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A enhanced interaction framework based on VR, AR and MR in digital twin

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Abstract

With the rapid development of 3R (VR, AR, MR) technology, there are higher continuously requirements for enhanced interaction characteristics of immersive, interactivity and multi-perception. As a new emerging information technology, 3R provide a potential solution to promote interaction and fusion for digital twin technology between physical space and virtual space, then provide various manufacturing service. This paper compare the interaction characteristics between VR, AR, and MR, then design a enhanced interaction framework based on VR, AR and MR in digital twin.

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Keywords: Digital twin; VR; AR; MR; Interaction

1. Introduction

With the rapid development of simulation technology, computer graphics technology and human-computer interaction technology VR, AR, and MR are gradually mature from a bran-new front direction, and continuously bring great concern in academe and industries. In recent years, 3R has become an effective tool in activities such as planning, guiding and training in different fields. Google, Microsoft, SONY, HTC [1], and others have joined the research of 3R to develop their own 3R products and occupy the market share.

In manufacturing field, VR, AR and MR technology can provide new approaches to industrial manufacturing by creating a new environment in which virtual and physical objects can coexist and merge, enabling a more immersive environment and a more natural way of interacting. In product design, Iqbal [2] discussed how to design and analyze a factory layout in a 3D virtual environment by means of VR and developed a new aisle system to reduce the material handling distance. Choi, SangSu [3] proposed a strategic plan and system design for the virtual factory to be effectively implemented and applied to the actual manufacturing companies. In manufacturing, Oyekan JO [4] presented effectiveness of virtual environments in developing collaborative strategies between industrial robots and humans. Jain [5] used the virtual factory concept as a manufacturing modeling and simulation tool to support design and production decisions during manufacturing. In assembly, Abdulrahman M [6] developed a fully functional virtual manufacturing assembly simulation system that uses a virtual environment to create an interactive workbench for evaluating assembly decisions and training assembly operations. De Sa and Zachmann [7] presented several interaction paradigms for virtual assembly and maintenance, which enables inexperienced users to work with virtual prototypes efficiently.

In service field, Due to the interaction characteristics of immersive, interactivity and multi-perception, 3R can create an interactive and immersive environment to augment the seamless integration between the physical and virtual worlds, many researchers and practitioners have attempted to apply

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3R in the industrial. In equipment maintenance**,** Lecakes [8] have developed a visualized engine health management system based on VR technology that can display data from multiple sensor measurements coupled to graphics for operators. L Bailin [9] proposed a low-complexity method to create an interactive virtual maintenance training system for hydroelectric equipment. In training**,** Kim N [10] combined virtual reality technology with bicycle to develop a new rehabilitation training system to improve posture balance control.

From the above research, we can see that virtual reality technology can be applied in many fields of industry. And VR, AR and MR have shown the potential for seamless integration and integration of physical and virtual space. In this paper, VR, AR and MR are combined with digital twin technology (DT) [11], which greatly enhanced interaction and fusion of DT.

2. Comparison of VR, AR and MR in Concept and Interaction Characteristics

2.1. Concept Comparison

VR technology is a kind of computer simulation system which can create a virtual space. It uses the computer technology to generate a simulation environment that is a multi-source information fusion, interactive three-dimensional visual scene and physical behavior system simulation. VR systems [12] use computer graphics to build model in real-time and picture the scene in three-dimensional and it mainly focus on perception, user interface, background software and hardware.

On the basic of VR technology, the AR can increase fusion between virtual space and physical space. AR system [13] builds a virtual three-dimensional environment model through human-computer interaction technology, opto-electronic display technology, three-dimensional real-time animation technology and computer graphics technology, and based on the registration tracking technology. the virtual model is mapped into the real world so that the user is in a fused environment and obtains brand-new experience. Beside, AR systems also increase the ability to capture information beyond the human perception range from the real world [14]. Thus, human perception is enlarged after this information is processed by AR system and become to be human-perceivable information.

Mixed reality (MR) [15.16] is sometimes called hybrid reality. It fuses the real world and the virtual space to create a new visual environment. In the new visualization environment, physical and digital objects co-exist and interact in real time. In the new visualization environment, physical objects and digital objects co-exist and interact in real time. The goal of MR is to integrate virtual and reality seamlessly to form a new virtual world which include characteristics of a real environment for virtual objects. For example, through gravity sensors, gyroscopes and other devices [17], the characteristics of real gravity and magnetic force in the real world are transferred to the virtual space. In fact, the objects in MR system is not a visible objects rather than digital object. In MR system, physical objects and digital virtual objects can co-exist and interact in real time, information interaction is realized by some key technology (registration tracking technology, gesture recognition technology, three-dimensional interactive technology, voice interaction technology, etc.).

2.2. Interaction Characteristics Comparison

Generally speaking, the objects seen in the VR system are illusory. The virtual objects that we see are realized by introducing human consciousness into the virtual space. Compared with VR system, the objects in AR system consist of virtual objects and physical objects. AR system brings virtual information into the real world, some information that human cannot perceive are captured and transform into appreciable information by AR system. Mixed reality includes both augmented reality and augmented virtual. In addition, from VR to MR, the characteristics of immersive, interactivity and multi-perception are continuously strengthened. Thus, there are many similarities and differences between VR, AR and MR and the comparison in detail is as follows:

(1) Similarities: ①Virtual information needs to be generated by computer simulation system, where virtual information is visualized by specific devices such as movable displays, data gloves, position trackers, and helmets etc. [18]. ② At the technical level, 3R technology are highly dependent on new generation information technologies (simulation technology, computer graphics technology and human-computer interaction technology etc). And with the development of new generation information, it will refine the user experience to keep users engaged. ③Currently, Portability is the common trend of VR/AR/MR according to these devices, which are still dominated by wearable devices.

(2) Differences: ①They have different requirements for equipment. For instance, VR devices cannot achieve interaction between user and virtual space, but AR and MR devices can do it. ②Immersive, interactivity and multi-perception is different among them. For example, VR and MR is better than VR in immersive experience.③The major difference is in interaction. The characteristic of interaction are mainly as follows and Figure 1 show the performance difference of VR, AR and MR.

Interaction in VR: One-way interaction in VR is a basic mode interaction e.g, one-way interaction (physical space→virtual space→user), and VR system is bridge for the interaction between virtual space and user. Firstly, Virtual twin model of physical objects with high fidelity is the key step for interaction. In this step, the geometric features, behavioral traits and function parameters of physical twin need to be depicted digitally, imitate or even predicted in the way of virtual twin entity. Then, the VR system deliver digitized information for virtual space to users, and users will receive a three-dimensional visual scene of immersion. As the user receives pure digital, but this immersion is merely based on virtual information synthesized from the computer, thus not strong, lacking directly interaction between user and physical space.

Interaction in AR: Different from VR, the interaction in AR have both one-way interaction and two-way interaction. For example, one-way interaction is physical space→virtual space→user or physical space→user→virtual space. Two-way interaction is virtual space→←user. For these interaction, AR system needs information both from virtual space, real-time information from physical space, and sensory&feedback information from user. Therefore, AR system will superimpose these sensory&feedback information to augment real scenes. Compared with VR system, the AR system emphasize the interaction process (physical space→user→←virtual space), which refers to user perception of the overall physical environment, then a cognitive feedback will be studied and simulated by AR system in virtual space according to augmented reality data. Finally, the result of which can be used to guide user behavior. However, in terms of interactive and immersion, AR system is better than VR system.

Interaction in MR: Compared with VR system and AR system, MR system has a comprehensive improvement in immersive experience and interactive forms. The MR system can not only realize the two-way interaction (virtual space→←user) between the users and the virtual space, but also could realize two-way interaction (physical space→←user) between users and physical space. Finally, due to MR system, physical space could also realize two-way interaction (physical space→←virtual space). For these two-way interaction, MR system needs information both from virtual space, real-time information from physical space, and sensory & feedback information from user. In addition, in the process of two-way interaction, MR system will play a role that process and convert key information. What’s more, these information is reasonably distributed and superimposed in order to build MR scenes we need.

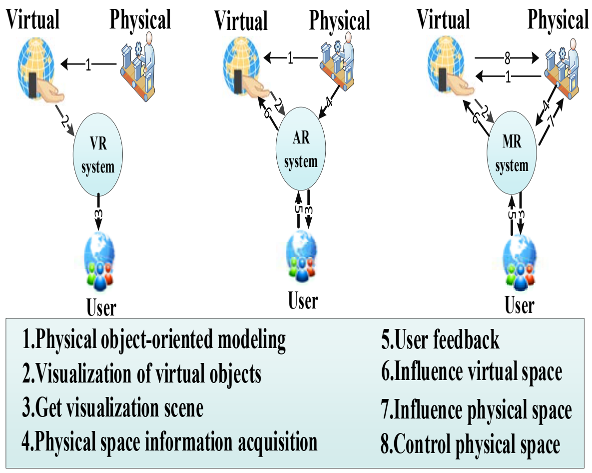

FIGURE 1 the interaction characteristic of VR/AR/MR

From the above description and analysis for VR/AR/MR, Table 1 is made to illustrate the differences and relations based on properties of immersive, interactivity, multi-perception and key technologies.

TABLE1 the performance introduction of VR/AR/MR

properties	Characteri-stics	VR	AR	MR
Immersive	Virtual space	✓	✓	✓
	Physical space		✓	✓
	Real-time Interaction			✓
Interactivity	User and virtual model	✓	✓	✓
	User and physical space		✓	✓
	Physical objects and Virtual models			✓
Multi-perception	Virtual information	✓	✓	✓
	Real information		✓	✓
	User's physiological information			✓
Key technologies	Simulation Technology	✓	✓	✓
	Display Technology	✓	✓	✓
	Computer Graphics Technology	✓	✓	✓
	Human-computer Interaction Technology		✓	✓
	Registration Tracking Technology		✓	✓

3. The framework of VR/ AR/ MR in DT

The application framework of DT combined with 3R technology in the manufacturing industry is composed of three parts, the physical space level, the virtual space level, and the 3R application level [19]. Physical space and virtual space achieve interaction each other. Virtual space and the application level of 3R technology achieve interaction each other. Physical space and the application level of 3R technology achieve interaction through virtual space where virtual space serves as links between physical space and virtual space.

3.1. The physical space level

The physical space level consists of three parts: physical modeling objects, execution modules, and IoT modules [20, 21]. The physical object model process to build digital twins. The digital twins include physical objects, virtual objects, and the connection of physical space and virtual space. The IoT module covers technologies such as RFID, smart meters, bar codes, sensors, and wireless networks etc. The function of the IoT module is to acquire the data of the physical space in real time and feed back instructions of the virtual space to the execution module. The execution module consists of various robots, mechanical arms, production lines, and workers. It is mainly responsible for executing the instructions from the virtual space.

3.2. The virtual level

The virtual space level is composed of two parts: twin data and models. The twin data includes real-time interactive data, design data, manufacturing data, and other necessary data etc. Twinning data play a role that provide data services with full-featured, full-process for the 3R technology and interaction application, physical space and virtual space. The models mainly cover three aspects of objects, rules and behaviors. Physical objects mainly refer to high-fidelity a physical model that describes geometrical and properties of physical objects. Rules mainly refer to a high-fidelity physical models that describes geometry and functional properties of physical objects. And rules mainly covers the rules of optimization, forecasting, and evaluation that are established on the operational rules. In addition, behavior mainly covers the behavior model that characterizes the behaviors of sequential, concurrency, and linkage of physical objects.

3.3. The application and interaction level

At 3R application and interaction level, virtual three dimension models are projected into physical space through virtual reality peripherals (movable displays, data gloves, position trackers, and helmets etc). Visualization of three-dimensional models allows users to observe the physical objects more clearly and remotely. And through the interaction between virtual space and 3R application and interaction level, the visualization of design manufacturing, assembly, disassembly are achieved. Due to visualization of virtual objects, interaction and fusion between virtual space and physical space is accessibility. Last but not least, 3R application and interaction level will serve as the interaction center between physical space and virtual space.

In order to minimise the cost of PSS, enterprises need feedback on the product according to the customer, and this leads to requirements mapping convert customer request elements into functional elements and engineering features, then design the corresponding product module and service module sets, the product and service module can match various service module system for customers to choose products. Enterprises pursue the maximization of value creation,it will consider the PSS solutions to minimize costs. However, customer satisfaction and enterprise cost are often not optimal at the same time. Therefore, there is an interactive process between enterprises and customers, and the instance combination of product module and service module needs to be constantly weighed and adjusted. In this paper, the application framework of DT combined with 3R technology can better help enterprises interact with their customers, the visualization of 3D model allows customers to select product and service modules more clearly and remotely, and through the virtual space and the application of 3R interaction level, it can balance the product and service module instance combinationto achieve the minimum product service system solutions.

FIGURE 2 the application framework of 3R in DT

4. The applications of VR/AR/MR in three-dimensional visual assembly based on DT

The assembly of complex products such as aircraft, automobiles, and engineering machinery are an integral part of the design and manufacturing process. And the assembly results directly affect the performance and quality of the product. Digital assembly technology that integrates DT and 3R technology is an effective way to achieve three-dimensional visual assembly, improve assembly quality and efficiency, and reduce assembly costs. The three-dimensional visible assembly technology that combines DT and 3R technology is to realize the interaction between the virtual space and the physical space through the building digital twins. Meanwhile, virtual models are projected into physical space based on 3R technology which makes users to feel immersive and multi-perception interactive experiences. In addition, this visual assembly allows the user to better understand the dynamics of the assembly process and to control the assembly process through real-time human-computer interaction systems.

DT assembly framework with 3R technology is the foundation for three-dimensional visual assembly. And the framework provides technical support for three-dimensional visual assembly. This framework includes assembly lines at the physical level, models and data at the virtual space level and 3R systems. The assembly line of physical space is the execution module which realizes the three-dimensional visual assembly. The product-related model at the virtual space level not only defines the geometric features of the product parts and components (such as shapes, dimensions, tolerances, etc.), but also describes a variety of assembly information including physical attributes, product parts and components fit relationships and assembly path planning etc. The virtual reality interactive system is composed of data glove, position tracker, helmet and other hardware and software modules supporting interactive system. It mainly realizes three-dimensional visualization of model and data in virtual space, and achieves the purpose of interacting with the physical space.

5. Conclusion and future work

This paper gives a brief introduction to the development history and characteristics of VR/AR/MR. Through the research and comparison of characteristics for VR/AR/MR and its development trend, it is proposed that the immersive and multi-perception interaction experience brought by VR/AR/MR can be introduced into DT and explains briefly how to apply proposed framework in PSS design. To illustrate the application of 3R technology in DT, a case study of three-dimensional visual assembly for complex product is illustrated in detail to show the application of 3R technology in DT. One of the bottlenecks faced by DT is how to realize the interaction between physical space and virtual space. And 3R technology is one of the effective ways to realize the interaction between physical space and virtual space. Therefore, how to integrate 3R technology with DT and apply it to product lifecycle is key point in future work.

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