Research and design of VR-based mechanical simulation interaction and network experiment platform

Zhenghong Liu¹, Huiliang Zhao², Jie Liu¹, Yuliang Xu¹ *
1. School of Mechanical Engineering, Guiyang University, Guiyang 550005, China
2. Guizhou Minzu University, Guiyang 550025, China
Corresponding author’s e-mail:415803168@qq.com

Abstract. This article takes mechanical basic experimental courses as the research object, and makes full use of virtual simulation, computer graphics, Internet and other technologies to innovate experimental teaching content and methods. First, construct a mechanical basic experiment teaching system based on four levels: guided cognition, basic experiment, comprehensive design experiment and research and innovation experiment. Then, combined with the existing virtual simulation related hardware equipment of the college, a software and hardware virtual experiment platform integrating virtual 3D display and interaction is built. Finally, with the help of Unreal Engine 4 (UE4) and network technology, a Web-based 3D virtual experiment platform is designed. Through the research of this article, a basic mechanical experiment system can be constructed, the experimental teaching training program can be improved, and the engineering practice education level can be further improved. The virtual reality (VR) experiment platform proposed in this paper can improve existing teaching methods, expand experiment content, solve problems such as insufficient educational resources, and improve students' interest and initiative in learning. The research of the network virtual platform enables students to break through the limitations of time and space, and realize different levels of mechanical experimental courses, such as online learning and hands-on operation of guided cognition, basic experiments, comprehensive design experiments, etc.

1. Introduction
Virtual Reality (VR) is a virtual simulation environment with three-dimensional effects, which has the characteristics of immersive interaction and multi-channel perception. The emergence and maturity of VR technology provides users with an interactive method closer to the real world. This advanced interactive method is widely used in various fields. In terms of teaching, it is mainly used in VR laboratories, VR libraries, and VR classroom, etc. With the popularization of the Internet and the continuous maturity of its technology, the combination of networking and VR technology has emerged, mainly in VR online classrooms, virtual museums, etc.

Since VR technology was first proposed by the United States, the United States is still in a leading position in related research[1]. Medicine School of Stanford University designed a 3D online learning platform on frog biology for middle school students; MIT built a VR-based media teaching and research room; Umich used VR modeling language to build an "art museum"; The University of Wisconsin System is a VR-based COVIRDS system that interacts with virtual modeling scenes through gesture operation and voice recognition to achieve rapid virtual conceptual design, thereby improving design efficiency[2]. The University of Calgary in Canada has developed the VLAB (Virtual Laboratory) platform, which can quickly build biological simulation models for users[3]; The network virtual course system developed by Kim and others in South Korea can simulate physical
phenomena such as water waves and electromagnetic induction; The University of Leeds in the United Kingdom Khalili and others developed the WebSet (Web-based Standard Education Tools) platform, which is based on VR technology to simulate the operation process and realize remote medical related teaching[4]; Georgiou and others in Greece developed a network virtual chemistry laboratory to enable students to familiarize themselves with chemistry in advance Experimental instruments and equipment to better carry out chemical experiments[5].

Compared with foreign countries where the research on VR technology and application is more advanced, my country's VR technology research started late, and the research time is shorter. There are still some gaps in basic equipment and technical theory. However, the development of VR technology in my country has been stronger in recent years. Some excellent works have emerged in the field of combining with network information. In the process of constructing national quality course resources, colleges and universities across the country have built a lot of better online course resources, but these course resources are basically stored and shared in the form of office documents, Flash animations, pictures, videos and other multimedia forms, so that teaching effect has been improved[6-11]. Only a small part of the course resources building an online learning platform by VR, and this part of the resource is very popular. Beihang University is one of the earliest universities in China to conduct VR technology research, and has established the State Key Laboratory of VR Virtual Reality Technology and Systems, which is mainly engaged in scientific research and application technology development in VR technology, visualization technology, image information processing, distributed systems, artificial intelligence, etc. Zhejiang University scholars use multiple client-side scripting languages such as JavaScript to achieve user interaction, download and run Java Applet, Active X and other programs from a web browser, and use Java Applet to call JDBC and specified data resources on the Internet establishing a connection to complete the interaction between the server and the user[12]; Based on Culd3D technology, Dalian University of Technology has built a network resource for high-quality mechanical courses, and users can browse all mechanical parts on the Internet; Tongji University has developed VR-based construction related course network laboratory, which can simulate the appearance of building structure[13-15].

Most of the existing experimental projects in universities at home and abroad are confirmatory experiments to verify basic theoretical knowledge. Students just complete the experiments mechanically and cannot understand the principles well. Unable to complete innovative experimental projects, lack of training of engineering technology and engineering experience. The main problems are as follows: i. The teaching method lacks novelty. The traditional teaching method is that the teacher explains the principle of the experiment, and then demonstrates an experiment. The students complete the experiment mechanically according to the teacher's handouts. Without the process of conception, design, participation, and interaction of the experiment, students' creative thinking cannot be cultivated. ii. The experiment content lacks systematic. Traditional experiments are mainly dependent on theoretical teaching. Experimental projects are mainly to verify unilateral theoretical knowledge points. The lack of integration among various knowledge points and the lack of systematic are not conducive to students' overall understanding of the curriculum theoretical knowledge system.

With the continuous increase of network resources for high-quality courses and the continuous improvement of the application of VR technology, the cost of virtual network teaching will become lower and lower, so it will become more and more popular. As a teacher, the focus is how to make high-quality online courses[16]. The network virtual teaching platform based on Internet technology and VR technology will develop into a comprehensive learning platform integrating learning, discussion, feedback and evaluation, and will be established in large numbers worldwide.

This article takes mechanical basic experimental courses as the research object, and makes full use of virtual simulation, computer graphics, Internet and other technologies to innovate experimental teaching content and methods. First, build a systematic experimental curriculum content system; then, combine the existing virtual simulation related hardware equipment of the college, to build a software and hardware virtual experiment platform integrating virtual 3D display and interaction; finally, integrate network technology to design a Web-based 3D virtual experiment platform.
The main contributions of this article are as follows:

(1) Construct an experimental teaching system and standardize experimental teaching content. Construct a mechanical basic experiment teaching system framed by four levels: guided cognition, basic experiment, comprehensive design experiment and research and innovation experiment. The system covers all basic mechanical experiments from simple to deep, simple to comprehensive, and focuses on holistic and systematic experiments, which can meet the training requirements of experimental courses for students of different mechanical majors at different learning stages.

(2) Combine with VR technology to improve experimental teaching methods. Traditional professional course teaching is taught in the form of physical models, blackboards, or slides. It cannot or is difficult to visualize the conversion process between the three-dimensional form of the model and the two-dimensional plane, which makes classroom teaching dull. i. In the teaching of "Mechanical Drawing", because students are just beginning to get involved with 3D, it is difficult to generally accept it. With the help of virtual reality experimental platform, students can get started quickly and stimulate learning initiative and interest. ii. In the course teaching of "Mechanical Principles" and "Mechanical Design", virtual reality technology and network technology are used to simulate the experimental process of mechanism cognition, mechanism diagram mapping, dynamic balance experiment, reducer disassembly and assembly, with the help of relevant external equipment, So that the experimenter is completely immersed in the virtual environment for interactive experimental operations, not only can solve the problem of insufficient educational resources, but also enable students to perform experimental operations without time and space constraints, which is conducive to giving full play to the experimenters’ innovative ability. iii. In the course teaching of "Modern Cutting and Processing Technology", "Jig Design", "Machinery Manufacturing Technology", the operation control of large and precision machinery is involved, especially the disadvantages of danger and high cost in certain machinery manufacturing processes. Carrying out the research of virtual mechanical manufacturing processing simulation experiment has certain practical value for the learning of mechanical manufacturing processing knowledge and operation training.

(3) Research the network virtual experiment platform and enrich the experimental teaching methods. Research the context and interactive methods of related experiments and publish them in the form of web pages to build a web-based virtual experiment platform. Enable students to break through the limitations of time and space, and complete experimental preparatory work, experimental homework and other learning outside the laboratory. At the same time, the interactive operation and learning materials are integrated, such as adding multimedia courseware, processing videos, operation instructions, equipment photos, linking learning websites and other auxiliary content of the corresponding machine tool working principle and operation in the mechanical processing virtual experiment system.

2. Construction of experimental teaching system of mechanical basics

Construct a mechanical basic experiment teaching system framed by four levels: guided cognition, basic experiment, comprehensive design experiment and research and innovation experiment. Take mechanical cognition, mechanical design and mechanical research as the main line, broaden the foundation, and focus on cultivating students’ comprehensive innovation and practical ability. The guided cognitive experiments mainly include mechanism, intersecting line model mapping, mechanism cognition, mechanical structure and parts cognition, mechanism diagrams; Basic experiments mainly include combined body model surveying and mapping, mechanism sketch mapping, dynamic balance experiment, Sliding bearing pressure experiment; Comprehensive design experiment mainly includes computer drawing, speed fluctuation adjustment, mechanical transmission design and performance analysis, reducer disassembly experiment; Research innovative experiment mainly includes mechanism innovation design, mechanical transmission scheme design.

By consulting materials, investigating experts and other methods, combined with the project team members’ years of front-line teaching experience, construct the mechanical basic experimental teaching system as shown in the figure below. The system has a clear level and reasonable system,
covering all mechanical basic experiments, and can meet the requirements of mechanical engineering. The training requirements of experimental courses for students of different majors at different learning stages.

3. Virtual simulation and interactive experiment construction based on VR
Based on VR technology, build a virtual simulation and interactive experiment platform that combines hardware and software. On the basis of constructing the experimental teaching system, firstly use 3D modeling, 3D scanning and other modeling techniques to construct the 3D model of the experimental equipment and parts; then combine the constructed model with the existing ring screen and 3D projection of the college virtual simulation laboratory Fusion of hardware devices such as instrument, 3D glasses, etc.; finally, through interactive process development, a virtual, realistic, interactive virtual experiment platform combining software and hardware is constructed.

Through modeling, the equipment, related parts, scenes, etc. included in the experiment are digitized, and the existing virtual reality hardware equipment of the college is integrated to analyze and develop the interactive process and complete the research of interactive virtual experiment based on VR. In addition to satisfying the experimental content of "Mechanical Drawing", "Mechanical Principles", "Mechanical Design", "Mechanical Manufacturing Technology" and other courses. The realistic virtual experiment system can continuously add new content with the development of technology, which can involve the models of various parts in the machinery industry, the processing process of parts from rough to finished products, various processing methods of parts, and dynamic simulation of the principle and processes of parts processing, etc.

4. Research on the network platform corresponding to VR experiment
Based on the UE4 game technology engine in virtual reality technology, using C++ scripting language for interactive process development, integrating network technology, designing a Web-based 3D virtual experiment platform through business process and demand analysis, architecture design, function design and other steps.

(1) Function design of network experiment platform: The function design of the network experiment platform is carried out through demand analysis. The function modules are shown in the
The experiment platform has three main functions: online virtual experiment, experiment teaching management and platform management.

Figure 3. Function module diagram of network virtual experiment platform

Students enter the experiment scene under the guidance of the teacher. Take the reducer assembly and disassembly experiment as an example. The platform has the following main functions: i. By dragging and dropping the mouse, the viewing angle of each component can be changed, and the scroll wheel can be used to achieve the zoom function of each component. ii. Use the mouse to click the relevant buttons in the scene to realize the assembly and disassembly demonstration of the reducer as a whole and its parts and components. iii. Use the mouse to drag and drop the corresponding parts for interactive assembly and give feedback on the operation sequence. If it is correct, continue the assembly. If it is wrong, a text and sound error prompt appears (the prompt can be hidden by mouse click), and the disassembly operation is similar. iv. Click the relevant button to measure the corresponding shaft diameter, gear tooth number, gear modulus and other parameters.

In order to improve the experimental effect, the virtual platform also has auxiliary experimental functions. For example, online assignments and tests: set the time and questions, conduct online tests for students, and students can submit real-time feedback on grades and correct answers and analysis after submission. Experiment report submission and correction: After the experiment is completed, students first submit the pdf version of the experiment report, and then the teacher corrects the experiment report on the experiment platform. After the correction is completed, the teacher informs the students to check their own experiment report on the experiment platform, thus realizing paperless experiment of report submission, correction, and review.

(2) Function realization of network experiment platform: Taking the disassembly and assembly experiment of the reducer of the virtual experiment platform as an example, the design and implementation of the virtual experiment are described in detail. The experiment can be divided into three steps: the construction of the 3D component model, the design and realization of the interactive function of the model, and the publishing network. The specific process is shown in Figure 4.
quality of the model directly affects the fineness and realism of the virtual experiment display and determines the smoothness and speed of the system operation to a large extent.

Figure 4. Flow chart of the realization of the network experiment design of the reducer disassembly and assembly

Making materials, textures and scenes: First, import the built 3D model of the reducer (completed through related parametric modeling software or 3D Max) into 3D Max, and assign shaders and textures to it. You can also edit the material directly in UE4. Then build scenes such as lighting and environment in UE4. The correct material information can make the model closer to the real object, and the lighting and environment settings can also obtain more realistic effects.

Virtual interaction design based on UE4 (The interactive control function in the virtual experiment is mainly developed in UE4, which is also the most critical and complex part of the entire virtual experiment): First, export the reducer 3D model file of .fbx containing the texture map from 3D Max. Then import the file from UE4. Finally, use C++ programming or blueprint technology for interactive design in UE4. UE4 supports the C++ scripting language, which can realize the interactive logic control between model objects or other buttons through scripts and can also control the input and output by calling the API interface. Mount the script to the corresponding Game Object and set the corresponding trigger mode to realize the interactive function of assembly, disassembly and related parameter measurement of the reducer model. Some simple interactive functions can also be designed directly through blueprints.

The project webpage is released (UE4 supports project releases on multiple platforms): First add corresponding scenarios. Then set the relevant parameters of the publishing webpage, and then the fully functional reducer disassembly and assembly experiment project can be published as a webpage.

Combine existing hardware equipment to build a network-based virtual experimental software and hardware platform to realize virtual 3D display and interaction of reducer disassembly and assembly projects.
5. Conclusion
This article proposes firstly construct a mechanical basic experimental teaching system to prepare for follow-up research. Then build a VR virtual experiment platform that integrates software and hardware to realize virtual teaching. Finally, on the basis of the constructed digital model, the corresponding network virtual platform is studied with the help of UE4 technology. The key to the design of this paper is: (1) The establishment of a virtual experimental environment based on VR is the key to improving teaching methods such as physical models, blackboards, or slides. The realistic and interactive virtual system can greatly stimulate students’ learning interest, improve students’ initiative and creativity. However, the establishment of a virtual environment with good interaction requires the integration of software and hardware, which has many technical difficulties and needs to be addressed. (2) The research on the network experiment platform allows students to break through the limitations of time and space, complete experimental preparatory training, experimental homework and other learning outside the laboratory, while integrating interactive operations and learning materials. In order to release the virtual experimental network platform, UE4 engine technology is needed to use C++ programming or blueprint technology for interactive design in UE4, which is also the difficulty of this project.

Based on advanced technologies such as virtual reality, interactive design, digitization, and the Internet, conduct innovative research on the teaching content, teaching methods, and teaching methods of mechanical basic experimental courses. Research on the network virtual platform based on UE4 engine technology can realize the integration of interactive operation and learning materials. At the same time, it enables students to break through the limitations of time and space, and further enhance their interest and enthusiasm in learning. It has a certain degree of innovation in terms of technical use and functional design.

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References
[1] Chang-ming Tang, Tao Jin, Research on product display based on VR-platform with virtual reality technology[J], Modern Electronics Technique 2021, 44(02): 51-55.
[2] Tuikka T, Salmela M. Facilitating designer-customer communication in the worldwide web[J]. Journal of Internet Research, 1998, 5(12): 56-58.
[3] Barceló J A. Virtual reality and scientific visualization. Working with Models and Hypothes[J]. International Journal of Modern Physics C, 2001, 1(12): 569-580.
[4] Kim J H, Park S T, Lee H, et al. Virtual reality simulations in physics education[J]. Interactive Multimedia Electronic Journal of Computer-Enhanced Learning, 2001, 3(2): 1-7.
[5] Georgiou J. A virtual reality laboratory for distance education in chemistry[J]. International Journal of Social Sciences, 2000(2):69-75.
[6] Xuan Zhou, Rui-fang Sui, Current status of virtual reality and augmented reality-based training tools in ophthalmology teaching[J]. Basic & Clinical Medicine, 2020, 40(12), 1744-1748.
[7] Pan-pan Tang, Research on precision parts design of laser VR virtual reality technology[J]. Automation & Instrumentation. 2020, (04), 163-166.
[8] Bao Cai, Kun-jv Shi, Wen-hua Zhu. Lathe Simulation System Based on Virtual Reality Technology[J], Computer Systems & Applications, 2018, 27(5): 86–90.
[9] Min-jie Chen, Rong-jin Yang, Meng-feng Shen. Research on application of virtual reality technology in experimental teaching of hydraulic transmission[J], Experimental Technology and Management2018, 35(04): 136-139.
[10] Wen Lei, Qing-kui Chen, Xiao-long Zhu, et al. Simulative Teaching System of “Agricultural Mechanics” Based on Virtual Reality[J], Computer Systems & Applications, 2018, 27(04): 76-81.

[11] Yang Cao. Application of Virtual Reality in Chemical Engineering Simulation[J], Chemical Engineering Design Communications, 2018, 44(03): 59.

[12] Hong-fei Zhan, Xin-jian Gu, Jian-rong Tan. Selection and application of tools for developing enterprise-modeling system based on internet/intranet[J]. Computer Integrated Manufacturing Systems, 2000(01): 61-65.

[13] Bo-hua Ma. Design of VR technology based 3D integration simulation system for architectural landscape features[J], Modern Electronics Technique, 2020, 43(20): 153-156

[14] Yao-dong Chen, Zhe Cui, Luo-xi Hao. Research on the Methodology of Evidence-based Design Based on VR Technology[J], 2019, 30(02): 123-129.

[15] Core M R, Stube J W. Computers and information systems[J]. McGraw-Hill Book Company, 2000(2): 36-39.

[16] Simon M, John M. E-Learning initiatives to support prescribing[J]. British Journal of Clinical Pharmacology, 2012, 74(4): 621-631