A Novel Networked Marine Engine Simulator for Crew Operation Examination with Auto Evaluation Using Virtual Reality Technology

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***Abstract*—*The purpose of this paper is to develop a novel marine engine simulator to make up the deficiency of the existing one in the aspects of crew's operation exam and auto evaluation at home and abroad. Unlike traditional products, this new type of marine engine simulator doesn't need any additional devices but a computer with virtual reality technology. The simulator mainly includes four parts, 3D marine engine simulation model, auto evaluation algorithm, question library and network communication platform. An operator can do scene roaming, human-computer interaction and operation examination just with keyboard, mouse or even Helmet Mounted Display (HMD) if economic conditions permitted. Besides virtual reality operation, auto evaluation is another attractive highlight. With the fuzzy evaluation algorithm proposed in this paper, a reasonable score can be given automatically according to the operations done by crew at the end of the examination. Further more, a number of simulators as examination terminals are networked by communicating with the examination center, forming a crew examination and evaluation network platform, being a powerful tool in crew training, examination and evaluation.*

Keywords-marine engine simulator; virtual reality; operation examination; auto-evaluation; networked

I. INTRODUCTION

How to effectively improve crew's operational ability and professional knowledge has became an urgent problem especially for the situation that modern ships are being more and more large-scaled and specialized, and meanwhile major shipping companies prefer to hire the crew who are well qualified under the mounting competition pressure of international shipping market. There is no doubt that rich sailing experience can greatly improve crew's operational ability but when it comes to those beginners, the operation training and examination becomes so important since rich experience for them is almost impossible. Actually, it is also impractical to let crew do training and examination in real ship engine room not only because of the high cost on time and money, but also the unpredictable operation mistakes probably resulting in serious accidents. Hence, marine engine simulator, an effective means to improve the operation ability of crew, plays an important role in crew training and examination.

Traditional marine engine simulator is usually hardware-based, which takes up much space but still can't provide a similar environment for crew operation, after all, the closer the simulator is to an actual marine engine room, the better the training effect will be. Another deficiency of traditional simulator is its low efficient manual evaluation mode, without a convenient auto-evaluation system. Aiming at these shortages, a novel marine engine simulator combining virtual reality operation with auto evaluation is developed in this paper. Unlike traditional marine engine simulator, the operation environment of this new kind of simulator is almost the same as that real scene. Thanks to the well developed virtual reality technology[1], as well as the network technology, the features engine room roaming, interaction operation and auto evaluation make the reform of existing crew examination possible, forming a more efficient and intelligent crew examination system in the future.

II. SIMULATOR COMPOSITION

The specific composition of the whole marine engine simulator is shown in figure 1. It is seen that the four parts, simulation model, question library, auto evaluation algorithm and network platform constitute the whole marine engine simulator. The more detail descriptions about what the function of each part and how to accomplish its function will be given in part 3.

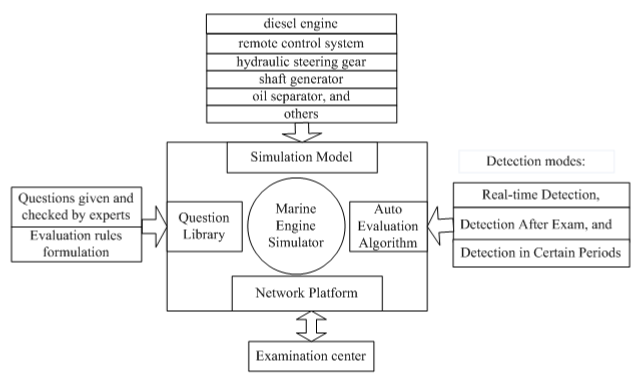

Figure 1. Composition of the new marine engine simulator

III. SIMULATOR IMPLEMENTATION

A. Virtual Reality System

The virtual scene and 3D entity model of marine engine as the main body of the simulator are constructed by 3DS MAX, and the virtual reality environment is developed by the popular 3D API rendering technology with the tools of Direct3D (DirectX Graphics). Although DirectX Graphics in the development of marine engine VR system is low efficient and needs a great deal of programming codes, the

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respond speed of its developed product is fast with low requirement of computer hardware.

The overall design of the virtual reality simulation system for marine engine is shown in figure 2.

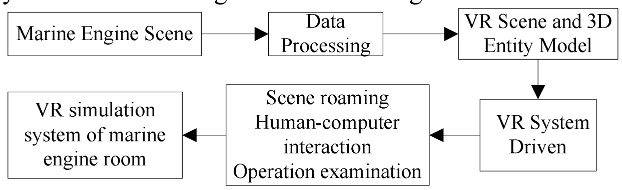

Figure 2. Overall design of the VR system for marine engine

First of all, the scene data of marine engine room should be collected and processed, and then the virtual scene and 3D entity model of marine engine is constructed by 3DS MAX. In order to achieve the scheduling and roaming of scene, it is necessary to change the 3D model into the document in the form of .x, which will be put into DirectX to drive in the environment of VC++6.0. Finally, by using the rendering function of DirectX, the scheduled scene can be rendered to realize the function of human-computer interaction and operation examination. For example, figure 3 and 4 are separately the virtual reality operation interfaces of ECR and generator. Figure 5 is the virtual reality operation interface beside main engine. In addition, readers can refer to literature [2] for more detailed description about the realization of VR system for marine engine.

Figure 3. Virtual reality operation interface of ECR

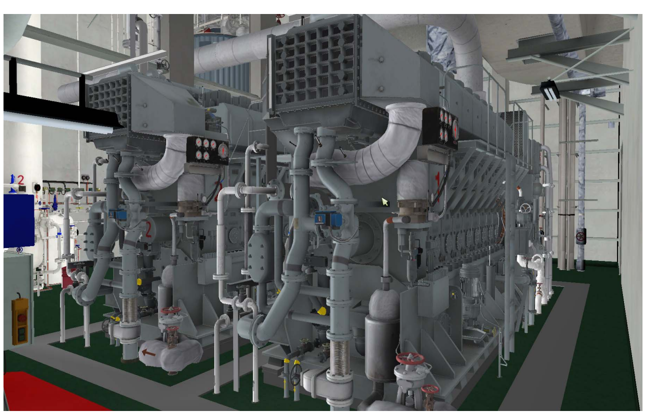

Figure 4. Virtual reality operation interface of generator

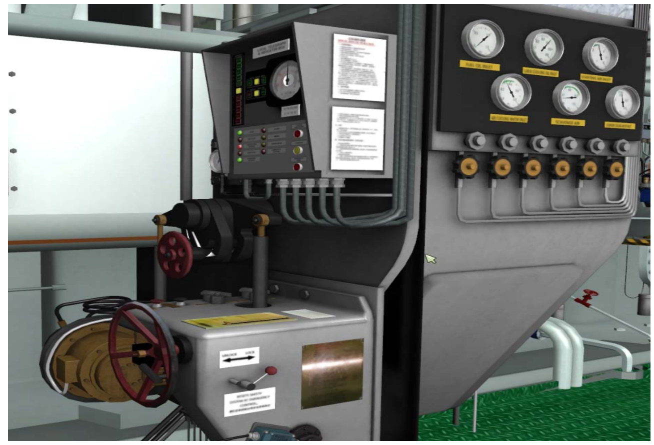

Figure 5. Virtual reality operation interface beside main engine

B. Simulation Model

Simulation model is the basic part of the entire simulator which can directly influence the accuracy and practicality of the simulator. The simulation model of traditional marine engine simulator is simplified especially in the modeling parts of diesel engine, propeller, turbocharger and controller, with low performance for simulator. So in this paper, for the sake of a novel simulator designed for operation examination in virtual reality system, a complete and detailed instead of simplified simulation model is demanded. A real marine engine system includes remote control system, diesel engine, hydraulic steering gear, shaft generator, oil separator and other key sub-systems, so as to a virtual marine engine room. Owing to space limitation, only the simulation model of diesel engine propulsion system, which is generally considered as the heart of the whole ship for its power supplying, will be elaborated in this paper.

Various modeling methodologies for the internal combustion engine are offered by literature, and scope of the application, accuracy and calculation time demand, are the determining parameters for the modeling approach. The existing modeling of diesel engine for the application in marine engine simulator can only simulate several preset operating points, for example, 100%, 90%, 80% of full load, but can not simulate the continuous running state of diesel engine form start to stable running. Aiming at this deficiency, a zero-dimensional instantaneous model of MAN B&W 6S35MC ship diesel engine propulsion system is established based on VC++ 6.0 in this paper. Unlike other simulation models [3], this zero-dimensional instantaneous model can satisfy the requirement of both state and dynamic simulation by combining the zero-dimensional model of diesel engine and the dynamic features of shaft and propeller together. The composition of ship diesel propulsion system is shown in figure 6, which includes cylinder, starting air bottle, intake and exhaust system, turbocharger, shaft, propeller and so on.

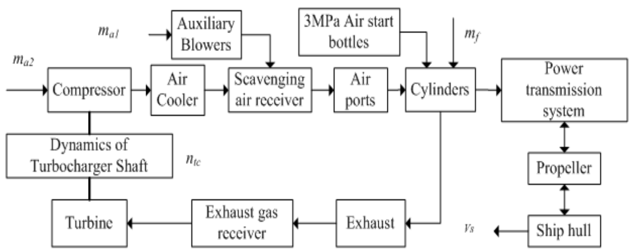

Figure 6. Composition of ship diesel propulsion system

The mathematical model of the whole ship diesel propulsion system is as follows [4].

$$m\frac{dv_s}{dt} = T_e - R_s \tag{1}$$

$$\frac{\pi}{30} I \frac{dn}{dt} = M_e - M_p - M_f \tag{2}$$

where m is the mass of the ship and sea water adhered to the hull; v_s is the speed of the ship; T_e is the thrust of the propeller in open water; R_s is the resistance of the hull, which is a function of v_s; I is the inertia mass moment of the rotate system; n is the rotate speed of the propeller, which is the same with that of diesel engine; M_e is the output torque of diesel engine; M_p is the hydrodynamic resistance torque of propeller; M_f is the torque of mechanical loss.

with

$$T_e = k_T \rho n^2 D^4 \tag{3}$$

$$M_p = k_Q \rho n^2 D^5 \tag{4}$$

where k_T is the thrust coefficient and k_Q is the torque coefficient, both of which are functions of the pitch angle and advance ratio of propeller but can not be expressed in an analytic form, and hence be calculated by using interpolation method according to the propeller diagram provided by manufacturer. ρ is the density of sea water; D is the diameter of the propeller.

In order to calculate the output torque of diesel engine M_e, a zero-dimensional instantaneous model is built for 6S35MC diesel engine. The cylinders and receivers considered as control volumes should meet the equations of mass balance and energy balance, as well as ideal gas equation, which are described as follows[5-6],

$$\frac{dm_z}{d\varphi} = \frac{dm_a}{d\varphi} + \frac{dm_s}{d\varphi} - \frac{dm_e}{d\varphi} + g_f \frac{d\chi}{d\varphi} \tag{5}$$

$$\frac{dT_z}{d\varphi} = [\frac{1}{m_z}(\frac{dQ_f}{d\varphi} + h_a\frac{dm_a}{d\varphi} + h_s\frac{dm_s}{d\varphi} - h_e\frac{dm_e}{d\varphi} - p_z\frac{dV_z}{d\varphi} - \frac{dQ_w}{d\varphi} - u_z\frac{dm_z}{d\varphi}) - \frac{\partial u_z}{\partial \alpha_k}\frac{d\alpha_k}{d\varphi}]\frac{1}{\partial u_z / \partial T_z} \tag{6}$$

$$p_z V_z = m_z R_z T_z \tag{7}$$

where p_z is the cylinder pressure; T_z is the cylinder temperature; V_z is the cylinder volume; m_s and h_s are separately the mass in cylinder and its enthalpy; m_e and h_e are separately the mass leaving the cylinder and its enthalpy; m_s and h_s are separately the mass flowing into the cylinder from scavenging air ports and its enthalpy; m_a and h_a are separately the mass flowing into the cylinder from 3MPa air start bottle and its enthalpy; Q_f is the fuel energy; Q_w is the wall heat loss; χ is the mass fraction burned; α_k is the excess air coefficient; u_z is the specific internal energy of the mass in cylinder; R_z is the gas const of the mass in cylinder; φ is the actual crank angle.

This paper does not intend to give more details on the modeling of the diesel engine, nor the other aspects of marine engine simulation. The innovation and attraction of this marine engine simulation model is its correct and consecutive simulation from engine start to stable running at the expected load with a model input value (fuel value for per cycle and per cylinder). In order to verify the simulation model, the comparison between indicator diagram simulated and measured at 90% load is shown in figure 7, and it is seen that the simulated data (dot) can well match the experimental data (solid). Figure 8 shows the engine speed changing from starting to stable running at fixed speed (173 rpm). Note that it almost takes about 2.5 second from engine start to fire speed (25 rpm). Figure 9 shows the simulation curve of ship speed running from 0 to the fixed speed (8.6 m/s), and about 10 minutes is needed.

Figure 8 and figure 9 are the simulation results at 100% load with the model input value of about 0.0127kg, and the fixed data (173rpm and 8.6m/s) are the sailing data of this ship. Different fuel value, different simulation result, but a too small value will lead to a start failure. The simulation results indicate that the zero-dimensional instantaneous model of ship diesel propulsion system can meet the requirement of the novel simulator in the aspects of both state and dynamic simulation for full operating range.

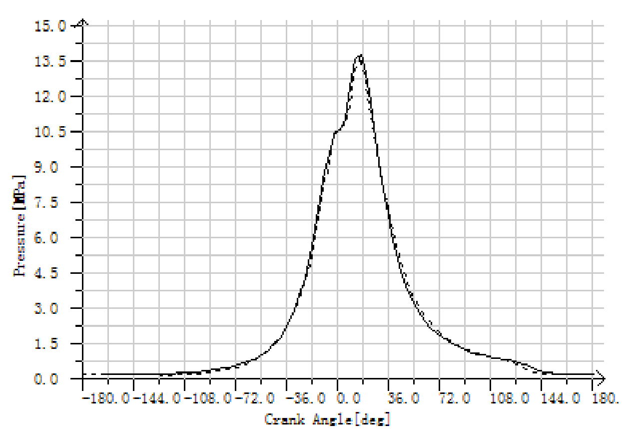

Figure 7. Validation of cylinder pressure model on experimental data at 90% load

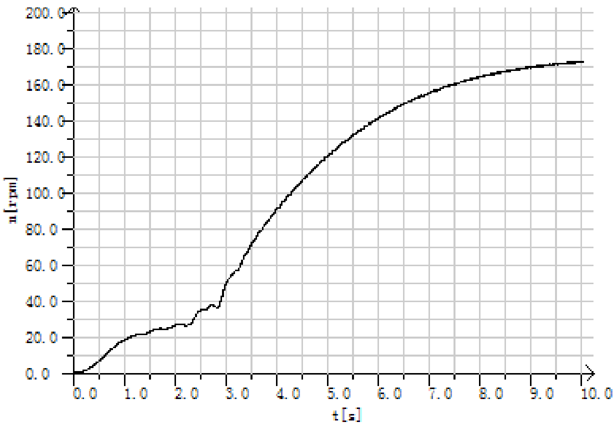

Figure 8. Simulation curve of diesel engine speed changing from starting to stable running at the fixed speed

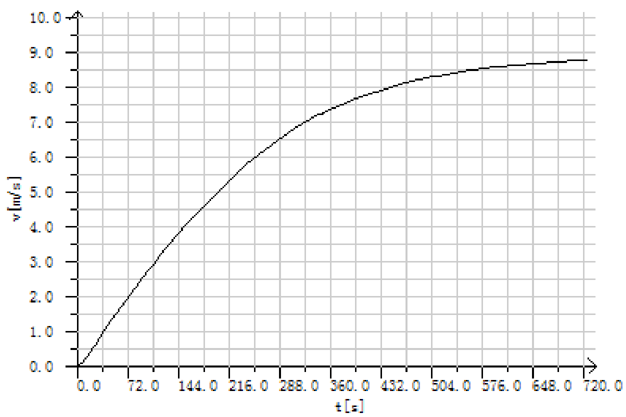

Figure 9. Simulation curve of ship speed running from 0 to the fixed speed

C. *Question Library*

Question library is designed by experts with a wealth of knowledge and experience. The variables of simulation system can be up to 200000, covering all aspects of the operation exam content, but the initial state of the 3D marine engine simulation platform prepared for exam can be updated as soon as an operation question is given out, with great real-time performance.

Fault setting, answering and dealing is also a very important part of crew operation examination, so a number of questions on fault operation are given in question library. Moreover, the given questions should be checked carefully to ensure their correctness, and the corresponding evaluation rule for each question must be given in detail.

Each operation question is graded on its several "Operations" and "Performance Parameters". Here, "Operations" means the steps needed to finish this question, which falls into two categories, sequence requirement and no sequence requirement. "Performance Parameters" reflect the running conditions of relevant status during operation. Both "Operations" and "Performance Parameters" are described in the form of variables, and each of them matches a variable. It is these variables which can represent the detailed process of each operation that describe the evaluation rule for each question. The universal evaluation rule for operation question is shown in table 1.

TABLE I. THE TABLE OF UNIVERSAL EVALUATION RULES FOR EXAM QUESTIONS

Variable Description		T_1	T_2	…	T_k
Variable Name		VN_1	VN_2	…	VN_k
Variable Type		VT_1	VT_2	…	VT_k
Detection Requirement		DR_1	DR_2	…	DR_k
Detection Type		DT_1	DT_2	…	DT_k
Detection Bounds	**Upper Limit**	DU_1	DU_2	…	DU_k
	Lower Limit	DL_1	DL_2	…	DL_k
Conditions Set		CS_1	CS_2	…	CS_k
Conditions Priority		CP_1	CP_2	…	CP_k
Item Score		IS_1	IS_2	…	IS_k

The meaning of each item in table 1 is as follows.

Variable Description: the description of what the variable is used for.

Variable Name: the name of the variable.

Variable Type: Boolean, integer and floating point.

Detection Requirement: real-time detection, detection after exam, and detection in certain periods.

Detection Type: the range of detection value as the scoring standard given according to Variable Type and Detection Bounds.

Detection Bounds: Upper and lower limits, the correct range of the variable.

Conditions Set: If the judgment of a variable has one or more conditions, a set of those conditions will be created, else, an empty set $\varnothing$.

Conditions Priority: If a variable is considered as a condition, its priority will be presented as an integer, and the number "1" means the highest priority. That different variables owning a same number means they have a same priority, and their corresponding operations are in no particular order. "NULL" indicates that the variable doesn't represent a condition.

Item Score: Each variable corresponds to a scoring item whose score is assigned in order of importance. There are two forms of Item Score, positive and negative, which is determined by questions givers. Especially, the Item Score of a variable will be set to "-100" if its operation is very critical, which means once the important operation is not finished correctly, final score of this question will be 0. If a variable represents a condition, its Item Score will be 0.

D. *Auto Evaluation Algorithm*

(1)Calculate final score S_{core}

Usually, there are m questions in an operation examination, and the formula for the calculation of the final score of an examination is as follows:

$$S_{core} = d_c \sum_{i=1}^{m} w_i S_i \tag{8}$$

Where m is the number of questions in an examination, and $i = 1, 2, 3, \ldots, m$. S_i is the final score of question i, and the full score value of each question is 100. d_c is the deduction coefficient, $d_c \in [0,1]$; if the operator can not finish examination within the given time while a small period of delay is permitted but at the cost of some discount. w_i is the weight coefficient of question i, which can be calculated by using Analysis Hierarchy Process (AHP) method[7] or given manually, and w_i should meet the following formula:

$$\sum_{i=1}^{m} w_i = 1 \tag{9}$$

Each question has n evaluation variables, that is, n scoring items called s_i ($i = 1, 2, 3, \ldots, n$). Especially, when a variable is a condition variable, $s_i = 0$. The final score of each question can be calculated as follows:

$$S_i = \sum_{i=1}^{n} s_i \quad (s_i \geq 0) \text{ or} \tag{10}$$

$$S_i = 100 + \sum_{i=1}^{n} s_i \quad (s_i \leq 0) \text{, when } S_i \leq 0 \text{, } S_{core} = 0 \tag{11}$$

(2)Calculate s_i

Define Boolean variable sc_i ($i = 1, 2, 3, \ldots, n$) as the scoring coefficient of s_i, $sc_i \in [0,1]$. The initial value of $sc_i \left(i = 1,2,3, \ldots, n\right)$ is NULL. The calculation formula is as follows:

$$s_i = sc_i * IS_i \quad \left(i = 1, 2, 3, \ldots, n\right) \tag{12}$$

(3)Calculate sc_i

The variables of an operation question can be classified into two kinds: Operation and Performance Parameter. The variable describing Operation is the representation of the operation on a valve or a button, whose corresponding sc_i value is "1" or "0" apparently. So the grading of such variables is quite fair. But when it comes to that variable used to describe Performance Parameter, whose value is within a range but still have an optimal value, it will be really unfair if its sc_i value is generally graded to be "1" or "0". In order to give a reasonable method to calculate the scoring coefficient sc_i, proper fuzzy membership function for variable adopted according to the attribute of variable is used to make the value of sc_i continuous within the closed interval [0,1].

There are several usual fuzzy membership functions such as triangular membership function, trapezoid shaped membership function, Gaussian membership function, k-degree parabola membership function, bell-type membership function and so on, or even a membership function fitted by Least Squares Method based on some relevant discrete data for a special expectation [8], or other methods.

E. Network Platform

The wired or wireless network platform is a platform for the communication between examination terminals and centers, and the structure of the network platform is shown in figure 10. It is seen that a simulator is considered as an examination terminal equipped with the information of questions and operation interfaces. An examination center is responsible for the management of its affiliated terminals, for example questions extraction, evaluation result collection and so on. All information of the operation examination and evaluation will be aggregated into Crew Examination and Evaluation Center, which can be shared or inquired on internet conveniently. In reverse, Crew Examination and Evaluation Center can send setting, inquiring or modifying commands to its examination centers and terminals.

Figure 11 shows the operation interface of the examination terminal. By clicking the buttons, their corresponding virtual reality environment will be presented for operation examination.

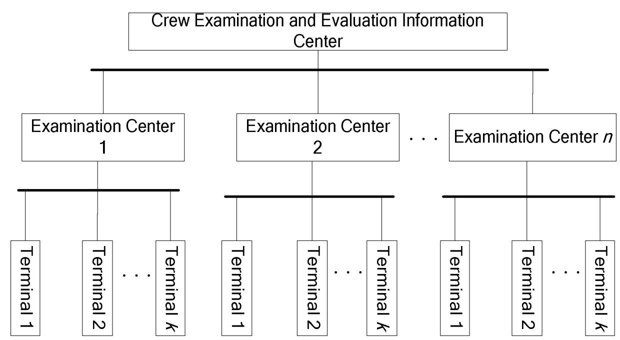

Figure 10. The structure of the network platform for crew examination and evaluation

Figure 11. The operation interface of the examination terminal.

IV. Conclusion

In order to provide an almost real environment for crew operation examination, this paper devotes itself to the implementation of a novel marine engine simulator which is different from that traditional one especially in the aspects of virtual reality operation and auto evaluation. The advantages of this new marine engine simulator are summarized below:

(1) Easy installation and maintenance, small occupation space, safe operation, and networked system.

(2) 3D visualization operation interfaces.

(3) Enough variables to meet the requirement of operation examination.

(4) Comprehensive question library which can be refreshed and improved by question-maker software.

(5) The initialization of simulation system prepared for beginning operating for each question can be finished instantly after the question is chosen to answer.

(6) Auto evaluation after the operation examination.

(7) Remote control.

(8) Upgraded conveniently, and so on.

The novel networked marine engine simulator is a great innovation in maritime fields, which not only has both theoretical and pedagogical implications, but also has a high value of practical application and market popularization.

Acknowledgment

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