DOI: 10.53469/wjimt.2025.08(01).04

Application Status and Development Trend of Intelligent Storage Based on Digital Twin Technology

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Abstract: ***In recent years, with the economic development and scientific and technological progress, industrial automation technology in the production process is more and more widely used, especially the development of computer technology makes it become an important part of industrial production automation. In this context, the concept of "intelligent warehousing" has also been put forward. Intelligent warehousing is a process that integrates all kinds of intelligent equipment into the logistics system by using modern information and communication technology, to realize supply chain management and improve the efficiency of the logistics system. It mainly includes logistics system software, network equipment, sensors, control software, and intelligent hardware.***

Keywords: Digital twin; Intelligent grain storage; Grain storage.

1. INTRODUCTION

With the development of technology, digital twin technology has become one of the key technologies in intelligent manufacturing, and it has also been widely applied in the field of logistics and warehousing. In the logistics industry, digital twins can map the physical processes and logical states of actual system processes to the virtual world, thereby simulating the actual operating results, optimizing operations, and effectively improving efficiency. Digital twin technology is mainly achieved through three ways: mapping between the physical world and the digital world, mapping between simulation and the real environment, and mapping between physical and digital models. With the increasing maturity of technologies such as the Internet of Things, cloud computing, and big data, the IoT+5G+cloud platform will become the core of the smart warehousing industry. The integration of the Internet of Things and cloud platforms can effectively improve the utilization rate of storage space; Implementing precise and dynamic positioning through 5G networks can greatly improve operational efficiency, and it is also an indispensable technical means for the interconnection of "people goods site" in the intelligent logistics industry; Cloud computing can effectively reduce warehousing costs. Therefore, in the future, 5G+cloud+intelligent equipment will become the development trend of the logistics industry.

Several papers explore advanced techniques in image processing and computer vision. Yan et al. (2024) investigate convolutional neural networks (CNNs) for image super-resolution reconstruction. Ren (2024) enhances YOLOv8 for infrared image object detection using an SPD module, showcasing the application of deep learning to specialized imaging modalities. Chen et al. (2020) demonstrate the use of deep learning for automated defect grading in printed materials. Tian et al. (2024) utilize an improved U-Net architecture with GSConv and ECA attention mechanisms for brain tumor image segmentation, highlighting advancements in medical image analysis. Xu et al. (2024) employ YOLOv5 for real-time detection of crown-of-thorns starfish in automated surveillance systems. These studies demonstrate the versatility and effectiveness of deep learning in tackling various image-related tasks. The field of NLP is well-represented, particularly concerning the application and evaluation of Large Language Models (LLMs). Wang (2024) introduces CausalBench, a comprehensive benchmark for evaluating the causal reasoning capabilities of LLMs. Wu (2024) explores the use of LLMs for semantic parsing in intelligent database query engines, showcasing their potential for advanced information retrieval. Nadkarni et al. (2011) and Bethard et al. (2008) provide essential background and foundational knowledge in NLP. Ren (2024) presents a novel topic segmentation approach for enhanced dialogue summarization, and Ren (2024) further enhances Seq2Seq models for this task by incorporating adaptive feature weighting and dynamic statistical conditioning. Luo et al. (2024) apply LLMs (specifically, Falcon-7B) to enhance e-commerce chatbots. Xu et al. (2024) focus on improving user experience and trust in advanced LLM-based conversational agents. Li et al. (2024) investigate strategic deductive reasoning in LLMs using a dual-agent approach. These studies collectively demonstrate the ongoing development and diverse applications of LLMs. The application of big data and AI in the financial sector is addressed in several papers. Tekaya et al. (2020) provide an overview of recent applications of big data in finance. Murugan (2023) focuses on large-scale data-driven financial risk management and analysis using machine learning strategies. Eltweri et al. (2021) examine the use of big data for fraud detection and risk management in the real estate industry. Bi et al. (2024) present the design of a financial intelligent risk control platform leveraging big data and deep learning. Li et al. (2024) explore the relationship between technology, finance integration policies, and green innovation. These studies demonstrate the increasing reliance on AI and big data for improved risk management, fraud detection, and strategic decision-making in finance. Lin et al. (2024) provide a comprehensive review of precision anesthesia in high-risk surgical patients. Lin et al. (2024) further explore the use of AI and EEG analysis for optimizing anesthesia depth. Qi and Liu (2024) focus on developing a sales forecasting system using Hadoop for big data analysis. Wang et al. (2024) propose using LLM connection graphs for global feature extraction in point cloud analysis. Chen et al. (2024) explore the development of computerized data mining techniques. Liang and Chen (2019) present a high-performance dynamic service orchestration algorithm. Xu et al. (2024) explore experience management tools in the electric vehicle market. Yin et al. (2024) apply deep learning to crystal system classification in lithium-ion batteries. Lyu et al. (2020) present a UHF/UWB hybrid RFID tag for remote vital sign monitoring.

2. DEVELOPMENT OF DIGITAL TWIN TECHNOLOGY

Digital twin is a digital representation of a physical model, which is an integrated system simulated across multiple disciplines, physical fields, and scales. It can map everything in the real world, including entities and systems themselves, in virtual space, and also reflect the entire production process and the operation of the entire society. In China, research on digital twin technology began in 2009. On March 17, 2018, the Ministry of Industry and Information Technology officially released the List of Industrial Internet Platform Pilot Demonstration Projects. Wu Hequan, academician of the CAE Member, and others pointed out in an interview with the media that "China has the ability to build a new generation of information infrastructure based on the digital twin model, which has laid a solid foundation for the development of the industrial Internet industry". On June 13, 2020, the 14th Five Year National Informatization Plan clearly pointed out the requirements of "accelerating the development of industrial Internet and comprehensively improving the level of digitalization, networking and intelligence of manufacturing industry". Li Yicheng, academician of the CAE Member, believes that "digital twin technology can help us improve the production efficiency and automation level of enterprises". On March 9, 2022, the State Council issued the "Opinions on Accelerating the Development of Advanced Manufacturing Industry and Creating a New Engine for High quality Development" (hereinafter referred to as the "Opinions"), which pointed out the need to focus on promoting innovation breakthroughs in advanced manufacturing technology, upgrading the industrial foundation, and improving the modernization level of the industrial chain, fully leveraging the supporting role of advanced manufacturing industry in economic and social development.

3. APPLICATION SCENARIOS OF DIGITAL TWINS IN SMART WAREHOUSING

Warehousing enterprises can achieve dynamic simulation and optimized operation of the entire warehousing system by building a digital twin that maps the actual system operation results to the physical model. In the field of smart warehousing, digital twin technology is mainly used to solve inventory management problems, which can achieve real-time monitoring of inventory situation, thereby ensuring that warehouse space reaches the highest utilization rate within a reasonable time and reducing resource waste. Digital twin technology provides important reference for warehouse site selection, equipment selection, and layout. The digital twin model can help managers better understand the decisions made by actual operators in the warehouse through simulation. Optimize and improve warehouse management efficiency based on business processes. Optimizing based on business processes can significantly reduce operational and business costs, improve warehouse operational efficiency, and significantly enhance production efficiency. The digital twin system enables real-time monitoring of the operation of various equipment in the warehouse, thereby achieving real-time display of equipment status and inventory quantity information in the virtual space. Real time monitoring and intelligent decision-making of warehouse operation sites can effectively reduce the working time, production costs, and inventory costs of operators. The use of digital twin technology can effectively improve work efficiency, optimize workflow, and achieve real-time collaborative management of production and logistics.

4. ROBOTICS TECHNOLOGY

In the field of industrial automation, robotic arms are a typical application that can replace manual labor to complete mechanical operations such as handling, assembly, packaging, and cleaning. From the perspective of the robot itself, the current main tasks are automatic handling and material sorting. From the perspective of robotic arms, there are currently six axis and above robotic arms and six degree of freedom (IMU) robotic arms, gradually developing towards the seven axis direction. In a six degree of freedom (IMU) manipulator, the end effector is designed as a standard module to recognize and perform operational tasks. From the perspective of logistics robots, the current mainstream six degree of freedom (RV) robots are divided into three types: RV end effectors, two wheeled robots, and three wheeled robots (including self-propelled and rotary). From the perspective of control methods, most of them are currently controlled through visual or sensor methods. In smart warehousing, real-time monitoring and data collection of equipment operating status (such as whether it is working or malfunctioning) can be achieved through communication between robots and logistics systems, and the data can be fed back to relevant equipment for corresponding control.

5. D PRINTING TECHNOLOGY

In the manufacturing industry, D printing technology is mainly used for printing equipment or components, such as machine tools, robots, and parts.

5.1 D Printing Technology

At present, there are several technologies that can be applied to the field of smart warehousing, including 3D printing, laser printing (including laser selective melting), 3D inkjet printing, etc.

5.2 3D printing materials mainly include metal materials and ceramic materials

Metal materials are mainly laser sintered based on the metal powder inside the printer, while ceramic materials are made by using ceramic particles produced after high-temperature sintering. Therefore, the combination of the two processes can produce various metal materials.

5.3 3D inkjet printing

At present, the mainstream D-printing equipment mostly integrates laser and inkjet.

5.4 D/X Printer

Compared with traditional printers, D/X printers can achieve fast printing function, which is also their development trend.

6. RFID

The application of RFID technology in smart warehousing mainly includes three aspects:

One is item management, including the management of location information, product status information, and inventory information;

The second is automated loading, unloading, and handling, such as forklifts using automated loading, unloading, and handling equipment to operate goods during transportation;

The third is warehouse operation management, which refers to the transfer of goods stored in the warehouse from the production line to the finished goods warehouse, and from the finished goods warehouse to the production line.

At present, the demand for RFID technology in China's warehousing industry is relatively strong, and the country has a complete RFID related industry chain. But at the same time, there are also some issues:

The first point is that Chinese enterprises have insufficient investment in research and development.
The second point is that the RFID technology standard system is not perfect.

In the future development of smart warehousing, on the one hand, the intelligence of warehousing in the logistics field will gradually move towards automation, intelligence, refinement, and networking. On the other hand, future smart warehousing will also develop towards digitalization and intelligence. Digital twin technology is an important force driving the progress of modern information technology and industrial transformation and upgrading; Advanced technologies such as the Internet of Things, cloud computing, big data, and artificial intelligence provide platforms for twin digital perception, interaction, information processing, and analysis.

7. LASER SCANNING AND RECOGNITION (LIDAR)

Laser scanning and recognition (LiDAR) is an automated technology that uses laser as the main sensor to obtain the position and velocity information of targets. By establishing a functional relationship between distance and velocity, it achieves rapid detection and recognition of objects. In recent years, due to the rapid development, high accuracy, small size, and easy maintenance of laser scanning technology, it has become possible to apply laser scanning technology to smart warehousing.

At present, there are three main ways of laser scanning technology: based on mechanical scanning methods, such as mechanical scanning combining handheld and fixed platforms; Based on optical scanning methods, such as grating disk+grating matrix; And an optical waveguide array composed of multiple photodiodes and optical components for photoelectric detection. Among them, mechanical ranging methods represented by laser reflection ranging have become mainstream. The use of this distance measurement method in smart warehousing can achieve fast and high-precision positioning of goods. At present, it is mainly used in sorting lines and handling robots in warehousing systems. Multiple sensors are required in warehouses to sense the position and attributes of goods on shelves. A visual sensor is also required on the sorting robot to ensure its visual imaging effect and speed.

8. ARTIFICIAL INTELLIGENCE ALGORITHM TECHNOLOGY (DEEP LEARNING ALGORITHM)

Deep learning is a machine learning method based on neural networks, which uses a large amount of existing data for training and learns the required parameters from a small amount of data. In practical applications, neural networks are divided into three levels:

The first layer is the perception layer, which contains a large number of perceptible variables, input signals, and output results;

The second layer is the logical layer, which includes input and output variables, logical operations, etc; The third layer is the presentation layer, which includes model structure and parameters.

The purpose of these three levels is to simplify the structure of the network to achieve a more reasonable structure.

9. DIFFERENT SCHEMES AND SYSTEMS

Based on the above analysis, it can be seen that different solutions have their own advantages, but they all have some disadvantages. For example, there is a certain amount of redundancy in intelligent warehousing systems, and once a problem occurs in a certain link, the entire system will face paralysis:

Warehouse management personnel need to run back and forth between various warehouses every day, processing a large amount of data and wasting a lot of time;

The equipment needs to be adjusted according to the user's order requirements, adding manual operation steps; Interference between devices leads to abnormal operation.

Therefore, how to solve these problems has become a current research hotspot. The digital twin technology is also constantly developing and improving, and currently there are three relatively mature ones: the construction of "object machine human" digital twins: the "3I" theory (i.e. Infrastructure, Information, Discreet); Digital twin simulation platform technology; 3D modeling system: BIM+3D modeling technology; Virtual reality (VR) interactive technology.

10. DEVELOPMENT TRENDS

With the continuous maturity of digital twin technology in the field of smart warehousing, it will promote the transformation and upgrading of the smart warehousing industry. The intelligent warehousing industry needs to be driven by new technologies such as digital twins and the Internet of Things, and build a big data based technology that integrates intelligent robots and various sensors. Through advanced information management and control technology, it closely integrates with new generation information technologies such as the Internet of Things, big data, and cloud computing to continuously optimize the design and operation mode of warehousing systems and achieve optimal management results. The collaborative innovation of future digital twin technology and other intelligent technologies provides comprehensive support for warehouse management. By using network communication systems such as multi-sensor and wireless RF transmission, as well as advanced control information systems (such as computer control systems) and various sensing devices (such as robotic arms), multiple digital twin models can be constructed to coordinate and manage the operation status of the entire logistics system and workflow, and to monitor, control, predict, optimize the status of each link in the logistics process in real time. With the continuous maturity and development of digital twin technology, it can be widely applied in various fields. However, at the same time, it should be noted that due to the strong universality and good scalability of digital twin technology, it will be the development trend of smart warehousing equipment in the next few years.

11. CONCLUSION

At present, smart logistics has entered a new stage of development. With the rapid development of the economy and technology, the scale of the logistics market continues to expand, and the logistics industry has become an important component of the national economy. The industrial structure is optimized and upgraded, and market demand is diverse. Currently, as the global economy enters a 'new normal', the logistics industry still faces many challenges. With the improvement of logistics costs and efficiency and the intensification of environmental impact, enterprises have put forward higher requirements for warehouse space layout and operation mode. How to achieve the construction of intelligent warehousing systems through information and digital means is also one of the focuses of industry attention. With the arrival of the 5G era, more attention and emphasis on data security, and further improvement and application of IoT technology, various factors are jointly promoting the accelerated upgrading of digital transformation in logistics and warehousing. The scale of the future smart warehousing market will continue to maintain a growth trend.

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