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5G+Artificial Intelligence AI Vision Assists in the Construction of Smart Ports

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Abstract: ***Traditional port business scenarios are complex and lack safety supervision and effective management tools. The port operating environment is harsh, with hundreds or thousands of operating machinery and a large number of human-machine joint operation scenarios. There are many video cameras and mobile operation equipment in the port area, making manual supervision extremely difficult. And the traditional network deployment mode is no longer able to meet the constantly increasing regulatory business needs of ports. This article focuses on the use of 5G, MEC, AI and other technologies to build 5G+AI (Artificial Intelligence) algorithm application scenarios at the forefront of various ports under Nanjing Port Group, realizing the empowerment of port AI applications, effectively reducing labor costs in the port area, minimizing human-machine contact, ensuring the safety of operators, and improving production management capabilities. The innovative application scenarios of 5G+AI promote the green and sustainable development of the port industry, solve operational safety issues in port areas, maintain enterprise management and decision-making capabilities, and comprehensively enhance the management innovation of integrated port services.***

Keywords: 5G; AI; Artificial Intelligence; MEC (Multi Access Edge Computing); Smart Port; Management Innovation.

1. STARTING RESEARCH ON THE INTEGRATION AND DEVELOPMENT OF 5G+AI AND THE PORT INDUSTRY WITH THE DIRECTION OF SMART PORTS

Nanjing Port is located at the junction of the "the Belt and Road" construction and the Yangtze River Economic Belt. It is one of the important container hubs for the integrated development of the Yangtze River Delta and the development of the Yangtze River Economic Belt. Its routes connect the middle and upper reaches of the Yangtze River, radiate the Ganjiang River, Xiangjiang River, Feihe River and the Subei Canal. Its offshore routes directly reach major ports in Japan and South Korea, and its ocean routes connect with Shanghai and Ningbo, radiating around the world. In 2021, Nanjing Port Group achieved a revenue of 2.826 billion yuan, with a cargo throughput of 103.9 million tons, loading and unloading of 73.69 million tons, and a container capacity of 3.046 million TEUs (Twenty foot Equivalent Units).

As a communication network and basic information service provider, the operator is a nationally licensed 5G service provider. 5G network is the focus and hotspot of new infrastructure and new industries, as well as the key digital infrastructure supporting the digital, networked, and intelligent transformation of the economy and society. With the advent of the 5G era, its advantages of large bandwidth, low delay, high reliability and wide connectivity, combined with edge computing and AI visual analysis, also bring new possibilities for the digital port to build the business bearing and intelligent management of the transportation and logistics industry with 5G [1].

In the domain of privacy protection, Li, Lin, and Zhang (2025) developed a framework incorporating federated learning and differential privacy for advertising personalization[1]. Intelligent system design includes Tu's (2025) platform-aware framework for 5G network test automation[2], Xie and Liu's (2025) multimodal sentiment analysis for recruitment processing[3], and Zhu's (2025) reliability engineering with automated causal tracking[4]. Industry-specific applications feature Zhuang's (2025) analysis of digital transformation in real estate marketing[5], Han and Dou's (2025) hierarchical graph attention network for recommendation systems[6], Zhang et al.'s (2025) AI-driven sales forecasting in gaming[7], and Cheng et al.'s (2025) investigation of executive human capital effects on stock volatility[8]. Computer vision research shows substantial progress with Chen et al.'s (2022) gaze-estimation based object referring[9] and Tian et al.'s (2025) cross-attention multi-task learning for digital advertising[10]. Medical imaging advances include Chen et al.'s (2023) vision-language pretraining for unified segmentation[11], while environmental finance applications feature Zhang et al.'s (2025) deep learning approach for carbon market forecasting[12]. The field of 3D vision and human pose estimation is significantly advanced by Peng et al.'s work on 3D vision-language Gaussian splatting[13] and their research on aggregation and segregation of representations for domain adaptive human pose estimation[14].

2. EXPLORING INNOVATIVE INTEGRATION POINTS OF 5G+AI SMART PORTS

At present, a certain number of surveillance cameras have been installed in all ports of Nanjing Port Group, achieving almost seamless video coverage. As most of them are traditional cameras, security personnel still need to conduct manual patrols within each port area. The port urgently needs to improve patrol efficiency through proactive security measures, in order to promptly detect various violations within the port area (such as truck parking violations, speeding, personnel entering illegal areas, etc.). At present, most ports have adopted remote monitoring technology to achieve 24-hour supervision of key work sites such as port areas, roads, and gantry cranes. This non site inspection mode of online supervision utilizes remote monitoring technology to achieve platformization and digitization of supervision, laying the foundation for the development of 5G smart ports. However, there are currently the following issues with the networking, video supervision, high traffic data transmission, and AI processing timeliness in various port areas:

(1) It is difficult to establish a network in multiple port areas. Currently, the four core ports of Nanjing Port and more than ten participating ports are distributed within a 100 square kilometer area along the Yangtze River. The cost of using fiber optic networking in enterprises exceeds tens of millions, and there are significant construction difficulties.

(2) There are a large number of cameras, with 18000 cameras in 8 port areas requiring real-time AI analysis. Each camera requires a bandwidth of over 8 Mbps, which cannot be met by existing 4G and WIFI.

(3) The image data processing is uniformly handled by the central platform of the group's computer room. The data will first be transmitted back to the video NVR (Network Video Recorder) storage platform of the terminal branch, and then to the group's central platform for disposal. Finally, the processing results will be fed back to the terminal branch platform, which will then push the results to the site. The overall delay is 1 to 2 seconds, and on-site problems cannot be reported in a timely manner. Safety hazards and personnel danger need to be alerted immediately, and every second counts.

3. BUILD A 5G+AI INTELLIGENT CONTROL PLATFORM FOR SMART PORTS

Utilizing 5G private network, artificial intelligence MEC Building a 5G intelligent AI control platform using information technology such as the Internet of Things. Based on the 5G private network of the port area and the MEC edge computing platform, the platform enables port intelligent application scenarios through AI algorithm warehouse and more than 30 port AI algorithms, covering container terminal operation, bulk cargo terminal operation, water transportation, port asset management, port tallying operation, port machine manufacturing and other port businesses.

The overall network architecture adopts a two-level cloud edge collaborative architecture: the edge platform deployed on the 5G-MEC in the port area is responsible for video stream access, decoding, and AI analysis, and reports the results to the group center platform for real-time warning; The group center platform is responsible for the management and distribution of AI algorithm models, analyzing, mining, and sharing algorithm analysis results, as well as training, iterating, and updating AI algorithm models, ultimately forming a proprietary algorithm model warehouse in Nanjing Port. At the same time, it also provides access standards for open algorithm warehouses and supports the integration of third-party algorithms. The Nanjing Port 5G intelligent control platform relies on cloud edge collaborative architecture, which can quickly distribute, deploy, and apply AI algorithms from the group center server to the MEC server in the port area. At the same time, the performance of AI algorithms is evaluated, iteratively optimized, and updated based on the reported results of the algorithms, thereby quickly unleashing the productivity of AI algorithms. The overall network architecture is as follows:

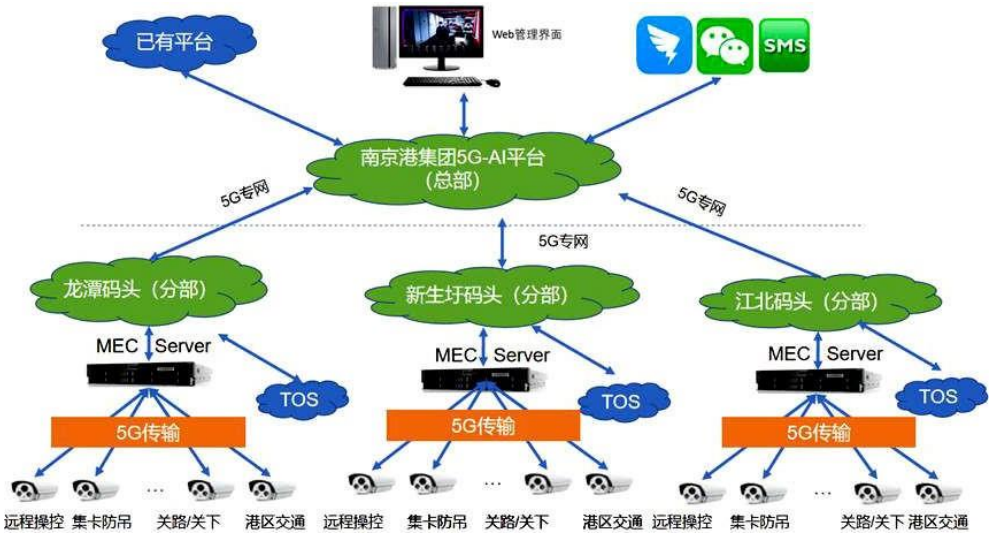

Figure 1: Network architecture of 5G+AI intelligent control platform

5G side access devices: Port scenarios mainly involve 5G industrial gateways, cameras, PLC industrial computers, and other devices accessing 5G networks.
5G wireless network: also known as 5G base stations, mainly providing 5G signal coverage for port areas, meeting the needs of mobile service terminals in port yards, roads, gates, banks, and berths to access the 5G network. The station types are mainly traditional macro stations, and pole micro stations are used for blind filling.

5G carrier network: also known as transmission network, used for 5G base station data transmission. The network adopts a ring network to achieve high reliability.

5G core network: including port UPF (User Plane Function) and operator 5GC (5GCore) network; UPF deployment sinks to the port area to meet the low latency requirements of remote control scenarios in the port area [4].

The AI intelligent control platform can view and manage analysis results through a web management interface, and can also push them to management personnel's mobile phones through enterprise WeChat, WeChat, or mobile SMS. The platform provides an open API (Application Program Interface) interface for interfacing with third-party systems and integrating with existing TOS (Terminal Operation System) systems, safety monitoring and environmental protection systems. By adopting 5G and MEC edge cloud deployment methods, the system's push processing time has been reduced from 1 minute to 15 seconds, and the emergency response time has been shortened from 10 minutes to 2 minutes now.

4. 5G+AI FUSION INNOVATION APPLICATION LANDING SCENARIO

4.1 Monitoring of gantry crane truck anti lifting

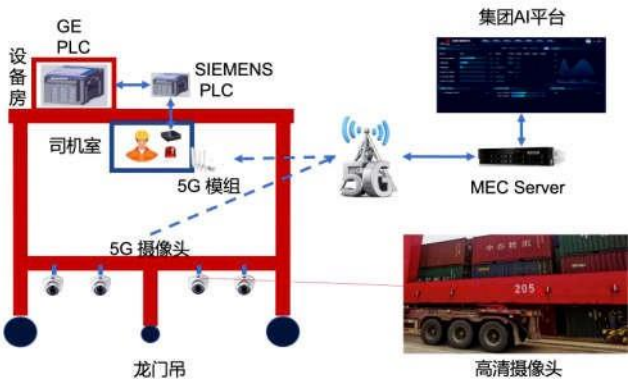

Figure 2: Framework of AI monitoring system for anti lifting of gantry crane trucks

As shown in the above figure, the four 5G high-definition cameras on the main body of the gantry crane capture the operation images and transmit them to the MEC server through the 5G base station. The MEC server analyzes the operation status in real time and transmits the results to the driver's cab. If there is a risk of the container truck being lifted during container lifting, the alarm in the driver's cab will trigger an alarm, and the driver will further confirm and process it, and report it to the group's AI platform. This algorithm can provide a warning when the truck is lifted within 50cm, and when it exceeds 50cm, it will be linked with the PLC (Programmable Logic Controller) to forcibly cut off the lifting action.

4.2 Monitoring of shore bridge/gantry crane anti fall box

During the loading and unloading process of quay crane/gantry crane containers, it is required that the lifting equipment pause for 3 seconds after the initial lifting of 30cm, confirm that the lifting equipment lock is securely locked or completely opened, and prevent container falling accidents. The 5G high-definition camera deployed on the shore bridge/gantry crane transmits real-time images of the operation to the MEC server. The MEC server analyzes in real time whether the lifting equipment pauses for 3 seconds during the initial lifting process. If the operation process is not compliant, an alarm signal will be transmitted to the driver's cab to remind the driver to operate in compliance, avoid falling accidents, and report the identification results to the group's AI platform.

4.3 Monitoring of personnel intrusion during operations in large equipment rooms

5G high-definition cameras are installed near the deceleration box in the port area to obtain real-time video of the deceleration box area, and 5G high-definition cameras are installed at the edge of the computer room to obtain real-time video of the entire computer room. Through 5G base station forwarding, the MEC server obtains the videos of the two cameras in the computer room and associates them with the information of the two videos. If it is recognized that the deceleration box is operating and someone enters the computer room, an alarm is triggered immediately to remind the intruders in the computer room to leave in a timely manner. At the same time, the risk situation is reported to the driver's cab of the computer room, which promptly handles the risk situation and reports it to the group AI platform.

5. THE EFFECTIVENESS OF 5G+AI APPLICATION IN 5 SMART PORTS

Compared to traditional fiber optic connections, 5G networks are more flexible in connecting devices in various port areas. The deployment of various mobile operation machinery in ports requires flexible, stable, reliable, high bandwidth, and low latency connection capabilities. At the same time, the use of fiber optic connections to transform and maintain large equipment in ports is costly and difficult. The solution of using 5G to connect equipment in various port areas and then uniformly connect them to the Nanjing Port 5G intelligent control platform is reasonable, practical, and cost-effective.

MEC edge servers deployed simultaneously in various ports and subsidiaries have more advantages than traditional end-to-end computing. Although the traditional terminal side monopolizes processing computing resources, it is limited by size and power consumption, has limited computing power, and has a large number of devices that are centrally managed, with high maintenance costs and difficulties; Using MEC edge servers to coordinate and schedule MEC computing resources through AI platform and TOS, time-division multiplexing improves resource utilization and reduces computing resource costs. At the same time, MEC provides sufficient high-performance GPU (graphics processing unit) computing power, resulting in faster recognition speed and higher recognition accuracy. The MEC edge service solution is more reasonable, practical, and cost-effective [5].

By combining traditional computer vision technology with deep learning and utilizing industry-leading AI technology, we have taken the lead in overcoming multiple pain points in the production and operation management of port and dock operations, including anti hoisting of gantry cranes, anti falling boxes for gantry cranes/gantry cranes, personnel warning for mobile machinery operation paths, compliance monitoring of operator wearing during machine tool operation, and CFS truck ton bag counting. The Nanjing Port 5G+MEC+AI platform and more than 20 related applications have been online for nearly a year of trial operation, identifying more than 200000 violations. The number of backend supervisors has been reduced from more than 100 people working in three shifts to 50 people, saving about 50% of labor costs. The efficiency of on-site supervisors in handling violations has been improved by 30%.

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