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Simulation Experiment and Teaching Research of a Land-Based Ship Engine Room

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ABSTRACT

In order to make up for the shortage of scientific research experiments and teaching in land-based engine room laboratory, a simulation system is designed and developed using B/S mode to simulate scientific research experiments, teaching and operation processes, and designed algorithms to simulate the propulsion characteristics of the main propulsion diesel engine. A large number of experiments were carried out, and the relationship curve between output power and fuel consumption rate of the main engine was obtained in the laboratory. Apache JMeter was used to test the pressure of the simulation system deployed in Dalian Maritime University Cloud. It is found that under the test conditions, the average response time of sample request is 330 ms, which is far superior the design standard of 2 s. There is no abnormal response to all requests, and all indicators fully meet the requirements of the project team. The simulation system fills the gap in the application of panoramic interactive technology in Marine engineering education, and provides a reference for the exploration of "intelligent +" experiment and teaching mode in maritime university laboratories.

KEYWORDS

Land-Based Engine Room, Panoramic Interaction, Propulsion Characteristics, Simulation System

INTRODUCTION

Dalian Maritime University's land-based ship engine room laboratory has a construction area of 5,600 m^2. It was constructed with the new generation of ocean-going merchant vessel electromechanical equipment. The system in the laboratory is complex and the equipment is expensive. The laboratory is a domestic leading and world-advanced full-function comprehensive scientific research experiment and teaching platform for marine engine rooms. In operation, management, maintenance, and scientific research and teaching, it is found that the amount of operation and maintenance costs is huge, and the security risk of scientific research and teaching is very high.

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At present, in the field of marine engineering, there are few reported cases of developing a simulation system for scientific research experiments and teaching using the Browser-Server (B/S) mode with the help of panoramic interaction information technology based on the world's advanced land-based ship engine room laboratory (Zhou, 2019; Sardar et al., 2022; Seok & Hur, 2022; Roh et al., 2019; Netek et al., 2020; Lasalandra et al., 2020; Cao, 2022; Li et al., 2013; Li & Li, 2022; Shih et al., 2022). To make up for the shortage of land-based engine room laboratories in scientific research and teaching, the project team developed a land-based ship engine room experiment and teaching simulation system.

DESIGN AND DEVELOPMENT OF SIMULATION SYSTEM

Overall Design of the System

According to the objectives and needs of the experiments to be conducted in the land-based engine room, cloud teaching, simulation operation, assessment, data tracking statistics, and export functions were designed. The requirements were as follows:

1. Build a complete cloud-based teaching and lecture system that enables users to learn online with digital materials, virtual reality (VR) objects, 3D models, and other online tools.
2. Establish an online simulation operation platform to complete standing by, maneuvering, constant speed, troubleshooting and other contents in land-based engine room through human-computer interaction and simulation operation.
3. Design algorithms to simulate the propulsion characteristics and other operating laws of the main propulsion diesel engine (main engine) of engine room laboratory.
4. Realize the function of tracking, recording, analyzing and exporting data, provide assessment basis and meet the demand of continuous improvement and upgrading of the system.
5. Complete the development of binocular split screen mode and other functions to realize VR simulation operation and enhance user immersion experience.
6. Use the B/S model to build an efficient cloud-based experiment and teaching simulation environment. When 400 users are accessing the system concurrently, the response time of a single page should be less than 2 s.

Modules Functionality and System Framework

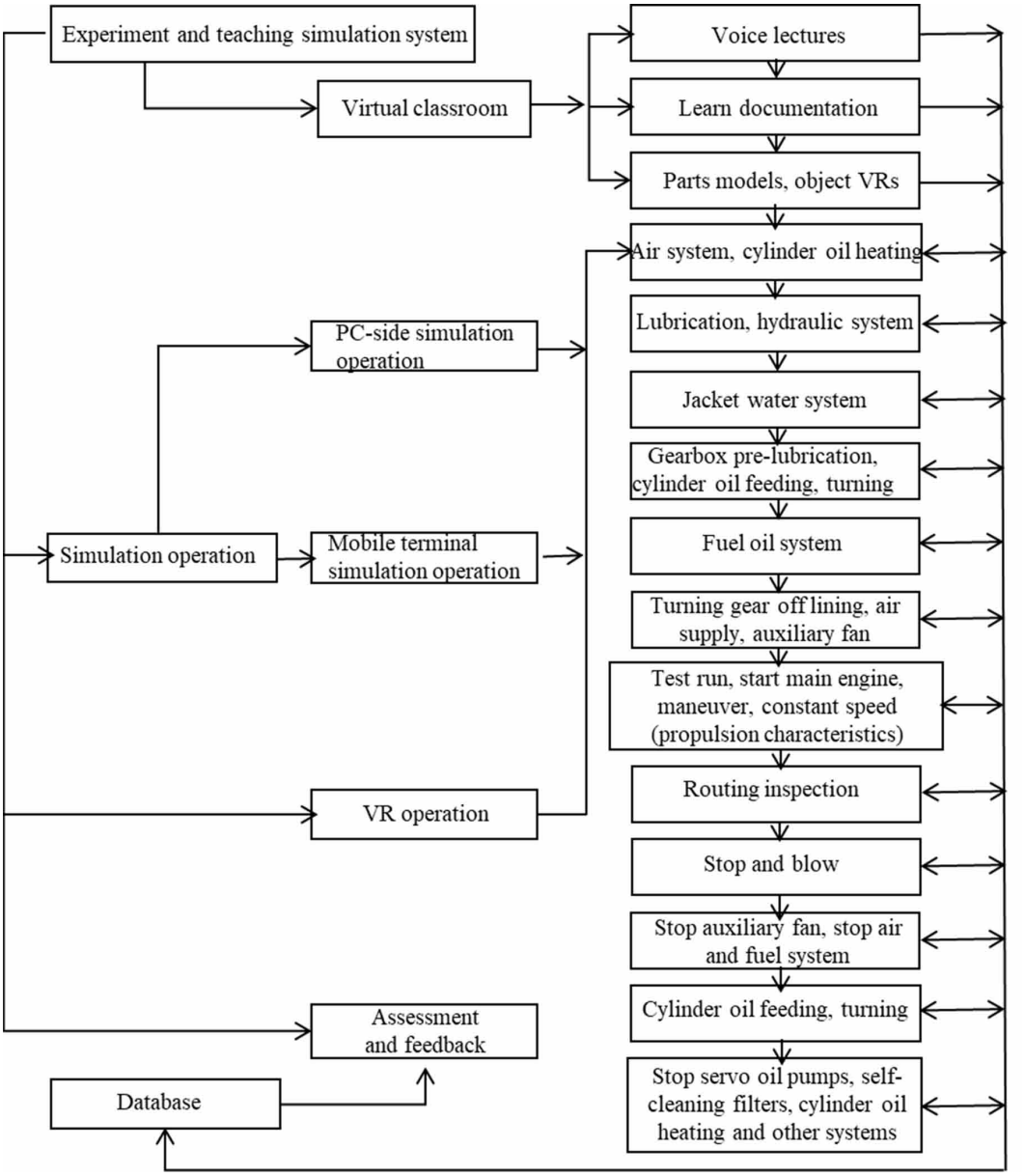
The experiment and teaching simulation system is divided into a user layer, a business layer, a data access layer, and a data storage layer. It also contains functional modules, such as a virtual classroom, simulation operation, and VR operation. These modules realize their respective functions through the four layers. The experimental and operational processes are shown in Figure 1.

Experimental and scientific research personnel logged into the system and followed the above processes to enter each module for simulation experiments and operations.

By logging into the Virtual Classroom module, users can activate various controls to access files such as audio, digital teaching materials, 3D models and objects VRs during their tour of the engine room. Simulation operation and VR operation can enter air, cylinder oil, lubrication, hydraulic, jacket water, gear box, fuel and other sub-modules and subsystems in the processes of standby, starting, maneuvering, oil change, constant speed inspection, finish with engine, complete various operations through human-computer interaction.

The main engine in the simulation system operates according to the designed algorithm simulating the propulsion characteristics of the main propulsion diesel engine of the land-based engine room laboratory, and system will provide real-time feedback on the output power, fuel consumption rate and other data. The operation steps, system status and all data will be recorded in the database. The assessment and feedback module can call the database data. The results of data analysis are not only used

Figure 1. Flow of the experiment and teaching simulation system



for scientific research and other activities, but also for the improvement of the experiment and teaching simulation system, thus completing the closed loop of the simulation system construction and application.

System Development Method

Software Development Methods

The land-based ship engine room experiment and teaching simulation system were developed with the help of tools such as 3ds Max, Dreamweaver, krpano, and MySQL, with hypertext markup language 5 (HTML5), JavaScript, extensible markup language (XML), hypertext preprocessor (PHP),

and structured query language as the development languages. The platform architecture is designed based on HTML5 and supports mobile terminals, gyroscopes, and VR binocular split-screen mode.

The 3D scenes in the system are composed of high-definition panoramas of land-based engine room laboratories. The human-computer interaction in the scene is implemented by a JavaScript program in the system reading XML parameters and then running them on the HTML page.

Some of the models in the scene are made using 3ds Max, using the Three.js engine to invoke the model file. The underlying technology is WebGL.

The display of VR objects, models, and digital teaching materials in the scene is accessed through text boxes. Values are assigned to text boxes with the <iframe> floating frame tag.

Trigger events activated hot spots that pop up the web page layers through text boxes. The web page layer loads web programs, which display items such as digital teaching materials, albums, and VR objects. These materials are made using tools such as Object2VR.

The system database is MySQL and the interface language is PHP embedded in HTML.

Dreamweaver was used as the script editing tool. Several programs, including Photoshop, PTGui, Autopano Giga, and Object2VR, were used as the graphics processing tools.

Simulation of Main Propulsion Diesel Engine

At present, the main propulsion power plant of most merchant ships is a diesel engine (Ghaemi, 2021). The engineer needs to understand the current propulsion characteristic curve of the ship's main propulsion diesel engine and data, such as exhaust temperature, exhaust gas emission, and fuel consumption rate corresponding to different rotational speeds of the ship's main engine under current working conditions (Matulić et al., 2020; Fan et al., 2022; Zhao et al., 2019; He & Chen, 2022; Liu et al., 2022). If the fuel consumption rate of the ship's main propulsion diesel engine at operating power (90% of rated power) is approaching the energy efficiency threshold, a warning about the condition of the ship should sound, and measures to enhance maintenance and management should be taken(Cong et al., 2019). The land-based ship engine room experiment and teaching simulation system can be personalized to simulate the propulsion characteristics of various main propulsion diesel engines, and can also be deployed on real ships with diesel-powered main engines for energy efficiency calculation and monitoring.

The power of the ship's main engine in the simulation system is calculated by the following formula:

$$P_e = \frac{M_p \times n_p}{9550} \tag{1}$$

where P_e is the output power of the main engine in a land-based ship engine room in kW; M_p is the torque of the propeller and main engine in kNm, without transmission loss; n_p is the rotation speed of the propeller and main engine in rpm. M_p is measured by the torque meter, and n_p is set by the operator.

The fuel consumption rate g_e of the main engine in the simulation system is calculated by the following formula:

$$g_e = \frac{G_t \times 1000}{P_e} \tag{2}$$

where: Gt is the mass of fuel consumed per unit time, kg/h. Gt is measured by the mass flow meter or calculated after the volume of fuel consumed is measured by the volume flow meter. Substitute the Pe value calculated in formula (1) into formula (2) to obtain the fuel consumption rate ge, g/kW•h.

After many experiments (bench tests), project team obtained a large amount of data. After calculation, the relationship curve between the output power and fuel consumption rate of the main engine (model: MAN 5S35ME-B9, rated power: 4,350 kW) in land-based ship engine room was obtained, as shown in Figure 2.

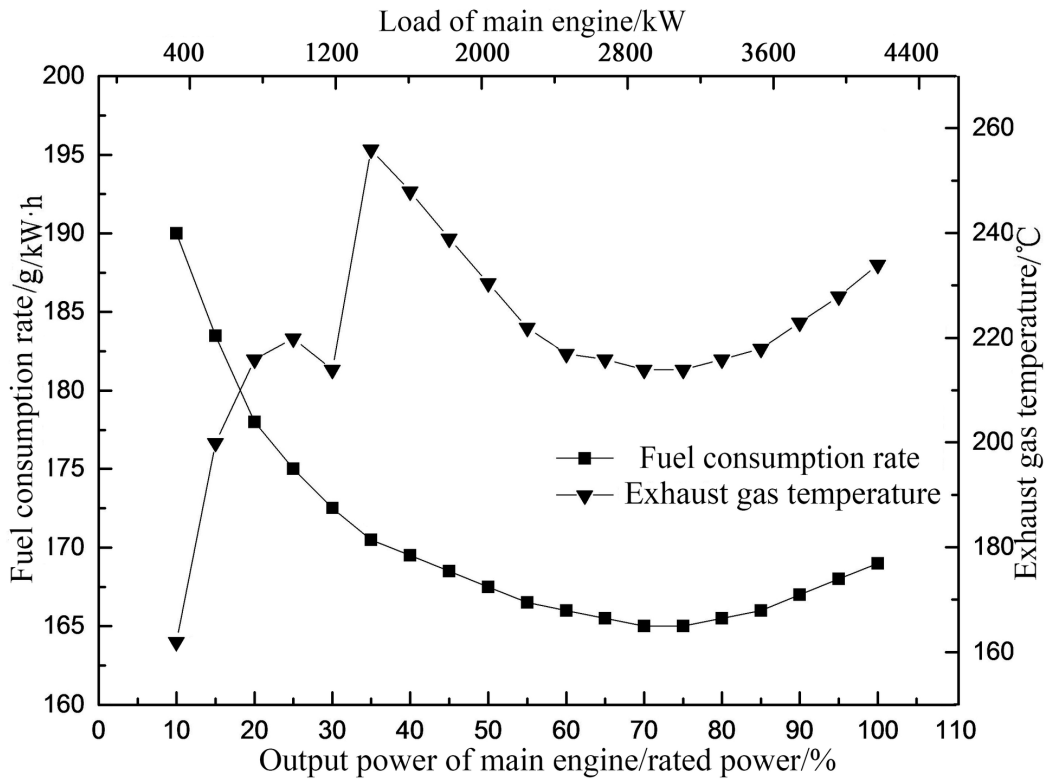
The fuel consumption rate (g/kW•h) and exhaust temperature (°C) of the main engine of the land engine room vary with the rotation speed, and the output power (kW) of the main engine is also different at different rotation speeds (rpm). The torque (kNm) of the propeller and the main engine are measured disregarding the transmission loss, and the system calculates the output power of the main engine. Based on the output power and the mass of fuel consumed by the main engine per unit time (kg/h), the fuel consumption rate of the main engine is calculated by the simulation system.

The relationship curve and data values in Figure 2 are consistent with those described in the manual of the main engine of the land-based ship engine room. This reflects that the main engine of the land-based ship engine room is almost new and the running time is shorter. The results are also nearly consistent with the manufacturer's bench test data (obtained by direct measurement with the dynamometer). This shows that the simulation algorithm designed by the project team is effective and reasonable.

In experiments and teaching sessions in the land-based ship engine room laboratory, the operator sets different main engine rotation speeds, and the simulation system sends back the power and fuel consumption rate of the main engine according to the above rule.

When the simulation system is deployed on an operating ship, the system substitutes the MP and Gt values corresponding to the different rotational speeds of the main engine under a particular ship condition (loading, climate, sea state and other conditions remain unchanged) into formula (1) and

Figure 2. Relationship curve of the main engine



formula (2) to obtain the relationship curve between the output power of the main engine and the fuel consumption rate. If the operating condition of the ship's main engine is poor, the results calculated by using the detected data will have a large deviation from the results of the manufacturer's bench test. When the deviation exceeds the threshold, the simulation system will issue an alarm. Therefore, the simulation system can monitor the energy efficiency of the ship's main propulsion diesel engine. This has a very important guiding significance for the management of engineers.

Deployment of the System

The land-based ship engine room experiment and teaching simulation system is developed in B/S mode and can be deployed in public cloud, private cloud or intranet server. At present, the simulation system has been deployed on the cloud server of Dalian Maritime University. The configuration of the virtual host is 4-core CPU/16G memory, and LAMP (Linux+Apache+Mysql+PHP) software is installed. It can be accessed by all kinds of terminals with the help of browsers, without installing any APP, application software or plug-ins. After the test, 360 extreme, QQ, Liebao, UC, Firefox and other browsers can access the system stably and perform operations. Terminal devices can be computers, cell phones, tablet PCs, VR devices, etc.

TEST RESULTS AND ANALYSIS

The performance of the experimental and teaching simulation system is evaluated by the response speed of the selected sample pages (Liu et al., 2022; Chen & Chiu, 2017; Lopez et al., 2022; Pang et al., 2023; Yu et al., 2022). The evaluation basis is shown in Table 1.

Apache JMeter was used as a pressure test tool to simulate 40 users to initiate requests and perform operations on the selected pages of user login, directory operation, starting air compressor, starting main lubricating oil pump, jacket water conversion, starting fuel system, main engine control and speed regulation scenarios within 5 s. Each of these users made 10 requests within 5 s.

Set the number of thread count (number of users) to 40, the progress (time needed to load) value to 5 s, the number of cycles to 10, the option to continue the test after an error, and set the monitor to View Results Tree and Aggregate Report.

The test results in the View Results Tree show that the test results of all sample requests are green, i.e., all requests and responses from the server are successful. The response code of each sample is 200, the number of errors in the response is 0, and the value of each response message is OK. This indicates that the experiment and teaching simulation system operates normally under the test conditions.

Some of the data in the Aggregate Report are shown in Table 2.

Observing the data in Table 2, we can find that: the overall response time of the sample requests has an average value of 330 ms, a minimum value of 42 ms, and a maximum value of 1,106 ms, with no abnormal response for all requests. It can be seen that: the response speed of this system is very fast under the test conditions and meets the design requirements of the project team.

Table 1. The "2-5-8" principle of response time

Time (s)	Response
t£2	Very fast
2<*t*£5	Fast
5<*t*£8	Slow
t>8	Very slow

Table 2. Pressure test data of the simulated system

Content	Samples	Average (in ms)	Min. (in ms)	Max. (in ms)	Abnormal (in %)	Throughput (in Transactions·s^{1})
Login	400	221.60	26	889	0	604.32
Directory operations	400	261.35	42	1,256	0	498.65
Start the air compressor	400	312.68	33	1,005	0	421.46
Start the main lubricating oil pump	400	333.62	53	1,321	0	408.98
Jacket water conversion	400	356.21	44	1,654	0	400.22
Starting the fuel system	400	387.12	47	1,141	0	381.05
Main engine control and speed regulation	400	545.25	101	2,991	0	299.91
Total	2,800	330	42	1,106	0	503.32

CONCLUSION

With the help of information technology such as panoramic interaction, based on HTML5 framework and B/S mode, the experiment and teaching simulation system was designed and developed to simulate the propulsion characteristics of main engine and various experiments and operations of the land-based ship engine room. Through a large number of experiments, the results such as the relationship curve between the output power and fuel consumption rate of the main engine in land-based ship engine room laboratory were obtained.

The simulation system has been deployed in the Dalian Maritime University Cloud. Scientific research personnel or trainees can access and operate through a browser using mobile terminal, client-side or VR devices, without installing any APPs. The system was conducted with pressure test and a series of data were obtained. The results of the data analysis show that the indicators such as stability and response time of the experiment and teaching simulation system under the test conditions fully meet the design requirements of the project team.

The simulation system made up for the shortage of land-based ship engine room laboratory in scientific research experiments and teaching, filled the gap in the application of the new generation of information technology such as panoramic interaction in the Marine engineering field, and provids a reference for exploration of "intelligent +" teaching and research mode in maritime universities.

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