Development and optimization of immersive virtual drilling
equipment teaching environment

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Abstract. In view of the phenomenon of scene jumps, slow model refresh speed and fixed
visual direction during virtual roaming, in the virtual drilling equipment teaching platform
developed based on Unity 3D, the Cardinal spline curve interpolation algorithm is used to
optimize the roaming path and improve the smoothness of the roaming. It uses rendering
optimization algorithm to improve the fluency of the scene and adjusts the visual angle of
observation through orientation change technology algorithm for design and optimization. The
results show that the optimized drilling equipment teaching platform improves the comfort of
roaming learning, the scene loading speed is increased by 28.73%, and the visual orientation is
more convenient to observe the experimental objects. On the whole, it provides students with a
comfortable and realistic teaching environment.

1. Introduction

In the study and research of the actual drilling rig optimization control system, there are "three highs
and one long" in talent training (that is, high equipment risk, high operator risk, high cost, and long
training period). The virtual experiment of drilling equipment is a teaching platform suitable for
students of petroleum-related majors to understand the oil drilling site in an all-round way. It is of
great significance for cultivating students’ engineering practice and innovation ability [1,2]. However,
when the three-dimensional virtual tour is applied to virtual teaching, the smoothness of the roaming
path, the smoothness of the scene, and the visual angle of observation directly affect the student’s
sense of experience during the roaming learning process. At present, the following problems exist in
the virtual experimental teaching environment:

(1) Unsmooth roaming path will cause scene jump and visual jitter. Li Xunmin [3,4] used the
position of the control point of the Bezier curve to adjust the curvature, which increased the workload;
Zhao Ye [4,5] used the Hermite curve interpolation algorithm to find the starting point and ending
point based on the known starting point and ending point. The tangent vector between points, but the
tangent value cannot be obtained intuitively;

(2) When the model structure in the scene is complex, the system needs to process a large amount
of information, which results in the frame processing cannot be completed in time, the refresh rate of
the image is too slow, freezes, and the smoothness of scene changes is destroyed;

(3) When roaming on a fixed path in the scene, the visual direction is fixed along the tangent
direction of the roaming path, which is not the best angle for students to observe and operate the
virtual scene equipment;

In view of the above phenomenon, the spline curve interpolation algorithm, rendering optimization
algorithm and orientation change technology are proposed in the virtual experimental teaching
platform of drilling equipment to improve the smoothness and loading speed, and enhance the comfort and immersion of students.

2. Design and optimization of experience upgrade

2.1 Experimental teaching platform

The virtual drilling equipment teaching platform integrates the professional knowledge of drilling engineering, and presents the whole learning process of introduction, operation, experiment and research in the form of graphic animation, text annotations, and audio explanations [6]. Based on the real drilling site, the functional structure of the virtual drilling equipment teaching platform is shown in Figure 1. It mainly includes two parts: a roaming system and a control system. The control system includes two operating systems, a lifting system and a well trajectory interactive system.

The virtual drilling scene is shown in Figure 2. Based on this scene includes two learning modes: autonomous and guided. The guided learning mode is mainly convenient for beginners to observe and learn, avoiding unfamiliar scenes and unskilled operations. Can enable students to follow the teacher to have a comprehensive understanding of the drilling site through text prompts, audio explanations and other auxiliary functions.

In the guided learning mode, students are the main body. This article will upgrade the students' sense of experience from three aspects: roaming path, scene fluency, and visual angle.

2.2 Roaming path optimization algorithm

In the virtual reality teaching scene, if the three-dimensional route connected by all the necessary points is directly used as the roaming path, the scene jitter and distortion will occur at the corners, which will distract students and affect the learning effect. In this paper, the Cardinal spline curve interpolation algorithm is used to smooth the initial three-dimensional path, to ensure the continuous change of speed and acceleration, and to achieve a smooth transition between tiny line segments.

The Cardinal spline function controls the shape of the curve by four continuous coordinate control points [7,8], and its spline interpolation function is:

\[
P(u) = P_{s-1}(-su^3 + 2su^2 - su) + P_s[(2-s)u^3 + (s-3)u^2 + 1] + P_{s+1}[(s-2)u^3 + (3 - 2s)u^2 + su]
+ P_{s+2}(su^3 - su^2)
\]

In Equation (1), the independent variable is \(u \in [0, 1]\); \(s = (1-t)/2\), the parameter \(t\) is the tension coefficient, and \(te\in [0, 1]\), \(t\) controls the tightness between Cardinal spline and the input
control point. When the curve changes linearly from 0 to 1, it will slowly move from the point \( P_k (t = 0) \) to \( P_{k+1} (t = 1) \).

Here, 17 key path points are set in the virtual field of drilling equipment, that is \( \{P_1, P_2, P_3, \ldots, P_{17}\} \), 2 auxiliary coordinate points \( (P_0, P_{18}) \) are respectively constructed at the beginning and the end of the drilling equipment, and let \( P_0 = P_1, P_{18} = P_{17} \). And then you take 4 points \( \{P_0, P_1, P_2, P_3\} \) you get the first curve; The second spline \( \{P_1, P_2, P_3, P_4\} \) can draw these four coordinate points, and so on, \( \{P_{15}, P_{16}, P_{17}, P_{18}\} \) to draw the last spline. Finally, the optimal roaming path of the virtual drilling equipment station is obtained. The algorithm flow of roaming path is shown in Figure 3.

![Figure 3. Flow chart of roaming path algorithm](image3)

In Figure 3, represents the total number of key points in the scene and represents the number of Cardinal spline curves currently drawn.

### 2.3 Design of model rendering optimization algorithm

Usually, the visual fidelity and the flow of the scene are mutually restricted. In this paper, LOD (Level of Detail, LOD) technology is adopted to present a strong visual realistic effect to students and ensure the smooth running of the scene [9]. LOD technology determines the allocation of rendering resources according to the importance of model nodes in the virtual drilling site, reduces the number of surfaces and details of non-important equipment models, and improves the efficiency of graphics rendering. The program logic is shown in Figure 4.

LOD technology is applied to the MCC room, mud pump, agitator, degouge and desilter models. Taking the mud pump model as an example, the accuracy of the three mud pump models (.FBX) in Figure 4 is 100, 50 and 25 respectively, LOD1_100, LOD2_50 and LOD3_25. Adjust the preview effect of LOD Group, calculate the vector mode through the coordinate of mud pump model and camera coordinate, and get the optimal conversion distance of the three levels are 50, 100 and 200 respectively.
2.4 Orientation algorithm design
In virtual scenes, iTween is often used to realize the camera roaming along the tangent line in a fixed direction [10], but this is not in line with people's learning and cognitive habits. To solve this problem, this paper proposes an orientation algorithm, which controls the camera to face the model in the roaming process, and students observe the learning object from a better angle. The algorithm diagram is shown in Figure 5.

Taking roaming to the mud separation equipment (point 4) as an example, the algorithm steps are as follows:

1. Initial parameter setting. Through manual testing, the visual range was determined, including the best viewing Angle value and the maximum viewing distance $h_{\text{max}}$. The best viewing Angle in this paper was left ($30^\circ$) and right ($30^\circ$), and the maximum viewing distance was 200.

2. Determine whether the mud separation equipment model is in the visible area? If so, the camera vision is oriented towards the mud separation equipment model; If not, the visual direction is toward the tangent direction of the roaming path ($T_b$).

3. When there are two models viewing area, such as mud separation equipment model and mud pump model, are compared to the current point $A_n$ ($n = 4$) and the distance between the two models, with mud separation equipment model of distance is less than the distance of mud pump model, the visual direction switch to the mud pump separation device model, or toward the mud pump model.

4. Determine whether the current point $A_n$ coordinate is the terminal coordinate? If $n = 17$, then the algorithm ends; If not, then jump to Step (2) to continue roaming.

3. Result test
3.1. Roaming test
Enter the virtual drilling project site and choose the guided learning mode. Students can walk along the path ($n=17$) according to the text and audio introduction of the equipment model: starting point (point 1), oil storage tank (point 2), VFD room (point 3), mud separation equipment (point 4), mud pump (point 5). The generator room (point 17) and the end point (point 1) are used for learning. The final roaming path after adopting Cardinal spline curve interpolation algorithm is shown in Fig. 6.
When using HTC Vive virtual device test, it is found that scene jitter is avoided in the process of roaming along the path on the whole, and the visual changes of roaming are uniform and smooth. Especially at the path points 4 and 7, the smoothness and comfort of vision before and after improvement are significantly improved, which improves the sense of learning experience.

### 3.2. Rendering algorithm test

Taking the mud pump model as an example, there are 97931 initial triangles. The simplified model has 47871 (LOD2_50) and 23447 (LOD2_25) triangles, respectively. It can be found that from LOD1_100 to LOD2_50, the texture details of the model surface are gradually reduced. In the process of simplification from LOD2_50 to LOD3_25, some local graphic features have been reasonably reduced.

![Mud pump model](LOD1_100, LOD2_50, LOD3_25)

Figure 7. Mud pump model

During the simplification of the mud pump model from LOD1_100 to LOD3_25, an example of the cylinder section of the mud pump marked in Figure 7 is further illustrated to illustrate the reduction effect of the rendering algorithm. The surface detail texture of the mud pump cylinder after amplification is shown in Figure 8. The reduction of the LOD_100 model to the LOD_25 model significantly changes the number of triangles and vertices as shown in Table 1.

![LOD model of mud pump cylinder part](LOD1_100, LOD2_50, LOD3_25)

Figure 8. LOD model of mud pump cylinder part
Table 1. LOD parameters of pump cylinder.

| model               | Mud pump | The pump cylinder |
|---------------------|----------|-------------------|
| parameter           | 100      | 50                |
|                     | 25       | Rendering time (ms)| 100 | 50 | 25 | Rendering time (ms) |
| Number of triangle surface | 97931 | 47871            | 23447 | 35.68 |
| Number of vertices  | 1563400 | 98730           | 71930 | 3003 | 1559 | 917 | 2.15 |

The LOD1_100 model is displayed when the distance is within 50, the LOD2_50 model is displayed when the distance is further away, and the LOD3_25 model is displayed when the distance is further away, ensuring that the virtual drilling equipment teaching scene is reduced in complexity and the rendering speed is improved without affecting the visual effect of the students. Compared with before and after rendering, the model loading speed of the virtual drilling equipment teaching platform was increased by 28.73%, and the system running fluency was improved.

3.3. Test the orientation algorithm

In the guided learning mode, take roaming to the second floor as an example to compare the visual angles without orientation algorithm and after the addition of this algorithm, as shown in Figure 9 and Figure 10.

As shown in Fig. 9, the visual direction at this time is along the tangent direction of the roaming path, which does not conform to the learning and cognitive habits of students. After the orientation algorithm is added, as shown in Fig. 10, the visual direction will be toward the winch model and the observation angle is better.

4. Conclusions

Based on the visualization of drilling equipment teaching platform based on virtual-reality combination, this paper designs from the following three aspects to improve the sense of experience and comfort. The conclusions are as follows:

1) The optimization algorithm of Cardinal path curve was designed to avoid visual jitter and scene jump, especially at points 4 and 7 of the roaming path, which effectively improved the comfort and immersion of students in roaming learning.

2) After adding the rendering optimization algorithm into the MCC room, mud pump, agitator, degasser, desilter and other models, the scene loading speed increased by 28.73%, solving the problems of real-time performance and fluency of the virtual scene operation.

3) The orientation change algorithm is adopted to control the roaming camera, so that the perspective faces the model, which is natural and smooth, and convenient for students to observe and experiment.
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