3D Display of Virtual Assembly of the Large Mechanical Structure Based on VR

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Abstract

Virtual assembly technology has been widely used in the fields of mechanical equipment and industrial simulations. However, the current virtual assembly is mainly centered on function and technology, without considering human interaction experience. Aiming at the realization, analysis and display of virtual assembly of large and complex mechanical structure, a complete set of technical solutions is introduced. 3D model establishment and assembly animation simulation are carried out based on UG and Tecnomatix platforms; Through VR technology, a human-computer interaction mode for structure-oriented virtual assembly process is built, which enables users to simulate the operations of assembly objects; Shutter 3D technology is used to output the experience picture of a single user in VR through a high-definition 3D projector, which can satisfy the immersive experience of multiple users in the 3D virtual assembly process at the same time. This technical route has a positive significance for simulating the assembly process of large complex mechanical structures more truly, verifying and improving the assembly scheme, and realizing the human-computer interaction oriented to the assembly process.

Keywords
Virtual assembly, VR, 3D.

1. Introduction
With the rapid development of science and technology and the increasingly intensified international competition, all countries in the world regard intelligent manufacturing as the commanding heights of developing advanced manufacturing industry. Under the guiding ideology and strategic deployment of "Made in China 2025", it has become an inevitable trend for Chinese traditional manufacturing industry to transform into intelligent manufacturing industry (Nitin and Divyank 2021).
Typically, the design of a large mechaHuonical structure begins with a part sketch and then moves on to a computer-aided design (CAD) workshop to build its detailed 3D models of the parts and assemblies (Sun et al. 2021). These files are transferred to the manufacturing departments and assembly departments to optimize the manufacturing and assembly process of the final mechanical structure (Wang et al. 2018). Usually, in this design stage, multiple factors concerning the assembly process need to be considered, such as assembly sequence, environment, equipment utilized, etc, where errors for each links are not allowed. If a link in the design process to be considered improper, it will lead to the actual assembly problems like serious economic losses and time delays. Therefore, it is necessary to carry out virtual simulation of assembly process before assembly implementation.
At present, most enterprises have adopted CAD technology for mechanical structure design and assembly process analysis (Chen 2013), but this method has many limitations since the ignorance of the practical assembly process and limitation on dynamic assembly problem of mechanical structures.
Virtual assembly is to assemble products in a virtual environment which has been widely used in mechanical equipment and industrial simulation fields. However, the current virtual assembly is mainly centered on function and technology, without considering human interaction experience. Theoretically speaking, virtual reality technology is a computer simulation system that can create and experience a virtual world. Studies have found that the assembly system based on VR environment can provide users with a mixed reality scene of virtual object fusion, so that users can physically watch the assembly process and interact with the virtual mechanical structure, which greatly improves users' experience (Chen et al. 2018). VR-based virtual assembly technology is able to realize visualization of assembly, verify the rationality of assembly process, enhance human-computer interaction experience, and play a guiding role in the real assembly process (Abidi et al. 2019). However, the application of VR equipment in virtual assembly also has limitations. For example, it can only allow one user to wear VR helmet and watch the assembly process in the virtual environment of VR system (Wei 2021), so there is no communication and discussion between users in the same assembly process. Therefore, this paper also aims at the problem. A method to output VR virtual environment images into 3D movies is proposed, so that more users can experience the virtual assembly process immersively, just like watching 3D movies (Sun et al. 2018).

2. The Workflow of the Virtual Display Production
The construction process of large mechanical structures is mainly divided into four parts: design stage, manufacturing stage, assembly stage and application stage (Sun et al. 2021). The assembly stages of large mechanical structures are important and complex which involve the formulation of the assembly process, the selection of the equipment needed for assembly, the auxiliary operation of assembly personnel, etc. To conduct virtual simulation and demonstration of such process, it is necessary to complete technical scheme formulation, three-dimensional modeling of display objects, timing planning of the assembly process, selection of the virtual display production platform, virtual display production and other steps at one time (Cui et al. 2019). The main process is shown in Figure 1.

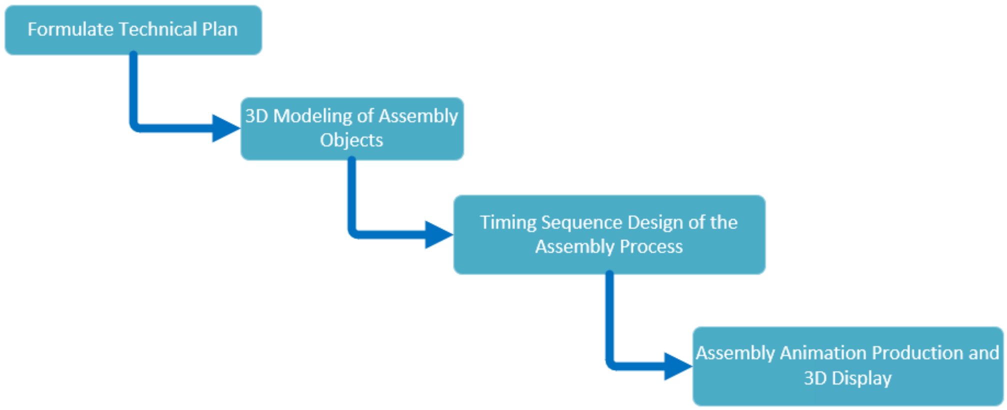

Figure 1. The main process of the construction of large mechanical structures

2.1 Formulate Technical Plan
To draw up a reasonable assembly technology plan for large mechanical structures, it should be based on the actual production situation, main equipment and technological process of large mechanical structures. Achieving the intended function is the primary goal and the basic principle to reduce the assembly period, ensure the assembly quality and reduce the assembly cost. At last, make use of the existing equipment in the assembly plant to determine the assembly sequence.

2.2 3D Modeling of Assembly Objects
3D modeling of assembly objects mainly includes modeling of the large mechanical structure, equipment required for assembly, assembly environment, virtual human, etc. All models are placed in the assembly environment according to the overall plan. This part of the work is the focus of the large-scale mechanical structure construction, in which the quality of modeling directly affects the effect of the final virtual assembly animation display.

2.3 Timing Sequence Design of the Assembly Process
According to the proposed technical scheme of the large mechanical structure and the required time of each assembly link, the timing sequence action of each assembly device was reasonably planned to ensure the assembly quality and minimize the time cost in assembly process, which laid a foundation for the virtual assembly display of large mechanical structure.

2.4 Assembly Animation Production and 3D Display
First of all, the choice of the production platform are supposed to be determined, and the most important consideration should be given to the conversion between 3D modeling and video production. The selection requirements of the 3D modeling software platform are: (1) To be able to show a clear modeling structure; (2) Certain engineering parameters need to be given in the process of modeling; (3) The models are easy to modify. Video production platform selection requirements are: (1) Easy to use in animation production; (2) High rendering speed; (3) Good artistic effect. For the virtual display of large mechanical structure assembly, it is recommended to use SolidWorks and UG NX, commonly used software in mechanical engineering, Tecnomatix with powerful functions, for simulation of virtual assembly, and Premiere Pro for video production (Wyssenbach et al. 2021).
Through human-computer interaction, users can realize the immersive experience of assembly process, which supports validate the rationality of the assembly process. It uses computers to generate a simulation environment to immerse users in this environment (Lan et al. 2021). After the simulation model and animation of virtual assembly are obtained through Tecnomatix, it can be connected with VR equipment through its external port to realize human-computer interaction (Sobrino et al. 2019).
When the user operates through VR, the 4K high-definition recording screen can be carried out. Finally, the entire assembly process and human-computer interaction process is shown in the form of 3D video after processing, providing an intuitive and realistic means for the demonstration of technical solutions of large mechanical structures.

3. 3D Modeling of Assembly Objects

Virtual assembly display of large mechanical structures is mainly aimed at displaying the assembly process, including many details such as hoisting equipment used in the assembly process and supporting testing equipment (Carandente et al. 2016). In the actual assembly process, the mechanical equipment does not exist isolated, but with the assembly process of the environment, a variety of support equipment, the necessary staff and so on constitute a complete system. Therefore, before the virtual display video making, the 3D modeling is required to be completed first (Shailesh et al. 2022).

3.1 Establishment of the Assembly Environment Model

Since the assembly environment determines the hoisting equipment used, the testing equipment adopted, the deployment of personnel, etc., for the assembly process of large mechanical structures, it is extremely important to clarify the assembly environment. If the assembly is carried out in the outdoor open area, the crane tonnage can generally be directly according to the tonnage of the lifting object, and reasonably selected according to the safety margin. If be in indoor assembly, hoisting work should use the driving of large tonnage to complete, at the same time, in hoisting the mechanical structure that rotated position posture in the air, still need small crane to undertake auxiliary work. In general, the assembly environment plays a decisive role in the formulation of whole assembly process, which makes that the modeling of the assembly environment is extremely important. The modeling of the assembly environment should be carried out as far as possible in combination with the environmental data of actual investigation.

3.2 Establishment of Assembly Mechanical Equipment Models

For different assembly processes, mechanical equipment models can be roughly divided into two categories: hoisting equipment (including the crawler cranes, electric traveling cranes, auxiliary hoisting tools, etc.) and testing equipment (including laser trackers, level instruments, etc.). The following principles are suggested for the modeling of mechanical equipment: (1) The sizes of the original equipment are modeled in a 1:1 ratio, and the models are mainly based on the shapes and sizes of the appearances without needs for internal structure models; (2) The newly designed equipment must carry out internal structure modeling and use SolidWorks for motion simulation to demonstrate its working principle and action coordination with other equipment; (3) Layered modeling should be carried out between parts with different materials or relative movements; (4) The connection between the detection equipment and the hoisting equipment should be fully considered in the design to ensure that each lifting in the permitted accuracy; (5) Lightweight modeling should be carried out for other equipment to eliminate unnecessary parts, so as to reduce the load on the computer during the post-production of video.

3.3 Establishment of the Virtual Human Model

Although the assembly of large mechanical structures is mainly operated by technicians to operate large hoisting equipment, for some small parts, technicians are required to carry out testing and assembly operations. In the process of assembly, the working space and safety of technical personnel should be ensured, and the hidden trouble elimination and equipment operation adjustment should be carried out at any time according to the assembly situation. The work of these operators can be demonstrated by virtual human modeling (Unnikrishnan et al. 2021). Virtual human modeling can be done in Tecnomatix software, and its actions can be realized through bone binding. Later, according to the human perspective of VR, the actions of technicians can also be simulated in the virtual assembly environment to verify the rationality of the technical scheme.

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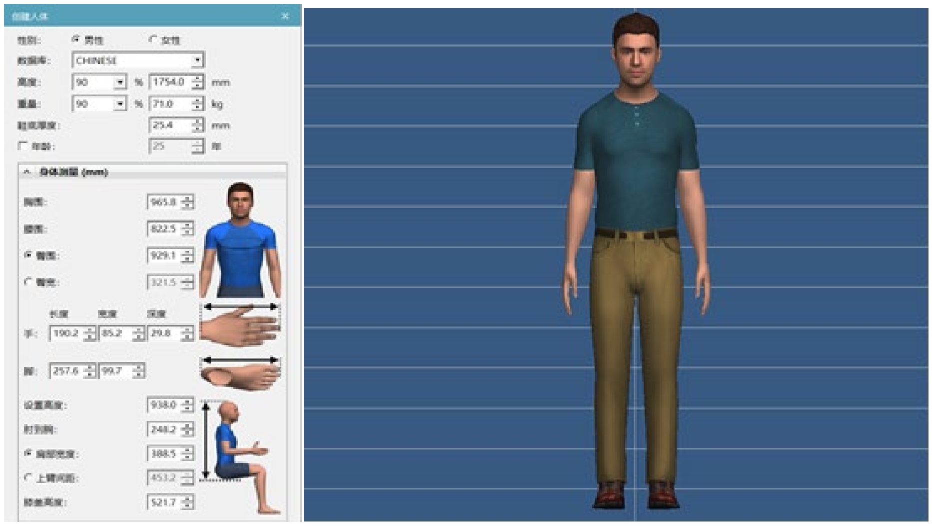

Figure 2. Establishment of the virtual human model

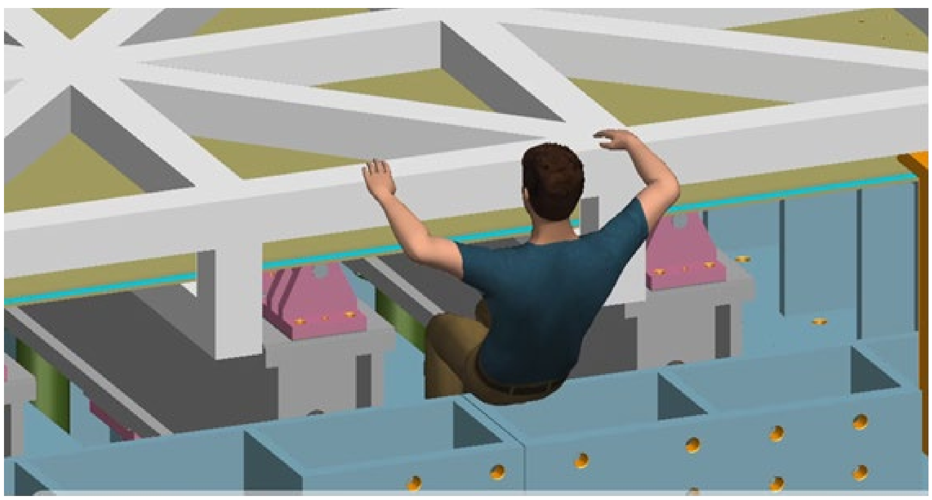

Figure 3. The virtual human enters a narrow assembly space

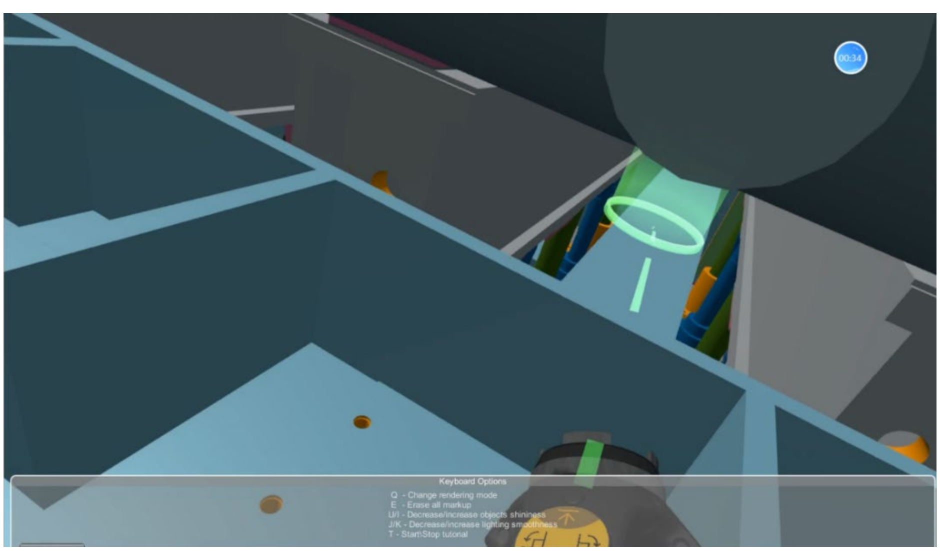

Figure 4. VR First View

Figure 2 shows the establishment of virtual human and the setting of parameters. Figure 3 shows the simulation of the operation process of technicians directly under the flexible plate assembly of the forming mechanism under the wind tunnel through Tecnomatix software, so as to verify the feasibility of the operation process of technicians. Figure 4 shows the user's first perspective in the VR virtual reality environment. The actual technician's operating space can be seen from the first perspective, which further proves the feasibility of the technician's operating process.

4. Timing Sequence Design of the Assembly Process

In the assembly design scheme of the large mechanical structure, the planning of assembly flow is an important content. Prior to the design of the assembly process, the individual pieces to be assembled shall be graded and classified. In general, a large assembly project should be divided into several sub-assembly projects, and finally the various parts are connected and matched.

Designers need to work out a reasonable assembly process while considering the cooperation between various devices, in order to prevent interference in the assembly process, ensure that each structure can realize its function after assembly, and improve assembly efficiency and reduce assembly cost (Pan and Lu 2021). Finally, the corresponding hoisting equipment and testing equipment are arranged in the assembly environment to form a complete assembly process system planning (Li et al. 2021).

After the overall scheme design of the assembly process is completed, 3D models of each device and virtual human models are inserted into the established assembly environment model according to the requirements of the assembly process to form a 3D model for the display of the entire virtual assembly.

After producing 3D models of large mechanical structure, the timing rhythm diagram are drawn according to the time required by each assembly step. The scheduling of hoisting and testing equipment and personnel are arranged in a reasonable order according to the needs, so as to avoid interference while maximizing assembly efficiency and shortening the construction period. The initial position and target position of the equipment assembly process were simplified as two endpoints on a straight line. The time was taken as the horizontal axis and the position as the vertical axis to draw the timing sequence beat chart. Figure 5 is the beat diagram of the ideal state with no time gap between each assembly process. The black line is the first assembly step, the long dotted line is the second, and the short dotted line is the third. A polyline of the same type is one cycle of an assembly device. When the current assembly step ends, the next assembly step begins immediately. The previous assembly device enters the next cycle when the subsequent assembly step continues to the point of no interference.

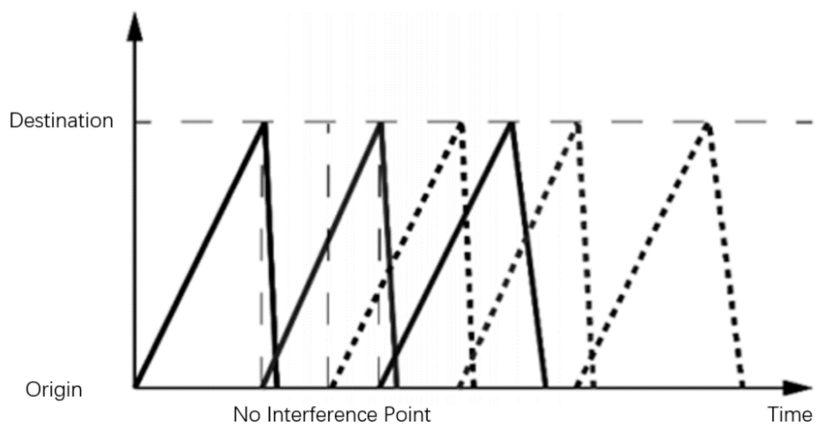

Figure 5. Timing interferogram

5. Assembly Animation Production and 3D Display

5.1 Animation Production of the Mechanical Equipment

The final output achieves 3D visualization, including details of large mechanical structure and assembly simulation information. Before making virtual assembly animation, the assembly process is firstly distinguished from parent process and child process (Huo and Lee 2021). Before importing the component models into Tecnomatix, the coordinate axes of each component model need to be centered to facilitate subsequent operations. The flow chart of virtual assembly animation is shown in Figure 6.

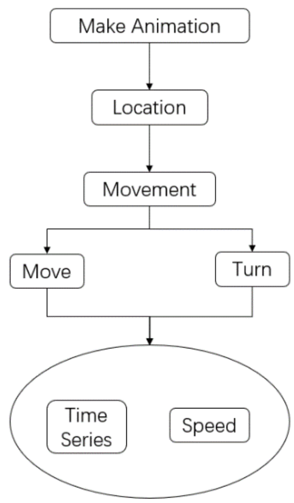

Figure 6. Assembly animation production process

In the assembly display model of the whole large mechanical structure established above, each structure and equipment are in the original position, and the action (movement or rotation) and its duration of each moving part are given according to the functional principle of each model and reasonable assembly sequence. Then, the virtual assembly animation of all models and equipment is completed in Tecnomatix.

5.2 Setting Render Parameter

For animation display of large mechanical structures, the main purpose is to clearly show the construction process of each structure, the layout of the assembly environment and the motion coordination process between each hoisting and testing equipment. The parameters of the critical parts can be set finer, while the parameters of the secondary part can be set coarser, so as to reduce the rendering time and improve the production efficiency of the display. The contents of the render Settings parameters are shown in Figure 7.

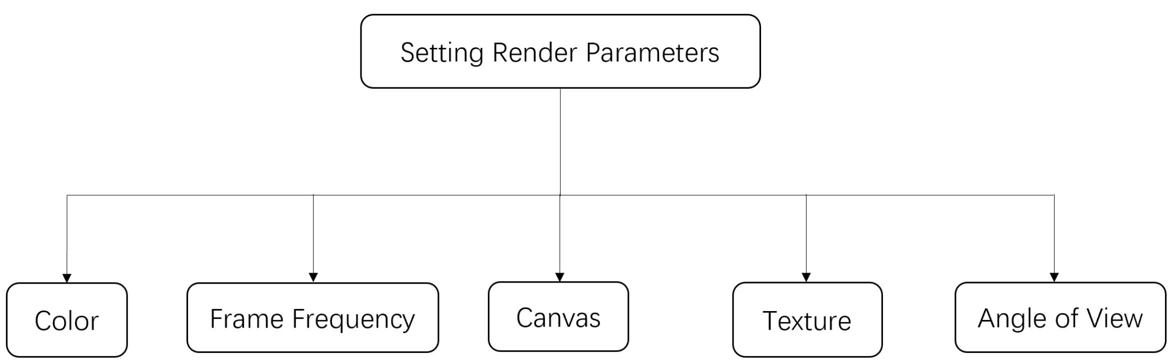

Figure 7. Setting render parameter

5.3 Man-machine Interaction

Connect the VR headset, locators and other parts with wires, and then connect the virtual assembly process built by Tecnomatix with VR. The user wears a helmet, holds VR handles and enters the search range of the locator, then he/she enters the world of virtual assembly simulation. Functions as shown in figure 8 below can be realized through the built-in functions of VR devices.

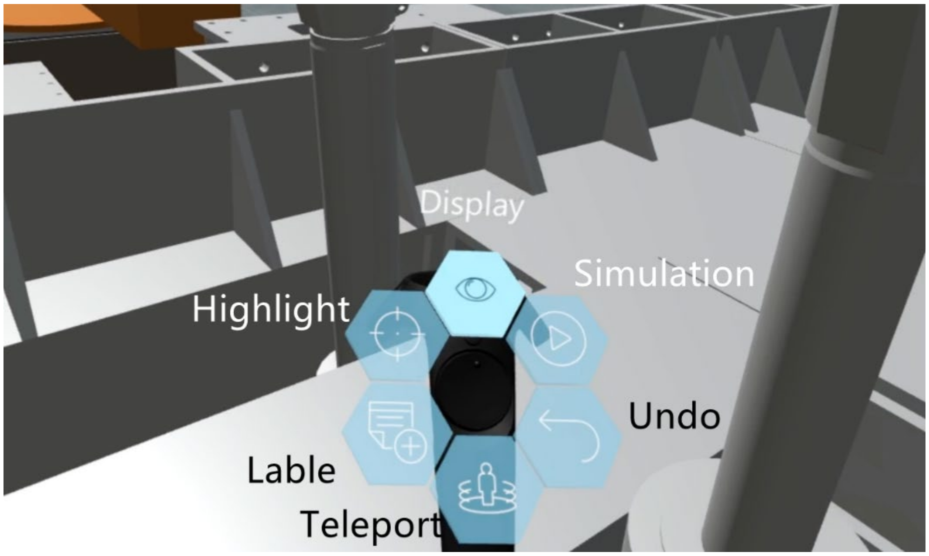

Figure 8. VR functions

The human-computer interaction system built by Tecnomatix and VR equipment allows users to experience the virtual assembly process in an immersive way, and simulate and present the perspective seen by the assembly site staff in the real assembly process. Through the built-in functions of VR, each size of mechanical structure in the assembly models can be evaluated, which can provide feasibility analysis for manual assembly operation and measurement of technicians.

5.4 Get High Quality Clips

As the input source of the original video is the dual screen of the VR display screen, as shown in Figure 9, the clarity of the display screen depends on the parameter Settings of the computer screen. The higher the display screen parameter is, the higher the definition of the original video recorded will be. Therefore, for the virtual assembly of large mechanical structures, It is best to use a 4K resolution screen to record the virtual assembly animation. There are many recording software chosen such as conventional EX, OBS Studio, etc.

The shot of the virtual assembly animation is actually the perspective seen by the user wearing a VR headset. The user's eyes just like the camera. The display video of large mechanical structure assembly scheme adopts the form of combination of distant view and near view. The distant view is used to show the overall system layout of the assembly environment, and the close view is used to show the detailed coordination of assembly equipment at each stage in the assembly process. The display of distant and close shots can be realized through the displacement function in the VR handle function. In close-range situations, after starting the assembly process, the user needs to ensure that he can see the assembly process at all times. The function of 90° view can be switched through the VR handle to make adjustments at any time. In the process of virtual assembly animation, users should also keep their perspective from jitter at all times. When rotating the Angle of view, the user's head should be moved smoothly to ensure the quality of the shot.

In general, the production materials of 3D virtual assembly animation are derived from various contents seen by users wearing VR devices during a series of operations in the VR environment provided by VR. The shooting quality depends on the VR setting parameters, the recording software setting parameters, the display parameters used, and the reasonable operation of the user in the virtual environment.

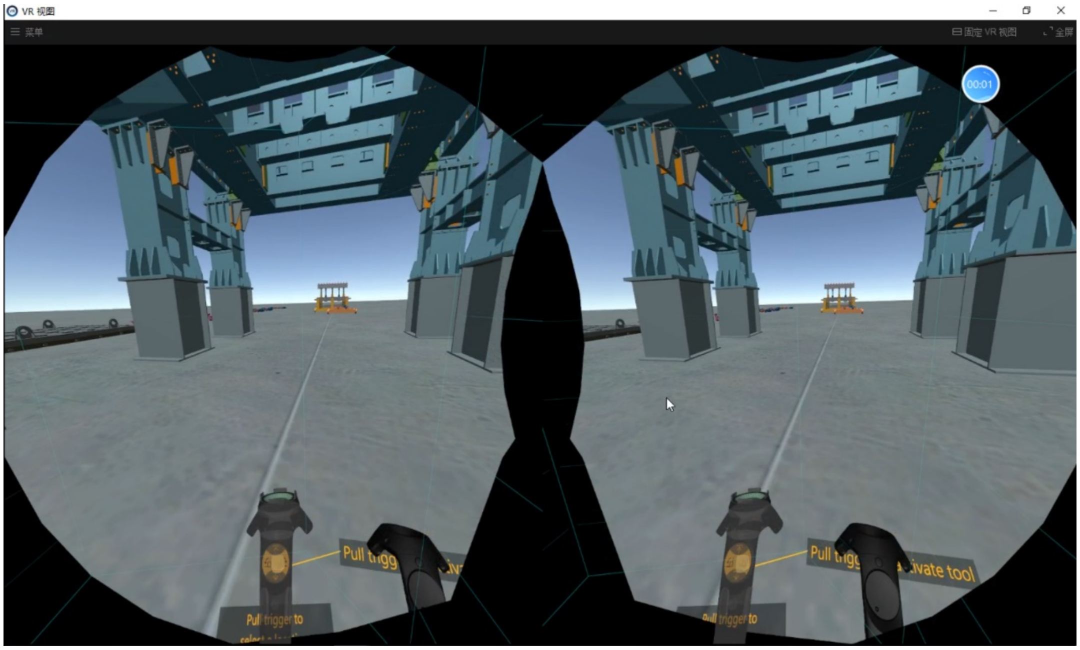

Figure 9. The dual view screen of VR

5.5 Virtual Assembly Animation 3D Display Scheme

Due to the limitation of VR equipment, only one user is allowed to experience the virtual assembly process, which will lead to the lack of technical communication and exploration with others. Therefore, in order to allow multiple technicians to discuss the virtual assembly process together, a multi-person immersive experience of the virtual assembly process is realized. By referring to the output mode of 3D movie, the 3D display scheme of virtual assembly animation can be formulated.

Shutter 3D works through increasing the refresh rate of the picture. By dividing the image into two frames, two groups of images corresponding to the left eye and the right eye are successively staggered and displayed. Meanwhile, the infrared signal transmitter will synchronize the 3D TV to control the switch of the left and right lenses of the shutter-type 3D glasses, so that the left and right eyes can see the corresponding picture at the right moment. This technology keeps the original resolution of the image, making it easy for users to enjoy the true full HD 3D effect without degrading the brightness of the image. The projection equipment used in the presentation scheme in this paper is BenQ TK800M projector, and the 3D shutter-type glasses are BenQ New 3D glasses, as shown in Figure 10.

(1) 4K high definition 3D projector (2) Shutter 3D glasses

Figure 10. The equipment of Virtual assembly animation 3D display scheme

The previously recorded and exported dual-view mode videos through the VR are clipped in PR. The circular perspective is edited into a cuboid perspective in a certain proportion, so as to make the subsequent integration effect of the double-perspective picture better, as shown in Figure 11. Then accurately position the switching node of the picture, adjust different pictures, and add background commentary and other audio files. Finally, the 3D format video of virtual assembly scheme of large mechanical structure with lifelike principle structure display details and good visual art effect is generated.

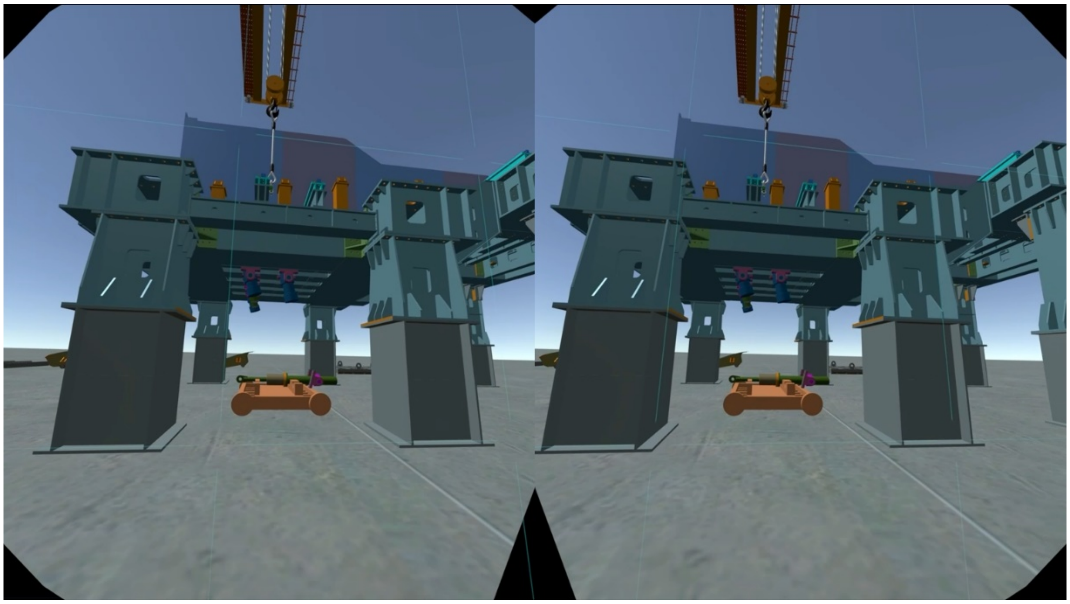

Figure 11. 3D format virtual assembly video

Using a 3D high-definition projector, the image of a computer screen is projected onto a white screen. Through the 3D setting of the 3D HD projector, using the left and right format projection, you can output the 3D format video from the computer playback software onto the white screen, at this time users can wear shutter 3D glasses for viewing. Shutter glasses allow multiple users to view virtual assembly animations at the same time, allowing technicians to discuss and analyze the assembly process. This achieves the ultimate goal of this technical solution and satisfies the virtual assembly process of immersive experience for multiple users.

6. Conclusion

The virtual assembly 3D display technology based on VR can vividly and intuitively display the assembly technical route of large mechanical structure, the composition and layout planning of the equipment used in the assembly, as well as the entire dynamic assembly process. In the design stage of virtual assembly technology scheme, the combination of 3D engineering modeling technology and virtual reality technology can quickly produce the virtual display video of the technical scheme of large mechanical structure, which provides an effective mean for the demonstration of its technical scheme. The method proposed in this paper is a summary of the 3D video generation process of the virtual assembly demonstration of the nozzle section base of a large wind tunnel which is a universality way. Using this method is devoted to effectively shorten the demonstration time of the assembly technology scheme, enhance the reliability of the assembly scheme, and provide a reference for the demonstration scheme of the virtual assembly technology of other mechanical structures.

Acknowledgements

This work was supported in part by the JCKY Project of China (#JCKY2019603C016).

References

Abidi, M. H., Al-Ahmari, A., Ahmad, A., Ameen, W., and Alkhalefah, H., Assessment of virtual reality-based manufacturing assembly training system, *The International Journal of Advanced Manufacturing Technology*, vol. 105, no. 2, 2019.

Carandente, M., Dashwood, R. J., Masters, I. G., and Han, L., Improvements in numerical simulation of the SPR process using a thermo-mechanical finite element analysis, *Journal of Materials Processing Technology*, vol. 236, pp. 148-161, 2016.

Chen, Y., Development and Application of CAD Technology, *Advanced Materials Research*, vol. 3513, 2014.

Cui, S., Wu, K., Zhang Q., Yu, Y., and Wang, Y., Analysis on Construction Mechanical Mechanism of Highway Tunnels with Large Span and Small Spacing, *Geotechnical and Geological Engineering*, vol. 37, no. 3, 2019.

Daniel, B., Frank, W., and Gerhard, R., Review of Three-Dimensional Human-Computer Interaction with Focus on the Leap Motion Controller, *Sensors*, vol. 18, no. 7, pp. 2194, 2018.

Huo, J., and Lee, C.K.M., Intelligent workload balance control of the assembly process considering condition-based maintenance, *Advanced Engineering Informatics*, vol. 49, 2021.

Lan, F., Yue, Y., Shen. H., Shen, H., Wang, Q., Yu, X., Chen, L., Li, Q., Wang, K., Liu, Q., and Xia, Y., Multi-Dimensional Display of Wang's Lymph Node Map Using Virtual Bronchoscopic Navigation System, *Frontiers in Molecular Biosciences*, 2021.

Li, J., Guo, S., Gu, L., Zhang, Y., Yang., Wang, G., Tao, Y., Wang, Y., Quan, X., and Hu, S., The Digital Assembly and Maintenance Training Platform for ITER-Type Mock-Up in Virtual Reality Environment, *Fusion Science and Technology*, vol. 77, no. 5, 2021.

Nitin, A., and Divyank, C. R., 'Made in China 2025': Poised for Success?, *India Quarterly*, vol. 77, no. 3, pp. 424-461, 2021.

Pan, W., and Lu, W.F., A kinematics-aware part clustering approach for part integration using additive manufacturing, *Robotics and Computer-intergated Manufacturing*, vol. 72, 2021,

Shailesh, P., Deshmukh, M., Shelke, R., and Deshmukh, D., Experimental Investigation on Hip Implant Materials Development through Analytical and Finite Element Analysis: 3D Modelled Computed Tomography, *Biointerface Rrsearch in Applied Chemistry*, vol. 12, no. 3, pp. 4103-4125, 2022.

Sobrino, D.R.D., Ružarovský, R., Holubek, R., and Velíšek, k., Into the early steps of Virtual Commissioning in Tecnomatix Plant Simulation using S7-PLCSIM Advanced and STEP 7 TIA Portal, *MATEC Web of Conferences*, vol. 299, 2019.

Sun, Q., Lu, Y., and Huang, F., Exploration on the Construction of Talent Training System of Mechanical Engineering for Emerging Engineering Education: A Case Study of An Application-Oriented University, *International Journal of Social Science and Education Research*, vol. 4, no. 5, 2021.

Sun, S., Xu, T, and Zhou, J., The Design and Implementation of Computer Hardware Assembling Virtual Laboratory in the VR Environment, *MATEC Web of Conferences*, vol. 232, 2018.

Sun, T., Liu G., Peng J., Meng, F., Liu S., and Zhu S., A new single-view 3D pantograph reconstruction aided by prior CAD model, *Measurement*, vol. 181, 2021.

Unnikrishnan, G., Hatwar, R., Hornby, S., Laxminarayan, S., Gulati, T., Belval, L.N., Giersch, G.E.W., Kazman, J.B., Casa, D.J., and Reifman, J., A 3-D virtual human thermoregulatory model to predict whole-body and organ-specific heat-stress responses, *Eupopean Journal of Applied Physiology*, vol. 121, no. 6, pp. 2543-2562, 2021.

Wang, Q., Huang, Z., Li, J., and Liu, J., A force rendering model for virtual assembly of mechanical parts with clearance fits, *Assembly Automation*, vol. 38, no. 2, 2018.

Wei, Z., Application of intelligent voice technology in VR intelligent teaching system of tourism management, *International Journal of Speech Technology*, 2021.

Wyssenbach, T., Zeballos, M., Loosli, S., and Schwaninger, A., Nonverbal behavior of interviewers influences the competence ratings of observers in recruitment interviews: a study investigating social influence using 360-degree videos with virtual reality and 2D screen displays, *Virtual Reality*, 2021.