A New Virtual Environment System for Large-Scale Complex Products Assembly

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Abstract. To deal with the problems of complicated process, difficult operation and low efficiency for large-scale complex products assembly, a new Virtual Assembly Environment System (VAES) was proposed, which applies Virtual Reality (VR) technology in the process of assembly planning and training. A series of key technologies were proposed, such as parallel rendering, stereoscopic display, geometrical correction, walking machine. A stereo video generator was developed to maintain real-time display and decrease costs. A geometrical correction method based on NURBS surface was presented. The system was applied in the process of satellite assembly, the result showed that it was feasible for the related research and application.

1. Introduction
Large-scale products such as aircraft, rocket and satellite, because of their huge volume, complex structure and various parts, lead to low efficiency in the assembly process that seriously affect the speed of product research and development. Therefore, people have developed the virtual assembly technology. A visual and interactive Virtual Assembly Environment System (VAES) is established to simulate the whole process of product assembly. In this way, the assembly effect can be analyzed easily, and the possible problems in the assembly process can be predicted, thus providing an economical and effective solution for the assembly problem of large-scale products.

At present, VAES includes semi-immersive Desktop [1], Workbench [2] and immersive HMD [3], CAVE [4], CABIN [5], Cosmos [6], etc. These systems can provide functions such as assembly performance analysis, assembly process design and optimization, man-machine interaction and on-site training. However, they immobilize the operator's workstation, so that it can only within a limited space to complete the planning task. However, in the assembly process of large products, workers often need to move to different stations to complete the assembly and disassembly tasks. Therefore, it is necessary to establish a virtual environment that takes full account of the operator's range of activities. In 2003, Britain's K. J. Fernandes et Al. developed the Cybersphere system for free walking[7]. The system uses a spherical curtain to provide an immersive panoramic display, in which the operator moves freely by rotating the sphere inside the curtain. As a result, the cost of the whole system is huge, and the operator has to carry the power supply and other wireless equipment on the spherical surface, and the operation activity is still limited.

According to the assembly characteristics of large and complex products, the operators can interoperate in the wide space, this paper presents a new immersive virtual environment system. The
key technologies of the system, such as parallel rendering, Stereo display, geometric correction and walking mechanism, are studied. The virtual assembly environment with high immersion effect is realized and applied to the developed satellite virtual assembly prototype system, with satisfactory results.

2. Components of a new virtual environment system

The new virtual environment system is shown in Fig.1. The main body of the system is a large ball screen, which is used to display the virtual scene interface. It is built on the horizontal ground with a diameter of about 6m. It is made up of a plurality of circular curved plexiglass sheets. The surface is semi-transparent after sandblasting treatment. The exterior of the ball screen is provided with a number of high-brightness stereoscopic projectors at different angles. Each projector projects a portion of the virtual scene onto the back of the screen. These images are corrected and fused to form the whole virtual scene. The operator can enter the interior of the ball screen through a small door under the ball screen to view a panoramic view with a high sense of immersion. A motion-sensing device is arranged at the bottom of the ball curtain to realize the free walking of the operator in the virtual scene. In the process of walking and operating, the environment system can generate the corresponding virtual scene according to the operator's position information, so that the operator has the feeling of being in the scene.

The system is composed of four functional modules: virtual scene generation, stereo display, geometric correction and human-computer interaction. The specific functions of each module are as follows: (1) the virtual scene generation module is the core of the whole system, which is composed of several graphics rendering nodes. (2) the stereoscopic display module is composed of a plurality of stereoscopic projectors and a large ball screen. Using the developed stereoscopic video generator, the left and right eye projection images are output alternately at high frequency to generate an active stereoscopic image. (3) the geometric correction module collects the projection image by the camera, and obtains the characteristic matrix by the computer, which is used for the geometric correction of the spherical three-dimensional image, and produces the regular figures visible to the human eye. (4) the man-machine interaction module includes the free walking perception mechanism, the data glove, the position tracker, the stereoscopic glasses and the auxiliary equipment. Among them, the motion mechanism is an important device to realize the operator roaming in the virtual scene. This module is used to identify the operator's position information and pass it to the virtual scene generation module.

3. Technical essentials and function realization

3.1. Parallel rendering

Usually, the spherical virtual environment system needs to display large-scale complex scenes. In order to ensure the real-time requirement of system rendering, rendering and refreshing display, it adopts the strategy of parallel rendering to form the basic projection image. The system uses multi-PC to construct a master-slave distributed Client-Server network structure parallel drawing method, as
shown in Fig.2. The Client node is responsible for virtual scene image drawing information distribution, scene data storage and management, and user interaction, and each Sever node is responsible for rendering the corresponding part of the scene display image, then the various parts of the image mosaic, fusion, forming a logical unity of the display screen. In the Client-Sever architecture, sort-first algorithm is used to divide the screen space into several parts before distributing the original scene data to each Sever, in order to realize parallel rendering.

![Client-Server distributed parallel rendering method](image1)

**Fig. 2 Client-Server distributed parallel rendering method**

3.2. **Stereoscopic display**

In order to improve the immersion effect of environment system, a stereoscopic video generator is developed, as shown in Figure 3, to realize the active stereoscopic display of virtual scene. It is mainly composed of left and right video interface, matching control unit, synchronization control unit and Stereo video interface. First, the left and right video interfaces are connected to the VGA interface of a common dual-head graphics card of a PC to provide two images or video from different angles. On the one hand, the matching control unit outputs the two images in high-frequency time sequence to generate stereo video, connected to the projector via a stereo video interface. On the other hand, the synchronization control unit connects and controls the infrared transmitter to generate high frequency signal synchronizing with the image sequence, which is used to further control the switch of the left and right eye liquid crystal valve of the stereoscopic glasses.

This method only needs 1 PC, 1 projector and 3D video generator to generate a channel 3D display image. Compared to the current passive stereoscopic display, which requires two PCs and two projectors and a metal screen with polarization characteristics, the active stereoscopic display requires a high performance SGI Visual Workstation and a projector, the stereoscopic display method proposed in this paper reduces the cost by at least 40%.

3.3. **Geometric correction**

When the projector projects the plane image of the virtual scene onto the screen of the ball, the projected image will be deformed. In addition to the brand projectors such as Barco and Keshi, the normal stereoscopic projectors do not have the function of automatic geometric correction, so it is necessary to carry out the geometric correction by software method to make the operators see the normal images. In this paper, NURBS surface is used as texture mapping surface for geometric correction to match Pixel points and spherical screen shapes of projectors. A camera is used to simulate the human eye viewing the projected image, as shown in Fig.4. Firstly, the spatial grid array is used to represent the shape of the ball screen, and the image is acquired by the camera. The Dot Matrix coordinates in the grid image are recognized and extracted by Matlab and used as the target grid for geometric correction (Fig.4a). Then the original equal-width grid image is projected onto the screen of the ball, and the projected image on the screen of the ball is also obtained by the camera, and is extracted as the control point of the grid to be corrected (Fig.4b). Then, through NURBS surface matching algorithm, the Mesh Control Matrix of the original image in the frame buffer is adjusted to the target Mesh, and the geometric corrected Mesh Image in the frame buffer is obtained, which is used to realize the normal projection display of the ball screen.
In this paper, a bicubic Bezier surface is used to correct the projection image. The adjustment of a single control point has a great influence on the position of the global lattice. In reference\[9\], geometric correction based on texture mapping in polar coordinate system is only suitable for regular shape projection screen. In this paper, NURBS surface based geometric correction is used, so that the adjustment of single or local control points will not affect the change of the position of the global lattice. Let \( P_{ij} \) (\( i = 0,\ldots,m; j = 0,\ldots,n \)) be a group of grid control lattice of \((m+1) \times (n+1)\), \( U = \{u_0, u_1, \ldots, u_m\} \) and \( V = \{v_0, v_1, \ldots, v_n\} \) are node vectors of horizontal direction \( u \) and vertical direction \( v \) respectively, then the NURBS surface equation is

\[
S(u,v) = \frac{\sum_{i=0}^{m} \sum_{j=0}^{n} W_{ij} P_{ij} N_{i,k}(u) N_{j,l}(v)}{\sum_{i=0}^{m} \sum_{j=0}^{n} W_{ij} N_{i,k}(u) N_{j,l}(v)} \tag{1}
\]

Where, \( W_{ij} \) (\( i = 0,\ldots,m; j = 0,\ldots,n \)) is the weight of \((m+1) \times (n+1)\) grid control points; And \( N_{i,k}(u) \) , \( N_{j,l}(v) \) are B-spline basis functions of NURBS surfaces in the direction of \( u \) and \( v \) respectively; \( k, l \) is the order of B-spline basis functions.

A geometric correction software based on cubic NURBS surface algorithm is developed by using OpenGL base graphics library, and the normal projection display of ball screen is realized. Taking the control lattice of 44 as an example, we get the lattice control lattice \( F_i \) \((i = 0,1,2,3; j = 0,1,2,3)\) by taking \( m = 3, n = 3 \), the original mesh control lattice Fig.5a), and select the appropriate weight \( W_{ij} \), using NURBS surface algorithm to adjust the spatial position of the control points, the corrected mesh control lattice (Fig.5b). Using the glCopyTexImage2D () function, two images with the size of 1024×768 pixels in the left and right eyes are mapped to the NURBS surface corresponding to the corrected grid control point Matrix, and the geometric correction image in the frame buffer is obtained, as shown in Fig.5c), and then projected to the screen of the ball, thus realizing the whole correction process of the projected image.

(a) The target grid   (b) The grid image to be corrected

Fig.4 Grid image captured by the camera matrix and mapped image

(a) Original mesh   (b) Corrected mesh   (c) Mapped image

Fig.5 NURBS surface original and corrected control dot

3.4. Free walking perception

By investigating the normal walking process of human beings, a kind of walking perception mechanism is designed, as shown in Fig.6, which enables the operator to simulate the walking and turning process in the virtual scene in a small space, with the help of a 3D position tracker attached to both feet, the position information collected is transmitted to the computer, which is used to control the position of the virtual scene. In this way, when the operator moves on the walking mechanism, the environment system automatically generates the corresponding three-dimensional virtual scene according to the operator's position, which enables the operator to complete the interactive operation of the virtual assembly in the vast space.

The free-walking sensing mechanism is mainly composed of four parts: the pedal rotation driving system, the main driving part, the pedal component and the base bracket. The pedal assembly comprises two sets of pedals supporting the two feet of the operator, which mainly cooperate with the foot movement of the operator to complete the walking process; The base bracket is connected with the ground to complete the movement of the main drive part, and plays the role of load bearing and
safety protection The pedal rotation drive system comprises a position tracker connected to the foot of the operator, an AC servo motor and a control system thereof. During the steering process, according to the information of the position tracker, control AC servo motor drive pedal rotation to achieve the following of the steering foot.

4. Application examples
The new virtual environment system is applied in the process of satellite assembly process planning, as shown in Fig.7. The system adopts 8-channel stereoscopic projection, uses parallel rendering method and stereoscopic video generator to realize fast stereoscopic display and generate video signal satisfying the requirement of projector. The stereoscopic image is projected onto a large ball screen by a projector, and the operator can observe the stereoscopic image inside the ball screen by wearing stereoscopic glasses, the data glove is used to accomplish the interactive operation and process planning of satellite product assembly. This shows that this environmental system for large-scale product assembly, as well as the related technologies such as stereo display, geometric correction and walking mechanism, are feasible and can be applied to the assembly process planning and online training of large-scale complex products, the utility model has strong practicability.

5. Conclusion
Aiming at the assembly requirement of large and complex products, a new virtual environment based on large ball screen is constructed, which makes use of PC cluster to form master-slave distributed network, and realizes real-time rendering of virtual scene based on parallel rendering method, the stereoscopic video generator, NURBS surface based geometric correction and free-walking perception mechanism are studied. The environment system is applied to the virtual assembly of satellite, and the feasibility and practicability of the system are verified.

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