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Integration Strategy of Edge Computing and Cloud Computing in Intelligent Manufacturing

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Absrtact: *This paper deeply studies the integration strategy of edge computing and cloud computing in intelligent manufacturing. With the rapid development of intelligent manufacturing, the traditional computing mode is difficult to meet the growing demand for data processing. Edge computing has the characteristics of low latency and distributed, while cloud computing has the advantages of resource concentration and elastic expansion. The integration of edge computing and cloud computing provides an efficient computing solution for intelligent manufacturing. This paper analyzes the theoretical basis of fusion, including the principle of improving data processing efficiency and the mechanism of enhancing system reliability. Through specific application scenarios, such as production line monitoring and optimization, industrial automation control, etc., the practical application of fusion strategy in intelligent manufacturing is described. At the same time, it also discusses the technical and security challenges faced by the integration, such as network bandwidth and delay constraints, multi-agent resource management problems, data privacy and security risks. Finally, the research is summarized, the application, challenges and solutions of the fusion strategy are summarized, and the future research directions are prospected, which provides a useful reference for the fusion development of edge computing and cloud computing in intelligent manufacturing.*

Keywords: *intelligent manufacturing; Edge calculation; Cloud computing; Integration strategy*

1. Introduction

In the wave of intelligent manufacturing, the demand for data processing is exploding. The traditional computing model gradually reveals contradictions when dealing with such a huge amount of data. On the one hand, the amount of data generated during the production process of intelligent manufacturing is huge, including sensor data, equipment data, production data, etc. Traditional data centers and computing resources often cannot meet the requirements of real-time and low-latency. On the other hand, network connections can be unstable or prone to interruptions, which poses challenges for real-time data transmission and collaborative work. For example, in an industrial environment, a large number of sensors are distributed in different geographical locations, and the stability of data transmission is difficult to guarantee. In addition, industrial data contains sensitive information, and the traditional cloud computing model, which stores data centrally in remote data centers, is vulnerable to hacking and data leakage risks. The integration of edge computing and cloud computing is the key to solving these contradictions. Edge computing pushes data processing and analysis to the edge of devices or sensors, reducing data transmission and computing load, and improving real-time performance and security. Cloud computing provides powerful computing and storage capabilities, and the integration of the two can play to their respective strengths to provide efficient computing solutions for intelligent manufacturing.

This study aims to explore the integration strategy of edge computing and cloud computing in intelligent manufacturing. Through in-depth analysis of the advantages, challenges, and future development trends of fusion, more efficient and reliable computing solutions are provided for intelligent manufacturing. Specifically, we will analyze how the integration strategy can improve data processing efficiency, reduce latency, enhance security, and explore the challenges that may be faced during the integration process, such as compatibility with heterogeneous environments, complexity of operation and maintenance management, data management and privacy issues. At the same time, we will look forward to the future development and provide theoretical support and practical guidance for the sustainable development of intelligent manufacturing.

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2. Theoretical basis

2.1. Overview of edge computing and cloud computing

2.1.1. Characteristics and advantages of edge computing

Edge computing has significant characteristics such as low latency and distribution. In intelligent manufacturing, the advantages of edge computing are mainly reflected in the following aspects: Firstly, the low latency feature enables real-time data in the production process to be quickly processed near the data source. For example, in industrial automation scenarios, sensor data can be immediately analyzed on edge devices to adjust production parameters in a timely manner and avoid equipment failure. According to statistics, edge computing can reduce data processing delay to the millisecond level, which greatly improves production efficiency and response speed compared to the delay of tens of milliseconds or even hundreds of milliseconds under the traditional cloud computing model. Secondly, the distributed nature of edge computing allows it to adapt to the complex production environment in intelligent manufacturing. Multiple edge devices can work together to share computing tasks, improving the stability and reliability of the system. For example, in a large factory, edge devices distributed in different areas can simultaneously process local production data, reducing the dependence on a single central node.

2.1.2. Characteristics and advantages of cloud computing

Cloud computing has the characteristics of centralized resources and elastic expansion. In intelligent manufacturing, the role of cloud computing cannot be ignored. On the one hand, the concentration of resources enables cloud computing to provide powerful computing and storage capabilities, which can handle large-scale production data and complex analysis tasks. For example, enterprises can use cloud computing platforms to conduct in-depth analysis of historical production data and explore potential production optimization solutions. On the other hand, the elastic expansion feature enables enterprises to dynamically adjust computing resources according to actual needs, meeting the requirements of different production stages. According to market research, enterprises adopting cloud computing can quickly increase computing resources to ensure the stable operation of production systems, improve resource utilization, and reduce costs during business peaks.

2.2. Theoretical basis of integration

2.2.1. Principle of improving data processing efficiency

Taking the voice assistant on smartphones as an example, when we use the voice assistant on our smartphones, the voice recognition and processing can be directly performed on the phone itself, without the need to transmit data to the cloud for processing, thus achieving faster response times. In intelligent manufacturing, the integration of edge computing and cloud computing can also bring similar effects. The edge device can perform preliminary processing and screening on the real-time production data, and only upload the key data to the cloud for further analysis and decision-making. This not only reduces the delay of data transmission, but also reduces the risk of network congestion and improves the efficiency of data processing. For example, in a smart factory, edge devices can monitor the running status of production equipment in real time. When abnormal data is detected, preliminary analysis is immediately performed and the results are uploaded to the cloud. The cloud then conducts more in-depth analysis and prediction based on these data, providing decision support for the factory's production scheduling.

2.2.2. System reliability enhancement mechanism

The integration of edge computing and cloud computing can reduce the dependence on cloud computing centers and improve the reliability of the system. Cloud computing centers usually have more powerful IT infrastructure and security measures, which can provide more reliable and secure data storage and processing services. However, in some cases, relying solely on cloud computing may bring about single point failures and security risks. By introducing edge computing, a part of the computing tasks and data storage can be distributed to edge devices. For example, in intelligent manufacturing, if the cloud computing center fails, the edge device can still perform some key production control and data processing locally to ensure the continuity of the production process. At the same time, edge devices are usually distributed in different geographical locations, which can better resist network failures and malicious attacks. In addition, edge devices can encrypt and store data locally, improving data security and reducing the risk of data leakage.

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3. Application of fusion strategy in intelligent manufacturing

3.1. Analysis of Application Scenarios

3.1.1. Production line monitoring and optimization

In the automotive manufacturing industry, the integration of edge computing and cloud computing plays an important role in production line monitoring and optimization. There are a large number of sensors distributed on the automobile production line, which are used to monitor the operating status of production equipment, the quality of parts and components, and the parameters of the production environment in real time. Edge devices can collect and process sensor data in real time, such as analyzing vibration and temperature data of the equipment. Once an abnormal condition is detected, an early warning is immediately issued and corresponding measures are taken to avoid equipment failure causing production line downtime. At the same time, the edge device uploads the key data to the cloud, which uses its powerful computing power to conduct in-depth analysis of the data and discover potential production optimization solutions. For example, through the analysis of historical production data, optimize the production process, improve production efficiency and product quality. According to statistics, the automobile manufacturing enterprises that adopt the integration of edge computing and cloud computing have reduced the failure rate of production lines by 30% and increased production efficiency by 20%.

3.1.2. Industrial automation control

In household appliance manufacturing enterprises, the integration strategy also plays a significant role in industrial automation control. Edge devices can monitor the real-time operational status of equipment on the production line and exercise precise control over the devices. For example, in the production process of smart refrigerators, edge devices can monitor the operating parameters of the refrigerator compressor in real time and adjust the operating frequency of the compressor according to the actual situation, so as to achieve the purpose of energy saving and improving product performance. At the same time, the edge device uploads the production data to the cloud, where the data from different production lines can be comprehensively analyzed to optimize production plans and resource allocation. For example, according to market demand and production capacity, reasonably arrange production tasks for different models of refrigerators to improve the production efficiency of enterprises. In addition, the integration strategy can also realize remote monitoring and fault diagnosis. When equipment malfunctions, technicians can remotely access edge devices through the cloud to quickly locate the cause of the failure and repair it, reducing equipment downtime.

3.2. Technical implementation method

3.2.1. Edge devices as part of cloud computing

The connection between edge devices and the cloud is the key to achieving integration. By establishing edge nodes, edge devices can be used as part of cloud computing to implement distributed intelligent applications. Edge nodes can be devices such as smartphones, edge servers, and IoT gateways, which have certain computing and storage capabilities and can communicate with the cloud. In automobile manufacturing enterprises, edge nodes can be deployed at various key positions on the production line to collect production data in real time and perform preliminary processing. The edge node uploads the processed data to the cloud for deeper analysis and storage. At the same time, the cloud can issue instructions to the edge nodes according to production needs, to achieve remote control and optimization of the production line. For example, the cloud adjusts the production speed and product specifications of the production line according to changes in market demand, and the edge nodes receive instructions and make corresponding adjustments to the production equipment.

3.2.2. Cloud-native edge computing driving

In the industrial field, cloud-native edge computing has significant advantages. Cloud-native edge computing can combine the elasticity, agility and scalability of the cloud with the low latency and real-time performance of edge computing to provide more powerful computing capabilities for intelligent manufacturing. Taking industrial automation as an example, cloud-native edge computing can achieve real-time monitoring and control of production equipment. Cloud-native applications deployed on edge devices can quickly respond to changes in the devices and make real-time adjustments to the devices. At the same time, the cloud can perform unified management and upgrade of applications on edge devices, improving the stability and reliability of the system. In addition, cloud-native edge computing can also achieve efficient processing and analysis of data. After the edge device performs preliminary processing on real-time data, it uploads key data to the cloud. The cloud then uses big data analysis and machine learning algorithms to conduct in-depth analysis of the data, providing decision support for enterprises. For example, through the analysis of production data, the risk of equipment failure can be predicted and maintenance can be carried out in advance to reduce the failure rate of equipment. According to research, industrial enterprises that adopt cloud-native edge computing have increased their production efficiency by more than 30% and reduced equipment failure rates by 40%.

4. Challenges of integration

4.1. Technical challenges

4.1.1. Network bandwidth and latency limits

Insufficient network bandwidth and high latency have a significant negative impact on the integration of edge computing and cloud computing. Although edge devices can perform local data processing to a certain extent, connectivity with cloud computing centers remains crucial. If the network bandwidth is insufficient, the speed of uploading data to the cloud and receiving instructions from the cloud by edge devices will be greatly reduced, resulting in bottlenecks in data transmission. For example, in a large-scale intelligent manufacturing factory, many edge devices try to upload a large amount of production data at the same time. If the network bandwidth is limited, data transmission will become slow, and congestion may even occur, affecting the real-time performance of the entire system. Too high a delay will also affect the effect of fusion. For some delay-sensitive application scenarios, such as industrial automation control, high latency may lead to untimely response of production equipment, affecting production efficiency and product quality. According to statistics, in some intelligent manufacturing scenarios, every 100 milliseconds increase in network latency may reduce production efficiency by about 5%. To cope with the limitations of network bandwidth and latency, various measures can be taken. On the one hand, it can optimize the network architecture and adopt high-speed and stable communication technologies, such as 5G networks, to improve data transmission speed and reduce latency. On the other hand, data compression and preprocessing techniques can be used to reduce the amount of data that needs to be transmitted, thereby reducing the demand for network bandwidth.

4.1.2. Multi-agent resource management challenges

Edge computing resources are scattered along the data transmission path and managed and controlled by different entities, which poses a huge challenge to convergence. In intelligent manufacturing, users control terminal equipment, network operators control communication base stations, network infrastructure providers control routers, and application service providers control edge servers and content transmission networks. The management objectives and methods of different subjects are different, making it extremely difficult to coordinate and unify the management of resources. For example, a smart factory may use edge devices and cloud computing services from multiple vendors simultaneously, and issues such as resource allocation, access control, and security management among various entities require complex coordination. At present, the research on edge computing mainly focuses on the management and control of single subject resources, and has not yet involved the management of multi-subject resources. It is a very challenging problem to achieve flexible multi-agent resource management. A potential solution is to establish a unified resource management platform, which can integrate and collaboratively manage resources from different entities through standardized interfaces and protocols. However, this requires the joint efforts and cooperation of all parties, involving issues at multiple levels such as technology, policy, and business.

4.2. Security challenges

4.2.1. Data privacy and security risks

In the intelligent manufacturing environment where edge devices are widely distributed, the risk of data leakage increases significantly. Edge devices are usually distributed in various public places and industrial environments, with relatively weak physical security protection, making them vulnerable to illegal intrusion and theft. For example, in a smart factory, edge devices may be hacked, resulting in the theft of production data, which may in turn lead to the disclosure of the company's trade secrets and customer information. In addition, due to the resource constraints of edge devices, there may be problems such as improper security configuration or untimely security updates, which further increases the risk of data leakage. There are many measures that can be taken to address these risks. Firstly, strengthening data encryption is a basic means to protect data security and privacy. In edge computing, encryption algorithms such as symmetric encryption or public key encryption can be used to encrypt data to ensure confidentiality and integrity during transmission and storage. Secondly, implementing strict access control policies is an important means to prevent unauthorized access and operations. In edge computing, access to data should be restricted, and only authorized users can access and process data. Permission management can be performed through models such as role-based access control (RBAC) or attribute-based access control (ABAC).

4.2.2. Security measures and encryption requirements

It is crucial to adopt encryption and other security measures to protect the data security of edge devices. In the intelligent manufacturing environment where edge computing and cloud computing are integrated, data is frequently transmitted between edge devices and the cloud. Without effective security measures, data can easily be intercepted and tampered with. For example, malicious attackers may modify or destroy the data transmitted by edge computing devices through man-in-the-middle attacks, packet sniffing, or malware, resulting in data integrity risks and serious impacts on intelligent manufacturing applications, such as data inconsistencies, decision-making errors, and economic losses. Encryption technology can effectively protect the confidentiality and integrity of data, preventing data leakage and tampering. At the same time, secure communication protocols such as Transport Layer Security (TLS) or Secure Socket Layer (SSL) can also be used to ensure the security of communication. In addition, regular security audits and monitoring are also important means to timely detect and handle security incidents. In intelligent manufacturing, regular security audits and monitoring of equipment and data should be conducted to detect and address security vulnerabilities and threats in a timely manner. Through security auditing and monitoring, security incidents such as data leakage and tampering can be detected and handled in a timely manner to reduce risks.

5. Conclusion and outlook

5.1. Summary of research conclusions

This study deeply explores the integration strategy of edge computing and cloud computing in intelligent manufacturing. In terms of application, the fusion strategy has played an important role in scenarios such as production line monitoring and optimization, industrial automation control, and has significantly improved production efficiency and product quality. For example, automobile manufacturing enterprises have reduced the failure rate and improved production efficiency through integration strategies; Home appliance manufacturers have achieved remote monitoring and fault diagnosis, optimizing production plans and resource allocation.

In terms of challenges, technical challenges include network bandwidth and latency limitations, and multi-agent resource management problems. To address network bandwidth and latency limitations, it is possible to optimize network architecture and adopt data compression and preprocessing techniques; For the multi-agent resource management problem, a unified resource management platform can be established to integrate and coordinate the management of different agent resources. The main security challenges are data privacy and security risks, as well as security measures and encryption requirements. These can be addressed by strengthening data encryption, implementing strict access control policies, adopting secure communication protocols, and conducting regular security audit monitoring.

Overall, the integration strategy of edge computing and cloud computing provides efficient computing solutions for intelligent manufacturing, but it also faces many challenges in the application process and requires continuous exploration and improvement of solutions.

5.2. Prospects for Future Research Directions

First, further optimize the network architecture and communication technology to better meet the requirements of edge computing and cloud computing for network bandwidth and latency. For example, in-depth research on the potential of 6G networks in smart manufacturing, exploring their higher data transmission speeds and lower latency performance.

Secondly, we should strengthen the research on multi-agent resource management and establish a more efficient and flexible resource management mechanism. We can use blockchain technology to achieve decentralized resource management and improve the security and reliability of resources.

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Furthermore, we will continue to improve the level of data security and privacy protection. With the development of intelligent manufacturing, the value of data is increasing, and the requirements for data security and privacy protection are becoming more stringent. In the future, more advanced encryption algorithms and security protocols can be studied to cope with changing security threats.

Finally, explore the application of integration strategies in the emerging field of intelligent manufacturing. For example, in the fields of smart healthcare and smart transportation, the integration of edge computing and cloud computing may bring new opportunities and challenges, which need further in-depth research and practice.

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