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DESIGN OF POWER GATEWAY BASED ON EDGE COMPUTING AND RESEARCH ON DATA TRANSMISSION SECURITY

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Abstract. In order to realize the centralized processing and remote management of data in the power grid, the author proposes the design of power gateway based on edge computing and the research on data transmission security. The author builds a computing service model in the gateway through Docker virtualization technology, analyzes the application of edge computing in the power industry, builds services based on Python language and Docker technology, and designs the edge computing gateway system. The experimental results indicate that: This model can accurately obtain the coordinate position and rotation angle of the grounding knife, and selects a convolution kernel size of 6 × 6 based on the information loss rate and defect removal rate of gateway image processing. Zone A is in the closed state (92 °, 98 °), zone B is in the middle state (98 °, 175 °), and zone C distinguishes the closed state (175 °, 179 °). This recognition algorithm can accurately analyze the status of the grounding knife, so it can be used to build a power gateway to ensure information security. The problem of logic confusion in Docker's design of power gateway is solved, follow up work is carried out with this idea, and a power gateway based on edge computing is designed and implemented.

Key words: Edge computing, Power gateway, Docker, cloud computing

1. Introduction. The concept of smart grid has emerged and gradually become a hot topic for research and exploration in the global power industry. With the development of society and economy, as well as technological progress, human society's dependence on electricity is increasing.

The intelligence network, also known as the intelligence of the power grid, is built on the basis of an integrated, high-speed bidirectional communication network. Through the application of advanced sensing and measurement technology, advanced equipment technology, advanced control methods, and advanced decision support system technology, it achieves the reliable, safe, economical, efficient, friendly environment and safe use of the power grid [1]. The intelligence of the power grid is reflected in six aspects: intelligent substations, power generation, intelligent transmission, intelligent distribution, intelligent electricity consumption, and intelligent scheduling [2]. Among them, the distribution system is a power network system composed of various distribution equipment (or components) and distribution facilities, which converts voltage and directly distributes electrical energy to end users; But the intelligent distribution system is an electrical energy management system with strong professionalism, high degree of automation, ease of use, and high reliability. It is developed according to user needs and follows the standard specifications of the distribution system. Through telemetry and remote control, the rational allocation of loads, optimization of operation, effective energy conservation, and recording of peak and valley electricity consumption have been achieved, providing necessary conditions for energy management [3].

With the continuous development of electronic communication technology and the successive formulation of a series of policies and corresponding technical specifications for energy conservation and emission reduction

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by the country, especially the current development and promotion of technologies and solutions such as cloud platforms and the Internet of Things. Currently, more and more large enterprise users in industries such as construction, electricity, and transportation hope to automatically manage various energy demands and achieve effective energy conservation, alternatively, real-time data on enterprise energy consumption can be obtained through cloud platforms, and distributed monitoring and centralized management of various energy systems can be carried out [4].

2. Literature Review. The intelligent gateway acts on the network layer of the three-layer architecture of the Internet of Things, controlling sensor devices to collect data downwards and connecting to cloud platforms upwards. Its main functions include data collection, data transmission, and protocol conversion, thereby achieving data interaction between terminal devices and the Internet of Things cloud platform. It is an important component of the Internet of Things system [5]. Feng, C. designed an intelligent industrial IoT gateway that integrates Modbus protocol and MQTT protocol, achieving real-time collection of industrial equipment operation status and data, and sending them to cloud servers through 4G mobile networks via MQTT protocol [6]. Singh, A. conducted research on communication protocols and solved the problem of message interaction and connection between Modbus-485 network and Ethernet [7]. Li, J. designed an Internet of Things gateway based on the actual situation and specific needs of a tea factory. The PLC is responsible for collecting relevant data and sending it to the cloud through the MQTT protocol, achieving the functions of data collection, transmission, and control [8].

Edge computing refers to providing a nearby intelligent service platform on the network side close to the terminal equipment. This platform integrates network, computing, storage, application and other capabilities to meet the digital needs of the Internet of Things industry. The working nature of edge computing is similar to cloud computing. The difference is that cloud computing processes and preprocesses the data collected by gateway devices at the application layer to achieve data persistent storage, while edge computing refers to processing and preprocessing the collected data at the edge of the network. In the implementation process of intelligent gateway, it refers to processing, computing and filtering the collected terminal data in the gateway to improve data transmission efficiency and reduce network resource consumption [9]. Li, X. In view of the network bandwidth problem existing in the greenhouse control system under the traditional cloud computing mode, the edge computing support service platform was built to analyze and process data at the edge side, reducing the pressure of cloud computing and improving the data transmission efficiency [10]. Kumari, P. applied the edge computing framework to the implementation of the Internet of Things gateway. Using the edge computing framework, data can be processed at the edge side, effectively solving the problem of high real-time data processing in solving massive data problems in traditional gateways [11].

By analyzing the structure and functional requirements of power gateway based on edge computing, and building a general service in the gateway through Docker technology, the author proposes a Docker application interaction structure based on message queue telemetry transmission protocol. Through the real-time object detection of the regional network, the cooperation between the edge computing node and the cloud center is realized, the author has designed a power gateway system based on edge computing.

3. Research Methods.

3.1. Edge computing and Requirements. Edge computing is proposed in the concept of Content Delivery Network, and has obtained preliminary definitions and specifications from the European Telecommunications Association. edge computing organizations have also made industry settings [12]. Through improvement, it is concluded that "edge computing is a computing model that provides computing services at the data source". Edge refers to the resources that devices arrive at the cloud server. In edge computing, on the one hand, sensors send data to the cloud center, and on the other hand, sensors respond to the request of the cloud center. Edge devices are both data producers and users, forming two factions with cloud computing.

Edge computing has the following characteristics:

Localization. The core is to process and store data close to the source. Compared with centralized cloud computing, edge computing can better avoid information leakage caused during data transmission [13].

Timeliness. With the increasing number of intelligent devices, the load of cloud computing is gradually increasing, making it difficult to ensure data timeliness. Deploying resources at the edge of devices for

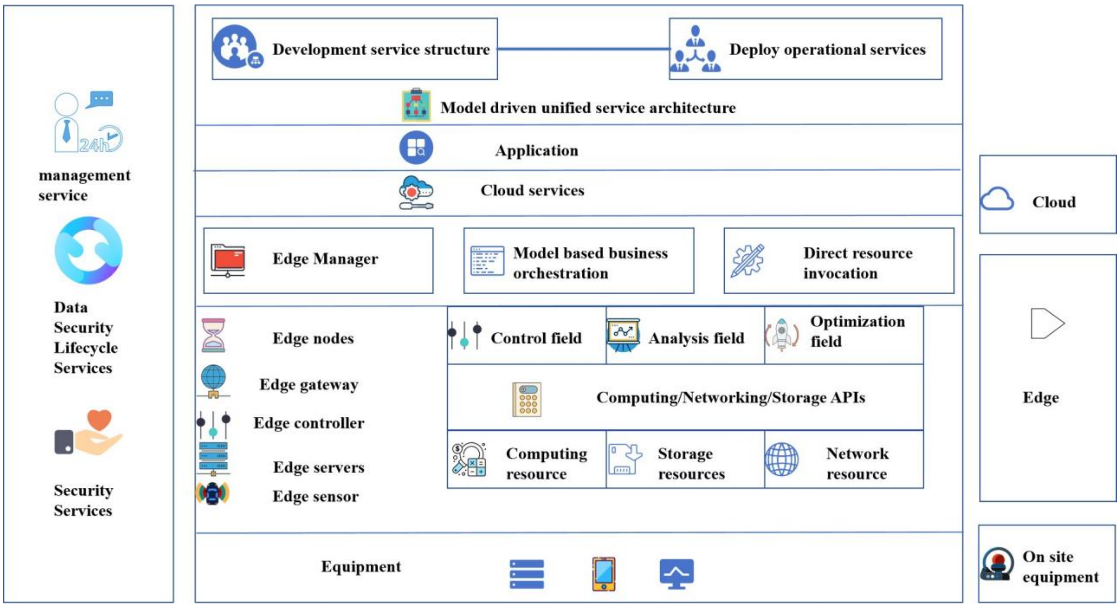


Fig. 3.1: Edge computing 3.0 Structural Framework

Table 3.1: Edge computing equipment requirements

ask	content
Multiple access methods	Due to the complexity of device communication protocols, the gateway is the only entry point for IoT devices, which requires protocol parsing and data transmission. In order to adapt to the data of underlying devices, the gateway needs to be suitable for various protocol interfaces
Cloud connectivity capability	The secure connection between the gateway and the device is a prerequisite for secure data transmission, which is related to the registration, connection method, and push method of the device
Local computing	Edge computing emphasizes processing at the data source, and requires hardware to have certain computing power and storage function

computing can effectively share the burden of cloud centers and improve data timeliness [14].

Low energy consumption. Because the data is complex and centralized, and the power resources consumed by the cloud center exceed 1.5% of the whole society, edge computing can disperse the center data for processing to effectively reduce the center load and energy consumption. Edge computing 3.0 emphasizes the cooperation between the physical world and the digital world to realize the decoupling requirements of software and language, as shown in Figure 3.1.

3.2. Characteristics of IoT gateway equipment and Docker virtual technology. The edge computing node is an important factor in establishing the model. The role of the IOT gateway is to ensure communication and realize network edge management. In edge computing, equipment needs to meet the requirements listed in Table 3.1.

Docker virtualization technology abstracts the network, computing, and storage functions of computers, eliminating hardware limitations on services and enabling users to fully utilize resources. This technology has the advantages listed in Table 3.2.

3.3. Service interaction structure for message queue transmission. The traditional Docker service structure has poor scalability, long resource response time, and complex service invocation methods. The author

Table 3.2: Docker Technical Advantages

advantage	content
Continuous Deployment	During the design process, different testing and development environments can lead to program errors. Virtualization technology ensures that the version configuration of the application is consistent with the requirements, improving development efficiency
Isolation	The system, network, process and other elements of the application are independent of each other, so that when modifying one factor, the other factors will not be affected
safety	Due to its isolation, different programs will not affect each other. Overall, this technology system can only use its own resources, ensuring security

designed a service structure based on Message Queuing Telemetry Transport (MQTT) to improve its orderliness and scalability.

Compared with traditional Docker structures, the structure based on MQTT protocol has the following characteristics:

Scalability: Service interaction relationships are based on topics, and there is no strict sequential logic. When adding or deleting an application, only the corresponding part needs to be modified .

Shared resource release: Two structural interaction modes. When A and B access C simultaneously, in the traditional structure, B needs to wait until the access to A is completed before accessing C, which leads to the inability of the service to respond in real-time.

In traditional structures, if errors occur, multiple applications need to be designed simultaneously, and chain interaction increases the difficulty of eliminating errors; Based on the structure of MQTT, a topic only designs services related to itself, which can effectively delineate boundaries and make it easy to detect errors [15,16].

3.4. Recognition framework based on real-time detection of regional networks. The recognition algorithm adopts the Forward RealTime Object Detection with Region Proposal Networks (Faster RCNN) to improve the calculation speed and result accuracy on the traditional basis. It uses a selection search method to mark the candidate boxes of objects, shorten the generation time of candidate boxes, and improve the calculation speed. The Faster RCNN structure mainly consists of feature extraction, candidate region generation network, investment return rate, and fully connected layers [17].

Feature extraction. Using convolutional neural networks to extract feature maps, the image size relationship of the convolutional layer is shown in equation 3.1, where ($volum_{size}$ represents the size of the convolutional kernel, pad represents the edge zeroing of the image, and stripe represents the step size):

$$Output_{size} = \frac{Input_{size} - volum_{size} + 2 * pad}{stride} + 1 \tag{3.1}$$

The pooling layer uses maximum pooling to reduce the feature map size by 50%, and reduces it to 1/16 of the original size through four pooling layers, the output features of the nth layer are shown in equation 3.2 (β_i^n represents weight, down (x) is matrix sum, b_i^n is bias value, f(x) is Softmax function):

$$x_i^n = f(\beta_i^n down(x_i^{n-1}) + b_i^n) \tag{3.2}$$

Generate a network of candidate regions. The candidate region mechanism of Faster RCNN adopts a generative network, which is different from traditional search methods. The generative network completes end-to-end training through convolutional mode. By annotating candidate boxes through intersection and comparison, objects with low probabilities are removed based on the results. The expression of intersection and union ratio (IoU) is shown in equation 3.3 (A represents the candidate boxes of the generated network, B represents the manually selected switch area):

$$IoU = (A \cap B)/(A \cup B) \tag{3.3}$$

The annotation of candidate boxes based on the intersection and union ratio results is shown in equation 3.4

$$label = \begin{cases} 1 \quad IoU > 0.7 \\ -1 \quad 0.3 \leqslant IoU \leqslant 0.7 \\ 0 \quad IoU < 0.3 \end{cases} \tag{3.4}$$

Candidate box annotation values greater than 0.7 indicate positive samples, while values less than 0.3 indicate negative samples. Candidates between these values will not participate in the experiment.

Based on the results of cls_layer and reg_layer, the optimal solution is selected using non maximum suppression mode, and the loss function is as follows:

$$L(\{pi\},\{ui\}) = \frac{1}{N_{cls}}\sum_i L_{cls}(pi, pi^*) + \lambda\frac{1}{N_{reg}}\sum_i pi^* L_{reg}(ti \cdot ti^*) \tag{3.5}$$

N_{cls} is the size of the feature map, L_{cls} is the logarithmic loss, L_{reg} is the smoothing loss function, pi is the candidate box switching probability, and pi^* is the label annotation, λ for the loss balance ratio, ti is the offset, and ti^* is the training offset.

3.5. General service settings of data gateway based on edge computing. Implementing a universal service through Docker using Python language, this service framework consists of three layers. The container layer includes file management and logging functions, while the interaction management layer is responsible for exchanging information, communicating with users, and providing universal services.

File management service is the circulation process of general resources in gateway devices. The privacy protection system is responsible for checking privacy protection when users search, store, and transfer files. After confirming security, it will be directed to the search or transfer interface, and privacy monitoring will be carried out throughout the entire process before finally entering the file storage system.

In the file storage process, users need to determine the file storage location or establish a new storage location when storing files. After confirming the file format, the device classifies and stores the files, providing users with the ability to modify the file extension name. Finally, the storage is completed [18].

The retrieval module is responsible for providing users with the function of searching for files. When users need a certain resource, they can search for keywords in the file name or content, and then the computer searches in the file library based on the keywords and pushes them to the user's device. The structural process realizes file upload and download functions. Match the uploaded file with the time through the renaming function, download it through the attachment link, and transfer the file to the user's device.

The file access management process implements file access encryption. Detect users, read user information, and review the allowed access conditions one by one. If one item is not satisfactory, unauthorized users are prohibited from accessing.

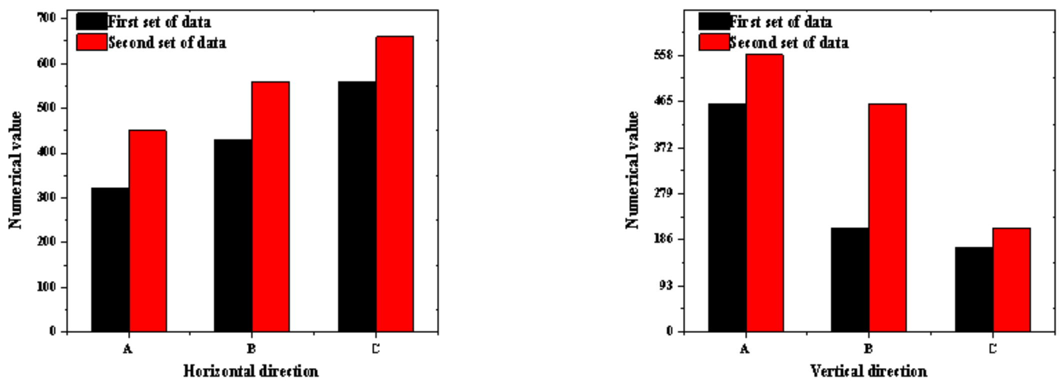
3.6. Coordinates of grounding knife. In order to explore the image processing capability of the gateway, obtain better image samples, and the on/off status of the grounding switch inside the gateway, it is necessary to reflect whether the Faster RCNN model can recognize the position coordinates of the grounding knife. Due to the model of the grounding knife, it is necessary to obtain both vertical and horizontal coordinates, and use equation (6) and Faster RCNN to identify the coordinates of the grounding knife [19].

$$x \cdot cos\theta + y \cdot sin\theta = \rho \rightarrow \rho = cos\theta \cdot x + sin\theta \cdot y \tag{3.6}$$

Among them, x and y are the coordinates of the two directions corresponding to the original polar coordinates of the parameters, and as an independent variable parameter.

4. Result analysis.

4.1. Grounding knife coordinates and convolutional kernel size. According to the Faster RCNN algorithm based on regional network real-time object detection, when optimizing data network management images, the minimum length data of the monitoring line is obtained by opening and closing the convolutional



(a) (b)

Fig. 4.1: Parameter Coordinates

kernel size, as shown in Figure 4.1. By analyzing the data, it can be concluded that the above data are all coordinate data of the grounding knife [20].

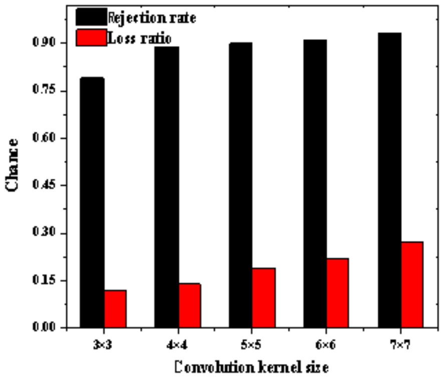
In Figure 4.1(a) (b), area A represents the coordinates of the opening area (320,450) and (460,560), area B represents the coordinates of the middle area (430,560) and (210,460), area C represents the coordinates of the closing area (560,660) and (170,210), and Figures 4.1 (a) and (b) represent the coordinates in two directions. The experimental processing algorithm was adjusted, and the image processing parameters were adjusted to improve the adaptability and accuracy of the algorithm, therefore, it is possible to determine the opening and closing status of the grounding switch inside the gateway based on the results [21].

An excessively large convolution kernel can cause image loss of information and have a negative impact on subsequent algorithms. Divide the range based on parameter coordinates, and change the size of the convolution kernel according to the actual position of the grounding knife to avoid the generation of a single kernel [22]. The author used convolution kernels of different sizes, where the rejection rate represents the proportion of image defects proposed through open close calculations to the total number of defects, and the loss rate represents the proportion of the area lost by the grounding knife contour to the original image, as shown in Figure 4.2(a) (b) (c).

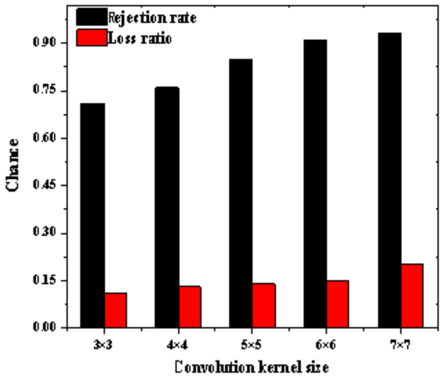
It can be observed that as the size increases, the rejection rate and loss rate of the gateway processing image both increase. The larger the convolution kernel size, the better the image defect removal effect, but at the same time, the edge information loss of the grounding knife also increases [23]. In the opening and closing areas, there is less image information compared to the middle area, so it is more appropriate to use smaller convolution kernels. For the middle area, there are more defects, and comprehensive judgment is needed, compared to 6×6, 5×5 has a lower rejection rate and no significant difference in loss rate; Compared with 6×6, the difference in loss rate between 7×7 and 6×6 is greater than the difference in protrusion rate, so using a convolution kernel size of 6 × 6 is the most suitable [24].

4.2. Grounding knife angle. Due to the different distances between the opening and closing distances of the image processing lens, there is a deviation in the angle of image recognition. Therefore, the three states of the grounding knife are tested. The test data is shown in Figure 4.3.

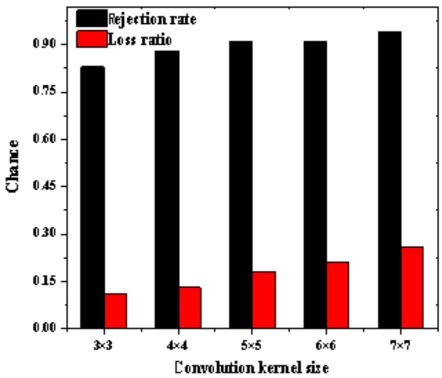
The above are the angle values for the three states of the grounding knife. Based on the rotation angle of the grounding knife, the region state in which the grounding knife forms three angles can be analyzed. Zone A is in the closed state (92 °, 98 °), zone B is in the middle state (98 °, 175 °), and zone C distinguishes the closed state (175 °, 179 °). The regional network object detection and recognition model can accurately intercept the angle of the grounding knife, and the model based grounding knife recognition model has a certain degree of



(a) Opening area



(b) The intermediate region



(c) Closing area

Fig. 4.2: Image processing results of convolutional kernels with open and closed operations

cyclicity and scalability through transfer learning [25]. According to the test results of the three states of the grounding knife, it can be seen that the recognition algorithm can accurately analyze the state of the grounding knife. Therefore, this algorithm can be used to build a power gateway to ensure information security [26].

5. Conclusion. By learning the basic concepts of edge computing and cloud computing, the author analyzes their advantages and disadvantages, uses a Docker virtual technology as a service deployment tool, and analyzes the adaptability of this technology in edge computing nodes. Through experiments, it was found that Docker has been widely used due to its advantages of lightweight, isolation, and application control. The achievement of building gateway related services has been achieved through the combination of Python language and Docker, and the service interaction structure based on MQTT protocol has solved the complex logic problems existing in traditional Docker structures. The author aims at realizing the operation function of edge computing node in the power gateway, and the research on applying edge computing to the production gateway is slightly insufficient; Moreover, the current application code in Docker is prone to causing user privacy data leakage. Therefore, in future research, how to apply encryption technology to service code and prevent data leakage is the focus of research.

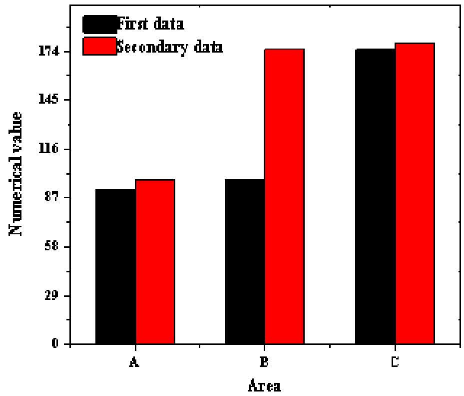


Fig. 4.3: Grounding Knife Status Test

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