel can view relevant user information, analyze users' parking behavior and parking habits, and obtain user attributes. The mobile client also supports online timing and parking fee query, online payment, and other functions. Therefore, drivers can query the timing and billing function in real time even when they leave the vehicle temporarily or leave the campus. The app's background management interface also supports the statistics and querying of parking space utilization

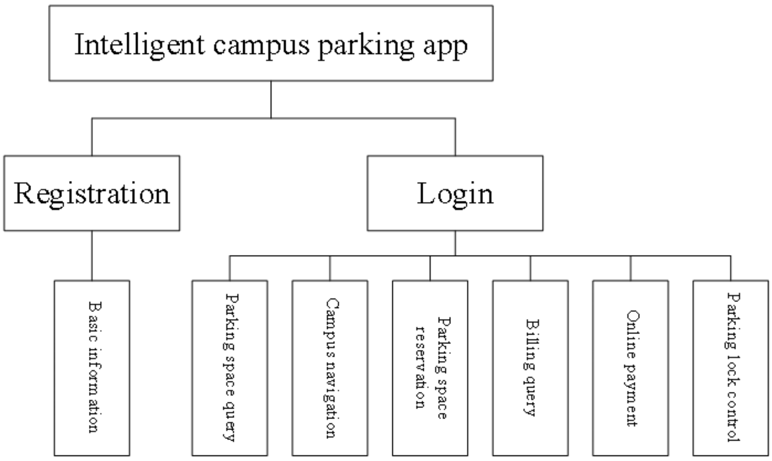

Fig. 5.2: Functional modules of the mobile terminal system

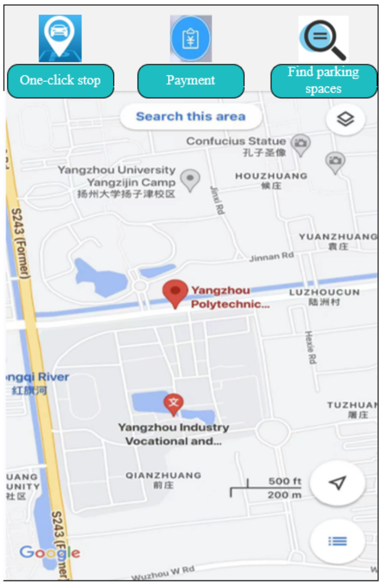

Fig. 6.1: App login UI

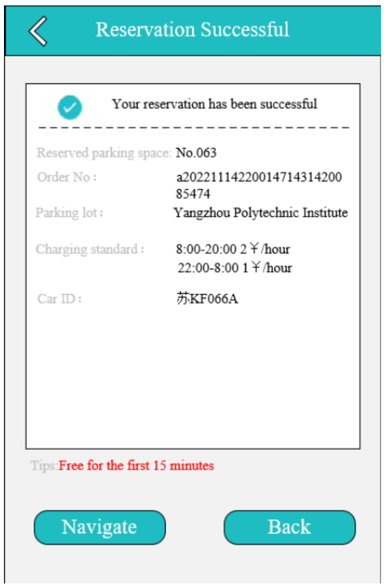

Fig. 6.2: App reservation UI

and revenue such as by time and parking space, the viewing of users' parking records and bills, etc. The functional design of the mobile terminal system is shown in Figure 5.2.

6. System Implementation. After system software and hardware are designed, there is a need to build a server, import campus map and parking space model data, install intelligent parking locks, and download the mobile app. When the entire system is powered on, each module will be initialized. After the initialization, all modules will be connected to the corresponding network and the campus intelligent parking server. After connection, a user can log in to the mobile app to view available parking spaces and find one, as shown in Figure 6.1, or reserve a parking space based on their needs and navigate to it, as shown in Figure 6.2.

7. Conclusion. This paper proposes an intelligent parking management system based on the YOLO algorithm to solve parking difficulties on campus. The solution provides major functions such as the intelligent management of parking spaces and vehicles entering and leaving campus and automatic vehicle billing. It also allows users to reserve and locate parking spaces and query parking duration and fees. All these functions will make parking easier for faculty members and those who visit campuses for business purposes. Therefore, the solution has important value for application and popularization. In future research, more efforts will be invested in applying this system to fields such as intelligent air traffic control.

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