Research of Marine Engine Room 3-D Visual Simulation System for the Training of Marine Engineers

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Abstract

Refactor the traditional marine engine room simulator (MERS) and a corresponding marine engine room (MER) three-dimensional (3-D) visual simulation system is integrated with it. The whole virtual MER scene is modeled by using 3D-Max and rendered by using Vray. Optimization methods including texture mapping and level of detail (LOD) technique are adopted to improve the user overall experience. Aiming at the enormous amount of interaction entities in MER, behavior modeling is adopted to classify all the interaction entities into several types and corresponding general interaction scripts are designed. Optimize the traditional 3-D picking algorithm by taking the horizontal occupation percentage of the picked-up object’s bounding sphere in the final rendering graphics to improve the pick accuracy. To enhance the practicability of the training system developed in this paper, auxiliary functions including navigation, information display and MER virtual panoramic map are developed to facilitate the training process. At last, an automatically evaluation function based on fuzzy comprehend evaluation method is developed to substitute the traditional manual evaluation. The MER 3-D visual simulation system developed in this paper has been applied in the education, training and evaluation tasks in several maritime colleges and training institutions in China.

Key Words: 3-D Visual Simulation, Marine Engineer, Human-machine Interaction, LOD, Fuzzy Comprehend Evaluation

1. Introduction

The MERS has a history of nearly thirty years in the field of modern navigation education and training and it has already become a necessary facility for educating and training the marine engineers and proved to be an effective method to improve the training quality and reduce the learning time and cost effectively according to the study of Orosa [1]. The main development purpose of the traditional MERS is to make the trainees master the principle of the marine engineering system (MES) and the standard operation procedure of the electromechanical equipment in the MER. Nowadays, most of the MERS are composed of the two-dimensional (2-D) simulation software and the semi-physical simulation consoles such as switchboards, engine control console, bridge control console and local control box. Several successful products can be found on the international market, for example the Neptune MC90-IV developed by Kongsberg Maritime in Norway [2], the VER series of MERS by UNITEST in Poland [3] and the DMS-2D series of MERS by Dalian Maritime University in China [4], which are used to educate marine engineers and students all around the world. Although the above-mentioned MERS have already obtained satisfactory education and training effect to some extent, its manifestation mode in the form of 2D simulation makes the learning and training environment far different from the real working environment, which becomes the fatal weakness for the traditional MERS [5].

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Aiming at the same problem, 3D visual simulation technology is applied widely in many education and training fields such as military live firing training [6], maintenance and operation of high-voltage overhead power lines [7] and training of emergency medicine personnel [8] and it has proved to be more active compared with 2D simulation technology because of high immersion, interactivity and imagination. So, in recent years many MERS are updated and 3D visual simulation technology is introduced into it, which can make the training environment more closely resemble the real working environment. In the way, training programs can be carried out in the “real” MER and even several dangerous training programs such as firefighting and sea-water intake [9], can be carried out in a more safe and vivid way. Based on the above-mentioned advantage, it is believed that the main manifestation mode of the MERS will change from 2D to 3D gradually. At present, several MERS based on 3D visual simulation can be found in the market, for example the LER3D, MED3D, MER3D, PSV3D and DED3D developed by UNITEST, K-Sim Engine Simulator developed by Kongsberg Maritime and ERS 5000 MERS developed by Transas in England [10]. Although these products have made contribution to the application of 3D simulation technology in the field of modern navigation education and training to some extent, several deficiencies still exist after experiencing them. These deficiencies can be summarized as follows [11]:

(1) The geometric model and material sense of the virtual MER is relatively rough, which makes the sense of reality not strong enough and consequently lowers user-experience greatly.

(2) Human-machine interaction content is not rich enough and the trainees can’t finish all the training programs in the virtual MER, additionally, the action behavior of interaction entity in the virtual MER is not standard, which will mislead the trainees.

(3) Lack of auxiliary operation functions makes it difficult for the fresh trainees to master the training system and finish the training tasks quickly, and consequently lowers the training efficiency.

(4) Lack of necessary evaluation function limits the practical value.

To solve the above weakness, a novel MER 3-D visual simulation system is developed in this study and technology details are also discussed in this paper and video clip about this software can be viewed at the website http://v.youku.com/v_show/id_XMTU3OTg0Mjc5Mg==.html?from=s1.8-1-1.2&spm=a2h0k.8191407.0.0

2. Design of MERS Integrated with 3-D Visual Simulation

The 2-D simulation software is usually designed to be the core of the traditional MERS, such as the famous “Neptune MC90-IV” developed by Kongsberg Maritime [12]. The real-time calculation of the math and logic model of the MES, human-machine interaction treatment and software management are all integrated in the 2-D simulation software. Such software design mode is out-of-date and goes against the division of labor based on specialization and it also has the disadvantages of poor maintainability and extensibility. Aiming at this problem, the traditional MERS is refactored by consulting the mainstream design mode of website, division of foreground and background, and introducing 3-D visual simulation technology into it in this study. Figure 1 shows the structure of the refactored MERS: The 2-D simulation software is divided into the math and logic model end and the 2-D interface end. The math and logic

![Figure 1. Structure of MERS integrated with 3-D visual simulation system.](image-url)
model end is in charge of the real-time calculation of the math and logic model of the MES such as main propulsion system, electrical power system and auxiliary equipment system. The 2-D interface end is in charge of the human-machine interaction, software management and processing of simulation data. The 3-D end is mainly in charge of the real-time rendering of the virtual MER scene and human-machine interaction, the states of interaction entities in virtual MER scene are updated in real time by receiving the real-time simulation data sent from the math and logic model end. Due to the separation of the MES math and logic model and the human-machine interaction interface including 2-D and 3-D, the use-pattern of the refactored MERS is more flexible. The 3-D end can be used alone or together with the 2-D end, what is more, such system structure makes team cooperative training mode possible. To meet the demand of team cooperative training mode and the promptness of human-machine interaction, multicast is adopted to implement the data transmission in the whole system. The math and logic model end, as the server, sends the real-time calculated simulation data to all the clients including the 2-D interface end, 3-D end and the semi-physical consoles in the same multicast group to update the states of interaction entities, at the same time the operation information from each client will be sent back to the math and logic model end to artificially interpose the calculation of math and logic model to make it run from a new state.

3. Establishing the Geometric Model of Virtual MER Scene

3.1 Marine Engineering 3-D Model Resource Library

Due to the enormous number of electromechanical equipment and complex pipe system in the MER, it obviously belongs to a kind of typical large scale scene, which makes the modeling workload of such scene relatively heavy. However, a large amount of components or equipment with similar or same appearance exist in the real MER, so a marine engineering 3-D model resource library as the Figure 2 shows is established according to the above-mentioned feature, which covers various valves, meters, buttons, etc. The models in the library can be imported into the Unity3D and saved as Prefab and then instantiated and placed in the right place of the virtual MER after adjusting slimly for the follow-up editing. The establishment of marine engineering 3-D model resource library can not only reduce the modeling workload effectively but also make the virtual scene more standard, what is more, the application of Prefab in Unity3D can improve the simulation efficiency.

3.2 Geometric Modeling Procedure of the Virtual MER

The 3-D geometric model of the whole MER is established according to the procedure as the Figure 3 shows. Firstly, the whole structure of the MER is modeled according to the lines plan and the engine room arrangement plan of the parent ship with precise dimension. Secondly, the electromechanical equipment in the MER is modeled according to the actual photos and in-

![Figure 2. MER 3-D model resource library.](image)

![Figure 3. Geometric modeling procedure of the virtual MER.](image)
structions and then they are placed in the right place in the MER according to the arrangement plan. At last, the pipe system is established according to the schematic diagram of the MES.

3.3 Final Effect of the Virtual MER

Figure 4 shows the comparison between the virtual main compressor room and the real one and it can be found that the virtual scene established in this paper is relatively similar with the real one. Figure 5 shows the final effect of the virtual MER developed by UNITEST and it can be found that the virtual MER established in this paper has advantages both in reality and complexity compared with the likewise productions.

4. Optimization Methods for the Virtual MER Scene

A significant purpose of the 3-D visual simulation technology is to provide the users a virtual environment with high sense of reality. Establishing high accurate geometric model for the virtual scene is an available method for achieving this target, but pursuing the accuracy of geometric model excessively will increase the resource size and the burden of computer system greatly, and consequently cause undesirable phenomenon such as reduction of the frame rate, increase of the interaction delay time and even abnormal collapse. So it is necessary to adopt effective methods to optimize the 3-D virtual MER scene. Aiming at this problem, Lee et al. adopts texture mapping optimization method to improve the quality and loading speed of the virtual reality software for preserving cultural asset and it proves to be an effective method [13]. In this paper, besides the texture mapping optimization method, LOD is also adopted to optimize the large-scale virtual MER scene with huge data size.

4.1 Texture Mapping Optimization Method

4.1.1 Alpha Map

In the real MER, objects such as the steel grating plate and cooling hole have the structure feature of reticulation and grid. To manifest this type of structure feature simply with geometric modeling method will not only increase the number of facets greatly but also cause sawtooth and graphics flickering. Aiming at this problem, alpha map is adopted in this study, the principle of which is shown in Eq. 1:

\[
\text{FinalColor} = \text{ScrColor} \times \text{ScrAlpha} + \text{DstColor} \times (1 - \text{ScrAlpha})
\]

where \(\text{FinalColor}\) is the final color after Alpha blending, \(\text{ScrColor}\) is the source color, \(\text{ScrAlpha}\) is the source alpha value and the \(\text{DstColor}\) is the objective color. According to Eq. 1, the part with higher \(\text{ScrAlpha}\) value in the alpha map will have higher weight of source color and lower weight of blending objective color, in contrast, the part with lower \(\text{ScrAlpha}\) value in the alpha map will have lower weight of source color and higher weight of blending objective color. So to manifest the object with the structure feature of reticulation and grid, the \(\text{ScrAlpha}\) value of the corresponding transparent part is set as 0 and the other part is set as 1 in the alpha map.

4.1.2 Normal Map

In the real MER, objects such as screw bolts, corrugated steel plate are widely used, which have the similar the similar realization problem with the objects such as the steel grating plate and cooling hole. To solve this problem, normal map is adopted to manifest the structure feature of the above-mentioned objects. The principle of normal map adopted in this paper can be summarized as [14]: store the disturbed unit normal vector information

Figure 4. Comparison between the virtual and real scene.

Figure 5. Virtual MER scene developed by UNITEST.
Normal\((x, y, z)\) of the texture mapping’s corresponding point in the color value \(Color(r, g, b)\) of the normal map’s corresponding point.

The value range of three components of the unit normal vector is \([-1, 1]\), but the value range of each component of corresponding point in the normal map is restricted between 0 and 1, so the normal map should be compressed when generating normal map as the Eq. 2 shows and consequently the normal map should be decompressed when sampling the normal map.

\[
Normal(x, y, z) = 0.5 * Color(r, g, b) + 0.5
\]  

(2)

4.1.3 Bump Map

The surface of some cast or painted objects in the MER is usually rough and it is very difficult to achieve expected effect only depending on geometric modeling method. In literature [15], Ren et al. uses the bump map to render the dock bank and satisfactory result is achieved. As similar as the dock bank, this paper adopts the same method to manifest the surface of the cast or painted objects in the virtual MER.

The final purpose of adopting texture mapping optimization is to relief the rendering burden of the computer and improves the user experience. Figure 6 shows several examples by using alpha map, normal map and bump map, and it can be obviously found that we can achieve the same or better effect by adopting mapping optimization method with the minimum quantity of facets. In the case of screw bolts, to realize the effect of screw thread and welding with pure geometric modeling method will cost about 500 triangular facets in Unity3D and the whole number will increase rapidly as a lot of bolts exist in the MER, which will consume a large number of computer resource. By adopting normal map for the screw bolts as shown in Figure 6b, the same sense of reality can be achieved only by applying a normal map for a simple geometric model, the whole facets number of which is less than 100. In this way, we can save 80%–90% of computer resource used to manifest the screw bolts in the virtual MER and the saved resource can be used to manifest the other details.

4.2 Level of Detail Optimization Method

Although the texture mapping optimization method is effective for reducing the quantity of the whole facets and improving the fluency of the graphics in the virtual scene to some extent, it is not so effective for the large scale scene such as the MER. The average frame per second (FPS) of the virtual MER scene already optimized by texture mapping optimization method is 10 and undesirable phenomenon such as the graphics discontinuity and drop-frames appear. At the same time, the average delay time of human-machine interaction is more than 0.5 second, which has lowered the user experience. The above-mentioned problems are caused by the limitation of computer graphics generating speed. Although the ability of computer graphics generating speed has improved greatly with the rapid development of CPU and GPU, it still can’t satisfy the pursuit of high reality in certain real-time simulation applications. Aiming at the above-mentioned problems, LOD technique is adopted in this paper to improve the whole quality of 3-D visual simulation system.

The basic principle of LOD technique is as follows [16]: Multi-models are established for a certain object in the 3-D virtual scene and the difference among the multi-models is the detail level. During the real-time rendering process of the virtual scene, the models with low detail level can be used to improve the rendering speed. The selection principle among models with different detail levels depends on various factors, such as the importance of the model, the distance between the main camera and the model, the occupation area proportion of the model in the screen space, etc.

![Figure 6](image-url)
The generation method of LOD models with different detail level in this paper is based on the Self-organizing Feature Map (SOFM) region segmentation algorithm [17]. The model is segmented into several regions in the early on the premise of reserving the detail characteristic, so this algorithm can generate LOD models in an efficiency and controlled way. The specific procedure of this algorithm is as follows:

Step 1: The model is segmented into several regions based on the SOFM region segmentation algorithm and the global merging scale $D$ is determined according to actual demand.

Step 2: The merging weight of the region $i$ is determined according to the proportion of the vertex number $N_i$ of the region $i$ in the vertex number $M$ of the whole model and the merging scale in region $i$ is determined as the Eq. 3 shows:

$$E_i = D N_i / M$$ (3)

Step 3: Calculate the linear average distance $d_i$ between the each vertex in the region $i$ and the surrounding adjacent vertex of it, and regroup the region $i$ by deleting the vertex with the maximal $d_i$.

Step 4: Go into the Step 5 if the merging scale of the region $i$ reaches the corresponding merging scale $E_i$, or return back to Step 3.

Step 5: Exit the algorithm if all the regions complete merging, or return back to Step 2.

Multi-models with different detail levels can be got by setting the global merging scale $D$ with different value based on the above-mentioned model simplification algorithm. Due to the heavy workload of the 3-D visual simulation system including the real time rendering of the virtual scene, management of human-machine interaction, etc., so static LOD method is adopted in the Unity-3D for improving the simulation efficiency of the 3-D visual simulation system.

Figure 7 shows the LOD models for stop valve and the detail degree decreases from LOD 0 to LOD 4 step by step. Figure 8 shows the LOD inspector panel in Unity-3D and the LOD models from LOD 0 to LOD 4 are respectively assigned to LOD Group from LOD: 0 to LOD: 4 accordingly. During the real-time rendering of the virtual scene, the LOD model with high detail degree will show when the distance between the virtual human and the model is near and the LOD model with low detail degree will show when the distance is far, and the LOD model will be culled when the distance is too far.

Table 1 shows the experiment effect by applying LOD to several virtual scenes with different scales. By applying LOD, the average FPS improves in different extent, meanwhile, the memory usage and the average human-machine interaction delay time decrease, which can satisfy the instantaneity of the roaming and human-machine interaction to some extent. As the scale of the emergency generator room and the steering gear room is relatively small, the optimization effect of LOD is less obvious than large scale scene such as the main engine room and the bulk pump room.

5. Design of Human-machine Interaction, Roaming and Auxiliary Function

5.1 Design of Human-machine Interaction

The purpose of MER 3-D visual simulation system should be not only the simple virtual roaming, but also establishing a self-learning platform with which the trainees can operate the virtual electromechanical equipment and management the MES in virtue of the human-machine interaction technique.

5.1.1 Behavior Modeling of Interaction Entity

The operation of virtual electromechanical equipment
and the management of MES are mainly performed by the operation of interaction entities, such as the buttons, valves and switches, and the dynamic change of interaction entities, such as the indicator light, pressure gauge and the liquid level gauge. Taking the parent ship for example, the number of interaction entities which can be operated or dynamic changed is more than 10000. Writing interaction scripts and creating animation individually for each interaction entity will increase the workload greatly and overmuch interaction scripts will influence the interaction efficiency. Aiming at the above-mentioned problem, the interaction entities with the same or similar action behavior are classified into one class by analyzing and abstracting the action behavior of a large amount of interaction entities in MER and each kind of interaction entity is described by defining a series of properties. In this way, a general interaction script is written to implement the interaction function for the large amount of interaction entities according to the description about the action behavior of interaction entity in MER in Zeng’s Ph.D. dissertation [18]. As the Table 2 shows is the behavior description of several interaction entities summarized in this paper based on the operation experience in the real ship. Table 3 shows the properties of the corresponding interaction entities in Table 2 and the action behavior can be considered as the combination of these properties.

5.1.2 3-D Picking of Interaction Entity

To make the trainees pick up and operate the interaction entities in the virtual scene, “Ray Picking Algorithm” is adopted in this paper. The basic principle of “Ray Picking Algorithm” is as follows: Firstly, get the coordinate value of the mouse cursor in the screen coordinate space; secondly, transform the screen coordinate value into the viewport coordinate value of the graphics device, meanwhile, a certain depth value is added for the viewport coordinate value, and then calculate the coordinate value of the corresponding point in the world coordinate space; at last, generator a ray from the main camera to the corresponding point and the virtual object in the virtual scene is picked up successfully when the ray intersects with the virtual object. Figure 9 shows the principle of the “Ray Picking Algorithm” [19].

<table>
<thead>
<tr>
<th>Marine engine room</th>
<th>Memory usage before optimization</th>
<th>Memory usage after optimization</th>
<th>Reduction rate of memory usage</th>
<th>Average FPS before optimization</th>
<th>Average FPS after optimization</th>
<th>Increase rate of average FPS</th>
<th>Average interaction delay time before optimization</th>
<th>Average interaction delay time after optimization</th>
<th>Reduction rate of interaction delay time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main engine room</td>
<td>2107 MB</td>
<td>1243 MB</td>
<td>41%</td>
<td>10 FPS</td>
<td>31 FPS</td>
<td>210%</td>
<td>2s</td>
<td>0.6s</td>
<td>70%</td>
</tr>
<tr>
<td>Steering gear room</td>
<td>1255 MB</td>
<td>1129 MB</td>
<td>10%</td>
<td>25 FPS</td>
<td>34 FPS</td>
<td>36%</td>
<td>0.8s</td>
<td>0.4s</td>
<td>50%</td>
</tr>
<tr>
<td>Emergency generator room</td>
<td>1008 MB</td>
<td>867 MB</td>
<td>14%</td>
<td>31 FPS</td>
<td>40 FPS</td>
<td>29%</td>
<td>0.7s</td>
<td>0.3s</td>
<td>57%</td>
</tr>
<tr>
<td>Bulk pump room</td>
<td>2005 MB</td>
<td>1243 MB</td>
<td>38%</td>
<td>15 FPS</td>
<td>35 FPS</td>
<td>133%</td>
<td>1.6s</td>
<td>0.4s</td>
<td>75%</td>
</tr>
</tbody>
</table>

Table 2. Behavior description of several interaction entities

<table>
<thead>
<tr>
<th>Serial number</th>
<th>Type of interaction entity</th>
<th>Action behavior description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Button</td>
<td>Move horizontally along a certain axis</td>
</tr>
<tr>
<td>2</td>
<td>Meter</td>
<td>Rotate continuously along the axis of meter</td>
</tr>
<tr>
<td>3</td>
<td>Indicator lamp</td>
<td>Switch between light on and off</td>
</tr>
<tr>
<td>4</td>
<td>Valve</td>
<td>Rotate continuously along the axis of valve and rise or drop simultaneously</td>
</tr>
<tr>
<td>5</td>
<td>Feeder switch</td>
<td>Rotate along a certain axis with a fixed angle</td>
</tr>
</tbody>
</table>
The traditional “Ray Picking Algorithm” can satisfy the general 3-D visual simulation system, however, the picked-up interaction entity, such as the valves, buttons and switches, must occupy a certain proportion in the final graphics for meaningful operation in the MER 3-D visual simulation system, which is not taken into account in the traditional “3-D Picking Algorithm”. Aiming at the above-mentioned problem, the “Ray Picking Algorithm” is optimized in this paper as follows:

Set the center coordinate value of the picked-up interaction entity’s bounding sphere in the world space as \( c \), and then \( c_s \), the center coordinate value of the bounding sphere in the screen space, can be calculated as the Eq. 4 shows:

\[
  c_s = c \cdot (M_w \cdot M_v \cdot M_p)
\]

where \( M_w \) is the world transformation matrix, \( M_v \) is the view transformation matrix and the \( M_p \) is the projection transformation matrix.

The distance \( X \) between the near clipping plane and the plane where the sphere center is in can be calculated as the Eq. 5 shows:

\[
  X = c_y \cdot (h_f - h_n)
\]

where \( c_y \) is the component in the \( Z \) direction of \( c_s \), representing the depth value of the sphere center in the screen space with the range between 0 to 1, \( h_f \) represents the distance between the main camera and the far clipping plane and \( h_n \) represents the distance between the main camera and the near clipping plane.

The horizontal occupation proportion of the bounding sphere in the final rendering graphics can be calculated as the Eq. 6 shows:

\[
  k_x = \frac{r}{c_x \cdot (h_f - h_n) \cdot \tan \left( \frac{\text{fov}}{2} \right)}
\]

where \( r \) represents the radius of the bounding sphere and the \( \text{fov} \) represents the field of view of the main camera.

The picking is considered valid only when the \( k_x \) is greater than a certain value, which can omit the invalid picking result and enhance the practicability of picking algorithm.

### 5.2 Design of Virtual Roaming

At present, the similar applications on the market all have implement the virtual roaming function. However,
under some circumstances the interaction entities can’t be observed and operated perfectly only in virtue of the general roaming function. Aiming at this problem, interaction visual angle is added to the general roaming function.

When developing the human-machine interaction function in Unity3D, the relatively centralized interaction entities are classified into one group and a specific camera with fixed position is bound with this group. All the interaction entities in this group are contained in the cone of the specific camera and face forward to the camera, so the interaction entity can be observed or operated handily by switching to the interaction visual angle no matter where the interaction entity is.

As the Figure 10 shows, the positions of gauges in the emergency diesel generator are too high or too low and it is difficult to distinguish the content of the meters and the corresponding name plates, which may result in operational errors. When switching to the interaction visual angle, the corresponding interaction entities will face forwardly to the trainees and the content of the meters and the corresponding name plates can also be observed clearly.

5.3 Design of Auxiliary Functions

As the description in literature [20], excellent auxiliary functions and interface design for a software can improve the user experience. Therefore, to improve the practicability of the 3-D visual simulation developed in this study, necessary auxiliary functions are developed in this system, which can remedy the poor practicability disadvantages of the like-wise products on the market. The auxiliary functions developed in this paper covers navigation of engine room and equipment, information display for interaction entity and virtual map of MER. Now these functions are introduced in brief as follows:

5.3.1 Engine Room and Equipment Navigation

The whole MER is usually divided into several independent rooms according to the space structure, so the trainees must switch among the different rooms and equipment for fulfilling a certain virtual training task. Figure 11 shows the engine room and equipment navigation function and the trainees can quickly switch to the corresponding engine room by clicking the thumbnail of a certain engine room, but it will still take some time to manually roam to the corresponding equipment for fulfilling a certain training task. Aiming at this problem, equipment navigation function is developed in this system. When developing the 3-D visual simulation system, name information, the number information and the space coordinates information of main equipment are stored in the database. As the Figure 11 shows, the trainees can motivate the equipment navigation function and input the name of the equipment for fulfilling a certain training task, and then the trainee will switch to the corresponding equipment immediately if the inputted name information matches with the name information in the database correctly.

5.3.2 Information Display Function of Interaction Entity

The quantity of interaction entities which can be operated or dynamically change is relatively numerous and it is usually difficult to confirm the usage of a certain interaction entity even for some experienced trainees. Aiming at this problem, information display function is developed in this system and an information box will pop up to show the name and state information of the interaction entity once it is picked up. The name information is obtained from the name property of the action behavior script and the state information is obtained from the real-time simulation data calculated by the math and logic model end. As the Figure 12 shows, the name and
state information of the valve will display when a certain valve is picked up (the state information “True” represents that the valve is open and “False” represents that the valve is closed), and the physical quantity measured by the meter, the meter reading and the physical quantity unit will display when a certain meter is picked up. In a practical application, this function will undoubtedly improve the practicability of the 3-D visual simulation system.

5.3.3 Virtual Panoramic Map of MER

As the MER belongs to typical large-scale scene, the complex environment will always confuse the fresh trainees and make them lost in the virtual scene. Aiming at this problem, a virtual panoramic map of the MER as the Figure 13 shows is developed in 3-D visual simulation system and the red cylinder shows where the trainee is in the virtual scene, meanwhile, the trainees can automatically roam to the target position based on the path planning algorithm by clicking a certain position in the virtual map.

6. Automatic Evaluation

The development purpose of the MER 3-D visual simulation system is intended not only to make the trainees get familiar with the structure of the MER and master the standard operation procedure of MES and equipment, but also to fulfill the evaluation task for the trainees in the 3-D virtual scene. The traditional evaluation task for the trainees is mostly fulfilled based on manual evaluation method. The manual evaluation method is influenced greatly by the subjective impression of the evaluation coach and the evaluation result is difficult to be quantified and justice, meanwhile, the traditional evaluation environment based on the 2-D simulation software has a great gap with the real operation environment. Aiming at the above-mentioned problem, an automatic evaluation function based on fuzzy evaluation algorithm is developed in the 3-D virtual scene, which proved to be an effective method for automatic evaluation [21]. The automatic evaluation function is introduced in detail as follows.

6.1 Design of Automatic Evaluation Function

Although the operation content of each evaluation item is not the same, all the operation content can be regarded as the combination of “Operation Type” and “State Parameter Type”. The “Operation Type” can be regarded as the operation of interaction entities such as the switch, button and valve, and the “State Parameter Type” can be regarded as the running state of the marine engineering system, such as the revolution speed value, pressure value and temperature value [22]. Both the “Operation Type” and the “State Parameter Type” are described in the form of variables, so the actual evaluation process can be regarded as the real-time tracing and recording of these variables and the evaluation report is eventually provided by analyzing these variables synthetically.
The evaluation item is described and defined in the form of Extensive Markup Language (XML) file in the evaluation module, and each evaluation item is composed of evaluation global information, evaluation initial state information and evaluation sub-item information.

(1) Evaluation Global Information
The evaluation global information mainly describes the evaluation item stem, the weight of this evaluation item in the whole evaluation task and the evaluation time limit.

(2) Evaluation Initial State Information
To improve the evaluation efficiency and shorten the evaluation time, each evaluation item should have a certain initial state, which is set in the evaluation state information as the Table 4 shows. $IV_1$ to $IV_n$ represents the corresponding variables of the evaluation initial state information, $VD_1$ to $VD_n$ represents the name of each variable, $VT_1$ to $VT_n$ represents the data type of each variable, $VV_1$ to $VV_n$ represents the initial value of each variable. In this way, the trainees can just focus on the corresponding operation of the evaluation item.

(3) Evaluation Sub-item Information
As the Table 5 shows, the evaluation sub-item information mainly describes the each evaluation sub-item and the corresponding evaluation parameter. $AV_1$ to $AV_n$ represents the variables of the corresponding evaluation sub-item; $VD_1$ to $VD_n$ represents the name of each variable; $VT_1$ to $VT_n$ represents the data type of each variable; $MF_1$ to $MF_n$ represents the type of adopted fuzzy membership function, which is determined according to the actual dynamic variation characteristics of the corresponding evaluation sub-item; $WV_1$ to $WV_n$ represents the weight of the evaluation sub-item in the whole evaluation item; $DV_1$ to $DV_n$ is used for judging whether the evaluation process by the trainees fails and the evaluation process is regarded as failure when the marine engineering system is in a certain condition.

6.2 Determination Basis of Fuzzy Membership Function
The selection basis of the fuzzy membership function is mainly based on the actual dynamic variation characteristics and the expected state of the corresponding evaluation sub-item. As the operation result of “Operation Type” evaluation sub-item is “True” or “False”, so the single-point membership function as the Eq. 7 shows is adopted. As the expected optimal value of several “State Parameter Type” evaluation sub-item is in a certain interval, so the middle trapezoidal fuzzy membership function as the Eq. 8 shows is adopted. The $a$, $b$, $c$, $d$ in Eq. 8 are used to determine the specific form of the function and it turns into triangular fuzzy membership function when $b$ equals to $c$, which represents that the optimum interval is a certain point. For several “State Parameter Type” evaluation sub-item, the optimum value is neither in a certain interval or a point, but better when the variable value gets larger or smaller, so the upper semi-trapezoid fuzzy membership function as the Eq. 9 shows and the lower semi-trapezoid fuzzy membership function as the Eq. 10 shows are adopted for such evaluation sub-item. As the Figure 14 shows are the function graphs of the above-mentioned fuzzy membership functions.

$$
\mu_a(x) = \begin{cases} 
0 & x = x_i \\
1 & others 
\end{cases} 
$$

(7)

**Table 4.** Evaluation initial state information

<table>
<thead>
<tr>
<th>Initial state</th>
<th>Variable description</th>
<th>Variable type</th>
<th>Variable initial value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$IV_1$</td>
<td>$VD_1$</td>
<td>$VT_1$</td>
<td>$VV_1$</td>
</tr>
<tr>
<td>$IV_2$</td>
<td>$VD_2$</td>
<td>$VT_2$</td>
<td>$VV_2$</td>
</tr>
<tr>
<td>$\ldots$</td>
<td>$\ldots$</td>
<td>$\ldots$</td>
<td>$\ldots$</td>
</tr>
<tr>
<td>$IV_n$</td>
<td>$VD_n$</td>
<td>$VT_n$</td>
<td>$VV_n$</td>
</tr>
</tbody>
</table>

**Table 5.** Evaluation sub-item information

<table>
<thead>
<tr>
<th>Assessment variable</th>
<th>Variable description</th>
<th>Variable type</th>
<th>Membership function type</th>
<th>Membership function parameter 1</th>
<th>Membership function parameter 1</th>
<th>Weight</th>
<th>Deny value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$AV_1$</td>
<td>$VD_1$</td>
<td>$VT_1$</td>
<td>$MF_1$</td>
<td>$MFP_1$</td>
<td>$MFP_n$</td>
<td>$WV_1$</td>
<td>$DV_1$</td>
</tr>
<tr>
<td>$AV_2$</td>
<td>$VD_2$</td>
<td>$VT_2$</td>
<td>$MF_2$</td>
<td>$MFP_1$</td>
<td>$MFP_n$</td>
<td>$WV_2$</td>
<td>$DV_2$</td>
</tr>
<tr>
<td>$\ldots$</td>
<td>$\ldots$</td>
<td>$\ldots$</td>
<td>$\ldots$</td>
<td>$\ldots$</td>
<td>$\ldots$</td>
<td>$\ldots$</td>
<td>$\ldots$</td>
</tr>
<tr>
<td>$AV_n$</td>
<td>$VD_n$</td>
<td>$VT_n$</td>
<td>$MF_n$</td>
<td>$MFP_1$</td>
<td>$MFP_n$</td>
<td>$WV_n$</td>
<td>$DV_n$</td>
</tr>
</tbody>
</table>
As the above-mentioned fuzzy membership functions have the characteristic of easy setup, simple form and rapid calculation, so they are widely applied in the evaluation module. However, the evaluation results are required to be more accurate for some important “State Parameter Type” evaluation sub-item, so the corresponding evaluation fuzzy membership function is also required to be more accurate, for example the fuzzy membership function of evaluation sub-item “the main engine revolution deviation” is as the Eq. 11 shows, which is used to evaluate the operation time in magnetic compass training and evaluation in the study of Yang et al. [23].

where $\Delta r$ is the deviation value of the actual and expected main engine revolution, $\Delta r_{\text{max}}$ is the allowable maximum of revolution deviation value, $\Delta r_{\text{min}}$ is the allowable minimum of revolution deviation value.

The fuzzy membership function applied in the evaluation module also includes Gaussian membership function, n-order parabola membership function, Sigmoid membership function, and bell-shaped membership function. In some cases, the membership function can also be generated by numerical fitting for several special “State Parameter Type” evaluation sub-item, for example Yuan et al. uses “Least Square Method” to generate the membership function [24].

6.3 Analysis of Evaluation Example

The “Manual Synchronizing Operation of the Ship Power Station” is taken as an example to verify the feasibility of automatic evaluation function developed in this paper. The evaluation item requires the trainees to finish the operation of synchronizing and load shifting manually in 5 minutes and the voltage deviation, frequency deviation and phase deviation in the closing moment should be in the allowed range, meanwhile, condition of reverse-power should not be generated by the synchronizing diesel generator. The initial state of this evaluation item is “NO.1 & NO.2 diesel generators are running, the NO.1 diesel generator is in the power network and the NO.2 diesel generator is not”. The standard operation procedure is as follows:

1. Turn the “Manual/Auto” switch in the NO.1 and NO.2 diesel generator panels from manual to auto.
2. Adjust the voltage of NO.2 diesel generator to rated value and the frequency a little higher than the rated value.
3. Turn the synchronizing selector to NO.2 diesel gen-
erator and observe the frequency deviation and phase deviation of NO.1 and NO.2 diesel generator.

4) Adjust the revolution speed of NO.2 diesel generator to make the LED red light of synchronizing meter to rotate clockwise (about 3-5 seconds/per round).

5) Push the switch-on button “ACB CLOSE” when the red light in the 11 o’clock direction turns on.

6) Turn the synchronizing selector to “OFF” once the synchronizing is successful.

7) Increase the revolution speed of NO.2 diesel generator and decrease the revolution speed of NO.1 diesel generator to shift the load from NO.1 diesel generator to NO.2 diesel generator. Stop adjusting the revolution speed of diesel generator when the power of NO.1 and NO.2 diesel generator equals.

As the Figure 15 shows is an evaluation report of “Manual Synchronizing Operation” for a certain trainee. As the frequency deviation, voltage deviation and phase deviation differ with the optimum value, a certain score will be deducted by the evaluation, meanwhile, as the synchronizing selector is not turned to “OFF” and the operation of load shifting is not fulfilled when the synchronizing is successful, a certain score will also be deducted by the evaluation module.

7. Conclusion and Future Work

A high quality MER 3-D visual simulation system is developed in this paper. The system structure of the traditional MERS is re-built and a corresponding 3-D visual simulation system is introduced into it. The geometric model of the whole MER is established and corresponding optimization methods for the virtual scene are adopted. The realization method of human-machine interaction, virtual roaming and auxiliary function are introduced in detail, meanwhile, an optimized 3-D picking algorithm is given in this paper. To enhance the practicability of the 3-D visual system, an automatic evaluation function based on fuzzy comprehensive assessment method in the 3-D virtual scene is developed in this paper.

Compared with the traditional training mode, the training mode based on 3-D visual simulation system has advantages on interactivity, intuition and safety, which will surely become the development direction of the modern MERS. This paper fully introduces the development method of the MER 3-D visual simulation system, which has a certain practical significance.

Based on the practical requirement, this paper will research the dynamic loading of virtual scene, novice teaching and guidance and the acting of MER emergency situation so as to improve the quality and practicability of the MERS.

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References


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