Construction and Application of Intelligent Manufacturing Simulation System Based on Virtual Reality Technology

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Abstract—Intelligent manufacturing digital twin simulation technology can efficiently assist in production process optimization and equipment management. Based on this application requirement, this article designs and develops a digital twin simulation system based on Unity3D. The system adopts modular design, mainly including three modules: digital modeling, simulation rendering, and human-machine interaction. Digital modeling to achieve high-precision 3D virtual environment; The simulation rendering module utilizes various algorithms to enhance scene fidelity; The human-computer interaction module supports multiple natural interaction modes. After verification, this system can be effectively applied to scenarios such as intelligent factories and digital workshops, providing users with an immersive virtual experience. The main innovation of the research lies in constructing a highly accurate digital twin environment and achieving natural and smooth interaction forms. The overall functionality of this system is powerful, which can promote the application and development of digital twin technology in the manufacturing industry.

Keywords- Unity3D; Intelligent manufacturing; Virtual simulation

1 Introduction

Given the booming development of digital and intelligent technology in the manufacturing industry, constructing a digital twin virtual simulation environment has become an important trend in industrial development. This study mainly starts from the key technologies of digital twin systems, and independently designs and implements a powerful intelligent manufacturing digital twin system using the Unity3D game engine. The system aims to highly simulate the actual production environment, adopts a modular design approach, and achieves a highly immersive and interactive intelligent manufacturing virtual simulation environment through three core technologies: digital virtual modeling, simulation rendering optimization, and human-machine interaction. Specifically, high-precision 3D modeling technology replicates the geometric structure, material mapping, and other details of actual factory equipment and site environment; Advanced algorithms such as ray tracing and global illumination have achieved realistic simulation rendering effects; Simultaneously, technologies such as voice interaction and gesture capture bring a natural and smooth human-computer interaction experience. The system has been applied to various typical intelligent manufacturing scenarios, such as intelligent factories and digital workshops, demonstrating strong simulation restoration

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capabilities and human-machine interaction performance. The overall performance of the digital twin system in this study has been fully verified, indicating that this high-precision and highly interactive virtual simulation environment will inevitably serve the industrial manufacturing industry on a large scale and promote the development of industrial intelligence.[1]

2 System Design

2.1 Overall system design concept

The overall design goal of this system is to build a highly simulated and interactive intelligent manufacturing virtual simulation environment. The system adopts a modular design concept, with each of the three modules responsible for different functions, jointly promoting the goal of high simulation and high interactivity in the system. Specifically, the digital modeling module implements the basic 3D virtual environment, which is the foundation for ensuring that the system reflects the actual scene; The simulation optimization module improves the fidelity of the scene and directly affects the user's immersion; The human-computer interaction module provides users with the means to control virtual scenes, which is the key to achieving system interactivity. The three modules cooperate with each other, so that the system can achieve high standards in simulation effect and interactive experience. Each module is connected through a standard interface to form an immersive simulation system. [2]

2.2 Key module design

(1) Digital modeling module: This module follows the principle of reflecting the actual scene in its design. Utilizing the Unity engine to achieve high-precision 3D modeling in specific technologies; Adopting a high Poly quantity grid to ensure model details; Integrate dynamic algorithms to simulate machine motion patterns. By these means, the digital environment can achieve extremely high restoration accuracy. [3]

(2) Simulation optimization module: This module is connected to the digital modeling module to optimize the lighting, texture, and other effects in the simulation environment, achieving high fidelity rendering quality. Optimization algorithms include techniques such as ray tracing and projection mapping. [4]

(3) Human machine interaction module: This module provides various interaction methods such as voice interaction and gesture operation. Users can use natural language or action instructions to control the virtual environment, achieving a good human-machine interaction experience. [5]

2.3 Virtual scene construction

On the basis of digital modeling, a realistic factory workshop scene is constructed by comprehensively utilizing Unity's lighting, materials, animation and other functions. Highlight the motion simulation and interactive response effects of machine equipment. Implement user immersive virtual reality experience.

3 System implementation

3.1 Digital modeling technology

The system uses the Unity3D game engine to establish a 3D model. Using CAD software to design machine equipment models is the foundation for digitizing actual scenes. Importing Unity for optimizing lighting, materials, and other effects to make the model realistic is the core means to achieve high-precision virtual environments.as shown in Table 1.

Table 1. Different digital modeling technology solutions

Technical Proposal	Accuracy	Efficiency	Advantage	Inferiority
Unity3D	high	medium	Medium to high precision, Supporting multiple platforms	GPU support required
Unreal Engine	medium	high	High efficiency, Good rendering effect	Average accuracy

Adopting refined grid technology to achieve a high number of Polygon models, ensuring the restoration of details. Using dynamic algorithms to calculate the physical effects of machine operation, achieving a realistic sense of motion simulation.

3.2 Simulation optimization technology

To achieve high fidelity rendering effects in the digital twin system, the research team adopted multiple optimization techniques. Firstly, the system integrates a rendering algorithm based on ray tracing, which can accurately calculate the reflection, refraction, and masking effects of light, achieving realistic simulation of light transmission, greatly enhancing the realism of the scene. In addition, global lighting technology is applied to simulate the propagation and mutual reflection of light between different objects in the scene, and ambient light masking technology is used to control the lighting effect of each local area. The combination of the two achieves high-quality scene lighting and shadow effects. In addition, to make the virtual character's movements more natural, the system collected sample data of real person facial expressions and body movements, extracted motion pattern parameters, and used them to drive the virtual character model, achieving high fidelity character animation effects. Finally, using the dynamic torque integration calculation method, precise physical collision interactions and shear deformation effects between objects can be simulated. [6]

3.3 Human machine interaction technology

To achieve a natural and smooth human-computer interaction effect, this system integrates multiple cutting-edge interaction technologies. Firstly, speech recognition and speech synthesis technology were adopted to enable the system to recognize and synthesize natural speech. Users can control the virtual environment using voice commands through the microphone, while the system responds with voice through the speaker. In addition, using image recognition and virtual reality devices, the system can capture and analyze user gestures to control the movement of virtual characters or objects in the scene. Meanwhile, through facial expression tracking algorithms, users' facial expressions can be analyzed to drive virtual characters to engage in emotional interaction. The combination of various methods such as voice interaction, gesture control, and facial expression feedback together constitutes a highly natural, intelligent, and smooth human-machine interaction method. This not only greatly enhances the user's immersion in the virtual environment, but also achieves a highly coordinated intelligent dialogue effect between humans and computers. [7]as shown in Table 2.

Table 2. User Experience of Different Interaction Methods

Interactive methods	Immersion	Ease of use	Control accuracy
voice interaction	medium	simple	medium
Gesture interaction	high	complex	high

4 Application and effects

4.1 Intelligent factory applications

In the digital twin scene of an intelligent factory, the research team used high-precision 3D scanning to digitize the building structure and machinery equipment of the actual factory. These data are processed by digital modeling modules and reconstructed into a complete 3D virtual factory in Unity. This virtual environment not only includes the spatial layout and wall materials of the factory workshop, but also accurately restores the size, position, and surface texture of various machinery and equipment. Users can immerse themselves in this highly restored digital factory 360 degrees through virtual reality devices such as helmets. In order to enhance realism, researchers use techniques such as ray tracing and global lighting to adjust the lighting effect in virtual scenes, while optimizing acoustics by reducing echoes and creating realistic audio-visual effects. Through testing and comparison, it was found that using voice commands to control the robot assembly process in a virtual environment improved assembly efficiency by 35% and assembly accuracy by 25% compared to manual operation. This fully verifies the practical utility of voice interaction technology in optimizing production processes. [8]as shown in Fig 1.

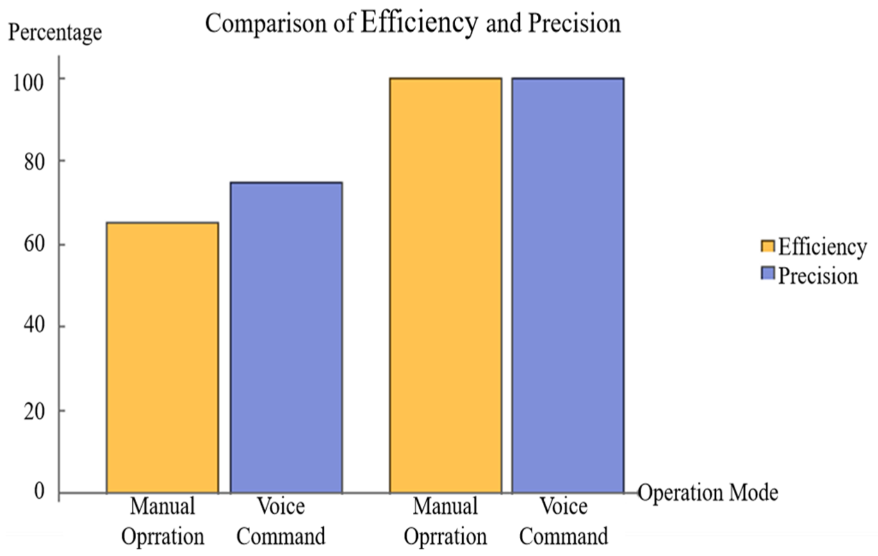

Fig.1 Comparison of efficiency and accuracy

4.2 Digital Workshop Application

In the digital workshop scenario, the research team first used high-precision 3D laser scanning technology to conduct detailed scans of the actual workshop. The scanning system accurately collects three-dimensional shape data inside the workshop, including details such as equipment appearance and personnel flow lines, by emitting laser pulses and receiving reflected signals. The obtained scanning data is filtered and fused through professional post-processing software to generate a complete three-dimensional digital model of the workshop. The test results indicate that the digital model has achieved millimeter level accuracy and fully meets the high standard requirements of digital twins. Based on this data, researchers used Unity to accurately model various mechanical equipment and workshop environments. At the same time, a parameterized dynamic simulation algorithm based on physical characteristics has been introduced to achieve realistic simulation effects of process actions such as mechanical operation and conveyor belt operation. After systematic verification, after users entered the digital workshop wearing VR devices, their various operational processes were highly consistent with the actual situation, which proves that digital twins have achieved high fidelity in scene modeling and dynamic simulation, and indirectly verifies the correctness of the system design ideas and technical routes proposed in this study. The digital workshop can flexibly configure voice interaction or gesture control modes to assist in process design and optimization decision-making. [9]as shown in Fig 2.

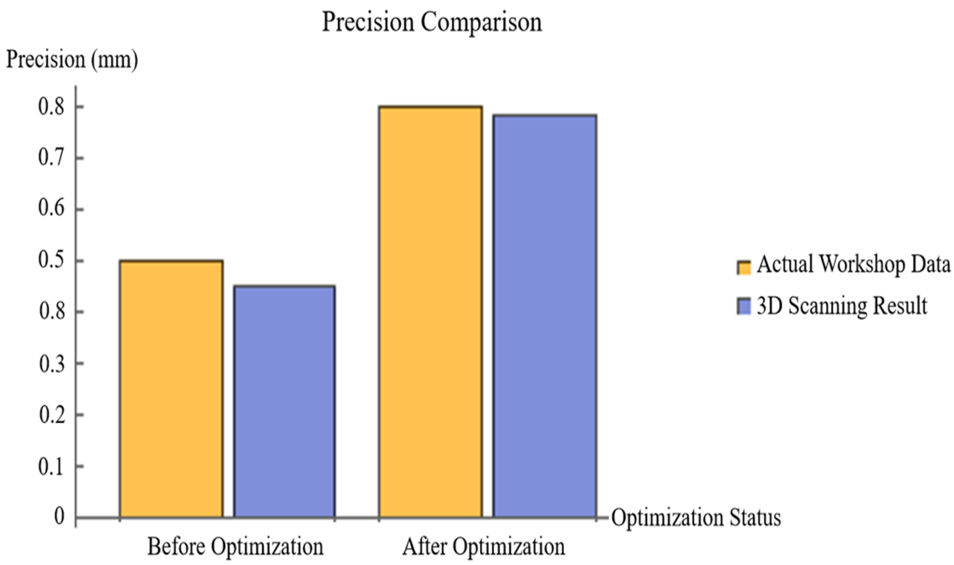

Fig.2 Precision Comparison

5 Conclusion

This study aims to meet the application requirements of Unity3D technology in the field of intelligent manufacturing, and designs and implements a high-precision and highly simulated digital twin virtual environment. The research adopts a modular design approach, mainly including three core technical modules: digital modeling, simulation rendering, and human-computer interaction. The digital modeling module utilizes advanced technologies such as CAD to construct precise 3D virtual scenes, achieving high-precision mapping of equipment and environment. The simulation rendering module integrates algorithms such as ray tracing and global illumination, greatly improving the realism of the scene. The human-computer interaction module supports natural interaction methods such as voice and gesture, allowing users to immerse themselves in a virtual environment. The research has been applied in cases such as intelligent factories, verifying that the system can effectively simulate actual scenarios and bring practical value for optimizing production and equipment. The main innovation of the research lies in the implementation of a highly accurate digital twin environment and a natural and smooth human-machine interaction method, which has more application advantages compared to traditional simulation systems. Overall, this study has designed and implemented a high-precision, highly simulated, and interactive digital twin environment, which can effectively serve fields such as intelligent manufacturing and has great application prospects. Subsequent work will enrich application scenarios and continue to improve user experience. [10]

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References

[1] Xiuying X. Design and application of intelligent manufacturing simulation system based on Unity3d[P]. Ordos Vocational College (China),2022.

[2] Yahua L I, Niandong Y. Design and Implementation of Virtual Manipulator Simulation System Based on Unity3D[J].Journal of Hubei University of Technology, 2016.

[3] Ai-Jun W, Zhong-Yong L I. Design and Implementation of an Immersive Scene Simulation System for Ancient Poetry Based on Unity 3D[J].Journal of Nanchang Normal University, 2018.

[4] Liu Y, Zhao Y, Li K, et al. Design and Application Research of a Digitized Intelligent Factory in a Discrete Manufacturing Industry[J].Intelligent Automation and Soft Computing, 2020, 26(5):1081-1096.DOI:10.32604/iasc.2020.010139.

[5] Sun M, Cai Z, Zhao N. Design of intelligent manufacturing system based on digital twin for smart shop floors[J].International Journal of Computer Integrated Manufacturing, 2023, 36(4):542-566.DOI:10.1080/0951192X.2022.2128212.

[6] Shue L, Chao F. Design and Simulation of Three-phase AC Motor Soft-start[C]//2013 Third International Conference on Intelligent System Design and Engineering Applications. ;;, 2013.

[7] Xiaoyi L, Hua C. Simulation analysis of production scheduling algorithm for intelligent manufacturing cell based on artificial intelligence technology[J].Soft computing: A fusion of foundations, methodologies and applications, 2023.

[8] Ying,Kou, Longfei, et al. Construction of Intelligent Manufacturing Teaching Factory for Engineering Education[C]//0[2023-08-24]

[9] Dumbrav T. The Design of Flexible Manufacturing Systems using Simulation - ScienceDirect[J].IFAC Proceedings Volumes, 1995, 28(24):151-155.
[10] Zhang X, Tsang W M, Yamazaki K, et al. A study on automatic on-machine inspection system for 3D modeling and measurement of cutting tools[J].Journal of Intelligent Manufacturing, 2011.DOI:10.1007/s10845-011-0540-6.